Electrical conductivity and nutrient concentration

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***Abstract*—Electrical conductivity, EC, is widely used in hydroponics as a rapid indicator of nutrient solution strength, yet its meaning is often simplified. This paper examines what EC reveals about a hydroponic nutrient solution and what it leaves unresolved. Drawing on accepted review and primary-study evidence, the paper explains that conductivity arises from the presence of dissolved ions whose ability to carry current depends on both the number of free charge carriers and their mobility. On that basis, EC can serve as a useful aggregate signal of dissolved ionic concentration, and rising ion concentration commonly raises EC, but the relationship is not perfectly specific or compositionally transparent [1], [2]. Evidence from hydroponic and related literature shows that EC estimates total ion concentration rather than the concentrations of individual nutrients, and that solutions managed at fixed EC can still drift substantially in ionic composition over time [3], [4], [5]. A lettuce nutrient film technique study demonstrates that calcium, potassium, and manganese can change differently under controlled EC, showing that similar EC values do not guarantee balanced nutrition [3]. The practical implication is that EC is a valuable monitoring variable, but it must be interpreted in context and complemented by composition-aware management when nutrient balance matters.**

I. Introduction

Electrical conductivity is central to hydroponic practice because it offers a fast, low-cost way to infer whether a nutrient solution contains enough dissolved ionic material to support plant growth. Its usefulness begins with the physics of electrolyte conduction. Conductivity depends on the number of free ions available to carry charge and on how readily those ions move through the solution. As concentration rises, conductivity often rises as well, but that response is shaped by ion mobility, ion association, and interactions that can reduce the effectiveness of charge transport at higher concentrations [2]. EC therefore has a sound physical basis as an aggregate indicator, yet its signal is inherently a combined response rather than a direct readout of each nutrient species.

In hydroponic management, this aggregate character makes EC both practical and potentially misleading. A hydroponic nutrient solution can be adjusted to a target EC, and that target may suggest an acceptable overall ionic strength, but the number does not specify which ions produced the reading. Evidence from lettuce grown in a recirculating nutrient film technique system explicitly states that EC reflects total dissolved ions rather than concentrations of individual nutrients, and further shows that solution composition changed substantially through time despite EC control [3]. This matters because growers often need more than confirmation that ions are present in bulk. They need confidence that essential nutrients remain available in suitable proportions.

The central question, then, is not whether EC is useful, but what kind of information it actually provides. The same lettuce study offers a clear warning: under fixed EC setpoints, individual nutrients did not behave uniformly. Calcium accumulated, while potassium and manganese declined, and other nutrients remained in solution at markedly different fractions [3]. This paper argues that EC should be understood as an aggregate signal of dissolved ionic concentration, not as proof of nutrient balance. To develop that argument, the paper reviews the conceptual basis of EC, explains the mechanisms that connect ions to conductivity, synthesises hydroponic evidence on interpretation limits, and outlines the practical implications for nutrient monitoring.

II. Background and Scope

Across relevant literature, EC is consistently treated as an indicator of dissolved ionic content rather than a direct chemical assay. A review of irrigation water quality explains that total dissolved solids represent dissolved constituents, while EC indicates total salt concentration and generally rises with higher ion concentration [1]. This framing supports the common hydroponic use of EC as a proxy for nutrient solution strength. At the same time, the same review notes that indices based on EC have limited scope [1]. That limitation is important for hydroponics because plant performance depends not only on the total amount of dissolved ionic material, but also on whether particular essential nutrients are present in the right relative amounts.

Hydroponic reviews sharpen this distinction by placing EC within an operational crop-management context. One review defines EC as an estimate of total ion concentration, notes that low EC can indicate nutrient scarcity and high EC can indicate salt stress, and explicitly warns that EC does not specify concentrations of individual elements [4]. This is directly relevant to the reader question addressed here. A hydroponic solution may register within a nominally acceptable EC range while still being chemically unbalanced. In other words, EC can indicate that ionic material is present at a broadly meaningful level, but it cannot confirm whether nitrogen, potassium, calcium, magnesium, or micronutrients are proportioned appropriately for the crop.

The scope of this paper is therefore explanatory and synthetic rather than experimental. It does not present a new measurement method or a new dataset. Instead, it clarifies how accepted evidence should shape interpretation of EC in hydroponic nutrient solutions. That need for careful interpretation is reinforced by conductivity modelling work showing

that conductivity depends not only on total concentration, but also on ion association, ion mobility, electrolyte identity, and solvent dielectric properties [2]. These factors mean that similar conductivity values can arise in materially different solution chemistries. The gap addressed by this paper is not a lack of EC measurements, but a need to understand what those measurements can justify scientifically and what they cannot.

III. Core Concepts and Mechanisms

At the level of practical interpretation, EC is best understood as a proxy for the collective presence of dissolved ions. A recent review on nutrient solution management states this clearly by treating EC as an aggregate-ion indicator while also identifying its core limitation: it does not provide ion-specific composition [5]. That distinction matters because hydroponic nutrition is not governed by total ionic content alone. Plant uptake depends on the identities, ratios, and changing availability of specific nutrients. An EC meter therefore reports an integrated electrical response of the solution, not a breakdown of nutrient adequacy. As a consequence, EC is informative about overall solution strength, but it is chemically nonspecific and cannot by itself diagnose whether the nutrient recipe remains balanced through time.

This aggregate property follows from what conductivity physically measures. When ions dissolve, they contribute mobile charge carriers that enable electric current to pass through the solution. Yet the measured EC condenses that behaviour into one bulk number. The lettuce nutrient film technique study captures the practical meaning of this by explicitly stating that EC reflects total dissolved ions rather than individual nutrients [3]. Although that study is not a mechanistic electrochemistry paper, it aligns well with the broader physical picture: the meter senses the combined conductive effect of all dissolved ionic species present. The implication is that EC is inherently unable to distinguish whether a given reading comes from a balanced nutrient formulation or from an imbalanced mixture dominated by only some ions.

The same conceptual limit is reinforced by review evidence that draws on hydroponic observations under controlled EC. A soilless cultivation review cites lettuce evidence showing that increasing EC from 1.2 to 1.6 dS/m did not significantly alter biomass, while calcium accumulated and potassium and manganese declined [6]. Even though this is second-order review evidence, it supports a crucial mechanism of interpretation: the bulk electrical signal can remain within a controlled range while biologically important ions change in different directions. Thus, a stable or similar EC does not mean the nutrient solution is chemically unchanged. Instead, EC should be read as a compressed response to the whole ionic ensemble, with nutrient-specific information hidden inside that aggregate signal.

IV. Evidence Synthesis

When the accepted evidence is considered together, the first robust conclusion is that EC tracks aggregate ionic loading reasonably well, but only at a general level. The irrigation-water review states that EC indicates total salt concentration and rises with higher ion concentration [1]. Hydroponic reviews likewise treat EC as an estimate of total ion concentration or an operational indicator of nutrient strength [4], [7]. These sources converge on the idea that EC is meaningful because dissolved ions produce the conductive pathway measured by the instrument. However, they do not all contribute equally to explanation. Some establish operational relevance, while the conductivity modelling paper provides the stronger physical account of why conductivity is tied to free ions and their mobility [2]. Together, they support EC as an informative but simplified aggregate measure.

The second conclusion is that aggregate meaning does not translate into compositional certainty. The irrigation-water review notes that EC measures total dissolved salt concentration rather than the identities of dissolved constituents [1]. That point is conceptual in the review literature, but it becomes empirical in the hydroponic lettuce study, where nutrient concentrations shifted differently under managed EC [3]. Considered together, these sources show why similar ionic totals need not imply similar nutrient composition. A solution can maintain an acceptable EC while some essential nutrients are depleted and others accumulate. This is the core interpretive hazard in hydroponics: the number can remain plausible while the chemistry required for balanced crop nutrition drifts away from the intended formulation.

A third conclusion concerns the limits of explanation in hydroponic review literature itself. One hydroponics review defines EC as an estimate of total ion concentration, which is useful and directly relevant, but it does not explain the conduction mechanism in physical terms [4]. Another review offers operational targets and treats EC as a control variable rather than unpacking how ions, mobility, and interactions shape the reading [8]. A broader review identifies pH, temperature, and nutrient concentration as key hydroponic parameters, yet it does not develop EC as an aggregate ion metric in detail [9]. This pattern suggests that hydroponic practice often relies on EC instrumentally, while the deeper meaning of the signal is under-explained unless electrochemical evidence is brought into the interpretation.

V. Practical Implications and Limitations

For hydroponic decision-making, the most important practical implication is that EC cannot confirm nutrient balance. A hydroponics review explicitly cautions that EC estimates total ion concentration but does not specify concentrations of individual elements [4]. This means that EC is well suited to detecting broad departures in solution strength, such as an overall drop linked to nutrient depletion or a rise associated with salinity, but it is poorly suited to identifying which nutrients changed. The limitation is not a minor technicality, it is a structural feature of the measurement. If a grower asks whether the solution contains the correct proportion of calcium relative to potassium, or whether a micronutrient has declined to a problematic level, EC alone cannot provide the answer.

A second implication is that target ranges should be interpreted cautiously rather than treated as self-sufficient indicators of nutritional adequacy. A systematic review of soilless agricultural systems treats EC as an operational indicator of nutrient strength and notes that values that are too low or too high can be associated with deficiency or osmotic stress [7]. That is useful guidance, but it does not eliminate the proxy problem. A target EC can help maintain the solution within a workable overall range, yet it cannot guarantee that the crop is receiving the right elemental profile. Accordingly, EC is valuable for routine monitoring, but the biological meaning of any given reading depends on crop context, solution history, and whether the underlying nutrient formulation remains aligned with plant demand.

The physical literature clarifies why this interpretive caution is scientifically necessary. Conductivity modelling shows that solution conductivity depends on the number of free ions and their mobility, and that ion association and short-range interactions can reduce effective charge transport as concentration increases [2]. The same work shows that conductivity is influenced by electrolyte identity and solution environment, not by concentration alone [2]. In hydroponic terms, this supports the principle that similar EC values can arise from different ionic compositions and different solution states. Therefore, EC should be combined with composition-aware nutrient management, especially in recirculating systems where uptake and accumulation progressively alter the solution [3], [5]. The main evidence gap is not whether EC is useful, but how often growers verify composition when the aggregate signal appears acceptable.

VI. Conclusion

Electrical conductivity is a useful hydroponic measurement because it is grounded in the conductive behaviour of dissolved ions and therefore provides a rapid aggregate indication of nutrient solution strength [1], [2]. The evidence reviewed here supports a clear answer to the central question. EC tells the grower something important about total dissolved ionic content, and low or high values can signal broad nutritional scarcity or excessive salinity risk [4], [7]. However, EC does not identify individual ions, does not report elemental proportions, and does not prove that essential nutrients are present in the correct balance [4], [5].

The strongest practical lesson comes from hydroponic evidence showing that solutions maintained at controlled EC can still undergo substantial compositional drift, with some nutrients accumulating while others decline [3], [6]. EC should therefore be treated as an aggregate monitoring signal, not as a complete description of nutrient chemistry. Its value lies in screening overall ionic status quickly, while its limitation lies in masking which ions created the reading. Interpreting concentration in context means relating EC to crop needs, recirculation history, and, where balance matters, additional composition-specific assessment rather than relying on the conductivity number alone.

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References

[1] 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.

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

[3] 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.

[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] 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.

[6] 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.

[7] 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.

[8] 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.

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