Interpreting pH together with EC and plant symptoms

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

***Abstract*—Hydroponic crop management often relies on routine observation of solution pH, electrical conductivity, and visible plant symptoms, yet these signals are frequently overinterpreted as direct diagnoses. The central problem is that pH and EC describe different aspects of nutrient solution behaviour and neither variable identifies the specific cause of plant stress on its own. This paper synthesises accepted evidence on how pH, EC, and plant observations should be interpreted together as contextual evidence rather than as diagnostic proof. The review shows that EC reflects total ionic strength rather than individual nutrient concentrations, while pH influences solubility, precipitation, and the chemical availability of ions. Evidence from nutrient mass balance, bicarbonate control, and hydroponic nutrient management demonstrates that similar EC readings can conceal different elemental imbalances, and that similar plant symptoms can emerge from distinct chemical, biological, or physical causes. The paper therefore argues for trend-based interpretation that links measurements to plausible mechanisms and concurrent plant observations. It also sets a clear boundary around the present task: the goal is chemical interpretation of operating signals, not definitive disorder identification or detailed measurement methodology. The practical implication is that growers and analysts should use pH and EC as structured clues that guide further investigation, while avoiding unsupported diagnosis from isolated readings or symptoms alone.**

I. Introduction

Electrical conductivity is attractive in hydroponics because it offers a rapid numerical summary of solution strength, but the available evidence shows that this apparent simplicity can mislead interpretation. In a nutrient film technique lettuce system, nutrient mass balance revealed that a stable or managed EC did not imply balanced nutrient uptake: calcium accumulated, potassium and manganese declined, and substantial fractions of several nutrients remained in solution, with losses differing by element rather than moving as a single pool [1]. The implication is that EC should be read as a bulk signal of dissolved ions, not as a direct representation of nutritional sufficiency. When plant symptoms appear, the analytical task is therefore to ask what mechanisms could produce the observed combination of EC behaviour, pH behaviour, and crop response, rather than to assume that one number already explains the disorder [2].

The same caution applies to pH, but for a different chemical reason. Accepted review evidence states that pH alters nutrient solubility and precipitation, whereas EC estimates only the total concentration of charged species and does not identify which elements are present or unavailable [3]. As a result, a visually similar symptom pattern may emerge from different chemical pathways, including precipitation losses, altered ion availability, or imbalanced nutrient composition under similar total conductivity. Interpreting pH together with EC is therefore necessary but still not sufficient for diagnosis. Their value lies in narrowing plausible explanations and in showing whether the root-zone environment is moving toward conditions that could reasonably impair uptake, while leaving open the possibility that several distinct causes remain consistent with the same observation set [4].

A further source of confusion is the tendency to merge chemical interpretation with instrument practice. Evidence from a review of photosynthetically active radiation measurement is useful here because it represents a clearly methodological literature: calibration, sensing principles, error sources, and benchmarking are all essential, but they answer a different question from the interpretive task addressed in this paper [5]. By analogy, the present discussion is not about how to design sensor systems or validate probes in detail. It is about how to reason from pH, EC, and plant observations once measurements have been obtained. The paper therefore develops a bounded argument: pH and EC are contextual signals, not diagnoses, and their proper use depends on trend interpretation, mechanism-based reasoning, and explicit recognition of uncertainty [6].

II. Background and Scope

Prior hydroponic literature consistently treats pH and EC as central operating variables, but it also shows why neither variable should be interpreted in isolation. One accepted review notes that hydroponic pH generally needs to remain within an appropriate range, commonly around 5 to 7, because deviations can alter nutrient solubility and promote precipitation, while EC reflects total ionic concentration rather than the concentration of each nutrient [3]. This distinction matters because the two variables report different layers of system behaviour. EC can suggest whether total dissolved salts are rising, falling, or remaining similar, whereas pH provides clues about chemical speciation and the likelihood that ions remain available in solution. The scope of this paper begins from that basic division and asks how those signals should be combined with plant observations without overstating what they prove [7].

Recent integrated hydroponic monitoring research strengthens the case for multivariable interpretation. In an AI-enabled platform, nutrient deficiency classification improved when pH

and EC were combined with temperature, humidity, water level, and temporal features, and the reported overlap between nitrogen and potassium sensor signatures showed that even richer datasets can struggle to separate causes cleanly [8]. This evidence does not make automation the subject of the present paper, but it does reinforce a narrower point of chemical reasoning: if even integrated models benefit from combining multiple signals and still encounter overlapping patterns, then a human interpreter should be especially cautious about assigning a single diagnosis from pH or EC alone. Plant symptoms should therefore be treated as corroborating or disconfirming observations within a broader evidence pattern, not as simple labels attached to a single reading [9].

The same integrated platform also clarifies the boundary of this review by illustrating what lies outside it. That study develops sensors, telemetry, machine learning classification, and closed-loop control, which are valuable for monitoring and automated decision support, but they belong primarily to the domains of measurement architecture and inference systems rather than to the interpretive chemistry question addressed here [8]. Accordingly, this paper does not attempt to specify sensor design, threshold engineering, or algorithm selection. Its explanatory purpose is more limited and more fundamental: to synthesise how pH, EC, and visible plant responses can be read together as evidence of possible nutrient-solution processes, while preserving the distinction between chemical interpretation, formal disorder diagnosis, and measurement methodology [10].

III. Core Concepts and Mechanisms

A central mechanism for interpreting pH alongside EC is buffering by bicarbonate and related alkalinity chemistry. Evidence from smart bicarbonate control in hydroponic irrigation shows that elevated pH can reflect bicarbonate load rather than a simple abstract shift in acidity, and that acid neutralisation changes both pH and EC because it alters the ionic composition of the solution during treatment [11]. This means that a rise in pH should not automatically be read as evidence of nutrient deficiency, just as a change in EC after acid addition should not automatically be read as a change in plant uptake. Both measurements are embedded in chemical processes involving neutralisation and dissolved ions. The interpretive implication is that pH trends gain meaning only when connected to plausible sources of buffering, amendment history, and the timing of observed plant responses.

The same bicarbonate-control work also helps separate chemical meaning from engineering implementation. Although the paper includes sensor architecture, wireless communication, and automated adjustment, its chemically relevant contribution is the demonstrated co-variation among alkalinity, bicarbonate neutralisation, pH, and EC [11]. For the purposes of interpretation, that co-variation matters more than the hardware design because it explains why a pH correction can carry an EC consequence and why the same final pH value may arise from different underlying water chemistries. Two systems could show a similar pH reading while differing in buffering load, recent acid dosing, or residual ionic composition. The limitation is equally important: pH cannot be treated as a self-explanatory state variable. It becomes informative only when placed in the chemical history of the solution and examined as part of a time sequence.

Broader hydroponic nutrient-management evidence leads to the same conclusion from a system perspective. A recent review states directly that EC measures total dissolved ions rather than individual nutrient concentrations, and it documents that crop performance problems may arise from salinity accumulation, ion imbalance, nutrient renewal interval, crop stage, and seasonal demand [12]. These factors create several plausible pathways from the same or similar EC values to different plant outcomes. A moderate EC may conceal an unfavourable ion ratio, while a rising EC may indicate concentration of salts, incomplete renewal, or altered uptake relative to water consumption. Plant symptoms observed at the same time therefore need to be interpreted against operating history and developmental context. The mechanism-based lesson is that pH and EC are most useful as trend signals embedded in crop, water, and management context, not as stand-alone verdicts.

IV. Evidence Synthesis

The available evidence consistently supports a boundary between interpretation and methodology. A lighting-uniformity paper in controlled environment agriculture is explicitly a benchmarking and measurement methods study, concerned with how to quantify spatial variability and evaluate a metric appropriately [13]. Its substantive value for the present topic is negative but important: it shows that method papers solve questions of measurement design, standardisation, and technical validation, whereas this paper addresses the distinct question of how to reason from already observed pH, EC, and symptom patterns. Maintaining that distinction reduces category errors. A reader who confuses interpretive chemistry with measurement protocol may seek precision from the wrong place, expecting diagnosis to emerge automatically from better instrumentation when the main limitation may instead be causal ambiguity in the biological system.

A broader review of soil and soilless cultivation reinforces the same boundary while also sharpening the substantive scope of interpretation. That review frames pH, temperature, and nutrient concentration as central operating variables in hydroponics, yet treats issues such as disease spread, disinfection, and sustainability as separate concerns [14]. This separation is analytically useful because it confirms that pH and EC belong among core operating signals, but not among complete explanatory accounts of crop health. Visible symptoms may be shaped by chemical operating conditions, but they may also intersect with pathogen pressure or other system stresses that require different evidentiary pathways. The practical outcome is that interpreting pH and EC with plant observations can justify hypotheses about nutrient-solution behaviour, while still stopping short of a full diagnosis whenever the same symptom complex could plausibly arise outside strictly chemical causes.

General root-zone chemistry provides a final layer of synthesis, but with clear limits. A soil-root review supports the idea of pH as a master variable and highlights processes such as cation exchange that influence nutrient uptake environments [15]. These principles help explain why pH deserves interpretive weight even when EC appears stable, because root access to nutrients depends not only on total ions but also on chemical conditions that shape availability. However, this source is not a direct hydroponic nutrient-solution interpretation study, so it cannot by itself justify specific hydroponic diagnostic rules. Its contribution is conceptual rather than prescriptive. When combined with the more direct hydroponic evidence, it supports a cautious synthesis: pH has strong mechanistic importance, EC has strong monitoring convenience, and plant symptoms matter as biological evidence, but no single signal should be promoted to definitive proof.

V. Practical Implications and Limitations

The strongest practical implication is diagnostic humility. Evidence from a bioponics review shows that poor growth can arise from multiple causes, including ammonium toxicity, phytotoxic organic compounds, oxygen-related constraints, nutrient imbalance, and microbial effects [16]. Although that literature is centred on organic nutrient solutions rather than conventional hydroponics, it still demonstrates a general interpretive problem: similar visible symptoms can emerge from very different mechanisms. For hydroponic practice, this means that pH and EC should be used to structure questions rather than close them. A pattern of high pH with chlorosis, for example, may justify concern about nutrient availability, but it does not eliminate other plausible explanations. The limitation of signal-based interpretation is therefore not merely a lack of data volume; it is the many-to-one relationship between symptoms and causes.

A second implication is that acceptable operating readings do not guarantee balanced nutritional conditions. The reviewed soilless-cultivation literature supports pH and EC as key nutrient-solution controls, yet also reports examples in which nutrient accumulation occurred despite unchanged yield or otherwise acceptable apparent performance [17]. This weakens any interpretive habit that equates a tolerable crop appearance or familiar EC range with confirmed chemical adequacy. In practice, the joint reading of pH, EC, and plant symptoms should remain provisional and comparative. Trends across time, responses to renewal or adjustment, and consistency across plants matter more than isolated snapshots. The limitation is that pH and EC can signal that conditions deserve attention without revealing whether the main issue is elemental imbalance, buffering chemistry, crop demand shift, or another operating factor.

A third implication concerns the scope of what can reasonably be concluded from symptoms themselves. The same soilless review describes cases where changes in EC or nutrient manipulation altered tissue composition, stress responses, or yield through different causal routes [17]. This supports the claim that similar outward plant responses need not indicate the same disorder. Consequently, the reader should not treat chemical interpretation as equivalent to formal disorder identification, nor should one expect it to substitute for dedicated methods literature on sensing and calibration or for broader system analysis of management and modelling challenges [5], [18]. The present evidence base supports a disciplined middle position: pH and EC, interpreted with plant observations, can indicate plausible mechanisms and guide next investigative steps, but they cannot by themselves deliver a scientifically secure diagnosis in every case.

VI. Conclusion

The accepted evidence supports a clear and restrained conclusion. pH and EC are valuable hydroponic signals because they capture complementary aspects of nutrient-solution behaviour: pH relates to chemical availability, solubility, buffering, and precipitation, while EC reflects the aggregate concentration of dissolved ions rather than the identity or balance of individual nutrients [3], [11], [12]. Plant symptoms add essential biological context, but they also introduce ambiguity because similar visible responses may arise from distinct chemical, physical, or biological causes [16], [17]. The most defensible interpretation is therefore pattern-based and mechanism-aware. Readers should use pH, EC, and plant observations together to generate and rank plausible explanations, to assess whether system behaviour is chemically coherent, and to decide what additional evidence is needed. What they should not do is treat any one of these signals as a diagnosis in itself.

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] K. Vought, H. K. Bayabil, J. Pompeo, D. Crawford, Y. Zhang, M. Correll, and A. Martin-Ryals, "Dynamics of micro and macronutrients in a hydroponic nutrient film technique system under lettuce cultivation," *Heliyon*, 2024.

[2] 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.

[3] 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.

[4] 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.

[5] J. Liu, Y. Cai, X. Pei, and X. Yu, "Advances in research and application of techniques for measuring photosynthetically active radiation," *Remote Sens*, 2025.

[6] 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.

[7] 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.

[8] J. Arshad, F. Azeem, A. Butt, M. Chaudhary, R. S. Safdar, M. K. Joyo, I. Ahmad, P. Valsalan, and H. M. Ahmed, "Ai-enabled iot-based hydroponic farming with embedded automation and nutrient prediction," *Future Internet*, 2026.

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

[10] C. Grierson, E. Nielsen, T. Ketelaar, and J. Schiefelbein, "Root hairs," *The Arabidopsis Book*, 2014.

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

[12] 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," *Canadian Journal of Plant Science*, 2024.

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

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

[15] 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.

[16] 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.

[17] 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.

[18] 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.