# Matter and nutrient flow through the ecosystem

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***Abstract*—Aquaponics connects aquatic animals, microorganisms and plants through the movement and transformation of matter. Feed enters the system, fish produce dissolved and particulate waste, microbial processes alter the forms in which nutrients occur, and circulating water carries dissolved nutrients towards plant roots. This paper synthesises review evidence to explain that causal sequence and distinguish nutrient transformation from physical transport and plant uptake. Decomposition makes nutrients in organic matter available for further processing, while nitrification converts nitrogenous waste into nitrate that plants can take up. The route taken by water and effluent depends on system configuration, so recirculation does not imply that every nutrient follows the same path or remains available indefinitely. Evidence from related soilless systems clarifies how growing media can retain nutrients and how recirculating solutions can accumulate or lose substances, but these comparisons do not establish identical behaviour in aquaponics. The central implication is that nutrient flow must be understood as a connected sequence of inputs, transformations, transport and removal, rather than as water circulation alone. The available reviews support this qualitative account but do not establish a universal nutrient balance for all aquaponic designs.**

## I. Introduction

Matter and nutrient flow through an aquaponic ecosystem begins with material entering the aquatic component, principally as feed. Fish use part of that material and release waste; decomposition and nitrification then change the forms in which nutrients occur before plants can take up nutrients delivered by water. These processes connect organisms that perform different roles, so the presence of nutrients in fish effluent is not equivalent to their immediate availability to plants [1]. Understanding the sequence matters because a description limited to water moving between components misses the transformations that give that movement biological significance. It also prevents a simple but misleading account in which all feed-derived matter is assumed to become plant nutrition.

The distinction between organic matter and plant-available nutrients is central to explaining the flow. Work on organic nutrient solutions in related soilless systems describes mineralisation as a process through which organic materials contribute to a nutrient-containing solution [2]. Aquaponics has a different initial context because fish and their waste are part of the connected system, but the comparison makes one point clear: recycling requires conversion as well as transport. A nutrient carried in water may have originated in organic material, yet its passage into a form plants can use depends on biological processes. The explanation must therefore follow changes in matter, not merely trace the path of a circulating liquid.

This paper examines the relationship among nutrient inputs, waste transformation, waterborne movement and plant uptake in aquaponics. It first establishes what circulation means in a connected soilless system, then explains the biological conversions that make fish-derived nutrients relevant to plants. It finally considers what related evidence can and cannot tell us about retention and removal. Reviews of nutrient-solution management show why the composition of circulating water matters alongside its route [3]. The argument developed here is qualitative: water links components, whereas decomposition, nitrification, uptake and other pathways determine the changing distribution of nutrients. No single circulation diagram, by itself, establishes the fate of all matter entering the ecosystem.

## II. Background and Scope

In soilless cultivation, a nutrient solution can circulate to plant roots, be reused or leave the growing system as nutrient-rich discharge [4]. These alternatives show why circulation and recycling should not be treated as synonyms: returning water to a reservoir describes a flow path, whereas retaining nutrients for subsequent biological use describes a possible outcome of that path. Aquaponics adds fish effluent and biological nutrient conversion to this general picture. The relevant question is therefore not only where water travels, but what material it carries at each point and whether that material is transformed, retained, taken up or removed. The evidence supports this distinction without requiring every design to have the same pattern of flow.

Aquaponic accounts place water and nutrient delivery alongside conversion and recycling, rather than presenting plant cultivation as an isolated use of a prepared solution [5]. That integration distinguishes the principal causal account from a conventional description of soilless nutrient delivery. Fish-derived material must pass through connected aquatic, treatment and plant-growing components; movement creates opportunities for conversion and uptake, but does not guarantee either outcome. The comparison also fixes this paper's scope. Related hydroponic evidence can clarify the behaviour of circulating solutions, yet it cannot replace direct evidence about feed, fish waste and microbial processing in aquaponics. The paper treats these related systems as explanatory comparisons, not as interchangeable ecosystems.

The physical route between components is not universal. Reviews of coupled and decoupled aquaponics describe fish-effluent transfer and filtration-mediated conversion of ammonia to nitrate while also distinguishing configurations with different connections between fish and plant components [6]. The

shared explanation is a sequence of nutrient input, movement, transformation and plant access, rather than a requirement that water always return along one particular route. This limits what can be inferred from the word 'recirculating'. A diagram showing a return flow may represent one configuration, but it cannot establish nutrient concentrations, conversion or uptake in another. A useful account of matter flow must identify the processes as well as the connections that permit them.

## III. Core Concepts and Mechanisms

Feed supplies material to the fish component, and fish waste introduces nitrogenous and other nutrient-bearing material into the aquatic environment. Reviews of aquaponics describe circulating water as the link that conveys this material towards microbial processing and plant-growing components, where converted nitrogenous compounds can become available for uptake [1], [7]. Water therefore acts as a carrier, not as the agent of conversion. This distinction explains why an input can move through the ecosystem without following a single uninterrupted path into plant tissue. The material's significance changes as it passes from feed to waste, from waste to dissolved nutrients, and from the water into organisms.

Decomposition and nitrification perform different parts of that transformation. Decomposition processes organic waste, while nitrification converts ammonia through nitrogenous intermediates to nitrate; filtration can provide a setting for the latter conversion in aquaponic flows [1], [6]. Plant uptake occurs after nutrients reach the root environment in an accessible form, rather than simply because waste has entered the water [7]. These linked stages explain both the value and the limit of connecting fish and plants. The connection offers a route by which fish-derived nutrients can support plant growth, but the reviews do not justify assuming that all nitrogen entering as feed is converted to nitrate or subsequently absorbed by plants.

Matter may also be retained or diverted before reaching a root. Reviews of soilless growing media describe how water and air relations affect nutrient movement and retention within a substrate [8]. This is relevant when interpreting a plant-growing component that contains media: delivery to that component need not mean immediate delivery to the plant. At the same time, the growing-media review addresses soilless cultivation broadly, not a measured nutrient balance for every aquaponic arrangement. Its contribution is to identify a plausible physical distinction between transport and availability. The aquaponic explanation must still rest on evidence for fish waste, biological conversion and plant uptake in the connected system [1].

## IV. Evidence Synthesis

Taken together, aquaponic reviews support a causal chain rather than a closed, loss-free cycle. Feed and fish waste provide nutrient inputs, decomposition and nitrification transform some of that material, circulating effluent carries nutrients between components, and plants take up available nutrients [1], [6], [7]. Each link answers a different question: where matter enters, how its chemical form changes, where it travels, and where some of it is incorporated. The strength of this synthesis is that the same basic sequence appears across accounts of integrated systems. Its limit is equally important: a qualitative sequence does not specify the fraction of an input following any one pathway or establish identical behaviour across configurations.

Evidence from closed hydroponic systems helps explain why recirculation alone cannot settle the fate of matter. A circulating solution can contain organic substances released by roots, while treatment can remove substances, including nutrients, from that solution [9]. Related reviews also describe nutrient-solution flow and reuse in controlled-environment cultivation [10]. These observations do not measure aquaponic losses, but they show why the inventory of a reused solution need not stay constant merely because the water returns. In aquaponics, a defensible description therefore separates the route of the water from the changing composition of what it carries. Claims about a particular system's nutrient balance would require evidence specific to that system.

Comparisons with other soilless approaches clarify mechanisms only when their boundaries remain visible. Organic-solution research shows the importance of mineralising organic matter, while work on growing media draws attention to retention along the delivery path [2], [8]. An aeroponic viewpoint instead considers nutrient-bearing droplets depositing and forming a film on roots; that proposed mechanism is specific to aeroponics and is partly hypothesis-based [11]. It cannot be used to explain how fish effluent circulates through an aquaponic system. The comparison illustrates a general interpretive limit: descriptions of nutrient arrival at roots are not substitutes for evidence about the upstream origin, transformation and movement of nutrients in a different system.

## V. Practical Implications and Limitations

A practical interpretation of nutrient flow should identify the form and location of matter at each stage, rather than label every movement 'recycling'. Fish waste is an input to further processing; nitrification changes the form of dissolved nitrogen; plant uptake removes available nutrients from the water into plant material [1], [7]. This sequence gives meaning to the connection between fish and plants without implying complete recovery of feed-derived nutrients. It also helps distinguish an interruption in transport from a limitation in conversion or uptake. The cited reviews establish the roles of these processes, but they do not supply a universal rate for each stage, so the explanation should remain causal rather than numerical.

The growing environment can complicate any direct reading of nutrient delivery. Where soilless media are present, nutrient retention and movement depend in part on the medium's water and air relations [8]. A description that follows only the water entering and leaving a plant-growing component may therefore overlook material retained within it. Conversely, the aeroponic account of deposition at exposed roots concerns a

different delivery mechanism and remains partly hypothetical; it should not be generalised to media-based or water-circulating aquaponics [11]. The implication is not that one pathway is preferable, but that the physical setting must be specified before claims about nutrient access can be transferred between systems.

Configuration is a further limit on generalisation. Fish effluent and nutrient-containing water can be routed differently in coupled and decoupled aquaponic arrangements, even though feed input, waste processing and plant uptake remain relevant to both [1], [6]. Establishing the fate of nutrients in a particular arrangement would require observations that distinguish inputs, changes in nitrogen form, movement between components and uptake or removal. The available synthesis supports those as distinct questions, not a claimed measurement protocol or a quantified balance. Without system-specific evidence, it is safer to say that conversion and uptake can occur along the flow path than to assert that a given share of the input reaches plants.

## VI. Conclusion

Matter and nutrient flow through an aquaponic ecosystem is best understood as a connected sequence of input, biological transformation, physical transport and plant uptake. Feed-derived waste does not become plant nutrition merely by entering circulating water: decomposition and nitrification alter nutrient forms, while the system's connections permit those nutrients to reach plants [1], [6], [7]. Related soilless evidence reinforces the distinction between water movement and nutrient fate because media can retain nutrients and recirculating solutions can change composition [8], [9]. The resulting account is a supported causal explanation, not a universal claim of complete nutrient recycling.

The highest-value next step for understanding any specified aquaponic arrangement is to establish how much material follows each part of that sequence, rather than infer its fate from the presence of a return flow. Configuration differences already limit the use of one flow pattern as a general model [6]. Until system-specific evidence resolves conversion, retention and uptake, the defensible conclusion is that aquaponics links these processes, but neither water circulation nor the presence of fish-derived nutrients alone establishes their relative contributions [1], [7].

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