Source water quality and crop performance

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***Abstract*—Source water is not a neutral carrier for hydroponic fertilisers. Its initial chemical and biological composition shapes nutrient-solution preparation, alters root-zone conditions, and influences the management effort needed to maintain acceptable crop performance. This paper synthesises review-based evidence on why two water sources can behave differently even when the same hydroponic nutrients are added. The evidence shows that meaningful differences among water sources include variation in pH, electrical conductivity, dissolved and suspended solids, alkalinity, hardness, sodium-related hazards, microbial contamination, organic load, and contaminants such as pesticides, heavy metals, antibiotics, and pathogens. These differences matter because they can change nutrient solubility, buffering behaviour, precipitation risk, oxygen conditions, disease pressure, and the amount of correction required before or during use. The paper also examines how excessive or unwanted constituents constrain formulation choices and plant response, and why universal source-water quality thresholds remain scientifically limited. Across the literature, acceptable conditions depend on crop sensitivity, system biology, recirculation strategy, seasonal conditions, and management capacity. The central implication is that growers are not adding nutrients to pure water, but to a variable chemical and biological starting point. Therefore, source-water quality must be interpreted as part of the nutrient recipe itself, rather than as a separate background condition.**

I. Introduction

In hydroponic production, source water is part of the crop input, not merely the medium in which fertilisers are dissolved. Reviews of water quality for irrigation show that waters can differ substantially in pH, electrical conductivity, total dissolved solids, total suspended solids, sodium-related hazards, carbonate balance, microbial presence, and biofilm burden. These variables provide a structured basis for explaining why two nominally similar fertigation programs may perform differently when prepared from different supplies. If the starting water already contains dissolved ions, suspended matter, or microbial contaminants, the grower is not creating the same nutrient solution each time, even when identical fertiliser masses are weighed out. The practical implication is that source-water assessment must precede nutrient formulation, because composition affects both the chemistry of mixing and the biological environment experienced by roots [1], [2].

Evidence from bioponic and organic nutrient-solution literature further demonstrates that the initial water matrix can amplify production risks when unwanted constituents are present. Excess ammonium, elevated biological oxygen demand, residual organic matter, high pH, and nutrient imbalance have all been associated with reduced yield, toxicity, and the need for dilution or supplementation. Although these findings arise from systems that include organic nutrient sources, the underlying lesson is directly relevant to hydroponics: the performance of a prepared solution depends on what is already in the water before additional nutrients are added. When source water contributes reactive nitrogen, organic load, or buffering capacity, the formulated solution can diverge from the intended chemical target, which in turn changes management burden and plant response [3], [4].

The same evidence base also shows that acceptable water or solution quality cannot be reduced to a single universal threshold. Reported responses differ with crop demand, ammonium sensitivity, processing method, and management regime, with leafy crops and tomato systems not behaving identically under comparable conditions. This context dependence matters for source-water interpretation because growers often seek simple pass or fail rules, yet the agronomic meaning of a given constituent depends on what crop is being grown, how the system is managed, and how much correction is feasible. Accordingly, this paper examines source-water composition, contaminants, and variability as determinants of nutrient-solution preparation, root-zone conditions, and crop performance, then explains why general guidance must remain conditional rather than absolute [3].

II. Background and Scope

Existing reviews establish that source-water quality should be understood through both chemical and operational lenses. High pH, suspended solids, sodium hazards, carbonate chemistry, and biofilm formation are not merely abstract quality descriptors, because they are linked to scaling, clogging, and other operational limits in irrigation systems. In hydroponics, these same mechanisms matter because obstruction, precipitation, and instability interfere with precise delivery of water and nutrients. A water source that appears usable on volume alone may therefore still constrain downstream formulation if its chemistry drives precipitation or if its particulate and biological load destabilises the delivery system. The scientific gap is not whether water quality matters, but how to explain its effects as part of the nutrient recipe itself, rather than as a separate engineering inconvenience [1].

The literature also cautions against universal interpretation frameworks. Reviews of irrigation water indices explicitly argue that no universal water quality index, or universally valid irrigation water quality index, can presently capture suitability across locations and times because water usefulness is spatially and temporally dependent. This limitation is central to hydroponic practice. A given source may be acceptable in one setting because correction capacity, crop tolerance, and

system design compensate for its deficiencies, yet problematic in another setting where those compensations are absent. The present paper therefore treats thresholds as context-bound guides, not fixed truths. Its scope is explanatory and synthetic: to clarify how source-water differences influence solution preparation and crop response, while recognising that acceptable limits vary with crop, system, and management context [1].

Hydroponic review literature provides an additional boundary for this synthesis by linking water chemistry directly to nutrient availability and plant performance. Reported guidance indicates that solution pH outside roughly 5 to 7 can reduce nutrient solubility or absorption, while contaminated or residual solutions may spread disease and promote mineral precipitation. These points define the paper's focus. The concern is not only whether a water source contains unwanted constituents, but whether those constituents push the prepared solution away from the chemical and biological conditions needed for uptake and root health. By centring the discussion on formulation, root-zone behaviour, and crop response, the paper addresses why identical nutrient additions can lead to different outcomes when the starting water is chemically or biologically different [5].

III. Core Concepts and Mechanisms

A first mechanism is that different source classes carry different background loads before any fertiliser is added. Reviews of specialty crop water use distinguish relatively uncontaminated roof-harvested water from operational runoff, noting that runoff can carry nutrients, pesticides, sediment, pathogens, and other contaminants. This distinction is agronomically important because the background composition of runoff may partly overlap with intended nutrient additions while also introducing unwanted substances. As a result, two sources can produce different nutrient solutions from the same fertiliser program: one begins from a comparatively clean baseline, while the other begins from a mixed load of dissolved nutrients, particulates, and contaminants. The implication is that source identity matters not only by origin label, but by the pathways through which material enters the water before it reaches the hydroponic reservoir [6].

A second mechanism is that unwanted constituents alter root-zone biology and system hygiene as well as chemistry. Runoff-borne nutrients, pathogens, sediment, and agrichemicals have been linked to water-quality and phytopathogen problems, which means source water can influence disease pressure, oxygen demand, and physical cleanliness of the system before crop uptake is considered. In practice, this helps explain why a solution prepared from contaminated water may perform poorly even if its measured bulk conductivity appears acceptable after fertiliser addition. Electrical conductivity alone cannot distinguish beneficial nutrient ions from contaminants, nor can it reveal pathogen presence or particulate burden. The management implication is that formulation based only on fertiliser recipe and EC risks overlooking biological and particulate constraints that materially affect root health and crop consistency [6].

A third mechanism concerns the mineral character of the source itself, particularly alkalinity and hardness. Reviews oriented to aquatic production explain that alkalinity and hardness reflect relationships among bicarbonate, carbonate, calcium, and magnesium, and that these variables influence broader water-quality behaviour rather than representing isolated numbers. In hydroponic preparation, such relationships matter because buffering from carbonate species can resist pH adjustment, while calcium and magnesium already present in the source contribute to the total ionic balance being delivered to the crop. Consequently, two waters with similar bulk salinity can still behave differently during acidification, nutrient mixing, and ongoing pH management. This is a key reason why the same nutrient formulation does not create the same root-zone chemistry when applied to waters with different alkalinity and hardness profiles [7].

IV. Evidence Synthesis

Across the reviewed literature, the most consistent synthesis is that source-water quality affects crop performance through control variables that hydroponics must already manage precisely. Comparative soilless-system reviews state that hydroponic success depends on control of pH, EC, and dissolved oxygen, while also warning that wastewater or sludge-derived sources may carry heavy metals, antibiotics, and pathogens capable of disrupting system function and plant performance. This synthesis is important because it connects source-water composition to both chemical precision and biological risk. A contaminated source does not merely complicate monitoring, it changes what pH, EC, and oxygen measurements actually represent in the root zone. Thus, source quality shapes interpretation of standard control variables, not just their target values [8].

The evidence also converges on non-universality across production systems. Comparative reviews of hydroponics, aquaponics, and bioponics show that acceptable water and nutrient conditions differ with system biology, crop characteristics, organic load, fish requirements, and sensing constraints. This means that even when a constituent is measurable in all systems, its agronomic meaning is not fixed. A background level of organics, ammonium, or microbial activity that is manageable in one biologically complex system may be undesirable in another system built around inorganic nutrient precision. Therefore, asking for a single acceptable source-water threshold across soilless production oversimplifies the interaction among water composition, system design, and crop response. The stronger conclusion is that suitability emerges from fit between source properties and management context, rather than from a universal numerical rule [8].

Evidence on wastewater classes strengthens this contextual interpretation by showing that water sources differ not only in magnitude of contamination, but in contaminant type. Reviews of wastewater hydroponics distinguish domestic, industrial, and livestock wastewaters, and summarise differences

in nutrients, heavy metals, microorganisms, and emerging contaminants. These differences matter because each source class imposes a different correction problem. Some waters alter nutrient accounting through background nutrient loads, while others raise concerns about toxic elements or microbial contamination that cannot be managed through routine fertiliser balancing alone. In this sense, the question is not whether all non-conventional waters are equivalent alternatives to freshwater, but how their distinct contaminant profiles alter formulation choices, treatment needs, and the reliability of crop response after nutrients are added [9].

V. Practical Implications and Limitations

For growers, the main practical implication is that source-water quality thresholds should be treated as conditional tools rather than universal standards. Reviews of nutrient-solution management repeatedly report crop-, season-, substrate-, and system-specific responses to EC control, nitrate management, renewal intervals, and moisture scheduling. These findings imply that the same starting water may be acceptable for one crop or management regime and less suitable for another, even before external stressors are considered. A source that can be managed successfully in a robust recirculating system with close monitoring may be less acceptable in a simpler system with limited correction capacity. The limitation of any general guideline, therefore, is that it cannot replace judgement about crop sensitivity, operational discipline, and how much compositional variation the production system can absorb [10].

A second implication is that bulk solution targets cannot by themselves guarantee equivalent crop conditions. Broader soilless reviews indicate that pH, EC, and micronutrient supplementation change growth, quality, and nutrient uptake, which reinforces the point that measured end values are influenced by the route through which they are achieved. Two growers may report the same nominal pH and EC after adding nutrients, yet one may have reached those values in water with stronger buffering, a different calcium and magnesium background, or a more complex contaminant profile. Under those conditions, equal headline numbers need not mean equal nutrient availability or equal root-zone stability. The evidence supports careful interpretation of routine measurements, but it also leaves gaps about how specific source-water chemistries translate into crop-specific performance outcomes in every hydroponic context [11].

The literature on alternative water supplies adds both opportunity and caution. Reviews discussing rainwater harvesting, greywater reuse, and aquaponic water suggest that different sources bring different management implications, yet they do not always provide equally strong direct characterisation of dissolved mineral and contaminant contrasts across common water classes. This means the conceptual case for source dependence is stronger than the availability of universally transferable thresholds. It is also consistent with other evidence showing that rainwater or borehole sources may introduce chemical contaminants or microbes, and that treatment effectiveness depends on contaminant type, concentration, goals, cost, and site-specific conditions. In practical terms, growers should expect validation needs to be source-specific, because no single correction strategy is equally appropriate for all water-quality problems [8], [12], [13].

VI. Conclusion

The reviewed evidence supports a clear answer to the central question: two water sources can behave differently after the same hydroponic nutrients are added because the grower is adding those nutrients to different chemical and biological starting conditions. Source water may differ in mineral composition, alkalinity, hardness, suspended matter, microbial burden, organic load, and contaminant profile, and those differences shape nutrient solubility, pH buffering, precipitation risk, oxygen conditions, disease pressure, and overall management burden. Accordingly, source-water quality is part of the nutrient formulation problem itself, not an external background variable [1], [6], [7], [8].

The literature also shows why universal source-water quality thresholds remain limited. Acceptable conditions depend on crop sensitivity, system biology, operational design, and the grower's capacity to monitor and correct deviations. The highest-value next work is therefore not the search for a single threshold, but better context-specific validation that links source-water chemistry and contamination classes to crop and system responses under defined management conditions. Until such evidence becomes more specific, prudent practice is to interpret source quality as a variable input that must be characterised and managed in relation to the intended crop and hydroponic system [3], [10], [13].

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