ADDRESSING NUTRIENT DEFICIENCIES IN AQUAPONIC SYSTEMS FOR SUSTAINABLE GROWTH

Abstract

Aquaponics, a sustainable agricultural system, integrates aquaculture and hydroponics to create a symbiotic relationship between aquatic animals and plants. In this closed-loop system, fish waste and metabolic by-products nourish hydroponically cultivated plants while the plants purify water through nitrification, a bacterial-driven process converting ammonia to nitrate. Fish species like tilapia, pangasius, pearl spot, carp, etc., are commonly raised in aquaponics. Plant selection includes leafy greens and herbs due to their resilience. The nutrients that originate from fish feed contribute to plant growth. While major nutrients come from water, aquaculture effluent, a fusion of waste products, offers additional nutrients. Still, these nutrients may not fulfill the absolute plant nutrient requirement, resulting in the poor growth of plants and consequently affecting the profits. Nitrogen, phosphorus, potassium, calcium, magnesium, and iron are vital nutrients that may become deficient. The nutrient deficiency can be corrected by altering fish stocking density, utilizing supplements like rock phosphate, potassium sulfate, and calcium chloride, and managing pH levels. Epsom salt addresses magnesium deficiency, while inorganic and natural iron compounds help to combat iron deficiency. In aquaponics, nutrient management ensures harmonious and productive interactions between aquatic life and plants.

Keywords: Nutrient, Aquaponic.

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I. NUTRIENT DEFICIENCIES IN AQUAPONIC SYSTEM

Aquaponics is a sustainable agricultural system that combines aquaculture (the cultivation of aquatic animals such as fish) with hydroponics (the cultivation of plants in nutrient-rich water) (Seawright et al., 1998). Aquaponics can be traced back to ancient civilizations such as the Aztecs, who practiced a form of it in their "chinampas" farming system. Chinampas were artificial islands on which crops were cultivated in shallow lake waters, utilizing the nutrient-rich mud and waste from fish raised in the same waters. Watten and Busch first introduced the term aquaponic system in 1984. Aquaponics is an integrated approach system where it creates a mutually beneficial relationship between the production systems of fish and plants, where the nutrient-rich waste produced by fish in their tank, which includes metabolic by-products and leftover food, is utilized as a nourishment of plants grown in hydroponically. The plants help in the purification of wastewater by the process called nitrification. The nitrification process is critical to the aquaponic system's nutrient cycle. This process is driven by beneficial bacteria that play a vital role in converting ammonia into nitrite and then further into nitrate (Rakocy et al., 2006). Ammonia Oxidizing Bacteria (AOB) and Nitrite Oxidizing Bacteria (NOB) are important nitrifying bacteria present in aquaponic systems. These bacteria are vital components in maintaining a balanced nitrogen cycle, which is essential for aquatic animals' and plants' health and vitality. AOB, including species like Nitrosomonas, is responsible for the first step of nitrification. They convert toxic ammonia (NH_3), excreted by fish and other aquatic organisms, into less toxic nitrite (NO_2^-) through ammonia oxidation. This conversion makes the ammonia less harmful to aquatic life. NOB, such as Nitrobacter, carry out the second step of nitrification. They further oxidize nitrite produced by AOB into nitrate (NO_3^-). Nitrite can also be toxic to aquatic organisms in higher concentrations, so the activity of NOB is critical for preventing nitrite accumulation. In contrast, nitrate serves as a nutrient source for plants. Once purified, the water is returned to the fish tanks, completing a closed-loop cycle. This symbiotic interaction between fish and plants minimizes waste and creates a sustainable ecosystem where both components thrive (Verma et al. 2010).

In aquaponics, fish are considered nutrient producers and offer the added benefit of generating income. Fish species that have been identified as appropriate for aquaponic production encompass a diverse range, including tilapia, trout, perch, arctic char, bluegill, largemouth bass, channel catfish, crappies, rainbow trout, pacu, common carp, koi carp, goldfish, Asian sea bass, and murray cod. Another important thing in aquaponics is the selection of plants to grow. Where Hydroponic plants can tolerate the unique chemistry of aquaponic systems. Like viz., leafy greens, herbs (basil and mint), and certain fruiting plants, such as tomatoes and peppers, are often favored due to their resilience and nutrient requirements (Thomas et al. 2021; Shete et al. 2015)

In the captivating world of aquaponics, the entrance of nutrients is predominantly from fish feed and fish waste. This feed, meticulously designed to cater to the specific dietary needs of aquatic inhabitants, sets in motion a chain of events that profoundly influences the system's balance and productivity. As the fish feed is introduced into the system, it becomes the source of sustenance for the fish. The residual components of the feed, along with the metabolic by-products released by the fish, undergo dissolution in the water. This process culminates in the formation of an aquaculture effluent, a nutrient-enriched solution that plays a pivotal role in furnishing the majority of the essential nutrients necessary for the growth of plants within the hydroponic segment of the system. The plants' nutritional needs encompass 16 essential nutrients in the aquaponic system. Out of these, significant macronutrients—carbon (C), hydrogen (H), and oxygen (O)—find their supply from water and carbon dioxide gas. These vital elements form the fundamental building blocks of plant life. The remaining essential nutrients, including nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), molybdenum (Mo), boron (B), chlorine (Cl), and more, are sourced from the very essence of the fish culture water itself. The system has an inherent knack for catering to these plant nutritional needs. The aquaculture effluent, a concoction formed by the amalgamation of fish waste and metabolic products, emerges as a generous contributor. It supplies substantial nutrients, but they alone may not fulfill all the plant nutrient requirements. Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), and Iron (Fe) require additional supplementation to fine-tune and optimize plant production within the aquaponic system. Deficient nutrients in aquaponics may vary based on the culture plant species, fish species, and feed type (Rakocy et al., 2006; Somerville et al., 2014; Stathopoulou et al., 2021; Tsoumalakou et al., 2022; Yang and Kim, 2020)

Supplementation of nutrients in the aquaponic system involves two vital techniques that are pivotal in optimizing plant health and growth: fertigation and foliar spray. These methods enhance nutrient delivery and absorption, ensuring aquatic and plant life thrive harmoniously. Fertigation, a portmanteau of "fertilization" and "irrigation," involves infusing essential nutrients directly into the irrigation water. This technique capitalizes on the recirculating nature of aquaponics, enabling precise and controlled nutrient delivery to plants (John et al., 2022; Harika et al., 2023). Foliar spraying allows plants to absorb nutrients directly through their leaves. Foliar feeding provides a supplementary source of perfectly balanced nutrients to help prevent deficiencies and enhance overall plant health. This supplementation process is particularly beneficial during high nutrient demand or when root uptake might be temporarily hindered (Meena et al.,2022).To effectively tackle the issue of nutrient depletion and elevate the productivity and overall health of an aquaponic system, it becomes imperative to introduce the essential nutrients in the quantities meticulously demanded. Within this context, the chapter delves into the prevalent challenges associated with nutrient deficiencies in aquaponic systems.

II. IDENTIFYING NUTRIENT DEFICIENCIES BASED ON THE SYMPTOMS AND REMEDIES

In aquaponic systems, nutrient deficiencies can manifest in various ways, such as modifications (or) changes in the plant leaves color, size, and overall appearance. Plants will provide a visual sign to understand the essential requirements of particular nutrients.

Plants in aquaponic systems exhibit the following nutrient deficiencies.

1. Nitrogen (N)
2. Phosphorus (P)
3. Potassium (K)
4. Calcium (Ca)
5. Magnesium (Mg)
6. Iron (Fe)

A detailed explanation of each nutrient deficiency and related symptoms is given below as follows:

1. **Deficiency of Nitrogen (N):** The deficiency of nitrogen leads to the development of some symptoms, which include the appearance of yellow to pale yellow colored leaves starting from the bottom of the plants. Nitrogen deficiency will lead to stunted growth of (leaves, fruits, and growth plants) and also reduces overall physical strength and good health of particular plants grown in aquaponic systems (Wongkiew et al., 2017)

   There are effective measures to consider to address nitrogen deficiency in aquaponics systems. Properly maintaining good water quality, increasing fish stocking density, maintaining healthy nitrifying bacteria, and adjusting the feeding rate and frequency of feed ration can help correct this nitrogen deficiency. In more severe cases of nitrogen deficiency, it's advisable to supplement with organic or inorganic ammonium-based fertilizers. However, it's crucial to be cautious and ensure that any supplementation doesn't adversely affect the health and well-being of the fish and plants.

2. **Deficiency of Phosphorus (P):** Plants with a phosphate deficiency may exhibit slow or stunted growth. New growth may be significantly affected, resulting in smaller leaves and reduced plant size. Leafy vegetables, like lettuce, will develop a reddish to dark purple coloration on the undersides of the leaves. The phosphorus deficiency leads to poor development of roots. Insufficient phosphate can delay flowering and fruiting plants (Nozzi et al., 2018; Cerozi and Fitzsimmons, 2017).

   Several remedies can be employed to address phosphorus deficiency in an aquaponic system. Increasing the amount of fish feed can contribute to higher phosphorus input into the system. Fish waste contains phosphorus, so adjusting the feeding rate can help elevate phosphorus levels. Choose plant species that are more efficient at absorbing and utilizing limited phosphorus. Maintaining a suitable pH range can enhance the solubility of phosphorus compounds, making them more accessible to plants. In another way, phosphorus deficiency in the aquaponic system can be countered by supplementation of rock phosphate. These supplements can be directly added to the grow bed. The addition of these nutrients should not adversely affect the growth performance and physiology of both production systems in aquaponics.

3. **Deficiency of Potassium (K):** One characteristic sign of the potassium deficiency is the appearance of yellowing or browning along the edges of older leaves. This particular symptom is called marginal chlorosis. Potassium deficiency is observed mainly in fruits and tubers as they need exceptionally high doses of potassium. The stems affected by the potassium deficiency can develop weak, brittle branches more prone to breaking or bending. Leaves and fruits grown with insufficient potassium resulted in poor growth, altered taste, and uneven color development. Plants affected with potassium deficiency lead to reduced flower and fruit production number and quality. The potassium-deficient plants in the aquaponic system were more susceptible to pest infestation, and eventually prone to developing diseases (Peter et al., 2021).

   Potassium deficiency in aquaponics systems can be countered by Increasing the amount of fish feed, leading to higher potassium input into the system. Fish waste contains potassium, and adjusting the feeding rate can help address deficiencies. Regular monitoring and adjustments of pH levels can improve nutrient availability. To correct the potassium deficiency, supplement potassium-rich sources like potassium sulfate and potassium hydroxide in aquaponics. These nutrient supplements can be directly added to water through fertigation or foliar spray (John et al., 2022; Harika et al., 2023).

4. **Deficiency of Calcium (Ca):** The plants grown in the aquaponic system with calcium deficiency may exhibit leaf deformation i.e., the growth of leaves will be irregular and smaller than usual. Particularly in leaf vegetables with young leaves and shoot tips, brown or black necrotic spots may develop with calcium deficiency. This symptom is known as "tip burn"—a common symptom (blossom end rot) in fruiting plants like tomatoes and peppers. The bottom end of the fruit becomes sunken, darkened, and leathery due to insufficient calcium transport to the developing fruit (Tsoumalakou et al., 2022).

   Calcium deficiency in aquaponics can be addressed by supplementing calcium chloride by foliar application. Water pH also plays a major role in plant calcium availability. Usually, in lower pH conditions, plants cannot absorb calcium so an increase in pH can increase the absorption of calcium for plants. Lime can be used to raise the water's pH and apply calcium carbonate to the tanks.

5. **Deficiency of Magnesium (Mg):** One of the most noticeable signs of magnesium deficiency is interveinal chlorosis, where the tissue between the veins of the leaves turns yellow while the veins remain green. This gives the leaves a mottled appearance. Leaves affected by magnesium deficiency may exhibit curling or cupping, particularly at the leaf edges. The magnesium deficiency also shows necrotic leaf margins and stunted growth of overall plants. (Nozzi et al., 2018).

   The addition of Epsom salt can address magnesium deficiency in aquaponics. It is a good source of magnesium and is quickly available to plants. Moreover, Epsom salt doesn't harm the nitrifying bacteria in the system.

6. **Deficiency of Iron (Fe):** Plants deficient in iron within an aquaponic system often exhibit distinctive symptoms that can aid in identifying the deficiency. One of the most prominent indicators of iron deficiency is interveinal chlorosis, where the tissue between the leaf veins turns yellow while the veins remain relatively green. This results from the inability of the plant to produce sufficient chlorophyll due to the reduced availability of iron. When iron is deficient in the culture system, enzymatic activities are hindered, leading to stunted growth in plants. Shoot and root development may be compromised, resulting in smaller and weaker plants (Kasozi et al., 2019; Farooq et al., 2023).

   Iron deficiency in aquaponic systems can be countered by supplementing inorganic iron compounds such as Fe salts, synthetic iron chelates (Fe-EDDHA, Fe-EDTA), and natural iron complexes (amino acids and humates). Iron can be supplemented through the foliar spray or fertigation (Meena et al., 2023).

III. CONCLUSION

In conclusion, the intricate symbiosis between fish and plants within aquaponic systems forms the basis of a sustainable and mutually beneficial approach. This integration minimizes waste while maximizing productivity, creating a closed-loop ecosystem. The nutrient cycle, driven by nitrifying bacteria, ensures the conversion of fish waste into valuable nourishment for plants. However, despite this inherent nutrient supply, certain essential nutrients like nitrogen, phosphorus, potassium, calcium, magnesium, and iron can become deficient in the system, affecting plant growth and health. Recognizing these deficiencies is crucial, as they manifest in distinct visual symptoms such as leaf discoloration and deformities. To address these issues, applying supplemental nutrients through techniques like fertigation and foliar spraying plays a pivotal role. These methods allow for precise nutrient delivery, promoting optimal plant growth and vitality. Adjusting fish feed, stocking density, and maintaining nitrifying bacterial populations can help correct nutrient deficiencies. Aquaponic systems can achieve sustainable and thriving agricultural practices for the future by maintaining a careful balance between the needs of aquatic animals and plants.

REFERENCES

[1] Cerozi, B.D.S. and Fitzsimmons, K., 2017. Phosphorus dynamics modeling and mass balance in an aquaponics system. Agricultural Systems, 153, pp.94-100.

[2] Farooq, A., Verma, A.K., Hittinahalli, C.M., Harika, N. and Pai, M., 2023. Iron supplementation in aquaculture wastewater and its effect on the growth of spinach and pangasius in nutrient film technique-based aquaponics. Agricultural Water Management, 277, p.108126.

[3] Harika, Ajit Kumar Verma, Kishore Kumar Krishnani, Chandrakant Mallikarjun Hittinahalli, Ramakrishna Reddy, Manjulesh Pai, Supplementation of potassium in aquaculture wastewater and its effect on growth performance of basil (*Ocimum basilicumin L*) and pangasius (*Pangasianodon hypophthalmus*) in NFT-based aquaponics, Scientia Horticulturae, Volume 323, 2024, 112521, ISSN 0304-4238, https://doi.org/10.1016/j.scienta.2023.112521.(https://www.sciencedirect.com/science/article/pii/S0304423823006891)

[4] John, V.C., Verma, A.K., Krishnani, K.K., Chandrakant, M.H., Bharti, V.S., Varghese, T., 2022. Optimization of potassium (K+) supplementation for growth enhancement of *Spinacia oleracea* L. and *Pangasianodon hypophthalmus* (Sauvage, 1878) in an aquaponic system. Agricultural Water Management, 261, 107339. https://doi.org/10.1016/j.agwat.2021.107339.

[5] Kasozi, N., Tandlich, R., Fick, M., Kaiser, H., Wilhelmi, B., 2019. Iron supplementation and management in aquaponic systems: A review. Aquaculture Reports. 15, 100221. https://doi.org/10.1016/j.aqrep.2019.100221

[6] Meena, L.L., Verma, A.K., Bharti, V.S., Nayak, S.K., Chandrakant, M.H., Haridas, H., Reang, D., Javed, H., John, V.C., 2022. Effect of foliar application of potassium with aquaculture wastewater on the growth of okra (*Abelmoschus esculentus*) and *Pangasianodon hypophthalmus* in recirculating aquaponic system. Scientia Horticulturae. 302, 111161. https://doi.org/10.1016/j.scienta.2022.111161.

[7] Nozzi, V., Graber, A., Schmautz, Z., Mathis, A. and Junge, R., 2018. Nutrient management in aquaponics: comparison of three approaches for cultivating lettuce, mint and mushroom herb. Agronomy, 8(3), p.27.

[8] Peter, R.M., Verma, A.K., Chandrakant, M.H., Mamatha, D., 2021. Effect of different potassium (K+) doses on growth of tomato (*Solanum lycopersicum*) with pearlspot (*Etroplus suratensis*) in a recirculating aquaponic system. Journal of Experimental Zoology. India 24(2), 951–959.

[9] Rakocy, J.E., Masser, M.P., Losordo, T.M., 2006. Recirculating aquaculture tank production systems: Aquaponics-integrating fish and plant culture. SRAC Publ. South. Reg. Aquac. center, 454. 1–16.

[10] Seawright DE, Stickney RR, Walker RB (1998) Nutrient dynamics in integrated aquaculture–hydroponics systems. Aquaculture 160(3–4):215–237. https://doi.org/10.1016/S0044-8486(97)00168-3.

[11] Shete AP, Verma AK, Chadha NK, et al (2015) A comparative study on fish to plant component ratio in recirculating aquaponic system with common carp and mint. Journal of Environment And Bio-Sciences, 29(2):323–329.
[12] Somerville C, Cohen M, Pantanella E, et al (2014) Small-scale aquaponic food production: integrated fish and plant farming. FAO Fish Aquac Tech Pap 589 Rome.
[13] Stathopoulou, P., Tsoumalakou, E., Levizou, E., Vanikiotis, T., Zaoutsos, S., Berillis, P., 2021. Iron and potassium fertilization improve rocket growth without affecting tilapia growth and histomorphology characteristics in aquaponics. Appl. Sci. 11(12), 5681. https://doi.org/10.3390/app11125681.
[14] Thomas RM, Verma AK, Krishna H, et al (2021) Effect of salinity on growth of Nile tilapia (*Oreochromis niloticus*) and spinach (*Spinacia oleracea*) in aquaponic system using inland saline groundwater. Aquac Res 52(12):6288–6298. https://doi.org/10.1111/are.15492.
[15] Tsoumalakou, E., Mente, E., Kormas, K.A., Katsoulas, N., Vlahos, N., Kapsis, P., Levizou, E., 2022. Precise monitoring of lettuce functional responses to minimal nutrient supplementation identifies aquaponic system's nutrient limitations and their time-course. Agriculture 12(8), 1278. https://doi.org/10.3390/agriculture12081278.
[16] Verma AK, Gupta SK, Isaac RK (2010) Long-term use of saline drainage waters for irrigation in subsurface drained lands: simulation modelling with swap. J Agric Eng 47(3):15–23.
[17] Wongkiew, S., Hu, Z., Chandran, K., Lee, J.W. and Khanal, S.K., 2017. Nitrogen transformations in aquaponic systems: A review. *Aquacultural Engineering*, *76*, pp.9-19.
[18] Yang, T., Kim, H.-J., 2020. Characterizing nutrient composition and concentration in tomato-, basil-, and lettuce-based aquaponic and hydroponic systems. Water 12(5), 1259. https://doi.org/10.3390/w12051259.