Review Article

How Organic Fertilizers can be used as a Plant Nutrient Source in Hydroponics: A Review

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Abstract
Sustainable crop production can be achieved by integrating the concept of modern agriculture with hydroponics for plant production and organic agriculture with the use of organic fertilizer as an alternative to the chemical-based nutrient solution. Organic fertilizers contain a significant amount of essential nutrients needed by the plant for growth and development. Various approaches have been studied to test the viability of organic fertilizer as a nutrient source in hydroponics, such as replacing inorganic substrates with organic substrates, partial replacement, and full replacement of chemical-based nutrient solutions with organic fertilizers. Full replacement of nutrient solutions with organic fertilizers is deemed to be the most sustainable approach. However, unlike nutrient solution, which has an established optimum operation parameter, organic fertilizer as a nutrient solution in hydroponics faces several challenges, such as variability of the quality of organic fertilizers, nutrient management and optimization of the operating parameters. This review provides a general overview of the various approaches to utilize organic fertilizer as a plant nutrient source in hydroponics. In addition, this review provides a synthesis of hydroponics and its applicability to sustainable production, nutrient content of commonly used organic fertilizers and chemical-based nutrient solutions, a comparison of the plant growth and quality using organic fertilizer and chemical-based nutrient solutions and important operating parameters on utilizing organic fertilizers in hydroponics.

Keywords: Agricultural waste, Bioreactor, Mineralization, Nitrification, Organic agriculture, Soilless culture, and Sustainable crop production

1 Introduction

Growers' increasing dependence on manufactured chemical fertilizers to produce food is a serious concern for the sustainability of modern agricultural production. These fertilizers can be expensive and difficult to obtain, and they are frequently manufactured using environmentally harmful methods. The manufacturing of chemical fertilizer accounts for a significant portion of total carbon dioxide emissions from agriculture and many of these essential minerals are rapidly depleting in quantity, with global shortages predicted within the next few decades [1].

A sustainable farming method must be used to produce food while reducing the use of chemical fertilizers and pesticides and conserving more water to address the issues raised above. One approach for sustainable farming is by integrating the concept of organic agriculture and modern agriculture with the utilization of hydroponics. It is necessary to realize the process and the working principle of how these two agricultural farming concepts will merge into a single concept as organic hydroponics.

Hydroponics is described as growing plants in the absence of soil using a chemical-based nutrient solution dissolved in water as a nutrient source, with or without the use of inert mechanical root support [2]. Faster growth, greater yield, simpler handling, and less fertilizer application are some of its advantages over traditional production techniques [3]. While hydroponics gives a significant advantage as compared to the conventional farming technique, there are also some disadvantages to the environment, such as heavy reliance on a chemical-based nutrient solution to support crop growth requirements [4].

These problems were meant to be resolved by using organic fertilizers to create a more sustainable growing environment [5]. However, using organic fertilizers as the main plant nutrient source in hydroponics possess several challenges, such as matching the growth performance of plants comparable to the inorganic nutrient solution, and managing of pH level and electrical conductivity (EC) level of organic nutrient solution [6]. In addition, the direct application of organic materials in hydroponics proved to be detrimental to plant growth due to the presence of soluble organic compounds, which are considered phytotoxic [7].

On the other hand, organic hydroponics is a soilless culture system that uses microbially processed organic materials as plant nutrient sources, as well as an organic substrate to offer mechanical support to plant roots. Organic hydroponics has the potential to reduce reliance on chemical fertilizers entirely by using organic-based fertilizers as the primary source of nutrients for crop production. However, inconsistent quality of organic fertilizers, optimization of operating parameters, and nutrient management were the main challenges that need to be addressed in organic hydroponics. Only a relatively small amount of study has been conducted so far on the use of organically generated solutions in different kinds of hydroponics systems.

This review article examines various approaches to use organic fertilizers as a nutrient source in hydroponics by evaluating the critical process involved in successfully utilizing the nutrient available in organic fertilizers by plants grown in hydroponics. In addition, it aims at advancing current perceptions of using organic fertilizer as a primary nutrient source in hydroponics. This review also provides information about the important parameters to be considered in implementing efficient hydroponics utilizing organic fertilizer. Furthermore, discussions on future aspects and research areas for consideration were presented in this paper.

2 Hydroponics as a Method of Modern Crop Production

The term soilless culture refers to a method of plant production without the use of soil as a growing medium. On the other hand, hydroponics is a soilless culture system where plant roots are partially or completely dipped in the nutrient solution for nourishment and with or without substrates as plant root support. There are different types of hydroponic systems, from simple backyard setups to quite complex commercial operations [8], [9]. Hydroponics can be used to cultivate a wide range of specialty and commercial crops, including fruits and vegetables. The specific setup of hydroponics varies depending on the physiological properties and physical properties of the plant to be grown in the system. Growing crops on hydroponics offer several advantages, such as the reuse of water and nutrients and the prevention of soil-borne diseases and pests as compared to the conventional farming system [10]. However, hydroponics utilizes a chemical-based nutrient solution, which manufactures in the factory that emits CO_2 to produce. In addition, if the leftover nutrient solution is not disposed of safely, it can cause excessive development of algae and other microorganisms in water bodies and effluents, leading to significant environmental concerns [11].

2.1 *Hydroponics industry*

In 2020, the worldwide hydroponics market valuation was at 9.5 billion US dollars and this market value was forecasted to increase by up to 17.9 billion US dollars in the year 2026 [12]. This phenomenon could be attributed to the continuous population growth, which will increase food demand [13]. Also, government and private sectors from many countries were pushing the modernization of the farming system to address food security with the increase of the hydroponics market worldwide. In contrast, this market increase will be one of the major reasons for the continuous dependence on

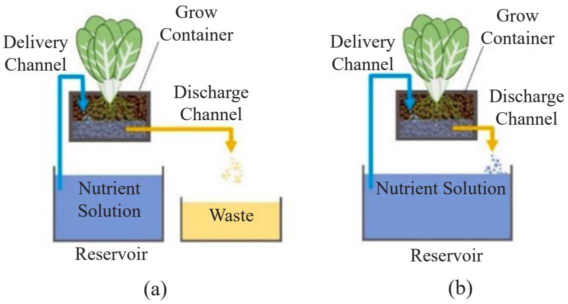

Figure 1: The schematic diagram of a hydroponics system based on how the nutrient solution is circulated in the system. (a) open system hydroponics and (b) closed system hydroponics.

inorganic nutrient solutions to produce crops, which could negatively impact the sustainable development goals (SDG) number 12: responsible consumption and production and number 13: climate action of the United Nations' 2030 agenda for sustainable development.

2.2 *Classification of hydroponics system*

Hydroponics could be classified based on how plant nutrient solutions circulated to the system, such as an open system and a closed system as shown in Figure 1. In open system hydroponics, the plant received nutrient solution regularly and does not reuse the supplied nutrient solution, whereas, in closed system hydroponics, the plant received a nutrient solution regularly and reuses the same nutrient solution introduced to the system [2], [3], [14]. Between these two systems, a closed system offers several advantages over an open system, such as optimal plant nutrient and water use, less amount of nutrients being wasted, and higher savings because of the reduced nutrient waste and efficient use of nutrients supplied to the system. However, there are some drawbacks, such as a high risk of plant disease, phytotoxicity and buildup of organic substances in the nutrient solution, and a high investment cost [2].

Hydroponics can also be classified based on how the nutrient solution is distributed to the plants and recycled back into the system as shown in Figure 2. The nutrient film technique (NFT) employs a thin layer of nutrient solution flowing inside the trough that is continuously recirculated over the plant's roots [15]. In deep water culture (DWC), the plant's roots are continuously submerged in the nutrient solution, which is given directly to the system [16]. Aeration is required in DWC, to maintain the optimal dissolved oxygen level required for efficient nutrient absorption by the plant roots. The Wick system supplies water with nutrients to the plant roots by capillary action through the cotton wick wetted with nutrient solution [17]. This type of hydroponics system does not require submersible pumps to deliver the nutrient solution to plant roots. It is done naturally employing capillarity of water that flows from wick cotton to the plant roots.

In ebb-and-flow hydroponics, the water with nutrients in the tank is supplied on the growth medium bed and stays there for a defined amount of time to supply water and nutrients for plant roots and after the planned amount of time, the nutrient solution is discharged back into the tank [10]. Drip irrigation hydroponics pumps the nutrient solution directly into plant roots at predetermined intervals and the leftover solution is returned to the reservoir [11]. On the other hand, vertical hydroponics operates in a gravity-fed system by supplying the nutrient solution on the top of the tower and draining at the bottom back to the nutrient solution reservoir [18]. While the plant roots in the aeroponics system were suspended inside a darkened sealed container with their exposed ends hanging into the atmosphere to receive nutritional solution spray from the mist nozzle.

2.3 *Chemical-based nutrient solution*

Developing a nutrient solution with a suitable ion ratio for plant growth and development is regarded as a key step in hydroponic agricultural production. Most of the nutrient solutions used in hydroponics to grow crops were derived from inorganic compounds and these were supplied byusing different chemical combinations [6]. A hydroponic nutrient solution is described as an aqueous mixture that contains inorganic ions from soluble salts of essential nutrients for plants, along with certain organic substances like iron chelates [19]. For most plants, key nutrients, including calcium, magnesium, nitrogen, phosphorus, potassium, and sulfur as well as micronutrients like zinc, molybdenum, manganese, iron, copper, chlorine, boron, and nickel are thought to be essential for plant growth and development [14].

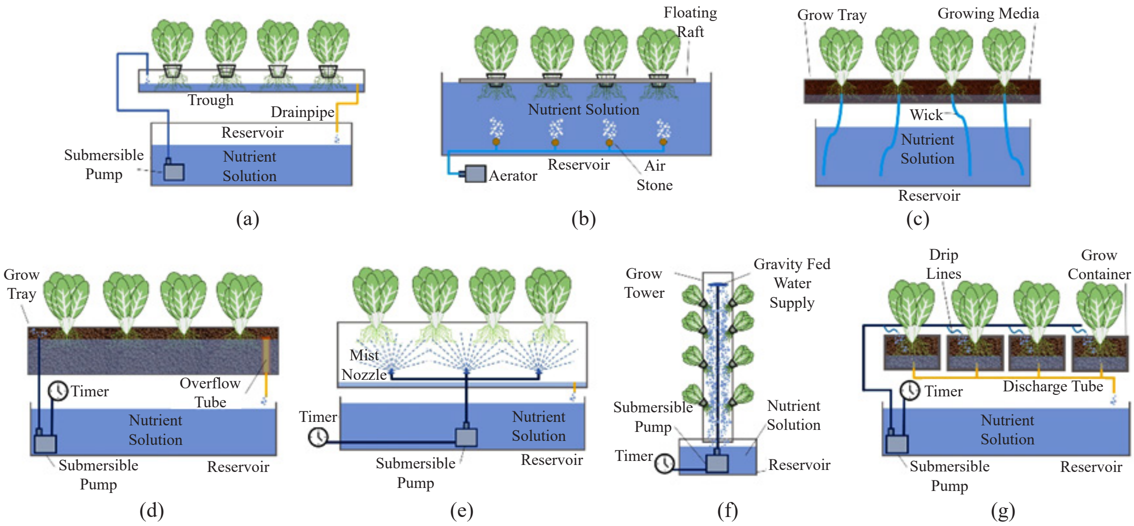

Figure 2: The schematic diagram of hydroponics based on how the nutrient solution is distributed to the plants and recycled back in the system, (a) nutrient film technique, (b) deep water culture, (c) wick system, (d) ebb and flow, (e) aeroponics, (f) vertical hydroponics, and (g) drip irrigation hydroponics.

Table 1 shows some of the commonly used formulated nutrient solutions in hydroponics research and development. Hoagland and Arnon formulated Hoagland numbers 1 and 2 as a result of experimentation done on tomato plants irrigated with the nutrient solution under controlled conditions [20]. These compositions served as the foundation for the majority of nutrient solutions, which are referred to as "modified Hoagland nutrient solutions" in the scientific literature [14]. Steiner developed the Steiner solution based on the concept of ionic mutual ratio of anions and cations in which the plant will grow well due to the proper balance of ions of elements [21].

Hydroponic systems have been proven to efficiently deliver optimum nutrients for growing plants and offer better control and formulation according to the plant nutrient requirement. However, the nutrient solution commonly utilized in hydroponics is based on elements extracted from limited and non-renewable resources, one of which is phosphorus [22], [23]. While there is limited scientific literature and uncertainties on projections of phosphorus depletion which range from 30 and 300 years, there is broad consensus that the quality and accessibility of existing reserves are deteriorating, and prices of these resources will increase [24].

As a result, this could lead to a massive shortage of complete fertilizer supply, and eventually, it will affect the food production system, and it will cause a decrease in productivity in farms due to a limited supply of these nutrient resources needed by the plant. Fortunately, organic fertilizers through various methods, such as processing agricultural waste through composting could help to minimize heavy reliance on inorganic nutrient sources. However, challenges on

Table 1: Nutrient content of the commonly used formulated nutrient solution in hydroponics (in ppm)

Nutrient Content	Formulated Nutrient Solutions		
	Hoagland No 1.	Hoagland No 2.	Steiner Solution
Macronutrients			
Nitrogen	242	232.6	170
Phosphorus	31	24	50
Potassium	232	230	320
Calcium	224	179	183
Magnesium	49	49	50
Sulfur	113	113	148
Micronutrients			
Boron	0.45	0.45	1–2
Copper	0.02	0.02	0.1–0.5
Iron	-	7.0	3–4
Manganese	0.50	0.05	1–2
Molybdenum	0.0106	0.0106	0.1
Zinc	0.48	0.48	0.2

variability in the nutrient quality and control of specific output characteristics of compost is ongoing research needed to be solved [25]. Still, organic fertilizer is the most viable option to solve the above-mentioned issues and concerns with the use of chemical-based fertilizers.

3 Plant and Fertilizer Relationship

Plant growth and development in hydroponics mostly rely on the concentrations of minerals in the chemical-based nutrient solution, and an absence of any of them can result in low plant productivity. Mineral nutrients enter the plant through the roots and show distinct selectivity in terms of which chemical elements are allowed to pass through [26]. These nutrients absorbed by the plant are in the form of an ion. As ions are taken up by plant roots, they are replaced by exchangeable ions from the colloidal reservoir. Additionally, if plants are nourished in an abundant nutrient solution flow, they have the capacity to choose ions in the complementary ratio that is beneficial for their growth and development [27]. Furthermore, the uptake of nutrients by most plants is enhanced by the association of the roots and microorganisms, especially fungi (mycorrhizae) [28].

In contrast, a poor supply of an essential element to plants will result in a nutritional problem leading characterized by a lack of certain traits. In hydroponics, the features of deficiency symptoms may be associated with a particular chemical element that is insufficient; however, in natural conditions, this association is more challenging to distinguish [29]. Deficiency of macronutrients, such as nitrogen, potassium, phosphorus, magnesium, calcium, and sulfur was manifested as visual symptoms of nutrient deficiency and affected the growth performance of seedlings and the concentration of nutrients in plant tissue [30].

Micronutrient deficiency alters the development pattern, chemical makeup, and antioxidant defense capability of plants, which in turn reduces the ability of plants to withstand biotic and abiotic environmental stresses [31]. Most of the signs of nutritional deficiency are noticeable and manifest on the plant shoot. The nutritional deficiency in plants can be caused by a small concentration of a mineral element in a solution and different element forms that plants have difficulty in assimilation. In addition, the pH level, water quality, the level of dissolved oxygen, and a high concentration of antagonistic elements can be a factor in the accessibility of essential elements to plants.

4 Sustainable Approaches to Reduce Reliance on Chemical-based Nutrient Solutions

Sustainability is built on the principle that we must attain our current necessities without compromising the ability of the next generations to attain their necessities. Research on many scales, from single crops to diversified cropping and farming systems, is necessary to develop production systems that adhere to the principles of sustainable agriculture [13]. Sustainable agriculture is described as an agricultural scheme that, over time, enhances environmental quality and the resource base on which agriculture depends, satisfies fundamental human food and fiber needs, enhances the standard of living for farmers and society at large, and is economically practical [32].

Integrating organic agriculture and modern farming through hydroponics is possible with the help of beneficial microorganisms to further process the available nutrients from organic fertilizer to be available for plant development. Replacing chemical-based nutrient solutions with organic fertilizers in hydroponics systems will be beneficial to the environment by preventing the improper disposal of used nutrient solutions, which poses a negative impact on soil and water bodies. In addition, crops produced using organic fertilizer as a nutrient source for hydroponics showed a comparable to chemical-based nutrient solutions in terms of growth performance [33].

Although hydroponics cannot yet be considered a more sustainable alternative to the conventional agricultural system, it does provide interesting ideas that might result in more sustainable food production [8]. The idea of replacing chemical-based nutrient solutions with organic fertilizers derived from various agricultural waste materials has been studied by several authors and resulted in a positive response on plant growth and development. Furthermore, using the organic substrate for mechanical support to the plant has been studied and deemed to improve plant nutrient absorption.

4.1 *The use of organic substrates*

Growing media, also known as "substrates" or "plant substrates", provide a root environment free of plant diseases and with qualities that enable optimal aeration, water and fertilizer delivery as shown in Figure 3. Mixtures of growth medium ingredients and additives are often utilized in the horticulture sector. Constituents might be organic or inorganic, and additions can be fertilizers, liming materials, or biocontrol or wetting agents [34]. Earlier studies have focused on testing a variety of substrates (organic, inorganic, and synthetic) on hydroponics to determine which substrate is feasible to utilize [35]. Organic substrates offer several advantages as compared to inorganic and synthetic substrates [36]. Organic substrates were described as growing media with high water holding capacity due to fiber content and moderate to high level of porosity, which affects root aeration and gas exchange [37]. A significant amount of the stored water is readily accessible to the plant, as seen by the less amount of substrate needed per plant to provide an adequate supply of water [38]. The research indicates that organic substrates influence plant development, either directly (absorption of humic substances, which improve plant nutrient uptake and enzymatic activities) or indirectly (enhance cation exchange capacity and invigorate microbiological activity in plant roots) [39]. Table 2 shows the main properties of organic substrates commonly used in hydroponics.

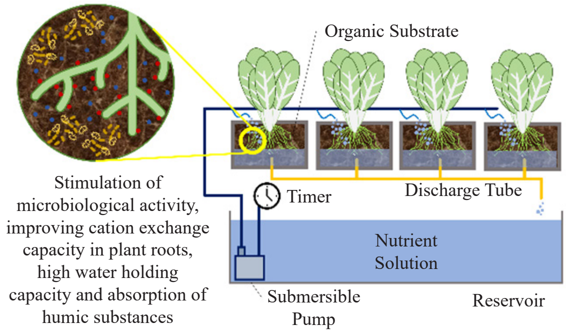

Figure 3: Schematic diagram of using organic substrate in hydroponics.

Table 2: Properties of various organic substrates commonly used in a hydroponics

Organic Substrate	BD	P	WHC	CEC	Remarks	Ref.
Biochar	0.10–0.64	55–86	120–353	16–524	Biologically inert that suppresses algal and fungal growth.	[40]–[44]
Coconut Coir Dust	0.40–0.80	84–98	750–1241	39–60	High water holding capacity which is suitable for use as substrates in hydroponics.	[45]–[47]
Compost	0.42–0.66	59–95	350–440	2.9–116	Contains a significant amount of nutrients as an amendment in plant nutrition	[48]–[51]
Peat	0.01–0.26	95.5	151–1322	100	High water holding capacity and low acidity level which it suitable as a growing medium for hydroponics, however massive harvesting, and slow formation of peat cause depletion of peatland areas.	[52]–[54]
Sawdust	0.14	36.1–89.8	379	25–46.5	Often mixed with other organic substrates and it is usually less than half of a mixture's constituents.	[39], [55]–[57]

Note: BD = bulk density (g cm^{-3}), P = porosity (v/v %), WHC = water holding capacity on a dry basis (w/w %), and CEC = cation exchange capacity (cmol kg^{-1})

In addition, organic substrates can support a beneficial microbial community. The rhizosphere's microbial populations are influenced by the plant as well as many biological, chemical, and physical interactions occurring in the growing substrates [58]. A diverse and stable microbe population on organic substrates provides functional variety, temporal stability, and tolerance to a varied and changing hydroponics environment [58]. In the study of the microbe and growing substrates (90% organic materials and 10% inorganic materials, v/v) interaction, the primary factor influencing plant performance was the bacterial amendment, although its efficacy and plant performance characteristics had an impact on the interactions between microbes and plants in the growing substrates and the bacterial source [59]. Furthermore, growing substrates without bacterial amendment did not perform well.

4.2 *Partial replacement of nutrient solution with organic fertilizers*

Partial replacement of nutrient solution with organic fertilizer (Figure 4) is one of the approaches being explored by many researchers to reduce the volume of consumption of chemical-based nutrient solution to produce crops in a hydroponic system in an environmentally friendly manner. The possibilities of reducing the concentration of nutrient solution utilized in hydroponics and supplemented with vermicompost water extracts were explored in the study conducted by Arancon *et al.* [60]. Based on the result of the study, the yield of marketable tomatoes significantly increased using a 50% reduction of nutrient solution concentration and supplemented with vermicompost tea when compared to full rate nutrient solution concentration dissolved in water. In addition, using a 25% and 50% reduction of nutrient solution concentration and supplemented with vermicompost tea boosted lettuce yield when compared to full rate nutrient solution concentration dissolved in water.

Another investigation done by Sunaryo *et al.*, explored the optimum volume ratio of AB-Mix nutrient solution (a well-known commercial nutrient solution) and liquid fertilizer made from manure goat with a treatment of 1:1, 3:1, 1:3, and AB-Mix nutrient solution as a control to observe the response of various crops, such as lettuce, spinach, and mustard green [61]. The results indicate that utilizing the nutrient solution and liquid fertilizer with a volume-to-volume ratio of 1:3 in hydroponics resulted in a comparable plant growth response to the control (nutrient solution only).

The partial replacement approach does not eliminate the reliance on nutrient solution as a primary nutrient source in a hydroponically grown crop. Positive responses to the partial replacement of chemical-based nutrient solutions with organic nutrient sources, on the other hand, imply the possibility of reducing nutrient solution consumption without sacrificing crop production or quality in a hydroponics system.

4.3 *Full replacement of nutrient solution with organic Fertilizers*

Utilizing organic fertilizer as a primary nutrient source in hydroponics could be a solution toward a sustainable approach to crop production. However, earlier reports

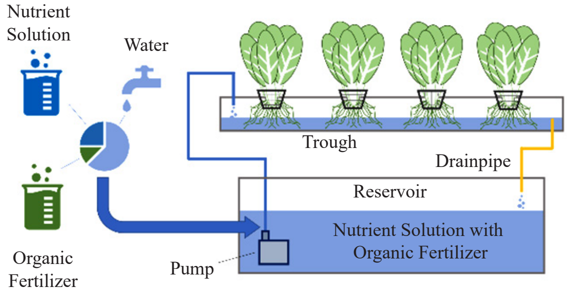

Figure 4: Schematic diagram of partial replacement of chemical-based nutrient solution with organic fertilizer.

on the direct use of leachate derived from crop residues as a nutrient source in hydroponics have resulted in a substantial reduction in plant growth [62]. The high organic content of leachates has phytotoxic effects on plants, which inhibit plant development [63]. On the other hand, innovations of this approach over the last decades have been evolving toward understanding the activity of microorganisms in making the nutrients from organic fertilizer available for plant growth and development.

One example of this innovation is organic hydroponics that provides nutrients necessary for plant growth and development from organic fertilizers derived from plants and animal waste. The productivity of this system is primarily influenced by microbial activity, which aids and controls nutrient availability/absorption and increases plant resilience to stress [64], [65]. Understanding these concepts will guide the farmers in growing crops in hydroponics using organic fertilizers as a primary nutrient source.

Nitrogen availability in organic fertilizers is one of the key determinants of crop productivity since it affects seed germination, plant growth and development, and root and leaf functionalities. Total nitrogen (the sum of all nitrogen forms, including ammonia, nitrite, and nitrate) is a vital ingredient found in proteins, nucleic acids, adenosine phosphates, pyridine nucleotides, and pigment [66]. Most of the total nitrogen in organic fertilizers is in organic form, which for the most part is not directly accessible for the plant to absorb [67]. For organic hydroponics to be practicable, the organic nitrogen present in organic materials must be converted into other forms of nitrogen, such as ammonia and nitrate through the mineralization and nitrification process permitting direct input of organic nutrient sources to the hydroponic system with the aid of microorganisms.

Mineralization is responsible for the process of converting organic nitrogen, organic matter, and crop residue present in agricultural waste into ammonia during the composting period. The by-product of composting, which is organic fertilizer contains significant ammonia that can be used as an organic nutrient source. On the other hand, many crops are sensitive to ammonia toxicity, especially at a high concentration resulting in stunted plant growth, leaf chlorosis, and poor root development [68]. Likewise, the plant grows well on a mixture of both ammonia and nitrate, but optimal ratios may vary from type of plant, age, and pH level of growing media [69].

Nitrification is the oxidation of ammonia from an organic nutrient source to nitrite and subsequently to nitrate by a specific group of microorganisms [70]–[73]. Nitrite is an intermediate product in the nitrification of ammonia to nitrate process, which is executed by ammonia-oxidizing bacteria, such as Nitrosospira, Nitrosococcus, Nitrosomonas, and Nitrosolobus [70]. The final result of nitrification, known as nitrate, is produced by a group of nitrite-oxidizing bacteria such as Nitrobacter, Nitrospira, Nitrospina, and Nitrococcus that oxidize nitrites [74]. Nitrifying bacteria play an integral part in the overall operation of hydroponics utilizing organic fertilizer as a plant nutrient source. This group of bacteria responsible for the nitrification process serves as a prime mover to work on the concept of integrating organic agriculture with hydroponics. Without these beneficial microbes, the nutrients from organic fertilizers cannot be used efficiently and can be led to phytotoxicity, which could stress and eventually kill the plants.

As compared to earlier attempts to directly use organic fertilizer as a nutrient source in hydroponics, a study on microbial processing of organic fertilizer to convert ammonia nitrogen into nitrate was done before its introduction to hydroponics [71], [72], [75]. The process is called multiple parallel mineralizations involving a concurrent process of ammonification and nitrification, which is commonly observed on soil and water bodies. The yield of lettuce with the use of organic fertilizer was not significantly different compared to the conventional hydroponics. In addition, the study conducted by Kano *et al.*, utilizing organic fertilizer processed through multiple parallel mineralizations as a plant nutrient source in hydroponics improves the yield, quality, and disease resistance of bok choy [76].

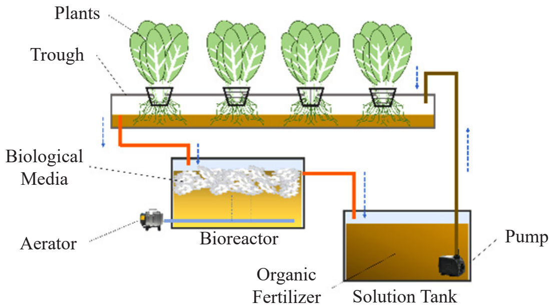

Figure 5: Schematic diagram of full replacement of chemical-based nutrient solution with organic fertilizer using bioreactor.

Another way to utilize organic fertilizers as a primary nutrient source in a hydroponics system is by using bioreactors (Figure 5). Bioreactors provide a location for bacteria to convert ammonia present in organic fertilizer into nitrate, more accessible nutrients for plants. Before the use of bioreactors in organic hydroponics, bioreactors are commonly used in wastewater treatment facilities and recirculating aquaculture systems wherein it is responsible for the nitrification process of ammonia-rich effluent and fish waste.

The operation of bioreactors in a hydroponics system is directly affected by the surface area and water conditions, such as dissolved oxygen level, pH level, light exposure and temperature [73], [77]. The higher the surface area available for the microbial community, the more bacteria will be able to oxidize the ammonia into nitrate. Also, the dissolved oxygen level of water is an important parameter to determine if the nitrifying bacteria are present in the bioreactor. Nitrifying bacteria were able to adapt to a wide range of pH, however, it is important to consider the pH level in terms of plant nutrient absorption at a certain range of pH levels. Temperature also affects the productivity of nitrifying bacteria. Typically, at a lower temperature, the productivity of nitrifying bacteria decreases by as much as 50% [78]. It is also recommended to prevent direct light exposure to bioreactors since nitrifying bacteria are photosensitive organisms.

An early study was conducted by Finger & Strayer to investigate the operating parameters of the bioreactor to process plant residue by biodegradation to extract nutrients in a form of liquid effluent and for possible use in hydroponics [79]. In the study conducted by Mackowiack *et al.*, they test the produced liquid effluent derived from inedible potato biomass from the same bioreactor in hydroponics using potato plants as a test crop [63]. The result of the study shows that the potato plant grown using liquid effluent from the bioreactor is comparable with the potato plant grown using modified half-strength Hoagland's nutrient solution. The results of the earlier study suggest the possibility of utilizing plant biomass as the main nutrient source in hydroponics using a bioreactor.

In a recent study on bioreactors, chicken manure was investigated as a plant nutrient source for hydroponics [73], [80]. The result of the study showed that the nutrient use efficiency of the system is comparable to the aquaponics system. Also, the working principle of the setup can be compared to an aquaponics system in which the waste released by fish will be processed through nitrification using a biofilter before delivering to the plant for nutrient consumption. In addition, a study was conducted to determine the effect of liquid digestate derived from pig manure on the growth and production of tomato plants in hydroponics production using a bioreactor [81]. The result of the study indicates that the tomatoes grown using liquid digestate derived from pig manure showed reduced growth rates but increases the average fruit size, which is also comparable with tomato plants grown using a nutrient solution. The result of the recent study also suggests the suitability of animal waste processed in the bioreactor as a plant nutrient source using hydroponics.

Furthermore, aquaponics production that utilizes fish waste as a primary nutrient source for the hydroponically grown plant is another example of organic hydroponics. To put it simply, aquaponics is a form of organic hydroponics that involves growing both plants and fish or other aquatic animals in closed or semi-closed recirculating systems that mimic the processes that naturally occur in the freshwater ecosystem. Typically, a biofilter is needed in an aquaponics system to process the fish waste via the nitrification process to convert ammonia present in fish urine and feces, which is toxic to fish, into nitrate, which is a more accessible form of nitrogen to plants [82]. In the comparison of aquaponics and standard hydroponics in terms of plant growth rate, the yield per area of lettuce grown in aquaponics is comparable to the yield per area of lettuce grown in standard hydroponics [83].

5 Organic Fertilizers as Nutrient Source for Hydroponics

The utilization of organic fertilizer has substantially led to environmental sustainability and increased agricultural production [84]. Organic fertilizers are naturally derived fertilizers containing essential elements that help the growth and development of plants. The common types of organic fertilizers based on origin are animal-based (ex. animal manure, digested animal slurry, blood meal, fish hydrolysates, etc.) and plant-based (ex. plant biomass, extract, and other by-products derived from plant), and mineral-based (ex. Epsom salt and rock phosphate). The quality of organic fertilizers depends on primary origins such as urban waste from kitchen and market waste, and agricultural waste from plants and animals [85]. Also, the production techniques of organic fertilizers, such as fermentation, composting, vermicomposting, aerobic digestion, and anaerobic digestion affect the availability of nutrients [86]. A balanced amount of organic nitrogen is included in the majority of organic fertilizers, acting as a slow-release fertilizer by releasing nutrients over time in smaller amounts [87]. It also contains beneficial microorganisms and can be produced from manure, crop residues, compost, and sewage sludge. The presence of microorganisms helps decompose organic material, increase nutrient availability for plants, improve soil water-holding capacity, enhance aeration, and improve soil aggregation [88].

Organic fertilizers as a nutrient source in hydroponics have been explored by many researchers with different methodologies, approaches, and types of organic fertilizers. Sustainable approaches to plant products, such as decreasing the dependence on chemical-based nutrient solutions, energy conservation, water use efficiency and reduction. Also, recycling of agricultural waste are major reasons for the utilization of organic fertilizers in hydroponics. Another reason for the growing interest in using organic nutrient sources in hydroponics is that crops produced on organic fertilizers have significantly lower nitrate content compared to crops produced on inorganic fertilizer [89]. Consumption of leafy vegetables with high concentrations of nitrate can cause an adverse effect on human health if not within the range of acceptable daily intake [90].

The parameter for the selection of organic fertilizers as a potential plant nutrient source in hydroponics was investigated by Shinohara *et al.* [72]. They observed that organic nutrient sources with a C/N ratio equal to or more than 11 were used not able to generate nitrate through mineralization. They suggest that organic nutrient sources with a C/N ratio of less than 11 should be used in organic hydroponics or that additional organic nutrient sources rich in nitrogen must be added to lower the C/N ratio. The carbon to nitrogen (C/N) ratio is a measure of how much carbon is present in an organic substance in relation to nitrogen. The C/N ratio affects the availability of inorganic forms of nitrogen for plant use in organic nutrient sources. A lower C/N ratio ranging from 1–15 will rapidly mineralize organic material by microbes and release nitrogen for plant uptake, a ratio of 20–30 will result in an equilibrium state between mineralization and immobilization, and a ratio greater than 35 will result in microbial immobilization, which inhibits the release of nitrogen [91].

Table 3: Nutrient content of commonly used organic fertilizer as a plant nutrient source in hydroponics

Organic Fertilizers	Macronutrients (%)						Micronutrients (ppm)						Ref.
	N	P	K	S	Ca	Mg	Zn	B	Mn	Fe	Mo	Cu	
Vermicompost	2.915	0.341	1.377	-	2.975	0.562	40	-	260	3770	-	30	[92]
Compost	2.249	0.337	1.124	-	2.660	0.497	30	-	270	3760	-	30	[92]
Vermicompost Leachate	0.0134–0.0464	0.0021–0.0087	0.0001–0.0236	-	0.0037–0.0129	0.0012–0.0036	-	-	-	-	-	-	[93]
Chicken Manure	5.96	1.38	2.24	0.78	5.84	0.70	-	-	-	0.13	-	-	[94]
Biogas digestate	0.021	0.0038	0.024	-	0.011	0.0023	0.81	0.21	1.2	33	0.0002	0.028	[95]
Plant Biomass (fermented)	0.00485	0.000341	0.00045	0.0084	0.0008	0.01	22.5	4.8	0.02	5.4	-	3.10	[96]
Fish emulsion	2.38	2.08	0.554	-	0.391	0.072	4.38	-	-	37.8	-	-	[97]
Aquaculture waste	0.01217	0.0058	0.01853	0.0013	0.0124	0.0017	0.83	0.05	0.02	1.24	0.01	0.03	[98]

Organic fertilizers are often characterized as inconsistent in terms of their macronutrients and micronutrient content. Microbial degradation through mineralization is required to improve the nutrient content of organic fertilizer to be used as the main nutrient source in hydroponics. Some organic fertilizers require the supplementation of both macronutrients and micronutrients from organic or inorganic sources. The use of liquid digestate from the pig as the main nutrient source in hydroponics requires supplementation of calcium, magnesium, phosphorus and sulfur to compensate for the unavailability of these nutrients [81]. In addition, supplementation of oyster shell lime on fish-based soluble fertilizer was done to provide additional micronutrients in organic hydroponics [72]. Table 3 shows the nutrient content of commonly used organic fertilizer as a plant nutrient source in hydroponics.

5.1 *Vermicompost and by-products*

Vermicompost is a product of the biological decomposition of organic waste using earthworms and microorganisms to form a balanced, uniform and hummus-like final product [85]. Vermicompost contains significant amounts of macronutrients and micronutrients essential for plant growth and it varies subject to what kind of organic materials are utilized during the decomposition process [85], [99]–[101]. Vermicompost increases plant growth, seed germination and development, flowering, and fruit production when added as an addition to soil or other plant growth media [102], [103].

The vermicompost was processed into vermicompost tea or vermicompost leachate before using as a nutrient source in the hydroponics system. Vermicompost is combined with water and fermented (aerated or non-aerated) for a specific amount of time to extract nutrients and cultivate bacteria to produce vermicompost tea [104]–[106]. Insoluble nutrients are transformed into soluble forms by microbes, which promotes a wide range of microorganisms in vermicompost tea during the brewing process [107].

The use of vermicompost tea as a supplement with a low concentration of the nutrient solution in static hydroponics significantly increased the plant yield of lettuce and tomato. The presence of plant hormones, such as humic acid, cytokinins, auxins, and gibberellins, causes a higher yield of tomato and lettuce grown using a lower nutrient solution concentration in static hydroponics [60]. Plant hormones are chemical compounds that control plant growth and crop production under various situations, including stress [108], [109]. Also, the presence of plant hormones in vermicompost tea has been documented and resulted to increase germination of lettuce and tomato seeds [110].

Nevertheless, there are also studies on the evaluation of vermicompost tea as a nutrient solution on the yield and antioxidant capacity of cucumber grown in hydroponics under greenhouse conditions. The results suggest that the yield of cucumber cultivated by using organic nutrient solutions was lower than the yield of cucumber grown by using inorganic nutrient solution, which could be related to lower nutrient concentrations in organic nutrient solution [111], [112]. However, cucumber produced in organic nutrient solution had a higher antioxidant capacity, which is preferred by consumers since those bioactive compounds reduce the risk of chronic degenerative diseases [112]–[114].

Another by-product of vermicompost used as an organic nutrient solution is the vermicompost leachate, which is a drained liquid coming from the vermicompost bed [93]. The yield of pak choi grown using pH-buffered vermicompost leachate as a nutrient source was reported to be comparable to those of plants that had been fertilized with conventional inorganic fertilizer using the ideal hydroponic management techniques [93]. The study also demonstrated the importance of pH adjustment of vermicompost leachate to be used as an organic nutrient source for pak choi.

5.2 *Animal manure*

Another source of organic nutrients is animal manure which contains macro and micronutrients that are vital for plant growth. Chicken manure as organic fertilizer improves the physical and biological properties of the soil when applied at a recommended rate [115]. Chicken manure that had been vermicomposted was discovered to have significant levels of plant growth hormones, which improved lettuce and tomato seedling germination and growth [110].

A study was conducted to examine the varying chicken manure loading in hydroponics with a biofilter that microbiologically processes the manure to release essential nutrients for lettuce growth and development [73]. The system loaded with chicken manure successfully grows lettuce and the nutrient use efficiencies of the system utilizing chicken manure as a nutrient source are comparable with the aquaponics system. However, the results of another study to determine how chicken manure affected plant yield in hydroponics showed that the plants were more negatively impacted by chicken manure at higher concentrations [88]. In both studies, it is important to take into consideration the difference between the hydroponics setup which could be a factor in efficiently utilizing the chicken manure as a plant nutrient source. In addition, manure extracts sourced from cows and turkey were also tested as a nutrient source in hydroponics and successful growth was attained using lettuce and kale as test crops [88]. The shoot weight (dry basis) of lettuce cultivated in a solution containing turkey dung extract was higher than the control (nutrient solution). However, the control had the biggest shoot weight (wet basis) for kale.

5.3 *Biogas digestate*

Biogas digestate is a by-product of the anaerobic fermentation of organic waste in a biogas plant, and it is rich in organic nutrient content. According to various research, biogas digestate is used as a hydroponic culture substrate, an organic product for disease and pest management, and a fertilizer amendment in soil [116]. Biogas digestate was successfully utilized as a primary nutrient source in hydroponic for vegetable production [95]. In this study, bok choy was grown in a hydroponic NFT system with biogas digestate as the only plant nutrient source. Nitrification in bioreactors was used to reduce the high ammonia concentration in the biogas digestate before the application. In contrast, the research conducted by Mupambwa *et al.*, suggested that biogas digestate derived from cow dung are not suitable to plant nutrient sources for tomato production in hydroponics [117]. The analysis of the impact of varying levels of biogas digestate replacement with the nutrient solution on tomato yield and fruit production reveals a detrimental impact on fresh output and fruit production. To employ biogas digestate as a nutrient supply in hydroponics, further processing of the digestate may be undertaken, such as lowering the ammonia concentration by nitrification in a bioreactor. Aside from animal manure, biogas digestate derived from plant biomass, such as rice straw could be examined as a plant nutrient source in hydroponics [118].

5.4 *Plant biomass and by-products*

A variety of plant biomass and by-products can be used as organic fertilizers. Sugarcane processing produced waste and by-products, such as bagasse, molasses and press mud [119]. A study was conducted to examine the feasibility of fermented sugarcane leaves, waste molasses and distillery slop to produce liquid fertilizer for hydroponics [33]. The produced liquid fertilizer demonstrated an excellent growth performance of lettuce produced in hydroponics and had comparable plant growth promotion properties to chemical-based nutrient solutions. Liquid fertilizer from fermented plant biomass from the stem and leaves of sunflower was also tested as an organic nutrient source for hydroponics [96]. The result of the study suggests that using liquid fertilizer from plant biomass is feasible to be used as an organic nutrient source in the production of tomatoes and cucumbers in hydroponics. These studies imply that other plant biomass and by-products that are rich in mineral elements could be tested as a primary nutrient source in hydroponics.

5.5 *Fish waste and by-products*

Fish waste and by-products include different materials from fish, such as intestines, fish trimmings, tails, fins, scales, bones, skins, heads and damaged fish bodies [120]. Fish waste and by-products were processed into liquid or solid forms of fertilizers, such as fish soluble fertilizer, fish hydrolysates, fish meal, fish emulsion and fish powder. Liquid organic fertilizers derived from fish waste when utilized as a plant nutrient in hydroponically grown lettuce show lower growth and fresh biomass as compared to the chemical-based nutrient solution [121]. However, when compared to chemical-based nutrient solutions, the flavonoid content, phenolic compounds, carotene, total chlorophyll, and antioxidant activity of lettuce grown with liquid organic fertilizers were higher. The result of the above study indicates a significant improvement in the nutritional quality of the crop with organic fertilizers as the main nutrient source in hydroponics.

6 Comparison of Organic Fertilizer and Chemical-based Nutrient Solution in Hydroponics

Many studies have been conducted on the investigation of the effects of organic fertilizers on a plant in comparison to chemical-based nutrient solutions concerning plant growth, development and quality. The results of these investigations vary depending on the approach of utilizing organic fertilizers as plant nutrient sources. Although cultivation in hydroponic systems takes place in a controlled environment, plant responses to organic nutrients in terms of yield and crop quality may still be influenced by the quality (physiochemical characteristics of various organic materials), and the processes for producing organic fertilizer [96]. Table 4 shows some examples of utilization of organic fertilizers as plant nutrient sources in comparison with chemical-based nutrient solutions in relation to the effect on plant growth and quality.

7 Important Monitoring Parameters in Utilizing Organic Fertilizers as Plant Nutrient Sources in Hydroponics

In conventional hydroponics, pH level and electrical conductivity were the most observed parameter in the nutrient solution. However, in organic hydroponics, there is no standard monitoring parameter for all types of organic nutrient sources, and it varies depending on the type of organic nutrient source, plant, hydroponics system and approach of utilizing organic fertilizer as a plant nutrient source. Table 5 shows the values of the commonly observed parameters for full replacement of nutrient solution with an organic fertilizer in hydroponics.

Table 4: The effects of using organic fertilizers as a plant nutrient source in hydroponics versus chemical-based nutrient solutions on plant growth and quality

Approach	Organic Nutrient Source	Method of Organic Fertilizer Processing for Utilization	Type of Hydroponics	Crops	Effect on Crop Growth and Quality in Comparison with Chemical-Based Nutrient Solution	Ref.
Full replacement of nutrient solution with organic fertilizers.	Fresh biomass from stems and leaves of Mexican sunflower	The biomass was immersed in water in a clean container for 14 days, during which time it underwent natural fermentation. The liquid by-product is then diluted in water at different rates	Drip irrigation hydroponics	Tomato and cucumber	When compared to the control (nutrient solution), tomato and cucumber fruits grown with organic fertilizers had higher growth, yield, leaf nutrient concentrations, and mineral contents.	[96]
Partial replacement of nutrient solution with organic fertilizers	Vermicompost derived from food waste and shredded paper	Vermicomposts and pre-mixed nutrient solutions were added directly into the tanks to produce vermicompost tea as a supplement for a nutrient solution at varying concentration	Non-recirculating hydroponics	Lettuce and tomato	When nutrient solution concentrations were decreased to 1/4 and 1/2 of the suggested full rate nutrient solutions, vermicompost tea treatments significantly boosted lettuce yields in comparison with treatments lacking vermicompost teas. Tomato yields were substantially improved when vermicompost teas were added to the lowered nutrient solution concentration.	[60]
Full replacement of nutrient solution with organic fertilizers.	Fish-based soluble fertilizer	A 50-day aeration period was done to a solution containing fish-based soluble fertilizer, water, and bark compost (as inoculum for microbes). After preparation, the hydroponic pot was filled with the organic solution	Non-recirculating hydroponics	Lettuce and tomato	The growth performance and quality of lettuce and tomato fruits produced using organic nutrient solution were comparable with lettuce and tomato fruit produced using the nutrient solution in the hydroponics system.	[72]
Full replacement of nutrient solution with organic fertilizers.	Sugarcane leaves, distillery slop, and molasses.	Six (6) various ratios of molasses, sugarcane leaves, distillery slop, and water were blended in terms of volume and weight to produce liquid fertilizer. Separate containers were used to incubate the mixture for 30 days at room temperature. Every seven days, the mixtures were agitated during the fermentation phase.	NFT hydroponics	Lettuce	The hydroponic lettuce production findings indicated that the certain mix of organic liquid fertilizer (distillery slop: sugarcane leaves: filtrate water at 1:0.1:0.25 v:w:v and 1:0.25:0.25 v:w:v) exhibited the highest growth productivity which is comparable with plants supplied with chemical-based nutrient solution.	[33]

Table 4: The effects of using organic fertilizers as a plant nutrient source in hydroponics versus chemical-based nutrient solutions on plant growth and quality (*Continued*)

Approach	Organic Nutrient Source	Method of Organic Fertilizer Processing for Utilization	Type of Hydroponics	Crops	Effect on Crop Growth and Quality in Comparison with Chemical-Based Nutrient Solution	Ref.
Partial replacement of nutrient solution with organic fertilizers	Goat manure	The air-dried goat manure was fermented with sugar, EM (effective microorganism), and water. The mixture was placed in a container and maintained at room temperature for three (3) weeks. Regular stirring of the mixture was done during a fermentation process. After fermentation, the mixture is then combined with nutrient solution at different ratios.	SFT (shallow flow technique) hydroponics	Mustard green, lettuce, and spinach	The ratio of 1:1:3 (v/v) of goat manure liquid fertilizer to nutrient solution produced similar plant growth for all vegetables and the highest chlorophyll content in mustard green. The nutrient solution's 1:1, 1:3, and 3:1 (v/v) ratios to control resulted in improved assimilation partitioning to the red spinach stalk.	[61]
Full replacement of nutrient solution with organic fertilizers.	Liquid digestate from pig manure	Moving bed biofilm reactor (MBBR) was used to process the liquid digestate through biological nitrification. The processed organic fertilizer was fertigated for a tomato plant.	Drip irrigation hydroponics	Tomato	When compared to high-mineral agriculture, tomatoes produced with organic fertilizer had slower growth rates but larger average fruits, hence the overall output was unaffected. The fruit quality of the plants produced with organic fertilizer, however, was noticeably inferior to that of the plants fed with the high-mineral solution.	[81]
Full replacement of nutrient solution with organic fertilizer	Chicken manure, cow manure, and turkey manure	Each organic material was diluted in water at different rates. The organic solutions were aerated using an air pump for 2 days. The processed organic solutions were filtered and diluted again with water to be used as a nutrient source in hydroponics	Ebb and flow hydroponics	Lettuce and kale	An organic nutrient solution containing 50 g/L of turkey dung extract utilized in hydroponics produced healthy lettuce and kale plants. But compared to the control, plants in organic nutrient solution from chicken and cow dung extract had lower aboveground wet and dry masses. Plants cultivated in organic nutrient solution from chicken extract (50 g/L) probably withered from ammonia toxicity. All nutrients, except for ammonia and phosphate, were below the recommended values for lettuce development.	[88]

Table 4: The effects of using organic fertilizers as a plant nutrient source in hydroponics versus chemical-based nutrient solutions on plant growth and quality (*Continued*)

Approach	Organic Nutrient Source	Method of Organic Fertilizer Processing for Utilization	Type of Hydroponics	Crops	Effect on Crop Growth and Quality in Comparison with Chemical-Based Nutrient Solution	Ref.
The use of organic substrates and full replacement of nutrient solution with organic fertilizer	Yard waste compost, swine compost, and mushroom compost for substrates and various commercial organic feed (plant and fish-based liquid fertilizer)	For substrates, various combinations of yard waste compost, swine compost, and mushroom post were tested and compared to control (peat and pearlite). Varying concentration of organic feed with different organic feed brand was done and compared to control (nutrient solution)	Drip irrigation hydroponics	Tomato	In certain treatments, the use of organic feed as a nutrient solution and different compost ratios as substrates resulted in yields that were comparable to the control.The mushroom compost added with a small amount of the liquid fertilizer derived from plants was the most productive organic treatment. In contrast to the hydroponic controls, organically grown tomatoes showed a lower postharvest decay index (greater shelf life), potentially as an indirect result of those treatments' overall lower yields.	[122]

Table 5: Values the commonly observe parameters on full replacement of nutrient solution with an organic fertilizer in hydroponics

Organic Nutrient Source	Parameters					
	DO ($mg·L^{-1}$)	pH level	Temp. (°C)	Nitrate Level ($mg·L^{-1}$)	EC ($mS·cm^{-1}$)	Ref.
Chicken Manure	6.30–6.53	8.38–8.45	30.8–31.2	7.0–11.2	-	[73]
Aquaculture waste	-	7.0	-	121.7	0.91–1.38	[106]
Corn Steep Liquor	4.0–6.0*	6.60–7.27	-	-	0.90–1.74	[76]
Vermicompost Leachate**	5.8–8.9	8.0	23–34	6–40	0.92–2.00	[101]
Fish soluble fertilizer	-	-	-	123	-	[72]
Solid food waste	-	-	-	10–56	-	[75]
Liquid digestate (livestock)	6.89 ± 0.45	6.3 ± 1.0	18.4 ± 2.3	-	0.5 ± 0.2	[81]
Liquid digestate	-	5.0	-	90	1.8	[103]

*Only figures in a form of a graph were available in the research article. The numerical value is based on the estimated value determined in the given graph.
**Study IV of the research with the direct linkage of hydroponics system to vermifarms.

7.1 *Dissolved oxygen (DO) level*

Oxygen is required for all life forms in hydroponics, including plants and nitrifying bacteria. The dissolved oxygen level (mg/L) indicates the quantity of molecular oxygen in the water. Microbes and plant roots often require lower DO concentrations and can thrive with DO levels as low as 3 mg/L. For roots to grow, fertilizer solutions' DO levels must be kept within a certain range [123]. Formic acid, ethylene gas, and dissolved carbon dioxide are known to accumulate as a result of inadequate gas exchange brought on by insufficient aeration. Therefore, root metabolic activity or growth may be constrained [123], [124].

To grow healthily and keep up high levels of productivity, nitrifying bacteria require sufficient concentrations of DO in the water. Oxidation of ammonia into nitrate called nitrification occurs when oxygen is mixed with nitrogen to provide the bacteria with the energy they need to survive. The ideal DO range is between 4 and 8 mg/L, which is also the range needed by both fish and plants. If DO concentration falls below 2 mg/L, no nitrification takes place. Aeration must be devoted to the biofilter to achieve proper biofiltration. This could be done by using flood-and-drain cycles in media beds, air stones in exterior biofilters, or falling water return lines to the canals and sump tanks [1].

7.2 *pH level*

It is helpful to have a fundamental understanding of pH when operating hydroponic systems. A solution's pH reflects how acidic or basic it is on a scale from 1 to 14. Anything with a pH value more than 7 is regarded as basic; anything with a pH value less than 7 is regarded as acidic, and a pH value of 7 is regarded as neutral. A solution's pH is determined by how many hydrogen ions (H+) are present, the higher the amount, the more acidic the solution. In a hydroponics system, pH regulation is crucial for maintaining a healthy system with good nutrient availability.

Both nitrification and plant uptake of nitrogen have an impact on the pH dynamics in hydroponic culture systems using biogas digestate as a nutrient source [95]. Factors affecting the accumulation of nitrite in nitrifying reactors using mixed culture is pH level [125]. Under optimum conditions with a pH level of 8 and DO level of 1.5 at 30 °C, as much as 77% of the removed ammonia accumulated in nitrite. Plants can get nutrients when a variety of microorganisms, such as nitrifying bacteria, are present, which is not feasible in conventional hydroponics, which solely depends on pH level to allow the availability of plant nutrients. Similar to other soil-based microorganisms, many of these microbe function in a broad range of pH values, like the nitrifying bacteria, which have a pH range of 6.5 to 8.0 [66].

7.3 *Temperature*

Temperature directly affects plant growth and development. In a hydroponics system, temperature changes in the nutrient solution can stress plants and lead to diseases [38]. High-temperature stress usually results in physiological disturbances and yield reduction in plants through a variety of physiological and biochemical alterations in plant metabolism, such as protein denaturation and disruption of membrane integrity [126]. On the other hand, low temperatures inhibit bacterial oxidation, which leads to accumulation within the plant that may cause toxic effects and harm to the aerial biomass and root system [19]. Low temperatures also prevent K and P assimilation and P translocation at the root level [38].

The temperature of the water influences the operating parameters of organic hydroponics. Temperature affects both DO level and ammonia in an organic nutrient solution, with higher temperatures producing lower oxygen levels and more unionized ammonia. High temperatures could also inhibit calcium absorption in plants [127]. The suitable temperature for ammonia-oxidizing bacteria is between 17 to 34 °C. This agrees with the observed operating temperature on hydroponics using organic fertilizer as a plant nutrient source as shown in Table 5. This temperature range increases the productivity of microbes to oxidize ammonia into nitrate which is preferable for plants to absorb. Unless the water temperature decreases below this range, the bacteria's productivity tends to decline. The Nitrobacter group, in particular, is less temperature resistant than the Nitrosomonas group, so as a result, nitrite should be more closely monitored during colder periods to avoid dangerous accumulations [128].

7.4 *Nitrate level*

Nitrogen is one of the important nutrients among other mineral elements for all living tissues of the plant from growth, development, and metabolism for allocation of resources [129]. Nitrogen is originally introduced in organic hydroponics with the use of organic fertilizer as its source. Depending on the source of the fertilizer, the amount of nitrogen that is available to plants in organic fertilizers differs, and a considerable portion of the nitrogen is present in an organically bound form [130]. Before plants can acquire the inorganic forms of nitrogen accessible to plants, such as ammonia and nitrate from organic fertilizer, the organic nitrogen must be broken down, usually by the action of bacteria through mineralization and nitrification.

Nitrate and ammonium are the accessible forms of nitrogen compounds for plant fertilizer. Nitrate is the preferred type of nitrogen for plants to absorb, and the relationship involving nitrate absorption and plant development in hydroponics has previously been established [72]. Nitrates can be stored without causing hazardous effects and are promptly absorbed by the roots of plants. High concentrations will negatively affect plants, resulting in excessive vegetative growth and unsafe nitrate accumulation in leaves that are harmful to human health [131]. In aquaponics, the nitrate levels should be maintained between 5 and 150 mg/L, and when they rise, water should be replaced [1]. However, in organic hydroponics, nitrate level observed in various experiments varies from 6 to 123 mg/L depending on the type of organic fertilizers, type of crop being cultivated, and processing methods of organic fertilizer (Table 5).

7.5 *Electrical conductivity (EC)*

The amount of total soluble salts or soluble nutrients (or ions) present in a growth medium is determined by the electrical conductivity (EC). Measurement of an EC level of nutrient solution is performed to assess the level of nutrient replenishment necessary to reconstitute the solution before consumption [14]. The strength of the nutritional solution can be inferred indirectly from the EC. Higher EC values on nutrient solution have an impact on the health and yield of the plant since it increases the osmotic pressure which affects the plant root nutrient uptake [116].

In organic hydroponics, lower values of EC have been observed on an organic nutrient solution when compared to a chemical-based nutrient solution which is due to the continuous nutrient influx caused by digestion of organic compounds and nitrification of bioreactor [81]. EC is also used to classify the materials that can be employed as substrates in soilless systems. Substrates with established nutritional content and low EC values are preferred. Substrates with high EC levels imply the existence of ions, which, while not essential as nutrients, can have a significant impact on the compatibility of substrates in hydroponics [38].

8 Conclusions

The use of various types of organic fertilizer as a primary nutrient source in hydroponics could solve the sustainability aspect of crop production by reducing the reliance on chemical-based nutrient solutions commonly manufactured and contributing to carbon dioxide emission in our atmosphere. However, unlike chemical-based nutrient solution, which has an established optimum operation parameter, organic fertilizer as a nutrient solution in hydroponics faces several challenges, such as variability of the quality of organic fertilizers, nutrient management, and optimization of the operating parameters, such as pH management on specific organic fertilizers.

The development of a bioreactor for hydroponics to process the organic fertilizers as a primary nutrient source is currently at the early stage of research progress and establishing the optimum operating parameters at various organic nutrient sources and growing high-value crops using bioreactor is a potential research area to expand understanding on the biochemical processes in a bioreactor. In addition, limited literature on the design calculation of bioreactors purposely used to process organic fertilizers to be used in hydroponics. Furthermore, research in the integration of biogas plant and hydroponics system may also be investigated, which could be combined with the utilization of a bioreactor to further process the biogas digestate to be utilized as an organic nutrient source for the hydroponically produced crop. These research initiatives to optimize the use of organic fertilizers in hydroponics could help the farmers to have an alternative environmentally friendly plant nutrient source as compared to chemical-based nutrient solutions.

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Conflicts of Interest

The authors declare no conflict of interest.

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