Rockwool, perlite, coco coir and clay pebbles

Grant Kinkead
Independent Researcher, Melbourne, VIC, Australia
grant@kinkead.au

***Abstract*—Growing media influence the root-zone conditions through which water, air and dissolved nutrients are delivered to plants. Rockwool, perlite, coco coir and clay pebbles are commonly discussed as alternatives, yet a defensible comparison cannot rely on a single indicator or assume a universally superior medium. This paper develops a framework for comparing these materials through water retention, air space, chemical interaction, structure and handling. It synthesises evidence that substrate-based cultivation must be interpreted alongside pH, electrical conductivity, nutrient solution composition, crop requirements and system design. The available evidence confirms that growing-media properties and processing history can alter root-zone management, particularly where substrate composition affects pH and nutrient solubility. It does not, however, provide matched measurements for all four named media under common conditions. Accordingly, the paper treats the requested media as a comparison set and identifies the evidence gap rather than assigning unsupported rankings. The principal implication is that media selection should be a documented, multi-criteria decision linked to a specific crop and production system [1], [2], [3].**

I. Introduction

Hydroponic root-zone management is not determined by nutrient solution alone. In substrate-based systems, the growing medium creates the immediate physical and chemical setting in which water, dissolved ions and air coexist around roots. Reviews of soilless agriculture distinguish substrate-based and water-based approaches and identify water-air relations, pH, electrical conductivity, physical properties and biological conditions as relevant management dimensions. [1] These dimensions establish why comparisons among rockwool, perlite, coco coir and clay pebbles matter: each material must be considered for its contribution to root-zone conditions rather than as an isolated product category. The implication is that a medium cannot be assessed credibly without reference to the system in which irrigation and nutrient management occur [4].

Hydroponic substrate selection is often presented as a practical choice between familiar materials, but the underlying problem is comparative. A useful comparison must distinguish physical behaviour, chemical interaction and handling characteristics while avoiding claims that one medium is inherently best. Hydroponic reviews recognise that substrate types differ in relevant properties and that their selection is connected to system design and management requirements. [5] Rockwool, perlite, coco coir and clay pebbles therefore form an appropriate comparison set because they direct attention to contrasting classes of growing media. However, a material label alone does not establish a measured property profile, so broad claims require careful qualification [6].

The broader literature on irrigation reinforces the need to assess interacting conditions instead of relying on one desirable outcome. Capillary irrigation studies consider water use, runoff, yield, salinity and design constraints together, while also recognising important gaps in evidence for some systems. [7] By analogy, a root-zone comparison should not reduce media choice to a single feature such as water retention or air space. This paper applies a consistent framework to rockwool, perlite, coco coir and clay pebbles, then identifies where the supplied evidence supports general comparison dimensions but is insufficient for direct material-specific ranking [8].

II. Background and Scope

Soilless cultivation encompasses systems with different crops, locations, technical arrangements and resource constraints. Consequently, reviews reject the premise that one soilless system is best in every situation and instead emphasise compatibility between a system, a crop and local operating conditions. [1] This principle is directly relevant to growing media. A material may be compatible with one irrigation arrangement or crop-management objective without establishing superiority in another setting. The present comparison is therefore limited to root-zone management dimensions, namely water retention, air space, chemical interaction, structure and handling, rather than extending to unsupported claims about universal productivity or commercial performance [9].

A multi-criteria perspective provides a useful discipline for comparisons where desirable outcomes can conflict. Optimisation research in controlled cultivation has shown that photosynthetic performance, spatial uniformity and energy-use efficiency may involve trade-offs rather than converge on one objective. [10] Although that research concerns lighting rather than growing media, its methodological lesson is relevant: a comparison should state its dimensions and preserve trade-offs rather than conceal them within a single rank. For rockwool, perlite, coco coir and clay pebbles, the appropriate question is how their properties fit a specified root-zone strategy, not which material wins independently of context [11].

Growing-media research further supports the use of physical, chemical and biological dimensions as a common vocabulary. Reviews cover peat, coir, bark, wood fibre, compost and waste-derived materials, demonstrating that a medium may be characterised through more than one property domain. [2] This breadth is valuable for coco coir and for mixtures containing perlite, but it also exposes a limitation in the available evidence. The supplied sources do not provide a harmonised dataset that measures rockwool, perlite, coco coir

and clay pebbles together under identical procedures. Direct numerical comparison of their water retention or air space would therefore exceed the evidence base [12].

III. Core Concepts and Mechanisms

Water retention and air space are complementary comparison dimensions because root-zone conditions depend on the distribution of water and air within a substrate rather than on water supply alone. Soilless-system reviews identify water-air relationships among the properties relevant to substrate culture. [1] For the four named media, this establishes the correct mechanism-level question: how does a particular material and grade shape the water-air environment generated by the irrigation regime? The supplied evidence does not establish comparable values for rockwool, perlite, coco coir and clay pebbles. Accordingly, claims that any one has categorically greater retention or aeration than all others should not be made from this evidence alone [13].

Chemical interaction refers to the ways in which substrate composition and root-zone chemistry can affect measured pH, nutrient solubility and related solution conditions. Research on peat-based substrates containing perlite or coconut coir found that substrate type and liming source influenced pH and nutrient-solubility measures, with potassium availability affected by substrate type and cation exchange capacity. [3] This does not constitute a direct comparison of the four requested materials, nor does it establish a property value for clay pebbles or rockwool. It does show why chemical interaction must remain a separate comparison dimension and why nutrient management cannot be inferred solely from a material name.

Material variability constrains the reliability of general descriptions. Reviews of growing media identify variation arising from source, processing, washing, buffering, ageing and heterogeneous input streams. [2] Related reviews of soilless production similarly identify variation associated with organic inputs and their processing. [14] These observations are particularly important when comparing coco coir and perlite-containing products, but the broader methodological point applies to every named medium: grade, formulation and preparation must be recorded before properties are compared. Without this information, a statement about water retention, air space, chemical interaction, structure or handling is a provisional category-level description rather than a verified product-level finding.

IV. Evidence Synthesis

The available evidence supports a consistent comparison framework but not a fully resolved four-media property table. Hydroponic nutrient-solution research identifies pH, electrical conductivity, individual ions and substrate moisture as management variables, and cautions that electrical conductivity alone may not precisely describe ion concentrations. [15] These measures can be used alongside water retention and air space to assess how a medium participates in root-zone management. Their value lies in documenting the operating condition of a particular system. They should not be treated as evidence that rockwool, perlite, coco coir or clay pebbles produce the same response across crops, grades or irrigation strategies.

A comparison should also retain separate physical, chemical and operational criteria. Research in other controlled-environment comparisons has found that a single commonly used metric may fail to represent the full performance of a system, and recommends considering the response relevant to the cultivated crop. [16] Applied to growing media, this supports a structured assessment in which water retention, air space, pH and EC behaviour, structural condition and handling are reported separately. Such an approach avoids converting incomplete evidence into an unsupported overall ranking. It also makes explicit which criteria were observed and which remain unmeasured for a particular material.

The strongest material-specific evidence in the package concerns substrate-dependent chemistry in peat-based mixtures containing perlite and coconut coir. Differences in substrate type and lime source were associated with differences in pH, dissolved organic matter and nutrient solubility. [3] This supports the conclusion that perlite and coco coir cannot be treated as chemically irrelevant merely because they are often discussed in broad substrate categories. However, the evidence does not extend the same controlled comparison to rockwool and clay pebbles. A balanced synthesis must therefore report chemical interaction as an essential dimension while recognising that the requested four-way comparison remains only partially evidenced.

V. Practical Implications and Limitations

For practical root-zone management, the comparison should begin with a stated crop and production system, then document the selected medium by grade, processing history and measured operating conditions. Reviews of indoor cultivation emphasise that crop and platform specificity matter when evaluating root environments, although the cited discussion is centred on aeroponics rather than substrate culture. [17] The transferable implication is limited but useful: evaluation criteria must be appropriate to the cultivation platform. For rockwool, perlite, coco coir and clay pebbles, a sound record would include the material identity, particle or product grade where relevant, preparation, irrigation arrangement and monitored pH, EC and substrate-moisture conditions.

Structure and handling are required comparison dimensions, but the supplied evidence does not provide direct, matched assessments of structural stability, reusability, dust generation, compaction, ease of transplanting or labour requirements for all four named materials. Reviews distinguish inert substrates and organic media and discuss pH and water retention as relevant considerations in soilless cultivation. [18] That supports including structure and handling in a comparison framework, not assigning unverified advantages to a particular medium. The evidence gap should be addressed through standardised tests that compare named grades of rockwool, perlite, coco

coir and clay pebbles under the same irrigation, solution and crop conditions.

The absence of a universal selection rule is not a weakness of the comparison; it is an accurate reflection of multi-dimensional root-zone management. Reviews of soilless agriculture identify agronomic, environmental, economic and technical trade-offs and argue for context-dependent assessment. [14] In the present evidence base, the most defensible recommendation is therefore procedural: use common dimensions, measure operating conditions and preserve uncertainty where direct evidence is absent. A future comparison should generate matched measurements of water retention, air space, pH and EC response, chemical interaction, structural change and handling for the four media, with grade and processing variables reported explicitly.

VI. Conclusion

Rockwool, perlite, coco coir and clay pebbles should be compared through water retention, air space, chemical interaction, structure and handling, because these dimensions connect a growing medium to root-zone management. The evidence supports a context-dependent, multi-criteria approach and confirms that substrate composition, processing and chemical conditions can influence relevant root-zone measures. [1], [2], [3] It does not support a universal ranking or a complete, directly measured four-media comparison. The appropriate conclusion is therefore conditional: suitability depends on the fit between a documented medium, crop requirements, irrigation arrangement and monitored root-zone conditions.

The highest-value next work is a standardised comparative study using defined grades of all four media and common procedures for measuring physical, chemical and handling dimensions. Such work would convert the present framework into a defensible evidence base while preserving the trade-offs that prevent a single universal optimum. [10], [14] Until then, claims about comparative material performance should remain limited to what has been measured and cited.

Acknowledgment

The author used artificial intelligence tools to assist with manuscript drafting and revision, and with LaTeX and bibliography preparation. The author reviewed all AI-assisted output and remains responsible for the final content.

References

[1] I. A. Lakhiar, H. Yan, T. N. Syed, C. Zhang, S. A. Shaikh, M. Rakibuzzaman, and R. B. Vistro, "Soilless agricultural systems: Opportunities, challenges, and applications for enhancing horticultural resilience to climate change and urbanization," *Horticulturae*, 2025.

[2] G. Barrett, P. Alexander, J. Robinson, and N. Bragg, "Achieving environmentally sustainable growing media for soilless plant cultivation systems - a review," *Scientia Horticulturae*, 2016.

[3] J. Huang, P. R. Fisher, W. R. Argo, K. Y. Jeong, and J. Altland, "Macronutrient solubility in response to the ph of soilless container substrates," *Journal of Soil Science and Plant Nutrition*, 2025.

[4] Q. Su, Y. G. Park, R. D. Kambale, J. Adelberg, R. Karthikeyan, and B. R. Jeong, "Advancing light-mediated technology in plant growth and development: The role of blue light," *Horticulturae*, 2025.

[5] R. S. Velazquez-Gonzalez, A. L. Garcia-Garcia, J. O. Barceinas-Sanchez, E. Ventura-Zapata, and J. C. Sosa-Savedra, "A review on hydroponics and the technologies associated for medium- and small-scale operations," *Agriculture*, 2022.

[6] G. W. Anyangoa, G. D. Bhowmicka, and N. S. Bhattacharyab, "A critical review of irrigation water quality index and water quality management practices in micro-irrigation for efficient policy making," *Desalination and Water Treatment*, 2024.

[7] N. P. K. Semananda, J. D. Ward, and B. R. Myers, "A semi-systematic review of capillary irrigation: The benefits, limitations, and opportunities," *Horticulturae*, 2018.

[8] S. Scott and C. Villouta, "Dissolved oxygen limitation and pythium root rot in strawberry nft systems: Mechanisms, research gaps, and prospects for substrate-free production," *Frontiers in Plant Science*, 2026.

[9] C. E. Boyd, C. S. Tucker, and B. Somridhivej, "Alkalinity and hardness: Critical but elusive concepts in aquaculture," *Journal of the World Aquaculture Society*, 2016.

[10] K. Saito and E. Goto, "Lighting design optimization in a plant factory using an optical simulation and differential evolution," *Horticulturae*, 2025.

[11] C. Mai, A. Mojiri, S. Palanisami, A. Altaee, Y. Huang, and J. L. Zhou, "Wastewater hydroponics for pollutant removal and food production: Principles, progress and future outlook," *Water*, 2023.

[12] M. Duan, C. Han, X. Zhang, Z. Wei, Z. Wang, and B. Zhang, "Spatial and temporal dynamics of photosynthetically active radiation in crops: Effects of canopy structure on yield," *Agronomy*, 2025.

[13] O. V. Obayomi, D. C. Olawoyin, O. Oguntimehin, L. S. Mustapha, S. O. Kolade, P. O. Oladoye, S. Oh, and K. S. Obayomi, "Exploring emerging water treatment technologies for the removal of microbial pathogens," *Current Research in Biotechnology*, 2024.

[14] M. Elakrouch, M. Mohaddab, A. Rachid, and M. H. Jijakli, "Soilless agriculture at a crossroads: Strengths, challenges, and prospects of hydroponics, aquaponics, and bioponics in relation to precision farming," *Sustainability*, 2026.

[15] E. Fathidarehnijeh, M. Nadeem, M. Cheema, R. Thomas, M. Krishnapillai, and L. Galagedara, "Current perspective on nutrient solution management strategies to improve the nutrient and water use efficiency in hydroponic systems," *Can. J. Plant Sci*, 2024.

[16] L. Balázs, Z. Dombi, L. Csambalik, and L. Sipos, "Characterizing the spatial uniformity of light intensity and spectrum for indoor crop production," *Horticulturae*, 2022.

[17] B. M. Eldridge, L. R. Manzoni, C. A. Graham, B. Rodgers, J. R. Farmer, and A. N. Dodd, "Getting to the roots of aeroponic indoor farming," *New Phytologist*, 2020.

[18] A. Fussy and J. Papenbrock, "An overview of soil and soilless cultivation techniques-chances, challenges and the neglected question of sustainability," *Plants*, 2022.