Iron chemistry, availability and supplementation

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***Abstract*—Iron supplementation in aquaponics raises three questions: whether an addition changes plant iron status, whether it changes plant performance, and which chemical processes make iron available. This paper examines two controlled lettuce studies that inform the first two questions. In a lettuce and tilapia system, Fe-DTPA alone and Fe-DTPA with potassium were associated with higher leaf iron than no nutrient addition. A separate aquaponic lettuce trial compared foliar Fe-Alg-CaCO3 microparticle treatments with a water-sprayed control and reported differences in rosette size, fresh weight and chlorophyll. These studies demonstrate responses to specific supplementation treatments, but their routes, formulations and measurements differ. Neither establishes the chemical forms of iron in circulating water or a causal relationship between water pH and iron uptake. Moreover, the combined iron and potassium treatment cannot isolate potassium's contribution. The evidence supports a qualified interpretation of iron supplementation in the tested lettuce systems, while leaving the principal chemical explanation of iron availability unresolved. Measurements linking water chemistry, plant iron status and treatment response are needed before a general causal account or supplementation recommendation can be justified.**

I. Introduction

Iron chemistry, availability and supplementation are connected questions, but a response to added iron does not explain every step between the addition and the plant. In a controlled aquaponic comparison involving lettuce and tilapia, Fe-DTPA was tested alone and alongside potassium against a treatment without nutrient addition. Both supplemented groups had higher leaf iron, and the study reported plant performance responses [1]. The leaf measurement bears directly on plant iron status; the performance observations show why the treatment matters to crop production. Neither observation, considered alone, identifies the chemical form of iron available in the circulating water. Separating observed uptake from its proposed cause is therefore essential to interpreting the experiment.

A second aquaponic lettuce trial examined a different way of supplying iron. Foliar Fe-Alg-CaCO3 microparticles at 10, 50 and 250 ppm were compared with a sterile double-distilled-water foliar control; each treatment comprised three panels of five plants [2]. Here the comparison concerns material applied to leaves rather than an Fe-DTPA nutrient addition in the lettuce and tilapia study. Its outcomes can broaden the account of supplementation responses, but the two interventions should not be treated as chemically or experimentally interchangeable. In particular, a crop response after foliar application cannot establish how much dissolved iron was available to roots.

The foliar treatments were applied five times at seven-day intervals, beginning on day 21 after sowing and continuing until harvest on day 55 [2]. That schedule defines the exposure under which the reported responses were observed, rather than a demonstrated optimal frequency or duration. This paper first distinguishes the two treatment comparisons, then examines what their plant and water measurements can establish about availability. It finally considers how far their findings can inform supplementation decisions. The central argument is deliberately bounded: controlled responses support conclusions about particular treatments and outcomes, while the causal chemistry governing iron availability requires evidence not supplied by those responses.

II. Background and Scope

The two studies approach supplementation from different starting points. The lettuce and tilapia comparison tests Fe-DTPA against no nutrient addition, with an additional treatment combining Fe-DTPA and potassium [1]. The foliar trial varies the concentration of an Fe-Alg-CaCO3 microparticle treatment against a water-sprayed control [2]. Each design can relate its own treatment to measured plant outcomes, but neither is a direct comparison between the two formulations. Their distinction matters because an apparent agreement in crop response would not demonstrate that the same iron chemistry or route of uptake produced it. The evidence can be read together as complementary observations, not as a ranking of supplementation methods.

The foliar trial reported mean circulating-water iron of 0.07 ± 0.08 mg/L and mean water pH of 8.65 ± 0.17 [2]. These measurements describe the environment in which its lettuce was grown. They do not show which iron species were present, what portion of measured iron the plants could acquire, or how a change in pH would alter either quantity. The distinction between a water measurement and plant availability is especially important in a foliar experiment: an observed response to material applied to leaves cannot be assigned to an increase in root-accessible iron without evidence connecting those steps. Water chemistry remains relevant context, but not a tested causal explanation here.

The foliar comparison nonetheless offers measured crop outcomes under its stated conditions. Rosette diameter was reported as 39.87% greater than the water control at 50 ppm and 49.02% greater at 250 ppm, with both comparisons statistically significant [2]. At 250 ppm, rosette fresh weight was reported as 229.49% greater than the control and 311.84% greater than at 10 ppm; these comparisons were also statistically significant [2]. Diameter and fresh weight are distinct measures, and their reported differences should not be collapsed into a single

estimate of treatment benefit. They establish responses in this lettuce trial, while leaving open whether those responses would persist with another formulation, application schedule or crop.

III. Core Concepts and Mechanisms

An operational meaning of iron availability can be drawn from the difference between an iron addition and an observed plant response. In the Fe-DTPA comparison, higher leaf iron in both supplemented groups is evidence that plant iron status differed from the unsupplemented condition [1]. This is closer to an uptake-related observation than a measurement of iron in the water, yet it still does not reveal the sequence of chemical changes preceding that difference. The combined Fe-DTPA and potassium treatment also prevents every associated performance response from being assigned specifically to iron. Thus, plant iron status can indicate that a tested addition mattered without identifying a complete chemical or physiological pathway.

The foliar trial provides a different kind of indicator. At 250 ppm, total chlorophyll was reported as 59.41% greater than in the water-sprayed control and 54.19% greater than at 10 ppm [2]. This pigment difference can be considered alongside the reported rosette outcomes, but it does not directly measure photosynthetic activity or establish that increased chlorophyll caused greater fresh weight. Nor does it identify how the applied material released iron or entered plant tissue. Treating chlorophyll as a measured response rather than proof of a mechanism preserves the distinction between a useful association and an explanation of iron chemistry.

A selective response across measurements further limits a single-pathway explanation. The foliar trial reported no statistically significant differences among treatments in carotenoid, total phenolic or total flavonoid content, despite its reported differences in total chlorophyll and several rosette measurements [2]. A failure to detect differences in those three measures is not evidence that they could never respond under other conditions. It does show that the reported treatment response should be described in terms of the outcomes actually observed, rather than as an undifferentiated change in all plant characteristics. The supported account of supplementation is consequently outcome-specific; the underlying iron chemistry remains uncharacterised by these measurements.

IV. Evidence Synthesis

Across the two comparisons, the strongest common observation is that an iron-containing intervention coincided with a measurable lettuce response, although the measured endpoints differ. The Fe-DTPA comparison reports higher leaf iron in both supplemented groups and plant performance responses [1]. The foliar microparticle trial reports differences in rosette diameter and fresh weight relative to its own water-sprayed control [2]. These findings support investigation of supplementation where plant performance is the concern. They do not justify combining effect sizes, because the studies used different interventions, controls and outcomes. In particular, higher leaf iron in one comparison is not the same result as greater rosette fresh weight in another.

The foliar trial's concentration comparisons allow a more precise statement than a general claim that more iron improves growth. Both 50 and 250 ppm treatments had significantly greater rosette diameter than the water control, while the reported 250 ppm fresh-weight difference was evaluated against both the control and 10 ppm [2]. These are specified comparisons within one application schedule, not a complete account of responses at every possible concentration. The 250 ppm treatment also had higher reported total chlorophyll than both the control and 10 ppm [2]. Taken together, those observations identify endpoints that changed in the tested range; they do not establish an optimal concentration or explain why the endpoints changed.

The water measurements in the foliar system and the leaf measurements in the Fe-DTPA system address different positions in a proposed causal chain. The former characterise circulating water at a reported mean iron concentration and pH [2]; the latter show that leaf iron differed between supplemented and unsupplemented plants [1]. Because these observations come from separate treatment comparisons, joining them into a claim that the reported water pH caused the reported leaf response would cross an evidential boundary. A synthesis can identify what needs connecting, but it cannot supply an unmeasured link. For iron availability, that missing link is the direct relationship between iron's chemical state under measured water conditions and the amount taken up by plants.

V. Practical Implications and Limitations

A supplementation decision should be tied to the outcome and route actually studied. The Fe-DTPA comparison supports the narrower proposition that its supplemented groups had higher leaf iron than the no-addition group [1]. The foliar trial supports treatment-specific statements about lettuce rosette dimensions, fresh weight and chlorophyll under repeated foliar application [2]. Neither finding specifies a transferable dosing rule for another system. Recommending the foliar trial's concentrations as targets for circulating water, for example, would conflate the concentration of an applied foliar treatment with a water concentration. The practical value of these studies lies in their measured comparisons, not in an untested conversion between application routes.

Interpreting the Fe-DTPA plus potassium treatment requires particular care. Because both nutrients were present in that treatment, its plant performance response cannot isolate potassium's contribution, even though both Fe-DTPA-containing groups had higher leaf iron than the unsupplemented group [1]. Likewise, the foliar trial compared an iron-containing microparticle formulation with sprayed water at several concentrations; its outcomes do not independently identify every contribution of the formulation to the observed response [2]. These limitations do not erase the treatment effects that were reported. They define the level at which causal language is justified: comparisons of complete treatments and measured outcomes, rather than claims about an isolated mechanism.

A fuller explanation of iron chemistry and availability would require measurements and comparisons that connect the presently separate observations. The foliar study supplies circulating-water iron and pH values but not evidence that those values determined its treatment effects [2]. The Fe-DTPA study supplies a leaf-iron response but, within the accepted findings, no account of the intervening iron species [1]. Future validation should therefore distinguish an addition's chemical state, the iron accessible to plants and the resulting tissue and growth responses within the same comparison. Until those links are established, neither a particular water pH nor a particular supplementation route can be claimed as the general cause of improved availability.

VI. Conclusion

The evidence gives a defensible but limited answer to the supplementation question. In one controlled lettuce and tilapia system, Fe-DTPA-containing treatments were associated with higher leaf iron than no nutrient addition [1]. In another aquaponic lettuce system, repeated foliar microparticle treatments produced specified differences in rosette measures and total chlorophyll relative to their stated comparisons [2]. These observations show that the tested interventions mattered to measured plant outcomes. They do not establish that the interventions shared a mechanism, that a reported water measurement explains uptake, or that their results define a generally effective dose.

Iron chemistry and iron availability remain the least resolved parts of the causal account. The reported water iron and pH values are contextual measurements, while the leaf, pigment and growth results are plant observations [1], [2]. A persuasive explanation must connect those kinds of evidence rather than treating one as a substitute for the other. Direct characterisation of iron's chemical state alongside plant iron status, with comparisons that separate co-supplied nutrients and application routes, is the highest-value next step. The present evidence supports carefully qualified supplementation conclusions, not a complete explanation of why iron was available under the tested conditions.

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References

[1] E. Tsoumalakou, E. Mente, K. A. Kormas, N. Katsoulas, N. Vlahos, P. Kapsis, and E. Levizou, "Precise monitoring of lettuce functional responses to minimal nutrient supplementation identifies aquaponic system's nutrient limitations and their time-course," *Agriculture*, 2022.

[2] D. Frassine, R. Braglia, F. Scuderi, E. L. Redi, F. Valentini, M. Relucenti, I. A. Colasanti, A. Macchia, I. Allegrini, A. Gismondi, G. D. Marco, and A. Canini, "Enhancing lettuce (lactuca sativa) productivity: Foliar sprayed fe-alg-caco3 mps as fertilizers for aquaponics cultivation," *Plants*, 2024. [Online]. Available: https://doi.org/10.3390/plants13233416