Challenges and prospects of utilizing treated animal manure as an alternative plant nutrient source in hydroponics system

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Abstract: Hydroponics has emerged as a sustainable alternative to conventional agriculture due to its efficient resource use, lower water demand, and reduced environmental footprint. However, the reliance on synthetic fertilizers raises concerns regarding cost, environmental impact, and long-term sustainability. Animal manure, traditionally valued as a soil amendment, is increasingly being explored as a sustainable nutrient source for hydroponic systems. If properly processed and treated, animal manure can be a valuable nutrient source for hydroponics, offering a sustainable alternative to nutrient solution, reducing reliance on synthetic fertilizers, and promoting circular economy in poultry & livestock waste management. This review synthesizes current knowledge on the physicochemical properties of animal manure, its processing and treatment methods, and its potential application as a hydroponic nutrient source. Treated manure—through composting, vermicomposting, anaerobic digestion, or aerobic bioprocesses—offers essential macro and micronutrients required for plant growth while reducing agricultural waste and dependence on synthetic inputs. Nonetheless, challenges persist in utilization of animal manure as main nutrient source in hydroponics, including nutrient imbalances, variable composition, ammonia toxicity, pathogen contamination, and risks of salinity and precipitation. Recent advances in bioconversion techniques demonstrate promising results in stabilizing manure-derived nutrients and improving crop growth and development, yet limitations in nutrient content consistency and food safety remain. This review emphasize the opportunities and challenges of integrating animal manure into hydroponic nutrient management, identifies gaps in current research, and outlines future directions for developing safe, efficient, and sustainable manure-based hydroponics systems.

Keywords: biofilter, bioponics, bioreactor, circular economy, nutrient reuse

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1 Introduction

With the growing global population and increasing urbanization, hydroponics offers a promising solution to address food security challenges while minimizing the environmental impact of agriculture (Premanandh, 2011). Hydroponics is an innovative soilless cultivation method where plants are grown in nutrient-rich water solutions with the support of inert growing mediums

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(Jensen, 1997). This method of crop production has garnered significant attention in the agricultural sector for its efficiency and sustainability. Hydroponic systems contribute to sustainable agriculture by using resources more efficiently than traditional soil-based methods (Majid et al., 2021). Water usage in hydroponics is significantly lower compared to conventional production methods due to the closed-loop design, which allows for recirculation and minimizes evaporation (Barbosa et al., 2015). The controlled environment provided by hydroponics also reduces the reliance on pesticides and herbicides, resulting in a more sustainable form of agriculture with less environmental impact (Al-Kodmany, 2018; Bradley and Marulanda, 2000). Furthermore, precision nutrient management in hydroponic systems leads to a reduction in fertilizer inputs and minimizes nutrient pollution (Campbell, 1994).

Nutrient solutions are critical to hydroponic systems as they provide essential elements required for plant growth in the absence of soil (Resh, 2022). The right balance of macronutrients and micronutrients, optimal pH management, and proper oxygenation of the nutrient solution all contribute to the successful growth and development of plants in hydroponic systems (Meselmani, 2022). However, the sustainability of nutrient solutions in hydroponics faces several challenges, such as nutrient pollution, and waste generation (Kumar and Cho, 2014). Implementing management practices, utilizing alternative sources like waste materials, and developing methods for recycling and reusing nutrient solutions can help address these issues and contribute to the overall sustainability of hydroponic systems.

Animal manure has long been a valuable resource in traditional agriculture as it provides essential nutrients for plant growth and development. Recently, researchers have been exploring the use of animal manure as an alternative nutrient source for hydroponic systems (Charoenpakdee, 2014; Gustiar et al., 2022; Sunaryo et al., 2018; Tikasz et al., 2019). The nitrogen in animal manure is mostly released as ammonia and nitrate via the mineralization process, making it an accessible source of nitrogen for plants (Azeez and Van Averbeke, 2010; Mikkelsen and Hartz, 2008). Moreover, animal manures were recognized as valuable agricultural resources for their function as an alternative plant nutrient source and as an agent for enhancing physical and biological properties of soil through addition of organic matter (Shober and Maguire, 2018). The hydroponic systems could potentially use animal manure as a source of nutrients needed by the plant for its growth and development.

Despite the potential benefits of using animal manure in hydroponic systems, there are several challenges and concerns needed to consider. These include nutrient imbalances due to the variability of nutrient content in animal manure, high salinity levels, and the depletion of dissolved oxygen in the nutrient solution as a result of organic matter decomposition (Ahmed et al., 2021; Atkin and Nichols, 2003; Dankwa et al., 2020; Kechasov et al., 2021). To successfully integrate animal manure into hydroponic systems, it is crucial to carefully manage these challenges by implementing proper treatment by adjusting nutrient levels, controlling salinity, and maintaining optimal oxygen levels through adequate aeration and circulation. By addressing these challenges, animal manure can serve as a promising and cost-effective alternative nutrient source for hydroponic systems, contributing to more sustainable and accessible agricultural practices.

In addition to these challenges, the practical application of animal manure in hydroponic systems faces other technical constraints. One major concern is the difficulty of sterilization, as untreated manure may introduce pathogens and harmful microorganisms into the system (Beuchat, 2006). Furthermore, the presence of organic and inorganic compounds often leads to precipitate formation (Christensen and Sommer, 2013), which can cause clogging, reduce nutrient availability, and destabilize system performance (Dasgan et al., 2016; Williams and Nelson, 2014). Another limitation is the lack of precise control over individual fertilizer elements, since the nutrient composition of manure is inherently variable and influenced by factors such as animal diet, manure handling, and storage conditions (Okorogbona and Adebisi, 2012; Rayne and Aula, 2020; Ewusi-Mensah et al., 2015; Malomo et al., 2018).

The purpose of the review is to provide an information on the current state of research and knowledge related to the utilization of animal manure as a plant nutrient source in hydroponic systems. This article also aims to synthesize existing literature on the utilization of animal manure as nutrient source in hydroponics, highlighting the potential benefits, challenges, and opportunities for sustainable and efficient crop production using animal waste-derived nutrients in hydroponics. In addition, the article seeks to identify knowledge gaps and areas for future research from current research which will contribute to the development of innovative and sustainable hydroponics with the use of animal manure as plant nutrient source.

The scope of the article covers various aspects of animal manure as a primary nutrient source in hydroponics including the physiochemical properties of animal manure, processing, and treatment methods of animal manure, utilization of animal manure in hydroponics and its challenges, environmental implications and future research and technological innovations.

2 Animal manure as a plant nutrient source

Animal manures are combinations of animal waste which includes feces and urine, bedding stuff such as straw or sawdust, and other materials associated with raising animals, such as leftover feed, soil, water used for cleaning, and any substances added while managing and storing the manure (Sims and Maguire, 2005). Identifying the properties of animal manure is vital for determining its suitability and effectiveness as a plant nutrient source in hydroponics systems. Organic manure derived from animal excretion has long been recognized for its value as an organic fertilizer in traditional soil-based agriculture (Shaji et al., 2021). However, its potential use in hydroponics has only recently started to gain attention to the researchers. Determining physicochemical characteristics of animal manure is vital for establishing nutrient balance for plant requirements in hydroponic cultivation system.

2.1 Composition and nutrient content

A complex mixture of organic and inorganic components, animal manure can vary based on the type of livestock, its food, its age, and its management techniques (Sommer et al., 2013). The potential uses of animal manure, primarily as a fertilizer, are influenced by its physical and chemical characteristics (Malomo et al., 2018). The components of animal manure include water, organic matter, and minerals, along with varying amounts of nutrients that are essential for plant growth. The primary nutrients of animal manure essential for plant growth includes nitrogen, phosphorus, and potassium and these nutrients are divided between organic and inorganic forms which affects the plant nutrient availability (Lorimor et al., 2004). Most of the forms of nitrogen and phosphorus present in animal manure are in the form of organic which must be mineralized before it is available for plant uptake (Eghball et al., 2002; Li and Li, 2014). The potassium present in animal manure is mostly soluble and readily available for plant nutrient uptake (Eghball et al., 2002; Wilkinson, 1979). The animal manure also contains secondary nutrients such as calcium, magnesium and sulfur and micronutrients such as boron, chlorine, copper, iron, manganese, molybdenum, and zinc.

2.2 Factors affecting nutrient content and availability

Several factors could influence the nutrient content and availability of animal manure for use as a plant nutrient source, and considering of these factors is essential for optimizing its application in hydroponic systems. The nutrient content and composition of animal manure vary depending on the type of livestock, such as cattle, poultry, or swine, with each species producing manure with different nutrient profiles (Shen et al., 2015). For example, poultry manure is generally richer in nitrogen (N) and phosphorus (P) (Nahm, 2003), whereas cattle manure contains higher levels of organic matter and potassium (K).

The feed and dietary supplements provided to the animal also influence the nutrient content of the animal manure (Nahm, 2002). Higher crude protein levels in the diet of dairy cattle (Bos taurus) increase manure nitrogen concentration and ammonia emissions, while lower protein diets reduce nitrogen excretion and emissions but also lower the short-term availability of manure nitrogen for plant uptake (Paul et al., 1998) while low-quality diets may lead to nutrient-deficient manure (Sutton et al., 2006).The age and health status of the animal can influence the efficiency of nutrient digestion and excretion, in result, affecting the manure's nutrient composition (Okorogbona and Adebisi, 2012; Rayne and Aula, 2020; Sharpley et al., 1997). For instance, the age of ruminants has been shown to affect the nutrient content of their manure, as young animals utilize more nitrogen, phosphorus, and calcium for body growth, resulting in dung with lower concentrations of these nutrients compared to that of mature animals (Okorogbona and Adebisi, 2012). The time interval between excretion and processing is another critical factor, as nutrient losses—particularly nitrogen volatilization—can occur if manure is left exposed for extended periods (Amon et al., 2021; Eghball and Power, 1994; Liu and Wang, 2020).

The presence of feed additives or veterinary treatments, including antibiotics and growth promoters, may alter microbial activity in manure and potentially influence nutrient transformations (Muhammad et al., 2020; Dolliver et al., 2008). While manure enhances microbial activity in soils, the presence of antibiotics (SDZ or sulfadiazine) temporarily suppresses this effect, with recovery depending on the antibiotic concentration and soil type (Kotzerke et al., 2008). Similarly, the carbon-to-nitrogen (C:N) ratio plays a vital role in determining the balance between organic matter decomposition and nitrogen mineralization, which affects nutrient release and plant availability (Macias-Corral, 2019; Probert et al., 2005; Qian and Schoenau, 2002)

Furthermore, manure management practices, such as bedding materials, manure handling, and storage conditions, can also affect the nutrient composition and quality of the manure (Ewusi-Mensah et al., 2015; Malomo et al., 2018). As manure ages from fresh to pad to stockpile, nutrient losses become more severe, with nitrogen reduced by up to 90% and phosphorus by up to 85%, thereby lowering its fertilizer value (Gopalan et al., 2013). On the other hand, well-managed manure systems can help retain essential nutrients, making fresh or properly handled manure more effective in improving soil fertility and crop productivity.

Processing and treatment methods, such as composting, anaerobic digestion, and chemical treatment, can impact nutrient availability (Möller and Müller, 2012; Samoraj et al., 2022; Shi et al., 2018). These methods can alter the nutrient content, reduce pathogens, and remove harmful substances, making the manure more suitable for use in agricultural use as organic fertilizer. Environmental conditions, including temperature, moisture, and pH, can affect the rate of decomposition and mineralization processes in animal manure, which in turn influence nutrient availability for plants (Li et al., 2012; Nahm, 2005; Reddy et al., 1979). Ensuring appropriate environmental conditions can optimize nutrient release and uptake by plants.

2.3 Comparison with nutrient solution

Nutrient solution used in hydroponic systems offers precise and consistent nutrient ratios, allowing growers to optimize plant growth (Jones Jr, 2016) when compared to animal manure. Nutrient solutions are formulated with a balanced proportion of essential macro- and micronutrients, ensuring that plants receive nutrients in the exact concentrations required for optimum growth and yield (Resh, 2022). This level of uniformity enables growers to avoid nutrient deficiencies and toxicities, and it allows for high reproducibility in controlled systems (Reza et al., 2025).

In contrast, the nutrient composition of animal manure is highly variable, depending on animal species, diet, age, health status, and manure management practices (Shen et al., 2015; Okorogbona and Adebisi, 2012; Ewusi-Mensah et al., 2015; Malomo et al., 2018). Unlike synthetic nutrient solutions, where nutrient ratios are carefully standardized, animal manure often contains nutrients in unbalanced proportions (Sharara et al., 2022), which can result in either insufficient supply or excess accumulation of certain elements in the growing medium. Moreover, the major nutrients in animal manure such as nitrogen and phosphorus were often in an organic form, requiring mineralization before becoming available to plants (Mikkelsen and Hartz, 2008). This dependence on biological processes introduces variability in nutrient release rates, making it more difficult to maintain optimal nutrient concentrations in hydroponic systems.

Another important distinction is that while synthetic fertilizers are free from biological contaminants, animal manure may harbor a wide range of pathogens, including bacteria (*Escherichia coli, Salmonella spp.*) (Tran et al., 2020), parasites (*Cryptosporidium, Giardia*) (Vermeulen et al., 2017), and even viruses. If untreated, these pathogens pose risks to both plant health and human food safety. Therefore, rigorous processing methods such as composting, anaerobic digestion, or chemical treatments are essential before manure can be safely applied (Malomo et al., 2018). Even with treatment, monitoring of manure-derived nutrient solutions is necessary to ensure that microbial contamination is minimized.

Synthetic fertilizers, although highly effective and immediately available, have been associated with several environmental concerns, including groundwater contamination, soil degradation, fossil fuel dependence, and greenhouse gas emissions (Savci, 2012; Wang et al., 2017). Animal manure, by contrast, represents a renewable and sustainable nutrient source, offering the additional benefit of recycling agricultural waste and reducing the environmental burden of intensive livestock production (Almeida et al., 2019). However, its effective use requires careful management to address challenges such as nutrient imbalances, slow and inconsistent nutrient release, and potential pathogen contamination. While animal manure offers sustainability and waste-reduction benefits but presents challenges related to variability, pathogen risk, and the need for rigorous treatment. Balancing these trade-offs is critical for developing safe and sustainable hydroponic nutrient management strategies.

3 Treatment methods of animal manure for nutrient recovery

Animal manure treatment involves various processes to manage and repurpose waste effectively as plant nutrient source. The main methods are aerobic treatment, anaerobic digestion, composting and vermicomposting that utilize bacteria and other microorganisms, transforming animal manure in a controlled environment into nutrient-rich fertilizers. These methods help mitigate environmental impact, reduce waste, and create value-added products, driving sustainability in agriculture.

3.1 Aerobic treatment

The process of microbial oxidation and breakdown of animal manure in the presence of oxygen is termed as aerobic treatment (Lorimor et al., 2006). Aerobic bacteria have the ability to oxidize the biodegradable organic material in animal manure into stable inorganic end products (Bicudo et al., 2000). During aerobic treatment of animal manure, oxygen is introduced to the system, which creates an environment favorable for aerobic bacteria. These bacteria consume organic matter present in the manure, including nitrogen compounds like ammonia, and convert them into nitrate through a process called nitrification. Since nitrate is more mobile than ammonium and does not attach to the cation exchange complex of soils, it is often more accessible for plant nitrogen absorption (Moreau et al., 2019).

Compared to raw slurry, the outputs of the aerobic treatment of animal manure have much less nitrogen (Loyon, 2017). The major facility of aerobic treatment for livestock wastes are naturally aerated lagoons, mechanically aerated lagoons, and oxidation ditches (Day et al., 1998).

3.2 Anaerobic digestion

Anaerobic digestion is a biochemical degradation of animal manure in an oxygen-free environment through the combined action of various microorganisms, which break down the organic compounds in the manure which has a major output of methane gas for fuel and digestate which can be used as fertilizers (Christy et al., 2014; Karim et al., 2005). Proteins and other complex organic substances present in the manure are broken down during digestion into simpler components like amino acids and then into ammonia, which plants may more readily absorb (Möller and Müller, 2012). This transformation of nutrients into accessible forms is essential for optimizing plant nutrient uptake, especially in hydroponic systems where precise nutrient management is crucial (Pelayo Lind et al., 2021).

3.3 Composting and vermicomposting

Composting and vermicomposting are two popular methods for processing and treating animal manure, converting it into a stable, nutrient-rich organic material suitable for use as a plant nutrient source. These methods provide an environmentally friendly approach to managing animal waste, reducing pathogen levels, and enhancing nutrient availability for plant uptake. Composting relies on microbial decomposition at higher temperatures, while vermicomposting utilizes earthworms to process animal manure (Loh et al., 2005). Composting involves the decomposition and stabilization of organic matter through the action of bacteria, fungi, and other microorganisms, which break down complex organic compounds into simpler, more bioavailable forms (Amir et al., 2008). Vermicomposting is a biological process that uses earthworms, primarily red wigglers (Eisenia fetida), to break down organic materials such as animal manure, converting it into a nutrient-rich, organic material called vermicompost or worm castings (Kaur, 2020; Raza et al., 2022).

Compost and vermicompost contain essential macronutrients such as nitrogen, phosphorus, and potassium, as well as micronutrients that are vital for plant growth (Soobhany, 2019). The decomposition processes during composting and vermicomposting transform complex organic compounds into simpler forms, which are more readily available for plant uptake (Khatua et al., 2018). Factors such as temperature, moisture, aeration, and the carbon-to-nitrogen (C:N) ratio of the feedstock can influence the rate and extent of decomposition and nutrient transformation (Guo et al., 2012; Tang et al., 2023). The maturity and stability of the compost and vermicompost are essential factors that can affect their suitability as plant nutrient sources and immature or unstable compost and vermicompost can contain phytotoxic compounds that can inhibit plant growth (Warman and AngLopez, 2010). Ensuring adequate maturation of the compost and vermicompost is necessary to minimize phytotoxicity and maximize nutrient availability for plant uptake.

In terms of effectiveness, composting and vermicomposting offer some advantages and limitations. Composting is generally more efficient for rapidly reducing pathogens and stabilizing large volumes of organic waste, as the elevated temperatures achieved during the process are effective in eliminating harmful microorganisms, and parasites (Erickson et al., 2014; Gurtler et al., 2018). This makes composting particularly suitable for large-scale manure management where sanitation and waste volume reduction are priorities. However, the high temperatures and prolonged microbial activity may also result in nutrient losses, particularly of nitrogen through volatilization (Martins and Dewes, 1992; Yang et al., 2019). Vermicomposting, in contrast, is more effective in pathogen reduction and produces a final product with higher nutrient bioavailability and improved microbial diversity compared to composting (Lazcano et al., 2008; Eastman et al., 2001). Earthworm activity enhances the breakdown of organic matter into humus-like substances, increases the concentration of plant-available nutrients, and enriches the substrate with beneficial microorganisms that promote soil health (Soobhany, 2019). Vermicompost also exhibits superior physical properties, such as finer particle size, higher porosity, and greater water-holding capacity, which improve plant growth conditions (Ma et al., 2022). Nevertheless, vermicomposting requires longer processing time, careful environmental control, and is less suitable for handling large waste volumes, making it more practical for small to medium-scale operations or for producing high-value organic fertilizers.

Composting is more effective for large-scale waste treatment and pathogen reduction, while vermicomposting is more effective in enhancing nutrient quality and improving soil biological activity. Integrating both methods—using composting for initial pathogen reduction and stabilization, followed by vermicomposting for refinement—has been suggested as a strategy to combine their respective strengths and produce a safe, nutrient-rich, and environmentally sustainable fertilizer (Ndegwa and Thompson, 2001).

4 Utilization of treated animal manure as plant nutrient in hydroponics

Treated animal manure as a nutrient source in hydroponic systems is both sustainable and eco-friendly, reducing reliance on synthetic fertilizers, which are often produced from non-renewable energy resources and can contribute to environmental pollution. Various researchers investigated the applications of treated animal manure in different types of crops using hydroponics. Partial and full application of treated animal manure such as biogas digestate, compost, vermicompost, and fermented manures were identified as major methodologies for incorporating animal manure as a plant nutrient source in a hydroponics system (Torres and Somera, 2023).

4.1 Partial application of treated animal manure in hydroponics

Incorporating animal manure partially as a nutrient source in hydroponic systems is a viable strategy to achieve a balance between the benefits of using organic amendments and the need for precise nutrient management. In this approach, animal manure is combined with synthetic fertilizers or other organic sources to supply essential nutrients to the plants. Using poultry biogas slurry in combination with mineral fertilizers or half-strength Hoagland solution for hydroponic lettuce production did not negatively impact plant growth and had additional benefits like reduced nitrate concentration and increased soluble sugar concentration (Wang et al., 2019). The study concluded that poultry biogas slurry could replace 50% of the mineral fertilizer used in hydroponic lettuce production, provided that electrical conductivity is controlled and missing nutrients, especially magnesium, are replenished.

On the other hand, while cow-based biogas digestates are an environmentally sustainable way to manage animal waste, they are not suitable for hydroponic tomato production, even when supplemented with mineral fertilizers (Mupambwa et al., 2019). Potential applications include using them for less nutrient-demanding crops like lettuce or exploring digestates from protein-rich manures like chicken or pig. It is recommended that further research should focus on mitigating ammonia phytotoxicity and monitoring nutrient content changes in various crop growth studies.

4.2 Full application of processed animal manure in hydroponics

The full application of processed animal manure in hydroponics involves using treated animal waste as the primary nutrient source for plants grown in a soilless environment. While animal manure has traditionally been utilized as a soil amendment in conventional agriculture, its application in hydroponic systems requires proper processing and management to ensure optimal plant growth and prevent potential issues such as disease and toxicity.

Organic liquid fertilizer derived from chicken manure in hydroponic basil production resulted in comparable yields to those achieved with inorganic nitrogen fertilizers. The findings suggest that such liquid fertilizer could be an attractive, sustainable alternative to conventional hydroponic fertilizers, particularly for urban food-producing systems aiming to reduce dependency on inorganic nitrogen inputs (Brousseau et al., 2022). Aerated solution from turkey manure extract (50 g L^{-1}) supported healthy growth of hydroponic lettuce and kale, however, aerated solution from chicken and cow manure extract resulted in reduced plant growth, likely due to ammonia toxicity, suggesting that a mixed manure/mineral fertilizer approach might be required to improve hydroponic nutrient solutions (Tikasz et al., 2019). Comparing hydroponic tomato plants to those grown in high-mineral soil, organic waste-based liquid fertilizer from pig manure digestion resulted in slower growth rates but larger average fruits sizes, with no discernible difference in overall yield (Kechasov et al., 2021). While this approach shows potential for sustainable greenhouse plant production, further adjustment of nutrient supply is needed to improve fruit quality.

In terms of food safety concern, the anaerobic digestate-based biofertilizer is microbiologically safe for hydroponic cultivation, but the persistent presence of viable Bacillus cereus emphasizes the need for continuous risk assessment for any modifications or supplements to the biofertilizer (Södergren et al., 2022). In addition, using anaerobic liquid dairy digestate (AD) in hydroponic lettuce production resulted in higher phytonutrient content and lower heavy metal bioaccumulation risks compared to traditional inorganic nutrient solutions, although it led to lower leaf area, chlorophyll content, and fresh biomass (Faran et al., 2023). These results suggest that integrating AD into hydroponic systems could offer a sustainable solution for both improved lettuce quality and reduced environmental risks associated with dairy waste by-product.

5 Recently developed methods of bioconversion of animal manure into liquid solution in hydroponics

The use of animal manure as a source of nutrients in hydroponic systems has gained attention as a sustainable alternative to conventional nutrient solution. Since raw animal manure contains organic compounds, direct application into hydroponic solutions is not feasible due to the risk of phytotoxicity, microbial contamination, and nutrient imbalance. To address this, several bioconversion methods have been developed to mineralize organic matter into plant-available forms, particularly conversion of organic nitrogen into inorganic forms such as ammonia & nitrates.

In a bioconversion of animal waste into nutrient source in hydroponics developed by Wongkiew et al. (2021), a nutrient film technique bioponic system was established consisting of an 18 L up-flow biofilter, a 17 L recirculating tank, and a 1.8 m grow bed with 18 lettuce plants, operated with continuous water recirculation at 900 L hr^{-1}. The biofilter contained polyethylene pads (surface area ~2000 m^2 m^{-3}) and a filter bag with 200–400 g dry chicken manure, which enabled microbial biodegradation and nutrient leaching while reducing suspended solids (<10 mg L^{-1}). The process was staged into (1) microbial acclimatization with liquid compost inoculation (20 mL L^{-1}) for two weeks, (2) nutrient release and microbial mineralization of organic nitrogen and phosphorus into plant-available forms, and (3) plant uptake and nutrient cycling across three 35-day harvesting cycles. Lettuce yield ranged 1208–2030 g per 18 plants, with nitrogen use efficiency of 35.1%–41.8% and phosphorus use efficiency of 6.8%–8.0%. Water quality remained stable (dissolved oxygen 6.30–6.53 mg L^{-1}, pH 8.38–8.45, temperature 30.8°C–31.2°C), while residual nitrogen (38.9%–49.3%) and phosphorus (30.5%–42.4%) in manure indicated incomplete mineralization but potential for extended nutrient recovery.

Furthermore, in the study conducted by Szekely et al. (2023), butterhead lettuce (Lactuca sativa var. Lucrecia) was grown in a nutrient film technique system inside a greenhouse. Each grow bed consisted of a 2.6 m gully with 12 net pots, connected to a 25 L tank containing 22 L of nutrient solution recirculated at 950 L h^{-1}. Chicken manure and goat manure were mixed in water to form 2.5% dry matter stock solutions, prepared by mixing 3.48 kg chicken manure with 96.5 L water or 15.1 kg goat manure with 134.9 L water for 8 days at 25°C, then filtered (250 µm) and diluted to obtain 60 mg total mineral N (TMN) L^{-1}. This initiated the aerobic digestion stage, carried out in tanks with 1.5 L biofilm carriers (836 m^2 m^{-3} surface area) to promote natural nitrifier development. An empty circulation phase of 27 days allowed microbial-driven nitrification to reduce TAN and NO_2^- below 5 mg L^{-1} before transplanting seedlings. pH was maintained around 7.5 by manual adjustment with 10% H_2SO_4 or NaOH. Lettuce was harvested 42 days after transplanting, and while initial trials with both manures yielded significantly lower biomass than mineral controls, optimized chicken manure treatments (60–120 mg L^{-1} TMN) achieved shoot yields and dry masses comparable to inorganic hydroponics, with improved quality (lower shoot nitrate). However, nitrogen losses of 50%–65% TMN during aerobic digestion, particularly in goat manure treatments, showed the challenges of residual organic matter and excessive microbial activity.

In the study that we conducted, a small-scale integrated hydroponics–animal waste bioreactor system was developed to utilize dried chicken manure as the main nutrient source for romaine lettuce (Torres et al., 2024). The system combined NFT hydroponic grow channels (10 planting holes per channel) with an animal waste bioreactor composed of a 50 L nutrient solution tank, 35 L filtration tank, and a bioreactor tank containing 500 g K1 biofilm media (500 m^2 m^{-3} surface area) suspended by aeration to support nitrifying bacteria. The aeration system maintained dissolved oxygen above 2 mg L^{-1}, while filtration (1 mm fishnet, fiber wool, 30 PPI foam) removed particulates from chicken manure tea. The operation followed three stages: (1) biofilm inoculation using vermicompost tea (5 L in 105 L water, brewed 24 h) for 15 days to establish beneficial microbes, (2) bioprocessing of dried chicken manure for 7 days with manure loading of 1.0, 1.5, or 2.0 kg to achieve target concentrations of 1000 ± 50 ppm, 1200 ± 50 ppm, and 1400 ± 50 ppm total dissolved solid compared against a commercial nutrient solution maintained at 1000 ppm TDS. After 30 days of growth, results showed that 1000 ppm produced romaine lettuce with growth parameters comparable to commercial nutrient solution, while higher concentrations (≥1400 ppm) reduced yield due to excessive salt accumulation & phytotoxic effects to plants. While optimized chicken manure treatments have achieved yields comparable to conventional hydroponics, challenges remain, including incomplete mineralization, nutrient losses, and sensitivity to high concentrations.

6 Challenges and limitations of treated animal manure as nutrients source in hydroponics

Utilizing treated animal manure in hydroponics poses several challenges and limitations that must be addressed to ensure the safety and effectiveness of the system. These challenges include imbalanced nutrient profiles that can negatively impact plant growth, ammonia toxicity, difficulties associated with processing animal manure, and risk of contamination from harmful pathogens in the manure.

The major limitation of utilizing animal manure in hydroponics is its nutrient composition. Animal manure does not have a balanced nutrient profile that is suitable for hydroponic crops. Low nutrient content per unit weight, variable nutrient content, and a balance of accessible nutrients that frequently does not match the crop's relative nutrient requirements are all problems with utilizing animal manure as fertilizer (Schoenau and Davis, 2006). These challenges can have a significant impact on plant growth, health, and productivity. Therefore, it is important to analyze the nutrient content of animal manure and supplement it with other organic nutrients as necessary to achieve a balanced nutrient profile for hydroponic crops.

The utilization of treated animal manure in hydroponics also poses nutrient management problem. Hydroponics relies on a nutrient solution that is continuously supplied to the plants. To utilize animal manure in hydroponics, it must undergo several treatments, which can be time-consuming. Moreover, the nutrient solution derived from treated animal manure must be closely monitored to ensure that the animal manure is not contributing to any nutrient imbalances that could harm the plants.

There are primarily two forms of N in manure: inorganic nitrogen (ammonia) and organic nitrogen. Plants can only absorb inorganic forms of nitrogen, such as ammonia and nitrate. Organic nitrogen must first be broken down into inorganic forms by microorganisms in the soil before it can be taken up by plants. This process is called mineralization (Marschner, 1995). However, ammonia can have negative effects on plant growth and development, particularly at high concentrations. The majority of plant species exhibit decreased growth, smaller leaves, and a stunted root system when exposed to high ammonium concentrations (Gerendás et al., 1997). In extreme circumstances, this can result in chlorosis, a condition in which a plant's leaves turn yellow as a result of a lack of chlorophyll (Hinsinger et al., 2009). At high concentrations, the biochemical and physiological responses of plants to nitrate and ammonium can differ significantly, which can affect plant growth (Gerendás et al., 1997).

Another limitation is the inability to achieve precise control over individual fertilizer elements when using organic input in hydroponics (Gartmann et al., 2023). Unlike commercial nutrient formulations, which are designed to provide consistent concentrations of essential elements, the nutrient composition of manure is highly variable (Sager, 2007) which is influenced by several factors, including the type of animal, their diet, manure handling, storage conditions, and even seasonal changes (Aguirre-Villegas et al., 2018). As a result, it is difficult to maintain an optimal nutrient balance tailored to specific crop requirements. For instance, deficiencies or excesses in nitrogen, phosphorus, or potassium may occur, negatively affecting plant health and yield (Jacobson, 2016).

Furthermore, the complex mixture of organic matter and inorganic salts in manure often leads to chemical reactions that produce insoluble compounds such as calcium phosphates or carbonates (Christensen and Sommer, 2013). These precipitates can accumulate within hydroponic systems, causing blockages in pumps, emitters, and tubing. In addition to mechanical clogging, precipitation reduces the solubility and availability of essential nutrients, thereby limiting plant uptake and growth. Furthermore, the continuous buildup of precipitates can destabilize the overall system by altering pH levels and electrical conductivity, which are critical for maintaining a balanced nutrient solution.

In addition, the utilization of animal manure as a nutrient source in hydroponics presents a significant challenge due to the potential risk of contamination. Animal manure may contain harmful pathogens like E. coli and Salmonella, which can pose a health risk to humans (Pell, 1997). If not properly treated, these pathogens may contaminate the nutrient solution and pose risks such as root infections, biofilm formation, and even food safety issues in edible crops (Beuchat, 2006). Common sterilization techniques such as heat treatment, pasteurization, and chemical disinfection are often costly, labor-intensive, or impractical for large-scale hydroponic systems. Moreover, excessive sterilization may also degrade beneficial organic compounds, potentially diminishing the nutrient quality of the manure. These challenges make sterilization a critical barrier that must be addressed before animal manure can be reliably adopted in hydroponic production.

7 Prospects for technological innovations

Developing new technologies for processing animal manure could help streamline the process of using it as a plant nutrient source in hydroponics. For instance, researchers could explore the use of microbial or enzymatic treatments that break down the manure into a more readily available form for hydroponic plants or develop new equipment that can efficiently process the manure into the nutrient solution. Bioreactor systems that use microbial processes to convert animal waste into usable nutrients (i.e. mineralization of organic nitrogen into inorganic forms and nitrification of ammonia into nitrate) have shown promise as a sustainable and efficient means of utilizing animal manure in hydroponics. Animal manure can be effectively processed in an organic fertilizer bioreactor within a hydraulic retention period of 7 to 14 days, resulting in an organic liquid fertilizer with optimal nutrient content, favorable operating parameters, and no inhibition of cucumber seed germination, offering a viable alternative to nutrient solution in supporting plant growth and development (Torres et al., 2023). Further research into the design and operation of these systems could help optimize their performance and reduce the risk of contamination.

Improving our understanding of the nutrient requirements of different hydroponic crops could help ensure that animal manure is used in a way that maintains a balanced nutrient profile in the system. This could involve studying the optimal nutrient ratios and concentrations for different crops. In addition, researchers could also explore the use of new supplements or amendments that can be added to animal manure to ensure that it meets the specific nutrient requirements of different hydroponic crops. This could involve developing new formulations of micronutrients or trace elements that can be added to the manure to ensure that it contains the appropriate nutrient balance for each crop. Alternatively, researchers could explore the use of other organic sources of nutrients, such as composted food waste or worm castings, that can be added to the nutrient solution to supplement the animal manure.

While animal manure can provide a valuable source of nutrients for hydroponic crops, there are other sustainable sources of plant nutrients that are less prone to contamination and more easily integrated into hydroponic systems. Research into new nutrient sources, such as algae-based biofertilizers could help expand the range of sustainable options available to hydroponic growers.

8 Conclusion

The utilization of animal manure as a nutrient source in hydroponic systems presents both promising opportunities and challenges. As a readily available plant nutrient source alternative to nutrient solution, animal manure has the potential to contribute to more sustainable agricultural systems. However, the challenges associated with ammonia toxicity, nutrient imbalances, and the risk of contamination must be carefully managed and addressed to ensure the successful utilization of treated animal manure in hydroponic systems. Current research has provided valuable insights into the physiochemical properties of animal manure, its treatment methods, and its application in hydroponic systems, both as a partial and full nutrient source for plants. Despite these advances, further research is needed to improve our understanding of the nutrient requirements of different hydroponic crops and to develop new technologies that can help streamline the processing and application of animal manure as nutrient source in hydroponics. Future research and technological innovations should focus on the development of new processing technologies, such as microbial or enzymatic treatments through bioreactor systems, to efficiently convert different forms of animal manure into usable nutrients for hydroponic systems. Moreover, the successful implementation of animal manure in hydroponic systems can support the development of circular agricultural models, in which animal waste products are efficiently repurposed, minimizing overall waste generation and its associated environmental impacts.

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