Chemical properties and inertness of growing media

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

***Abstract*—Growing media are commonly used to provide root support in hydroponic cultivation, yet they may also influence the chemical environment around roots. This paper examines the practical meaning of inertness by distinguishing media that have comparatively limited chemical interaction from media that retain, exchange, release or adsorb ions. It synthesises evidence on cation exchange capacity, nutrient retention, pH buffering, dissolution, adsorption and precipitation, with attention to the relationship between substrate properties and nutrient-solution behaviour. The evidence indicates that inertness is a relative operational property rather than an absolute material condition. Inorganic and organic media differ in chemical stability, water retention, exchange behaviour and biological activity, so their effects on root-zone chemistry cannot be inferred solely from their physical appearance or use in a soilless system. The paper concludes that media selection and nutrient management should consider the combined behaviour of the medium, irrigation water and nutrient solution. Better characterisation of media under operating conditions is needed to determine when chemical interactions materially affect crop nutrition and solution control.**

I. Introduction

Hydroponic growing media are often selected primarily for root support, aeration and water retention, but these physical functions do not remove their potential chemical influence. Soilless cultivation literature distinguishes among substrate categories through differences in nutrient retention, cation exchange capacity, microbial activity and water behaviour. These differences mean that a medium can alter the chemical environment experienced by roots even where nutrients are supplied in solution. The central issue is therefore not whether a medium is present, but whether its interactions with dissolved ions are sufficiently small or sufficiently predictable for it to be treated as relatively inert in operation [1], [2].

Cation exchange capacity is especially important because it describes the capacity of a material to retain and exchange positively charged ions. In a substrate with appreciable exchange behaviour, nutrient ions may be temporarily retained rather than remaining entirely in the solution phase, thereby changing their immediate availability in the root zone. This can moderate concentration changes in some circumstances, but it can also complicate interpretation of solution measurements and nutrient adjustments. Evidence linking substrate exchange capacity and retention behaviour to nutrient availability indicates that media selection is part of nutrient management, not merely a mechanical design decision [2], [3].

The term inert is useful only when it is qualified by the relevant chemical, biological and operating conditions. A medium may be relatively unreactive with a particular nutrient solution while still affecting pH, retaining ions, accumulating deposits or changing behaviour after repeated irrigation. Hydroponic reviews accordingly treat inertness as a property requiring chemical and operational qualification rather than as an absolute label. This paper explains the mechanisms behind those qualifications, compares relatively inert and chemically interactive media, and considers the implications for root-zone management [4], [5].

II. Background and Scope

Chemical behaviour in the root zone cannot be separated completely from the chemistry of the incoming water and nutrient solution. Alkalinity and hardness can influence pH adjustment, while carbonate-related reactions may contribute to precipitation and scale formation under suitable conditions. These processes demonstrate that dissolved ions can be redistributed or removed from solution through chemical equilibria, independently of plant uptake. For growing media, the implication is that observations of pH or conductivity may reflect interactions among water chemistry, fertiliser salts and substrate surfaces or constituents, rather than the nutrient formulation alone [6], [7].

Prior hydroponic scholarship considers substrate selection in relation to chemical properties, buffering capacity and nutrient interactions as well as physical suitability. This framing is valuable because it rejects a simple binary distinction between active and inactive materials. A medium may have low chemical reactivity relative to an organic alternative, yet still contribute to local chemical conditions through its initial composition, surface properties or retained solution. The relevant practical question is therefore whether a particular material materially changes the solution available to roots over the intended cultivation period [4], [8].

pH and electrical conductivity provide useful indicators of solution condition, but neither measurement independently identifies the mechanism causing a change. pH is associated with nutrient solubility and precipitation behaviour, whereas conductivity is shaped by the concentration and mobility of dissolved ions. A medium that changes retention, dissolution or precipitation can therefore affect measured solution behaviour without necessarily producing a simple or uniform nutrient response. This paper is limited to these chemical interactions and does not treat inertness as a guarantee of biological cleanliness, crop performance or universal suitability [4], [9].

III. Core Concepts and Mechanisms

Relatively inert and chemically interactive media should be understood as positions on a continuum of material behaviour. Reviews of soilless media compare inorganic and organic substrates through chemical stability, cation exchange capacity, water retention and nutrient behaviour. Materials with lower exchange capacity and greater chemical stability may exert less direct influence on dissolved nutrient composition, whereas organic or otherwise reactive materials may retain or exchange ions more readily. However, chemical stability alone is not a complete predictor because water retention determines the volume and residence time of solution held near roots [10], [11].

Ion exchange, adsorption, dissolution and buffering describe distinct pathways through which a medium can affect hydroponic solution behaviour. Ion exchange involves reversible association of ions with charged sites in the medium. Adsorption involves retention at surfaces, which may reduce the dissolved fraction of a substance. Dissolution adds material from the medium to solution, while buffering moderates changes in acidity or alkalinity. These processes can alter pH, electrical conductivity, nutrient retention and solubility, although their importance depends on the medium, solution composition and irrigation conditions [10], [12].

The distinction between inorganic and organic media should not be converted into a rule that one class is always inert and the other always chemically active. Substrate categories differ in chemical and biological behaviour, and no single medium is universally optimal across crops or production settings. A chemically interactive medium may offer retention or buffering behaviour that is useful in one management context but undesirable where rapid and direct solution control is required. Conversely, a relatively inert medium may simplify interpretation of nutrient inputs while offering less capacity to moderate chemical fluctuations [10].

IV. Evidence Synthesis

Electrical conductivity is often used to assess the ionic status of nutrient solution, but it is not a direct inventory of individual nutrients. Electrolyte conductivity depends on the number of free ions, their mobility, concentration and interactions such as ion pairing. Accordingly, a conductivity change in a substrate system can indicate a change in dissolved ionic conditions without revealing whether the cause is nutrient uptake, ion retention, dissolution, dilution or precipitation. This limitation reinforces the need to interpret conductivity alongside pH, water chemistry and the known chemical behaviour of the growing medium [13].

Buffering and dissolution are particularly important where alkalinity and hardness influence the chemical response of irrigation water. Bicarbonate and carbonate species can affect pH control and can participate in precipitation processes, while hardness-related ions contribute to the overall ionic composition of water. In a substrate-based system, such solution chemistry may interact with the medium's capacity to retain water or ions. A claim that the medium is inert should therefore be limited to the conditions tested, because changing water chemistry can alter the relevance of otherwise modest material interactions [14].

Organic growing media are widely discussed as chemically and biologically interactive alternatives to more inert media. Their importance in the present context is not that all organic materials have identical effects, but that their composition can make nutrient retention, pH response and biological activity more consequential to root-zone conditions. This creates a management trade-off: interactions may support water and nutrient retention, yet they can also make solution behaviour less directly attributable to fertiliser input. The evidence supports comparative assessment of media rather than categorical assumptions about their chemical neutrality [15].

V. Practical Implications and Limitations

Organic and biological inputs can make hydroponic systems chemically and biologically dynamic, which further limits any simple interpretation of medium inertness. Reviews comparing hydroponics, aquaponics and bioponics show that organic inputs and biological activity create conditions that differ from mineral nutrient solutions alone. Although this paper focuses on growing media, the comparison illustrates that material behaviour must be interpreted within the wider root-zone system. A medium may appear chemically stable in a mineral solution yet behave differently where organic constituents, microbial activity or changing solution composition alter the conditions at its surfaces [16].

Routine solution control should recognise that bicarbonate neutralisation, acid dosing, pH adjustment, electrical conductivity changes and carbonate precipitation may be interconnected. These processes can produce apparent changes in nutrient-solution behaviour that are not attributable to a single factor. For this reason, media should be assessed with the actual irrigation water and nutrient formulation intended for use. Operational monitoring can identify changing conditions, but measurements should not be treated as proof that the medium itself is the sole source of a chemical shift [17].

Adsorption and ion exchange are also relevant because hydroponic solutions can accumulate dissolved substances that require treatment or removal. Evidence on solution treatment identifies adsorption and ion-exchange processes as mechanisms capable of altering dissolved constituents. This does not establish that every growing medium will provide useful treatment, nor does it justify assuming that retention is beneficial. Instead, it highlights a validation requirement: where nutrient balance is important, the direction, magnitude and persistence of a medium's retention behaviour should be determined rather than inferred from the label inert [18].

VI. Conclusion

Growing media are not chemically inert in an absolute sense. The evidence shows meaningful differences among media in chemical stability, cation exchange capacity, nutrient retention, water behaviour, buffering potential and biological interaction. Relatively inert media may reduce direct material

influence on nutrient solution, but they remain part of a root-zone system shaped by irrigation-water chemistry, dissolved ions and operating conditions. Conversely, chemically interactive media can retain, exchange, release or adsorb ions, making the material relevant to nutrient availability and solution interpretation [2], [4], [10].

The most defensible use of inertness is therefore conditional: it describes limited chemical interaction for a specified medium, solution and operating context, not permanent chemical neutrality. Future validation should compare media using the intended water source and nutrient formulation while observing pH, conductivity and nutrient behaviour over time. Such assessment would clarify whether measured changes arise predominantly from the medium, the solution chemistry or their interaction, and would support more reliable selection of root-support materials [13], [14], [17].

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] N. Joshi, R. Kaur, and T. Nawaz, "The soil-root nexus: how soil health shapes plant nutrient uptake and food nutritional security," *Plant and Soil*, 2026.

[2] A. Tuxun, Y. Xiang, Y. Shao, J. E. Son, M. Yamada, S. Yamada, K. Tagawa, B. Baiyin, and Q. Yang, "Soilless cultivation: Precise nutrient provision and growth environment regulation under different substrates," *Plants*, 2025.

[3] I. Szekely and M. H. Jijakli, "Bioponics as a promising approach to sustainable agriculture: A review of the main methods for producing organic nutrient solution for hydroponics," *Water*, 2022.

[4] 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.

[5] 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.

[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] J. C. Majsztrik, R. T. Fernandez, P. R. Fisher, D. R. Hitchcock, J. Lea-Cox, J. S. Owen, Jr., L. R. Oki, and S. A. White, "Water use and treatment in container-grown specialty crop production: A review," *Water, Air, & Soil Pollution*, 2017.

[8] 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.

[9] 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.

[10] 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.

[11] 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.

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

[13] W. Zhang, X. Chen, Y. Wang, L. Wu, and Y. Hu, "Experimental and modeling of conductivity for electrolyte solution systems," *ACS Omega*, 2020.

[14] 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.

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

[16] 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.

[17] C. Cambra, S. Sendra, J. Lloret, and R. Lacuesta, "Smart system for bicarbonate control in irrigation for hydroponic precision farming," *Sensors*, 2018.

[18] S. Wang, Y. Kleiner, S. M. Clark, V. Raghavan, and B. Tartakovsky, "Review of current hydroponic food production practices and the potential role of bioelectrochemical systems," *Reviews in Environmental Science and Bio/Technology*, 2024.