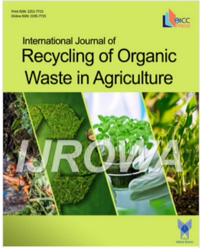

Volume 13, Issue 3, 132425 (1-18)

International Journal of Recycling Organic Waste in Agriculture (IJROWA)

https://dx.doi.org/10.57647/j.ijrowa.2024.1303.25

Transforming organic waste into productive resources through vermicompost and hydroponics in rice agriculture: A review

Syarifinnur Syarifinnur[1*], Ahmad Suriadi[2], Lia Hadiawati [2], Yudhistira Nugraha[2]

[1]*National Research and Innovation Agency Republic of Indonesia (BRIN), Cibinong Science Center, Jl. Raya-Bogor, Cibinong, Bogor, Indonesia.*
[2]*Research Center for Food Crops, National Research and Innovation Agency Republic of Indonesia (BRIN), Cibinong Science Center, Jl. Raya-Bogor, Cibinong, Bogor, Indonesia.*

[*]**Corresponding author:** syarifinnur@gmail.com

REVIEW PAPER

Received:
25 August 2023
Revised:
4 September 2023
Accepted:
17 December 2023
Published online:
19 January 2024

Abstract:

Purpose: Integrating vermicompost and hydroponics in rice agriculture presents an innovative and sustainable solution for transforming organic waste into valuable resources. This review explores the possible utilization of organic waste into productive resources through vermicompost and hydroponics in rice agriculture.
Method: A comprehensive literature review was conducted to investigate the potential use of vermicompost derived from organic waste for hydroponic rice agriculture. The available literature was analyzed to reveal and explore the various aspects of this application.
Results: The literature review reveals that the utilization of vermicompost derived from organic waste in hydroponic rice agriculture holds the potential to evolve into effective strategies for reducing, reusing, and recycling or-ganic waste. Vermicompost decreases used inorganic fertilizers, with studies reporting up to 30% reductions. The application of vermicompost can enhance plant growth by approximately 15% to 30% and positively impact increasing specific nutrients in plants. Using vermicompost can also increase the average crop yield by about 5% to 25% compared to other organic materials.
Conclusion: This study found that integrating vermicompost and hydroponics represents a promising approach for transforming organic waste into productive resources. This integration allows organic waste to be effectively converted into nutrient-rich vermicompost and valuable growing medium in hydroponic systems. Scientific research has demonstrated the potential benefits of this approach, including improved nutrient availability, enhanced plant growth and yield, and reduced environmental impact. By combining the nutrient-rich properties of vermicompost with the precision and efficiency of hydroponic systems, farmers can achieve sustainable and resource-efficient crop production.

Keywords: Integration; Cultivation; Land; Application; Recycling

1. Introduction

Rice agriculture is crucial in global food security, providing a staple food for millions worldwide. Predictions indicate that global rice production is projected to increase significantly, with estimates ranging from 58 to 567 Mt by 2030 (Fukagawa and Ziska, 2019; Mohidem et al., 2022). However, conventional rice farming practices often pose significant challenges regarding resource utilization and environmental sustainability. The excessive use of chemical fertilizers, water wastage, and improper management of organic waste contribute to pollution, nutrient depletion, and ecosystem degradation (Kumar et al., 2022; Mallareddy et al., 2023; Vinci et al., 2023).
In recent years, innovative approaches have emerged in rice agriculture, including integrating hydroponic techniques.

Hydroponic rice cultivation represents a departure from traditional flooded paddy fields, as it involves growing rice plants in nutrient-rich water solutions instead of soil. This method offers several advantages: water conservation, reduced land usage, and controlled nutrient delivery to plants (Velazquez-Gonzalez et al., 2022; Wang et al., 2022). By optimizing the nutrient balance and environmental conditions, hydroponic rice systems can accelerate growth and enhance yield potential. While still in its experimental stages and needing refinement, hydroponic rice farming showcases the potential to revolutionize how rice is grown, contributing to more sustainable and efficient agricultural practices in the face of evolving global challenges (Al-hashimi, 2023; Dewi et al., 2022; Du et al., 2020).

Combining hydroponic techniques with organic ingredients in rice agriculture presents an innovative approach that marries modern technology with sustainable farming practices. Organic waste can be used to integrate with hydroponic systems. Organic waste is a valuable source of nutrients for agriculture as it contains essential macronutrients such as nitrogen, phosphorus, and potassium, as well as micronutrients necessary for achieving optimal plant growth and productivity (Subhash et al., 2015). Diverting organic waste from landfills, which contributes to methane emissions, a potent greenhouse gas, and occupies valuable space, can benefit the environment and improve sustainability in agriculture (Nigussie et al., 2016).

One effective method of utilizing organic waste for agriculture is vermicomposting (Syarifinnur et al., 2023). Vermicomposting is a process that employs earthworms to decompose organic waste, resulting in nutrient-rich vermicompost that can be used as a fertilizer (Alipour et al., 2022; Sharma et al., 2022; Ngo et al., 2013). Earthworms digest the organic waste, breaking it into simpler compounds more readily available to plants (Castillo et al., 2014; Huang et al., 2014; Ngo et al., 2012). Vermicompost contains high levels of beneficial microorganisms, enzymes, and plant growth hormones that enhance plant growth. Utilizing organic waste through vermicomposting can reduce the need for synthetic fertilizers and promote sustainable agricultural practices. In addition, using vermicompost can ultimately support food security and sustainable agriculture (Chaoui et al., 2003; Sattolo et al., 2017).

Furthermore, integrating vermicompost from organic waste with rice hydroponic agriculture is an alternative that can replace commonly used growing media such as rock wool, perlite, vermiculite, coconut coir, fired clay pellets, expanded shale, and grow stones. Utilizing vermicompost derived from organic waste can offer supplementary nutrients for plant growth. When compared to the use of conventional materials, the price is lower because its obtained from no longer used materials and offers a sustainable solution for managing organic waste (Jouhara et al., 2017; Mousavi et al., 2017).

In this innovative approach, vermicompost is utilized and serves as a natural source of fertilization for hydroponic rice cultivation (Khan and Ishaq, 2011; Rini et al., 2020; Subhash et al., 2015). The process involves incorporating vermicompost into the hydroponic setup, allowing the nutrients and beneficial microorganisms to leach into the liquid solution. This nutrient-rich vermicompost solution is then introduced into the hydroponic system, replacing the need for synthetic nutrients (Huang et al., 2014; Gillani et al., 2022; Pramanik et al., 2010; Villar et al., 2016).

This paper explores the integration of vermicompost and hydroponics in rice agriculture as a sustainable approach for transforming organic waste into productive resources. By synthesizing existing research and case studies, this paper provides valuable insights into the feasibility and potential of adopting this innovative approach in rice agriculture. Integrating vermicompost and hydroponics can establish a promising pathway toward a sustainable and resilient rice production system. This approach effectively tackles the ecological and socioeconomic challenges that modern agriculture faces.

2. Hydroponic system

A hydroponic system, also known as a soilless culture system, is a method of cultivating plants without using soil, using a nutrient-rich water solution instead (Pathma and Sakthivel, 2016). This approach has gained popularity as an alternative to traditional soil-based agriculture because it can produce high yields in a smaller space, uses less water, and requires fewer pesticides and fertilizers (Pomoni et al., 2023; Ekoungoulou and Mikouendanandi, 2020). Hydroponic systems can grow various crops, including vegetables, herbs, and fruits (Ashok and Sujitha, 2020). They are also highly customizable, with different hydroponic setups, such as deep-water culture, nutrient film technique (NFT), and drip irrigation. With its many advantages, the use of hydroponic systems has become increasingly popular among farmers, gardeners, and researchers looking to explore more sustainable and efficient ways of growing crops (Sharma et al., 2018; Jensen et al., 2022).

In recent decades, the modern agriculture industry has increasingly adopted hydroponic, which involves using porous growing media that retains air and water in suitable ratios for plant growth. Hydroponic refers to any method of plant cultivation without using soil as a rooting medium, and it has become a crucial component of modern agriculture due to its ability to sustain profitable crop growth (Savvas et al., 2013). The success of hydroponics can be attributed to the development of suitable growing media, such as rock wool and coir, that possess optimal physical, hydraulic, and chemical properties (Savvas and Gruda, 2018). Additionally, advances in plant nutrition and irrigation through modern fertigation equipment and automation technologies have contributed to the widespread adoption of hydroponics a leading cultivation technology. Hydroponic systems, on the other hand, offer a more efficient and sustainable alternative to conventional farming methods. Hydroponic systems require less water, space, and resources and can produce higher crop yields by providing a nutrient-rich water solution to the plants. Casey et al. (2022) and Majid and Khan (2021) investigated the environmental impacts of hydroponic and soil-based lettuce cultivation. The study found that the hydroponic system had a lower carbon footprint, consumed less water, and produced higher crop yields

than the soil-based system. Another also reported that the hydroponic system had a lower nutrient leaching rate and higher nutrient use efficiency (Fussy and Papenbrock, 2022; Martinez-Mate et al., 2018).
The success of a hydroponic system depends on several factors, including the choice of hydroponic growing media, the quality of the nutrient solution, the pH and EC levels, and the management of environmental factors such as light, temperature, and humidity. Proper management of these factors can help ensure optimal plant growth and yield in hydroponic systems, making it a promising technology for sustainable agriculture (Khan et al., 2020; Casey et al., 2022; Majid and Khan, 2021). Hydroponic growing media are an essential component of hydroponic systems. They are materials that provide support and anchorage for the roots of plants while allowing the delivery of nutrient-rich solutions to the plants. The choice of hydroponic growing media depends on several factors, such as the plant species, the hydroponic system being used, and the availability of the media. Common types of hydroponic growing media include Rockwool, perlite, vermiculite, coconut coir, clay pebbles, and sand (Arcas-Pilz et al., 2022; Zeljkovic et al., 2022; Lei and Engeseth, 2021).

3. Rice cultivation in the hydroponic system

Rice is the most widely consumed cereal for human consumption, making its production one of the most vital activities for the global population. Therefore, considering its economic and nutritional significance, evaluating the sustainability of this production process could be noteworthy (Vinci et al., 2023). Rice cultivation has long been associated with traditional flooded paddies, but recent innovations in agricultural practices, such as hydroponics, are challenging this age-old approach (Fischer and Connor, 2018). Hydroponics offers a new perspective on rice cultivation by providing a controlled environment that optimizes water usage and nutrient delivery. This method involves growing rice plants in nutrient-rich water solutions, eliminating the need for vast water fields while promoting efficient nutrient absorption (Laribi et al., 2023; Putra and Yuliando, 2015). Hydroponic systems also minimize the risk of pests and diseases, leading to healthier plants and potentially higher yields. Although transitioning rice to hydroponics presents its share of challenges, including adapting the rice plant's unique growth habits to this system, the prospect of reducing water consumption, increasing sustainability, and securing food production in the face of changing climate conditions makes hydroponic rice cultivation a promising avenue for the future of agriculture (Al-hashimi, 2023).
Transitioning rice to hydroponics is not without challenges, however. Rice plants have evolved to thrive in flooded conditions, with their elongated submerged stems called 'stems' being a unique adaptation. Adapting these plants to hydroponic systems requires meticulous adjustment of factors like water levels, nutrient compositions, and lighting (Velazquez-Gonzalez et al., 2022). Researchers and farmers are working to optimize hydroponic systems that simulate the submerged growth of traditional paddies. Developing these systems involves understanding the intricate interplay between nutrient availability, oxygenation, and root development while also addressing concerns related to space, energy, and cost efficiency (Meselmani, 2022; Calişkan and Calişkan, 2018). Despite these complexities, the potential rewards of hydroponic rice cultivation, including increased yields, decreased resource usage, and resilience against changing climate patterns, make pursuing this innova-tive approach both valuable and necessary (Preite et al., 2023).
Rice cultivation through hydroponics also intersects with urban farming, addressing the limitations of available agricultural land in densely populated areas. Urbanization has reduced arable land, making it increasingly challenging to sustain local food production (Mamun et al., 2023). Hydroponic rice farming offers a viable solution by enabling cultivation in controlled indoor environments, such as vertical farms or rooftop gardens. This approach not only maximizes land use efficiency but also reduces the need for long-distance transportation of food, minimizing the carbon footprint associated with traditional agriculture. Hydroponic methods could contribute to food security and promote a more sustainable urban lifestyle by bringing rice cultivation closer to urban centers.

4. Vermicompost and vermicomposting

Vermicompost comes from the word Vermis (Latin), which means worm. Vermicompost is a process of decom-posing organic matter using earthworms, which helps to break down organic matter more quickly and has a higher level of plant-available nutrients such as nitrogen, phosphorus, and potassium. Vermicompost also improves water retention and microbial activity to produce essential hormones for plants (Alipour et al., 2022; Bhat et al., 2018; Biswas et al., 2022). Vermicomposting is a sustainable and eco-friendly method of managing organic waste, which involves using earthworms to break down organic materials into a nutrient-rich fertilizer that can be used in gardening, farming, and other agricultural applications. Compared to traditional composting, vermicomposting has several advantages, making it an increasingly popular method for managing organic waste (Pattnaik and Reddy, 2009; Ravindran et al., 2019; Soni et al., 2016).
Another advantage of vermicomposting is the higher nutrient content of the compost. Earthworms break down the organic materials and add beneficial microorganisms and enzymes to the compost, resulting in a nutrient-rich fertilizer richer in nitrogen, phosphorus, and potassium than traditional compost. This higher nutrient content makes vermicompost an excellent soil amendment for growing various plants, including vegetables, fruits, and flowers (Parthasarathi et al., 2016; Soobhany et al., 2017; Zziwa et al., 2021). Vermicomposting is also a perfect option for individuals who have limited outdoor space. Unlike traditional composting, vermicomposting can be done in smaller spaces like apartments or balconies. Worm bins are easy to set up and maintain and can be used to convert kitchen scraps and other organic materials into nutrient-rich vermicompost. It makes vermicomposting a more accessible and convenient option for individuals who live in urban areas with limited outdoor space (Mancini et al., 2019; Jara-

Samaniego et al., 2017; Singh et al., 2011).

One significant advantage of vermicomposting is that it produces high-quality compost in less time than traditional composting. Earthworms can break down organic materials faster and more efficiently than microbes, resulting in quicker composting. Vermicomposting can produce high-quality compost in as little as two to three months, making it an ideal option for individuals who want to reduce their carbon footprint or produce compost for their gardens quickly (Kauser and Khwairakpam, 2022; Liegui et al., 2021; Vyas et al., 2022; Zulhipri et al., 2021).

Vermicomposting is a more environmentally friendly option for managing organic matter than traditional composting. Vermicomposting is an aerobic process that occurs in the presence of oxygen. It produces carbon dioxide, less harmful to the environment than methane, a potent greenhouse gas produced by anaerobic composting. By using vermicomposting to manage organic matter, individuals can reduce their carbon footprint and contribute to a more sustainable future for the planet (Nigussie et al., 2017; Yasmin et al., 2022).

5. Vermicompost from organic waste

Improper organic waste management is a serious environmental threat worldwide, leading to a global struggle to balance waste generation and environmental protection (Enebe and Erasmus, 2023). Vermicomposting has become increasingly popular in recent years due to its distinct benefits of reduced operational and maintenance expenses compared to alternative waste management technologies (Parthasarathy and Narayanan, 2014; Singh and Singh, 2017). Waste management is an essential aspect of vermicomposting, and the success of the process depends on the type of waste materials used and their management (Deka et al., 2011a; Li et al., 2020). Using suitable waste materials can help ensure that the compost is balanced regarding carbon and nitrogen. The ideal waste materials for vermicomposting are dry grass clippings and rice straw (Ramnarain et al., 2019), fruit and vegetable scraps (Garg and Gupta, 2011), coffee grounds (Adi and Noor, 2009), market organic waste (Syarifinnur et al., 2020), eggshells (Biswas et al., 2022), banana steam (Khatua et al., 2018). These materials provide a range of nutrients and can help maintain a healthy composting environment. This process promotes plant growth and increases crop yields, all while reducing organic waste that would otherwise contribute to environmental pollution. The vermicomposting method has gained popularity due to its many benefits, including improving the quality of organic fertilizer and reducing waste (Devi and Khwairakpam, 2020; Rajkhowa et al., 2019; Wani et al., 2013).

However, successful vermicomposting requires careful management of several critical factors, including the type and combination of organic matter used, the species and number of earthworms, and how these elements interact (Arora and Kaur, 2019; Ganguly and Chakraborty, 2019; Yuvaraj et al., 2021). One of the primary factors affecting vermicompost production is the type and combination of organic matter used as feedstock (Alipour et al., 2022). Earthworms require diverse organic matter to thrive, including plant residues, animal manure, and food waste. The ideal feedstock mix depends on the specific species of earthworms used and the final vermicompost's desired properties (Kumlu et al., 2018; Ramnarain et al., 2019; Suleiman et al., 2017). For example, a mix of plant residues, such as straw, leaves, and grass clippings, can create a balanced carbon-to-nitrogen ratio in the vermicompost, promoting healthy microbial activity and nutrient cycling. In addition to the type of organic matter used, the number and species of earthworms also play a crucial role in vermicomposting. Different species of earthworms have varying feeding and burrowing habits, which can affect the speed and quality of the composting process (Bakar et al., 2014; Devi and Khwairakpam, 2020; Mousavi et al., 2017). The research conducted by Kaur et al. (2010) and Ravindran and Mnkeni (2016), and Singh et al. (2010) using *Eisenia fetida* is a common species used in vermicomposting due to its rapid reproduction and a high tolerance for a wide range of organic matter types. However, other species, such as the African nightcrawler (*Eudrilus eugeniae*), may be better suited for certain types of feedstock, such as animal manure, due to their larger size and more powerful digestive system (Ashok and Sujitha, 2020; Esaivani et al., 2015; Soobhany et al., 2015b).

Several measures can be taken to ensure efficiency and effectiveness for optimal results in the decomposition process of organic matter using earthworms. It is necessary to pay attention to the type of earthworm, the number of earthworms, and the organic material used. The type commonly used is the epigeic type of earthworm (Blakemore, 2009; Liu et al., 2012; Soobhany et al., 2015a; Suthar, 2009). These earthworms have several characteristics, including living on the surface of the soil, eating organic matter, being able to adapt to environmental factors, having high reproduction rates, and having resistance to specific treatments. Some earthworms are epigeic types, such as *Eisenia fetida*, *Perionix excavates*, *Eudrillus eugenia*, and *Eisenia andrei*, which have been widely used in the decomposition process of organic matter. Types of organic materials commonly used include market vegetable waste, household waste, municipal waste, garden waste, fruit residue, crop residues such as straw, coffee grounds, and liquid waste. Mixed materials used in the manufacture of vermicompost include cow manure, straw, weeds, sawdust, livestock manure, and goat manure. This difference in composition also causes the quality of the vermicompost produced to vary (Table 1).

6. Application of vermicompost on crop performance

Vermicompost, also known as worm castings, is a nutrient-rich organic fertilizer. This organic fertilizer is a valuable resource for plant growth and development (Karmegam et al., 2021; Rehman et al., 2023). The role of vermicompost in plant growth is primarily due to beneficial microorganisms, enzymes, and nutrients such as nitrogen, phosphorus, and potassium. These elements provide a well-balanced diet to the plants, promoting their growth and reducing plant diseases and overall health (Singh et al., 2017; Malinska et al., 2017). The nutrients in vermicompost are readily available to plants, which means they can be absorbed quickly and

Table 1. Several types, the number of earthworm species, and combinations of waste organic matter in making vermicompost.

Earthworm Species	Number of earthworms	Types of Organic Waste	Supplementary Materials	References
Eisenia fetida	20 tails	Market vegetable waste	Cow dung	(Suthar, 2009)
Eisenia fetida	75 tails	vegetable waste	Cow dung, straw, and weeds	(Goswami et al., 2017)
Eisenia Andrei	120 tails	Municipal organic waste	Compost	(Villar et al., 2016)
Eisenia. fetida, Eisenia. Andrei	20 tails	Municipal organic waste	Sawdust	(Suleiman et al., 2017)
E. fetida and Dendrobaena veneta	$1.5kg$	Garden organic waste	Cow dung	(Yasmin et al., 2022)
Eisenia fetida	50 tails	Vegetable and fruit waste	Cow dung	(Huang et al., 2017)
Eudrilus eugeniae	20 tails	Solid organic waste	Cow dung and leaf litter	(Soobhany et al., 2015b)
Eudrilus eugeniae	1700 tails	Food waste	Cow dung	(Lalander et al., 2015)
Eudrilus eugeniae	100-120 tails	Water hyacinth	Goat manure	(Varma et al., 2016)
Lumbricus rubellus	60 tails	Coffee grounds and Kitchen trash	Cow dung	(Adi and Noor, 2009)
Eudrilus eugeniae	150 tails	The rest of the distillation of lemon grass	Cow dung	(Deka et al., 2011b)
Lumbricus rubellus	36 tails	Vegetable waste	Cow dung	(Bakar et al., 2014)

used for growth. This enhanced nutrient uptake can lead to healthier and more productive plants (Scaglia et al., 2016). Hussain et al. (2017) studied the utilization of vermicompost derived from Salvinia weed, which exhibited a significant positive impact on the germination, growth, and yield of lady's finger plants. In addition to the remarkable improvements in plant growth, vermicompost treatment resulted in elevated levels of minerals and biochemicals, exceeding those observed in the control group (Chauhan and Singh, 2020; Verma et al., 2018). Furthermore, vermicompost application was vital in reducing the incidence of fruit borer infection and inducing plant resistance against pests and diseases (Xiao et al., 2016). (Amooaghaie and Golmohammadi, 2017) observed the effects of different percentages of vermicompost on seedling emergence indices, plant growth, and essential oil content. The results showed a lower percentage of vermicompost (25%) promoted the best seedling emergence indices. A higher percentage (50%) significantly impacted various aspects of plant growth, including length, photosynthetic efficiency, chlorophyll, carotenoid contents, and the fresh and dry weight of aerial parts and roots. Manh and Wang (2013) also reported using vermicompost from rice hulls and coconut husk. According to the study, a vermicompost mixture resulted in Muskmelon's (*Cucumis melo* L) highest germination rate, plant height, leaf area, and plant biomass. Syarifinnur et al. (2022) studied the effect of compost and vermicompost derived from organic waste obtained from the market on both soil chemical properties and maize growth. The experimental setup included three doses of compost (2.5, 5, and $10t/ha$), three doses of vermicompost (2.5, 5, and $10t/ha$), and a control group without compost or vermicompost. During the harvest period, ten weeks after the planting phase, measurements were taken for maize shoot dry weight, cob length, root dry weight, cob diameter, cob dry weight, and cob with husk. The findings revealed that compost and vermicompost considerably impacted the maize yield. Specifically, applying $10t/ha$ of vermicompost resulted in the highest yield of maize. The effect of vermicompost on crop performance is presented in Table 2. The Growth of plants using vermicompost is superior due to its higher concentration of nutrients than regular compost. The process of vermicomposting involving earthworms enhances the availability of nutrients such as nitrogen, phosphorus, and potassium in a more readily absorbable form by plants. By utilizing vermicompost, plants receive improved nutrition, enabling optimal growth while reducing dependence on chemical fertilizers. This result is consistent with the research conducted by Subhash et al. (2015), which demonstrates that the compost obtained from a mixture of 50% Eichhornia and 50% cow dung underwent GC-MS analysis, resulting in the identification of 21 peaks listed in Table 3. The highest peak area was observed for Benzene, $1,2,4-$trimetho (22.17%), followed by 9-Octadecenoic acid (18.52%) and 1-Dodecanamine, $N,N-D$ (11.03%). Peaks with areas below 10% were also detected. Similarly, the GC-MS analysis of vermicompost produced from the same mixture exhibited 12 peaks. The predominant peak area was Benzenepropanoic acid (95.98%), followed by 2-Propanone, 1-Phenyl-, OXIM (10.10%). Other peaks displayed areas below 10%. Benzene compound, also known as 3-Phenylpropanoic acid found in vermicompost, can act as a carbon and energy source for soil microorganisms, promoting nutrient cycling, enhancing plant growth, helping to regulate pH, and improving nutrient retention (Liu et al., 2015; Bhattacharya et al., 2016; Gerke, 2018; Wagner et al., 2019).

Table 2. Effect of vermicompost on crop performance.

No.	Plants	Source of vermicompost	Effect of vermicompost on crop performance	Reference
1.	Tomato (*Lycopersicum esculentum* L.)	municipal solid waste	Vermicompost enhances growth physiology when integrated as a substrate element in hydroponic cultivation. It leads to higher root fresh and dry weight, increased root volume, improved mean photosynthesis, and a more significant number of fruits at all stages of physiological development compared to the control, about 20% to 25%	(Haghighi et al., 2016)
2.	Thyme (*Tymus vulgaris* L.)	Cow manure	The findings revealed that using 25% vermicompost enhanced seedling emergence, while 50% vermicompost led to maximum length, weight of plant parts, chlorophyll, carotenoid content, photosynthetic efficiency, and essential oil yield. Vermicompost also proved effective in biocontrol against Fusarium oxysporum and Phytophthora infestans. The pathogen suppression increased with higher vermicompost substitution rates, peaking at 75%. Disease protection was associated with increased activity of defence-related enzymes, including $\beta-1,3-$glucanase, phenylalanine ammonialyase, polyphenol oxidase, peroxidase, and total phenolic content.	(Amooaghaie and Golmohammadi, 2017)
3.	Tobacco	Pleurotus eryngii	Preventing the nematode infection caused by Meloidogyne incognita while simultaneously bolstering the plant's natural resistance.	(Yang et al., 2023)
4.	Bitter Gourd (*Momordica charantia*)	Cow manure	50% vermicompost enhances fruit diameter, length, number, and weight by about 25% compared to the control.	(Ghimire et al., 2023)
5.	wheat-maize rotation	Cow and pig manure	The application of vermicompost as a fertilizer led to a 5% increase in crop productivity	(Raza et al., 2023)
6.	Cucumber (*Cucumis sativus* L.)	Local agricultural residues	The study revealed that a combination of vermicompost (50%) and biochar (50%) yielded the highest fruit quality and increased cucumber yields by 29.2% to 56.0%	(Wang et al., 2021)
7.	Banana (*Musa spp.*)	Cow and horse manure	The study found that a mix of 33.3% vermicompost, 33.3% vermiculite, and 33.3% sand produced the best results for vegetative growth parameters. Furthermore, a 50% vermicompost and 50% peat moss combination significantly increased banana plant chlorophyll content. Additionally, a 75% vermicompost and 25% peat moss blend yielded the highest mineral content values for nitrogen (N), phosphorus (P), and potassium (K) during two measurement periods.	(Ravindran et al., 2019)
8.	Hot Pepper (*Capsicum annuum var. Red chili*)	Cow manure	Applying vermicompost significantly improved plant growth parameters, such as height, internode distance, and lateral branches in both seasons. Using 15 tons per hectare of cow vermicompost enhanced chlorophyll content, fruit yield, and fruit number in both years. The third treatment (10 tons per hectare of cow vermicompost) consistently yielded the highest leaf count, fruit weight, and total soluble solids throughout both seasons. Additionally, 1000-seed weight and vitamin C content were influenced by cow vermicompost.	(Aminifard, 2022)
9.	Pepper (*Capsicum annuum* L.)	Bovine manure	No significant agronomic differences were observed in growth parameters or total chlorophyll levels. Using various dilutions of vermicompost showed no notable disparities among them or when compared to the yields obtained from chemical fertilization.	(Ardisana et al., 2020)
10.	Rice	Cow manure	The results demonstrated the synergistic interactions between vermicompost and biochar in promoting crop yield. When compared to biochar amendment alone, the combination of vermicompost and biochar significantly increased rice yield by 26.5% to 35.3%	(Wu et al., 2019)
11.	Muskmelon (*Cucumis Melo* L.)	Rice waste, mixed rice hulls ash, and coconut husk	The study revealed that a mixture of vermicompost resulted in the highest germination rate, plant height, leaf area, and plant biomass, about 25% to 30%	(Manh and Wang, 2013)
12.	Garlic (*Allium sativum* L.)	Green plants, animal dung, poultry manure, sheep manure, leaves and ash	Vermicompost application significantly boosts garlic yields, mean clove size, bulb weight, fresh biomass yield, total bulb production, bulb dry matter percentage, and harvest index by approximately 15% to 35%	(Degwale and Gedamu, 2016)
13.	Carrot (*Daucus carota* L.)	Cow dung and vegetable waste	The results revealed that vermicompost led to the highest carrot root length, root volume, root weight, and root yield.	(Chatterjee et al., 2014)
14.	Mustard (*Brassica campestris* cv)	Cow dung and dried chopped Eichhornia	The application of 2.5 t/ha of vermicompost reduced the use of chemical fertilizer. It improved various parameters, including Leaf Area Index (LAI), Leaf Area Duration (LAD), Leaf Area Ratio (LAR), Crop Growth Rate (CGR), Net Assimilation Rate (NAR), Photosynthetic Rate (PR), Harvest Index (HI), and biochemical attributes like total chlorophyll, sugar, and proline content in physiologically active leaves, by approximately 20% to 30% compared to the control.	(Mondal et al., 2017)
15.	Maize, millet, and sorghum	Cattle manure	The addition of vermicompost promoted the plant's growth, leading to increased shoot and root dry biomass enhanced root length, volume, surface area, and diameter. Improved absorption of both macro- and micronutrients about 15% to 30% compared to the control	(Esteves et al., 2020)
16.	Capsicum annum (Linn.) Hepper	Cattle dung	The application of 50% vermicompost can enhance plant growth parameters such as shoot length, internode length, leaf count, and branch number throughout the $3rd$, $4th$, and $5th$ weeks of the treatment period, with an average $20\%-35\%$	(Rekha et al., 2018)
17.	Groundnut and Cotton	Organic waste like grass clippings and cattle dung	The results indicated that applying vermicompost at 3 tons per hectare in groundnut resulted in higher yields, gross returns, and a higher percentage increase in yield. Similarly, using vermicompost at 5 tons per hectare in cotton crops led to higher yields, gross returns, and a percentage increase in yield of about 20%. In both crops (groundnut and cotton), those planted in organically amended plots did not experience any moisture stress during dry spells due to improved moisture retention.	(Chavda and Rajawat, 2015)
18.	Chinese cabbage (*Brassica campestris ssp. chinensis*)	Cow manure	The application of vermicompost ($4:7$ treatment) significantly increased the weight of the nutrient content of Chinese cabbage leaves, particularly in terms of soluble sugar, soluble protein, vitamins, total phenols, and total flavonoids. Compared to the full soil treatment, these contents saw increases of 25%, 62%, 18%, 200%, 25%, and 17%, respectively.	(Wang et al., 2010)
19.	Potato (*Solanum tuberosum* L.)	Microalgae	Applying vermicompost and bacteria increased tubers' number, size, and diameter by approximately 15% to 30% compared to the control in mini potatoes produced from tissue culture plants after 120 days of planting.	(Boubaker, 2021)
20.	French marigold (*Tagetes patula*)	Cow dung	The application of vermicompost has significant positive effects on the growth and flowering of marigold seedlings about 2.3 times. This enhancement is observed in various aspects, including increased plant biomass, greater plant height, and more buds and flowers.	(Gupta et al., 2014)

Table 3. Comparison of GC-MS analysis on compost and vermicompost of *Eichhornia* and cow dung.

Compost 50% combination of *Eichhornia* and 50% cow dung					Vermicompost 50% combination of *Eichhornia* and 50% cow dung			
Peak	Retention time	Area	Height%	Name	Retention time	Area	Height %	Name
1	7.130	0.13	0.30	Acetonyl decyl ether	5.712	1.45	1.87	Oxirane, (bromomethy)
2	8.908	2.80	4.81	Nonane, 3,7−dimethyl-	7.557	-19.90	6.46	Dodecana, 1,1 difluoro
3	9.823	0.20	0.33	Disulfide, diheptyl	8.575	4.39	2.58	Oxirane, (bromomethy)
4	10.401	0.21	0.49	Butane, 1-isocyano-	8.745	1.53	1.98	Oxirane, 2, 2′-[oxybis(ME
5	13.301	0.85	1.77	1-Tetradecanol	16.010	10.10	2.62	2-Propanone, 1-Phenyl-, OXIM
6	13.994	1.12	1.82	Tetracyclo[4.1.0.02,4.03	16.916	-1.62	0.16	Isoxazolidine
7	15.825	4.91	4.30	1-Tetradecanol	17.504	3.32	1.78	1,3-Butadiene-1,1,4,4-D4
8	15.985	22.17	13.59	Benzene, 1,2,4-trimetho	17.606	0.06	1.08	O-Toluidine, N-ethyl-
9	16.212	6.22	5.30	1,2,4-Trimethoxy-5-[(1E)	17.722	8.66	4.31	Ethanone, 2-ethoxy-1,
10	17.136	11.03	7.66	1-Dodecanamine, N,N-D	18.246	6.77	4.53	Benzenamine, N-ethyl-2-methyl
11	17.250	3.02	2.38	1,4-Naphthalenedione	20.409	-10.73	3.76	Onanoic acid, methyl
12	17.339	2.51	2.31	Phenol, O-nonyl-	20.684	95.98	68.86	Benzenepropanoic acid
13	18.043	0.92	1.26	Hexanoic acid, 4-meth	–	–	–	–
14	19.174	4.05	1.99	3-Hexanone, 1-(2,5,6,6-TE	–	–	–	–
15	19.276	4.02	2.95	(1S,2S,3S)-2-allyl-2-(hyd	–	–	–	–
16	19.468	18.52	20.50	9-Octadecenoic acid	–	–	–	–
17	19.724	7.59	12.73	Methyl ester of 3-(3,5-D	–	–	–	–
18	19.925	-1.01	-0.29	7-Ethylidene-6B,7,8,8A-T	–	–	–	–
19	21.135	5.26	7.65	7-Tetradecyne	–	–	–	–
20	21.182	6.04	8.52	9-Octadecenoic acid	-	-	-	-
21	21.417	-0.56	-0.36	2,3-Diethoxybutane	–	–	–	–

7. Hydroponic media from vermicompost

Recent studies have demonstrated the benefits of hydroponic growing media derived from vermicompost. This innovative technique provides a suitable plant growth medium and a valuable source of essential nutrients for optimal plant growth (Ansari et al., 2019; Yadav and Parveen, 2023). These findings suggest that vermicompost-based hydroponic systems may offer a promising solution for enhancing the productivity and sustainability of agriculture. Researchers have been exploring using vermicompost as a potential hydroponic growing medium, which offers several advantages over conventional growing media such as soil or rockwool. Studies have reported that vermicompost can improve plant growth and yield, increase nutrient uptake, and reduce environmental impact. One study by Haghighi et al. (2016) was conducted to investigate the effectiveness of different materials, including municipal solid waste compost, peat, perlite, and vermicompost, in promoting the growth of tomatoes (*Lycopersicon esculentum* L.) in hydroponic systems. Several material combinations were examined, and it was evident that including 25% vermicompost in the compost notably boosted the yield of ripe tomatoes compared to the control group. In addition, using vermicompost, peat, and perlite resulted in notable improvements in root fresh and dry weight, root volume, mean photosynthesis, and the number of fruits at all stages of development, surpassing the control group. Based on these findings, it can be concluded that incorporating vermicompost as a substrate component in hydroponic culture has the potential to enhance the physiological growth of tomatoes. Another study by Arancon et al., 2019 research study investigated the effects of low concentrations of vermicompost, derived from food waste, in static hydroponic systems. For lettuce, concentrations of 1.6% and 3.2% were tested, while for tomatoes, concentrations of 0.14%, 0.28%, and 0.56% were examined. The results showed that vermicompost significantly affected lettuce yield when nutrient solution concentrations were reduced to 25% and 50% of the recommended rate, compared to treatments without vermicompost. Even lower concentrations of vermicompost as a supplement in nutrient solutions reduced to 50% significantly increased tomato yields. This improvement in yield is attributed to the presence of trace amounts of plant hormones like auxins, cytokinins, gibberellins, and humic acids in the vermicompost teas, which effectively enhanced plant growth and yield in static hydroponic systems with reduced nutrient concentrations, indicating its potential as a more sustainable and environmentally friendly option for hydroponic farming.

Using vermicompost as a hydroponic medium has significant implications for developing sustainable and ecofriendly agricultural practices. Vermicompost production can provide a sustainable solution to waste management as it can be produced from organic waste materials, such as food waste and agricultural residues (Alipour et al., 2022; Esmaeili, 2020). By diverting organic waste from landfills and using it to produce vermicompost, its possible to reduce greenhouse gas emissions and create a valuable resource for agricultural production (Savvas et al., 2013; Nigussie et al., 2017). The main advantage of vermicompost is that it can significantly reduce the negative environmental impacts of conventional hydroponic growing media. Traditional hydroponic growing media, such as rock wool and perlite, can be non-renewable and require significant energy to produce, transport, and generate large amounts of waste. Using vermicompost can offer a sustainable and environmentally friendly alternative that can contribute to developing circular and closed-loop agricultural systems (Kennard et al., 2020). The utilization of a hydroponic rice system with vermicompost obtained from organic waste is described in Fig. 1.

8. Challenges and considerations for implementing vermicompost and hydroponics integration

While integrating vermicompost and hydroponics offers promising benefits for sustainable agriculture, several challenges and considerations must be addressed to ensure successful implementation. Scientific research has identified these challenges and provides valuable insights into overcoming them for optimal outcomes.

1. Nutrient Management: Effective nutrient management is crucial in integrating vermicompost and hydroponics. It is essential to determine the appropriate nutrient composition and concentration in the hydroponic solution to meet the specific nutrient requirements of the plants (Du et al., 2020). Careful monitoring and adjustment of nutrient levels, pH, and electrical conductivity are necessary to prevent nutrient imbalances and ensure optimal plant growth and development (Muktamar et al., 2017; Rini et al., 2020).

2. Vermicompost Quality and Stability: The quality and stability of vermicompost play a vital role in its effectiveness as a nutrient source in hydroponics. It is essential to confirm that the vermicompost being used has reached maturity., well-composted, and free from contaminants or pathogens (Joshi et al., 2015). Vermicompost production processes should be carefully managed to maintain consistent nutrient content and microbial activity. Quality control measures, such as regular testing and monitoring, are essential to ensure the stability and reliability of vermicompost (Ganguly and Chakraborty, 2019; Rehman et al., 2023).

3. Disease and Pest Management: While vermicompost can contribute to disease suppression in hydroponics, it is crucial to implement proper disease and pest management strategies (Jara-Samaniego et al., 2017). Introducing pathogens or pests through vermicompost can pose a risk to plant health. Strict sanitation practices, such as proper composting techniques and pathogen control measures, should be employed to minimize the risk of disease outbreaks. Integrated pest management strategies, including biological controls, can help address potential pest issues (Arancon et al., 2019).

4. System Design and Maintenance: The design and maintenance of the integrated vermicompost and hydroponic system require careful consideration. Proper system design should ensure efficient nutrient delivery, water circulation, and aeration to promote optimal plant growth (Li et al., 2018). Regular system maintenance, like cleaning, moni-

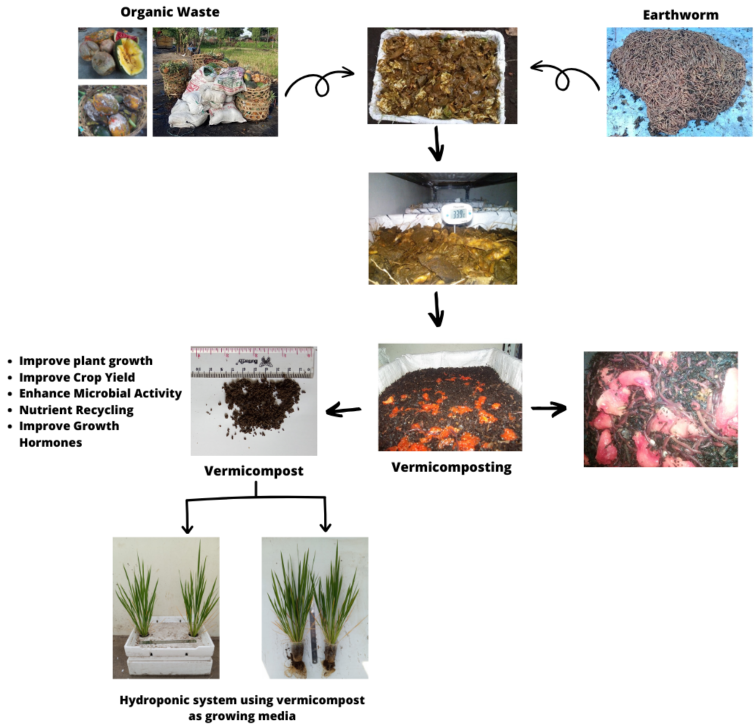

Figure 1. The basic process of a hydroponic rice system using vermicompost from organic waste.

toring of nutrient levels, and preventive measures against clogging or blockages, is essential for long-term system performance (Bouadila et al., 2022; Li et al., 2022; Wiegmann et al., 2023).
5. Economic Viability: Assessing the economic viability of integrating vermicompost and hydroponics is crucial for practical implementation. The costs associated with vermicompost production, system setup, and maintenance should be carefully evaluated and compared to the potential benefits, such as increased crop yields and reduced input requirements (Folorunso et al., 2023; Gumisiriza et al., 2022). Economic feasibility studies can provide valuable insights into the profitability and long-term sustainability of the integrated system (Folorunso et al., 2023; Ekaputri et al., 2021).
By addressing these challenges and considerations, the integration of vermicompost and hydroponics Rice Agriculture can be successfully implemented, maximizing the benefits of both techniques for sustainable agriculture. Continued scientific research, practical experimentation, and knowledge exchange among practitioners and researchers are essential for advancing the understanding and optimization of this integration.

9. Future directions and research opportunities

Integrating vermicompost and hydroponics in agriculture holds significant potential for sustainable and resource-efficient crop production. However, there are still several areas that warrant further investigation and research. Scientific studies have identified vital future directions and research opportunities to advance the integration of these techniques and maximize their benefits.

1. Optimization of nutrient formulations: Further research is needed to optimize nutrient formulations in hydroponic systems utilizing vermicompost, including determining the ideal nutrient ratios and concentrations for different crop species and growth stages. Understanding the nutrient release dynamics from vermicompost and its interaction with hydroponic nutrient solutions will contribute to the development of precise nutrient management strategies (Nguyen et al., 2016; Arif et al., 2023; Oliveira et al., 2023; Ng et al., 2023).
2. Exploration of microbial interactions: The role of microbial communities in vermicompost and their interactions with hydroponic systems require in-depth exploration (Thomas et al., 2023; Jiang et al., 2023). Investigating the specific microbial populations involved in nutrient cycling, disease suppression, and plant growth promotion will contribute to harnessing the full potential of vermicompost integration in hydroponics (Cao et al., 2021; Huang et al., 2014; Chavda and Rajawat, 2015; Wang et al., 2023).
3. Environmental impacts and sustainability assessment: Assessing the environmental impacts and sustainability aspects of vermicompost and hydroponic integration is crucial. Research should focus on quantifying resource use efficiency, greenhouse gas emissions, water consumption, and nutrient losses to determine the overall environmental footprint and identify opportunities for improvement (Ngo et al., 2013; Sharma et al., 2022; Yadav and Samadder, 2018).
4. Scaling up and commercialization: Integrating vermicompost and hydroponics for commercial applications requires practical research on large-scale system design, operation, and economics. Evaluating the economic viability, scalability, and feasibility of implementing this integration in

different agricultural settings will support its widespread adoption by farmers and stakeholders (Pattillo et al., 2022; Zhang et al., 2018).

5. Crop-Specific Studies: Conducting cropspecific studies to assess the performance of vermicompost and hydroponic integration in different crops is necessary. Understanding the specific nutrient requirements, growth characteristics, and responses of various crops to this integration will provide tailored recommendations and guidelines for optimizing crop production (Vandam et al., 2017; Gillani et al., 2022; Pathma and Sakthivel, 2016).

6. Comparison with Conventional Systems: Comparative studies between vermicompost and hydroponics integration and conventional soil-based systems can provide valuable insights into the advantages and limitations of each approach. Evaluating plant growth, nutrient uptake, water use efficiency, and economic parameters will help assess the competitiveness and potential of vermicompost and hydroponic integration (Majid and Khan, 2021; Xu et al., 2018)

By addressing these future directions and research opportunities, the integration of vermicompost and hydroponics can be further refined and optimized for sustainable agriculture. Continued collaboration among researchers, practitioners, and stakeholders is essential to drive innovation, knowledge exchange, and practical implementation of this integrated approach.

10. Conclusion

Integrating vermicompost and hydroponics represents a promising approach for transforming organic waste into productive resources in hydroponic rice agriculture. This integration allows organic waste to be effectively converted into nutrient-rich vermicompost, a valuable growing medium in hydroponic systems. Scientific research has demonstrated the potential benefits of this approach, including improved nutrient availability, enhanced plant growth and yield, and reduced environmental impact. By combining the nutrient-rich properties of vermicompost with the precision and efficiency of hydroponic systems, farmers can achieve sustainable and resource-efficient crop production. This integrated approach offers advantages such as reduced reliance on conventional soil cultivation, efficient nutrient management, and minimized water and nutrient losses. Furthermore, it presents a solution for managing organic waste, reducing landfill contributions, and promoting a circular economy in agriculture.

Acknowledgment

The authors thank the Post-doctoral Management Talents for providing the essential resources needed to complete this work.

Author contribution

The authors confirm the study conception and design: Syarifinnur, Suriadi, Lia, Nugraha; data collection: Syarifinnur; analysis and interpretation of results: Syarifinnur, Suriadi. The draft manuscript preparation and results were evaluated by all authors, and the final version of the manuscript was approved.

Conflict of interest statement

The authors declare that they are no conflict of interest associated with this study.

References

Adi AJ, Noor ZM (2009) Waste recycling: utilization of coffee grounds and kitchen waste in vermicomposting. *Bioresour Technol* 100 (2): 1027–1030. https://doi.org/10.1016/j.biortech.2008.07.024

Al-hashimi AM (2023) A review: growing rice in the controlled environments. *Biosci Biotechnol Res Asia* 20 (1): 13–28. https://doi.org/10.13005/bbra/3064

Alipour SM, Fataei E, Nasehi F, Imani AA (2022) Vermicompost quality and earthworm reproduction in different organic waste substrates. *Int J Recycl Org Waste Agricul* 12 (3): 325–339. https://doi.org/10.30486/IJROWA.2022.1944906.1371

Aminifard MH (2022) Effect of cow vermicompost on growth, fruit yield, and quality of hot pepper (*Capsicum annuum* var. Red chili). *Int J Recycl Org Waste Agricul* 11 (3): 363–374. https://doi.org/10.30486/ijrowa.2021.1913049.1154

Amooaghaie R, Golmohammadi S (2017) Effect of vermicompost on growth, essential oil, and health of *Thymus Vulgaris*. *Compost Sci Util* 25 (3): 166–177. https://doi.org/10.1080/1065657X.2016.1249314

Ansari AA, Raghubeer H, Jaikishun S (2019) The effect of vermiwash and vermicompost produced from leaves of *Azadirachta indica* and *Citrus aurantifolia* on the growth parameters of celery through hydroponic system. *Trop Drylands* 3 (1): 11–16. https://doi.org/10.13057/tropdrylands/t030102

Arancon NQ, Owens JD, Converse C (2019) The effects of vermicompost tea on the growth and yield of lettuce and tomato in a non-circulating hydroponics system. *J Plant Nutr* 42 (16): 2447–2458. https://doi.org/10.1080/01904167.2019.1655049

Arcas-Pilz V, Parada F, Rufi-Salis M, Stringari G, Gonzalez R, Villalba G, Gabarrell X (2022) Extended use and optimization of struvite in hydroponic cultivation systems. *Resour Conserv Recycl* 179:106130. https://doi.org/10.1016/j.resconrec.2021.106130

Ardisana EFH, Garcia AT, Tellez OAF, Guerra JLC, Alcivar JBZ (2020) Effect of a bovine manure vermicompost leachate on yield of pepper (*Capsicum annuum* L.) hybrid nathalie. *Int J Recycl Org Waste Agricul* 9 (3): 249–257. https://doi.org/10.30486/ijrowa.2020.1885386.1008

Arif M, Iram A, Fayyaz M, El-Hack ME Abd, AE Taha, Al-Akeel KA, Swelum AA, et al. (2023) Feeding barley and corn hydroponic based rations improved digestibility and performance in Beetal goats. *J King Saud Univ-Sci* 35 (2): 102457. https://doi.org/10.1016/j.jksus.2022.102457

Arora M, Kaur A (2019) *Azolla pinnata, Aspergillus terreus and Eisenia fetida* for enhancing agronomic value of paddy straw. *Sci Rep* 9 (1): 1–11. https://doi.org/10.1038/s41598-018-37880-1

Ashok DA, Sujitha DE (2020) Hydroponic vegetable cultivation. *Int J Chem Stud* 8 (5): 1207–1213. https://doi.org/10.22271/chemi.2020.v8.i5q.10468

Bakar A Abu, Gawi SNA Syed Mohd, Mahmood NZ, Abdullah N (2014) Vermicomposting of vegetable waste amended with different sources of agro-industrial by-product using *Lumbricus rubellus*. *Polish J Environ Stud* 23 (5): 1491–1498. https://doi.org/10.5555/20143402072

Bhat SA, Singh S, Singh J, Kumar S, Vig AP (2018) Bioremediation and detoxification of industrial wastes by earthworms: vermicompost as powerful crop nutrient in sustainable agriculture. *Bioresour Technol* 252:172–179. https://doi.org/10.1016/j.biortech.2018.01.003

Bhattacharya SS, Kim KH, Ullah MA, Goswami L, Sahariah B, Bhattacharyya P, Cho SB, Hwang OH (2016) The effects of composting approaches on the emissions of anthropogenic volatile organic compounds: a comparison between vermicomposting and general aerobic composting. *Environ Pollut* 208:600–607. https://doi.org/10.1016/j.envpol.2015.10.034

Biswas I, Mitra D, Mitra D, Chattaraj S, Senapati A, Chakraborty A, Basak G, Mohapatra PKD (2022) Application of egg shell with fortified vermicompost in Capsicum cultivation: a strategy in waste management. *Int J Recycl Org Waste Agricul* 11 (4): 451–461. https://doi.org/10.30486/IJROWA.2022.1940565.1338

Blakemore RJ (2009) Cosmopolitan earthworms-a global and historical perspective. in: annelids in modern biology. 257–283. Annelids in modern biology https://doi.org/10.1002/9780470455203.ch14

Bouadila S, Baddadi S, Skouri S, Ayed R (2022) Assessing heating and cooling needs of hydroponic sheltered system in Mediterranean climate: A case study sustainable fodder production. *Energy* 261:125274. https://doi.org/10.1016/j.energy.2022.125274

Boubaker H (2021) Agriculture, environment and food sciences effects of the bio-fertilizers on potato mini tubers number and size produced from tissue culture plants. *Int J Agric Environ Food Sci* 5 (4): 514–523. https://doi.org/10.31015/jaefs.2021.4.11

Calişkan B, Calişkan AC (2018) Potassium nutrition in plants and its interactions with other nutrients in hydroponic culture. 9. Improvement of quality in fruits / vegetables through hydroponic nutrient management https://doi.org/10.5772/intechopen.68611

Cao Y, Tian Y, Wu Q, Li J, Zhu H (2021) Vermicomposting of livestock manure as affected by carbon-rich additives (straw, biochar and nanocarbon): A comprehensive evaluation of earthworm performance, microbial activities, metabolic functions and vermicompost quality. *Bioresour Technol* 320:124404. https://doi.org/10.1016/j.biortech.2020.124404

Casey L, Freeman B, Francis K, Brychkova G, McKeown P, Spillane C, Bezrukov A, Zaworotko M, Styles D (2022) Comparative environmental footprints of lettuce supplied by hydroponic controlled-environment agriculture and field-based supply chains. *J Clean Prod* 369:133214. https://doi.org/10.1016/j.jclepro.2022.133214

Castillo E, Benito SG, Iglesias MC (2014) Influence of earthworms on organic waste composting and characterisation of vermicompost end products. *Spanish J Agric Res* 3 (1): 145. https://doi.org/10.5424/sjar/2005031-134

Chaoui HI, Zibilske LM, Ohno T (2003) Effects of earthworm casts and compost on soil microbial activity and plant nutrient availability. *Soil Biol Biochem* 35 (2): 295–302. https://doi.org/10.1016/S0038-0717(02)00279-1

Chatterjee R, Bandyopadhyay S, Jana JC (2014) Evaluation of vegetable wastes recycled for vermicomposting and its response on yield and quality of carrot (*Daucus carota* L.). *Int J Recycl Org Waste Agricul* 3:1–7. https://doi.org/10.1007/s40093-014-0060-4

Chauhan KH, Singh K (2020) Potency of vermiwash with neem plant parts on the infestation of Earias vittella (Fabricius) and productivity of Okra (*Abelmoschus esculentus*) (L.) Moench. *Asian J Res Pharm Sci* 5 (1): 36. https://doi.org/10.5958/2231-5659.2015.00006.5

Chavda VN, Rajawat BS (2015) Performance evaluation of vermicompost on yield of Kharif groundnut and cotton crops. *Int J Crop Improv* 6 (2): 127–131. https://doi.org/10.15740/has/ijfci/6.2/127-131

Degwale A, Gedamu ND Fikreyohannes (2016) Effect of vermicompost on growth, yield and quality of Garlic (*Allium sativum* L.) in Enebse Sar Midir District, Northwestern. *J Nat Sci Res* 6 (3): 51–63.

Deka H, Deka S, Baruah CK, Das J, Hoque S, Sarma H, Sarma NS (2011a) Vermicomposting potentiality of *Perionyx excavations* for recycling of waste biomass of *java citronella* - An aromatic oil yielding plant. *Bioresour Technol* 102 (24): 11212–11217. https://doi.org/10.1016/J.BIORTECH.2011.09.102

Deka H, Deka S, Baruah CK, Das J, Hoque S, Sarma NS (2011b) Vermicomposting of distillation waste of citronella plant (*Cymbopogon winterianus Jowitt.*) employing *Eudrilus eugeniae*. *Bioresour Technol* 102 (13): 6944–6950. https://doi.org/10.1016/j.biortech.2011.04.027

Devi C, Khwairakpam M (2020) Bioconversion of *Lantana camara* by vermicomposting with two different earthworm species in monoculture. *Bioresour Technol* 296 (24): 122308. https://doi.org/10.1016/j.biortech.2019.122308

Dewi U, Handayani S, Jamilah J (2022) Potential of rice waste water and good-plant nutrition to increase hydroponic growth and production of pakcoy (*Brassica rapa* L.). *Proceedings of International Conference on Education Technology and Social Science* 1:149–157.

Du F, Liu P, Wang K, Yang Z, Wang L (2020) Ionomic responses of rice plants to the stresses of different arsenic species in hydroponics. *Chemosphere* 243:125398. https://doi.org/10.1016/j.chemosphere.2019.125398

Ekaputri RZ, Jumiarni D, Usman B, Karyadi B, Putra EP (2021) The potential of hydroponics as a solution for food security and economics resilience: issues and challenges of smart-agriculture. *Engagement* 5:493–505. https://doi.org/10.52166/engagement.v5i2.457

Ekoungoulou R, Mikouendanandi EBRM (2020) Lettuce (*Lactuca sativa* L.) production in Republic of Congo using hydroponic system. *Oalib* 7 (5): 1–17. https://doi.org/10.4236/oalib.1106339

Enebe MC, Erasmus M (2023) Vermicomposting technology - A perspective on vermicompost production technologies, limitations and prospects. *J Environ Manage* 345:118585. https://doi.org/10.1016/j.jenvman.2023.118585

Esaivani C, Esakiammal B, Nithya KVR, Chairman K (2015) Vermiconversion of leaf wastes (*Ficus benghalensis* and *Ficus racemosa*) by employing *Eudrilus eugeniae*. *Int J Adv Res* 3 (8): 798–806.

Esmaeili F (2020) Investigation of the compost of different organic wastes usage combined with zeolite and perlite on the growth of *codiaeum variegatum* cv. Norma. *Int J Recycl Org Waste Agricul* 9 (3): 323–332. https://doi.org/10.30486/IJROWA.2020.1885335.1004

Esteves GF, Souza KRD, Bressanin LA, Andrade PCC, Junior V Veroneze, Reis PE, Silva AB, et al. (2020) Vermicompost improves maize, millet and sorghum growth in iron mine tailings. *J Environ Manage* 264:110468. https://doi.org/10.1016/j.jenvman.2020.110468

Fischer RA, Connor DJ (2018) Role of biochar in promoting circular economy in the agriculture sector. Part 1: a review of the biochar roles in soil N, P and K cycles. *Issues for cropping and agricultural science in the next 20 years. F Crop Res* 222:121–142. https://doi.org/10.1016/j.fcr.2018.03.008

Folorunso EA, Schmautz Z, Gebauer R, Mraz J (2023) The economic viability of commercial-scale hydroponics: Nigeria as a case study. *Heliyon* 9 (8): e18979. https://doi.org/10.1016/j.heliyon.2023.e18979

Fukagawa NK, Ziska LH (2019) Rice: Importance for global nutrition. *J Nutr Sci Vitaminol* 65:S2–S3. https://doi.org/10.3177/jnsv.65.S2

Fussy A, Papenbrock J (2022) An overview of soil and soilless cultivation techniques—chances, challenges and the neglected question of sustainability. *Plants* 11 (9): 1153. https://doi.org/10.3390/plants11091153

Ganguly RK, Chakraborty SK (2019) Assessment of qualitative enrichment of organic paper mill wastes through vermicomposting: humification factor and time of maturity. *Heliyon* 5 (5): e01638. https://doi.org/10.1016/j.heliyon.2019.e01638

Garg VK, Gupta R (2011) Optimization of cow dung spiked pre-consumer processing vegetable waste for vermicomposting using *Eisenia fetida*. *Ecotoxicol Environ Saf* 74 (1): 19–24. https://doi.org/10.1016/j.ecoenv.2010.09.015

Gerke J (2018) Concepts and misconceptions of humic substances as the stable part of soil organic matter: a review. *Agronomy* 8 (5): 76. https://doi.org/10.3390/agronomy8050076

Ghimire S, Dhami D, Shrestha A, Budhathoki J, Maharjan M, Kandel S, Chhetri B Poudel (2023) Effectiveness of different combinations of urea and vermicompost on yield of bitter gourd (*Momordica charantia). Heliyon* 9 (8): 1–9. https://doi.org/10.1016/j.heliyon.2023.e18663

Gillani SA, Abbasi R, Martinez P, Ahmad R (2022) Comparison of energy-use efficiency for lettuce plantation under nutrient film technique and deep-water culture hydroponic systems. *Procedia Comput Sci* 217:11–19. https://doi.org/10.1016/j.procs.2022.12.197

Goswami L, Nath A, Sutradhar S, Sundar S, Kalamdhad A, Vellingiri K, Kim K (2017) Application of drum compost and vermicompost to improve soil health, growth, and yield parameters for tomato and cabbage plants. *J Environ Manage* 200:243–253. https://doi.org/10.1016/j.jenvman.2017.05.073

Gumisiriza MS, Ndakidemi P, Nalunga A, Mbega ER (2022) Building sustainable societies through vertical soilless farming: a cost-effectiveness analysis on a small-scale non-greenhouse hydroponic system. *Sustain Cities Soc* 83:103923. https://doi.org/10.1016/j.scs.2022.103923

Gupta R, Yadav A, Garg VK (2014) Influence of vermicompost application in potting media on growth and flowering of marigold crop. *Int J Recycl Org Waste Agricul* 3 (1): 1–7. https://doi.org/10.1007/s40093-014-0047-1

Haghighi M, Barzegar MR, Silva JAT da (2016) The effect of municipal solid waste compost, peat, perlite and vermicompost on tomato (*Lycopersicum esculentum* L.) growth and yield in a hydroponic system. *Int J Recycl Org Waste Agricul* 5 (3): 231–242. https://doi.org/10.1007/s40093-016-0133-7

Huang K, Li F, Wei Y, Fu X, Chen X (2014) Effects of earthworms on physicochemical properties and microbial profiles during vermicomposting of fresh fruit and vegetable wastes. *Bioresour Technol* 170:45–52. https://doi.org/10.1016/j.biortech.2014.07.058

Huang K, Xia H, Cui G, Li F (2017) Effects of earthworms on nitrification and ammonia oxidizers in vermicomposting systems for recycling of fruit and vegetable wastes. *Sci Total Environ* 578:337–345. https://doi.org/10.1016/j.scitotenv.2016.10.172

Hussain N, Abbasi T, Abbasi SA (2017) Enhancement in the productivity of ladies finger (*Abelmoschus esculentus*) with concomitant pest control by the vermicompost of the weed Salvinia (*Salvinia molesta*, Mitchell). *Int J Recycl Org Waste Agricul* 6 (4): 335–343. https://doi.org/10.1007/s40093-017-0181-7

Jara-Samaniego J, Perez-Murcia MD, Bustamante MA, Paredes C, Espinosa AP, Gavilanes-Tera I, Lopez M, Marhuenda-Egea FC, Brito H, Moral R (2017) Development of organic fertilizers from food market waste and urban gardening by composting in Ecuador. *PLoS ONE* 12 (7): e0181621. https://doi.org/10.1109/WSC.2017.8248173

Jensen M, Elavarasan G, Balamurugan A, Dhanusiya B, Freedon D (2022) Hydroponic farming – a state of art for the future agriculture. *Mater Today Proc* 68:2163–2166. https://doi.org/10.1016/j.matpr.2022.08.416

Jiang X, Lu C, Hu R, Shi W, Zhou L, Wen P, Jiang Y, Lo YM (2023) Nutritional and microbiological effects of vermicompost tea in hydroponic cultivation of maple peas (*Pisum sativum var. arvense* L.). *Food Sci Nutr* 11 (6): 3184–3202. https://doi.org/10.1002/fsn3.3299

Joshi R, Singh J, Vig AP (2015) Vermicompost as an effective organic fertilizer and biocontrol agent: Effect on growth, yield and quality of plants. *Rev Environ Sci Biotechnol* 14 (1): 137–159. https://doi.org/10.1007/s11157-014-9347-1

Jouhara H, Czajczynska D, Ghazal H, Krzyzynska R, Anguilano LAJ (2017) Municipal waste management system for domestic use. *Energy* 139:485–506. https://doi.org/10.1016/j.energy.2017.07.162

Karmegam N, Jayakumar M, Govarthanan M, Kumar P, Ravindran B, Biruntha M (2021) Precomposting and green manure amendment for effective vermitransformation of hazardous coir industrial waste into enriched vermicompost. *Bioresour Technol* 319:124136. https://doi.org/10.1016/j.biortech.2020.124136

Kaur A, Singh J, Vig AP, Dhaliwal SS, Rup PJ (2010) Cocomposting with and without *Eisenia fetida* for conversion of toxic paper mill sludge to a soil conditioner. *Bioresour Technol* 101 (21): 8192–8198. https://doi.org/10.1016/J.BIORTECH.2010.05.041

Kauser H, Khwairakpam M (2022) Organic waste management by two-stage composting process to decrease the time required for vermicomposting. *Environ Technol Innov* 25:102193. https://doi.org/10.1016/j.eti.2021.102193

Kennard N, Stirling R, Prashar A, Lopez-Capel E (2020) Evaluation of recycled materials as hydroponic growing media. *Agronomy* 10 (8): 1092. https://doi.org/10.3390/agronomy10081092

Khan A, Ishaq F (2011) Chemical nutrient analysis of different composts (Vermicompost and Pitcompost) and their effect on the growth of a vegetative crop *Pisum sativum*. *Asian J Plant Sci Res* 1 (1): 116–130.

Khan S, Purohit A, Vadsaria N (2020) Hydroponics: Current and future state of the art in farming. *J Plant Nutr* 44:1–24. https://doi.org/10.1080/01904167.2020.1860217

Khatua C, Sengupta S, Balla V Krishna, Kundu B, Chakraborti A, Tripathi S (2018) Dynamics of organic matter decomposition during vermicomposting of banana stem waste using *Eisenia fetida*. *Waste Manag* 79:289–295. https://doi.org/10.1016/J.WASMAN.2018.07.043

Kumar N, Chhokar RS, Meena RP, Kharub AS, Gill SC, Tripathi SC, Gupta OP, et al. (2022) Challenges and opportunities in productivity and sustainability of rice cultivation system: a critical review in Indian perspective. *Cereal Res Commun* 50 (4): 573–601. https://doi.org/10.1007/s42976-021-00214-5

Kumlu M, Beksari A, Eroldo OT, Asuman HY, Sar M, Enes K, Turchini MG (2018) DHA enrichment of the red earthworm *Eisenia fetida* for improving its potential as dietary source for aquaculture. *Aquaculture* 496:10–18. https://doi.org/10.1016/j.aquaculture.2018.07.005

Lalander CH, Komakech AJ, Vinneras B (2015) Vermicomposting as manure management strategy for urban small-holder animal farms-Kampala case study. *Waste Manag* 39:96–103. https://doi.org/10.1016/j.wasman.2015.02.009

Laribi B, Annabi HA, Bettaieb T (2023) Effects of *Ulva intestinalis* Linnaeus seaweed liquid extract on plant growth, photosynthetic performance and water status of two hydroponically grown *Lamiaceae* species: Peppermint (*Mentha piperita* L.) and purple basil (*Ocimum basilicum var. purpurasce* Benth). *South African J Bot* 58:63–72. https://doi.org/10.1016/j.sajb.2023.04.049

Lei C, Engeseth NJ (2021) Comparison of growth characteristics, functional qualities, and texture of hydroponically grown and soil-grown lettuce. *LWT* 150:111931. https://doi.org/10.1016/j.lwt.2021.111931

Li G, Tao L, Li X, Peng L, Song C, Dai L, Wu Y, Xie L (2018) Design and performance of a novel rice hydroponic biofilter in a pond-scale aquaponic recirculating system. *Ecol Eng* 125:1–10. https://doi.org/10.1016/j.ecoleng.2018.10.001

Li W, Bhat SA, Li J, Cui G, Wei Y, Yamada T, Li F (2020) Effect of excess activated sludge on vermicomposting of fruit and vegetable waste by using novel vermireactor *Bioresour Technol* 302:122816. https://doi.org/10.1016/j.biortech.2020.122816

Li X, Zhou J, Tang Y, Li Y, Jin Z, Kong H, Zhao M, Zheng X, Bei K (2022) A hydroponic vertical greening system for disposal and utilization of pre-treated Blackwater: optimization of the operating conditions. *Ecol Eng* 183:106739. https://doi.org/10.1016/j.ecoleng.2022.106739

Liegui GS, Cognet S, Djumyom GVW, Atabong PA, Noutadié JPT, Chamedjeu RR, Temegne CN, Kengne IMN (2021) An effective organic waste recycling through vermicomposting technology for sustainable agriculture in tropics. *Int J Recycl Org Waste Agricul* 10 (3): 203–214. https://doi.org/10.30486/ijrowa.2021.1894997.1080

Liu J, Lu Z, Yang J, Xing M, Yu F, Guo M (2012) Bioresource technology effect of earthworms on the performance and microbial communities of excess sludge treatment process in vermifilter. *Bioresour Technol* 117:214–221. https://doi.org/10.1016/j.biortech.2012.04.096

Liu Y, Li X, Cai K, Cai L, Lu N, Shi J (2015) Identification of benzoic acid and 3-phenylpropanoic acid in tobacco root exudates and their role in the growth of rhizosphere microorganisms. *Appl Soil Ecol* 93:78–87. https://doi.org/10.1016/j.apsoil.2015.04.009

Majid M, Khan JN (2021) Evaluation of hydroponic systems for the cultivation of Lettuce (*Lactuca sativa L.,var. Longifolia*) and comparison with protected soil-based cultivation. *Agric Water Manag* 245:106572. https://doi.org/10.1016/j.agwat.2020.106572

Malinska K, Golanska M, Caceres R, Rorat A, Weisser P, Slezak E (2017) Biochar amendment for integrated composting and vermicomposting of sewage sludge – the effect of biochar on the activity of *Eisenia fetida* and the obtained vermicompost. *Bioresour Technol* 225:206–214. https://doi.org/10.1016/j.biortech.2016.11.049

Mallareddy M, Thirumalaikumar R, Balasubramanian P, Naseeruddin R, Nithya N, Mariadoss A, Eazhilkrishna N, et al. (2023) Maximizing water use efficiency in rice farming: a comprehensive review of innovative irrigation management technologies *Water (Switzerland)* 15 (10): 1802. https://doi.org/10.3390/w15101802

Mamun A Al, Naznen F, Jingzu G, Yang Q (2023) Predicting the intention and adoption of hydroponic farming among Chinese urbanites. *Heliyon* 9 (3): e14420. https://doi.org/10.1016/j.heliyon.2023.e14420

Mancini E, Arzoumanidis I, Raggi A (2019) Evaluation of potential environmental impacts related to two organic waste treatment options in Italy. *J Clean Prod* 214:927–938. https://doi.org/10.1016/j.jclepro.2018.12.321

Manh VH, Wang CH (2013) Vermicompost as an important component in substrate: effects on seedling quality and growth of Muskmelon (*Cucumis Melo* L.). *APCBEE Procedia* 8:32–40. https://doi.org/10.1016/j.apcbee.2014.01.076

Martinez-Mate MA, Martin-Gorriz B, Martínez-Alvarez V, Soto-García M, Maestre-Valero JF (2018) Hydroponic system and desalinated seawater as an alternative farm-productive proposal in water scarcity areas: energy and greenhouse gas emissions analysis of lettuce production in southeast Spain. *J Clean Prod* 172:1298–1310. https://doi.org/10.1016/j.jclepro.2017.10.275

Meselmani MAA (2022) Nutrient solution for hydroponics. In: recent research and advances in soilless culture. IntechOpen. Rijeka. https://doi.org/10.5772/intechopen.101604

Mohidem NA, Hashim N, Shamsudin R, Man HC (2022) Rice for food security: revisiting its production, diversity, rice milling process and nutrient content. *Agriculture* 12 (6): 741. https://doi.org/10.3390/agriculture12060741

Mondal T, Datta JK, Mondal NK (2017) Chemical fertilizer in conjunction with biofertilizer and vermicompost induced changes in morpho-physiological and bio-chemical traits of mustard crop. *J Saudi Soc Agric Sci* 16 (2): 135–144. https://doi.org/10.1016/j.jssas.2015.05.001

Mousavi SA, Faraji M, Janjani H (2017) Recycling of three different types of rural wastes employing vermicomposting technology by *Eisenia fetida* at low temperature. *Glob Nest J* 19 (4): 601–606. https://doi.org/10.30955/gnj.002259

Muktamar Z, Sudjatmiko S, Chozin M, Setyowati N, Fahrurrozi (2017) Sweet corn performance and its major nutrient uptake following application of vermicompost supplemented with liquid organic fertilizer *Int J Adv Sci Eng Inf Technol* 7 (2): 602–608. https://doi.org/10.18517/ijaseit.7.2.1112

Ng SW, Rosli NS Mohd, Razali RB Raja, Abdullah R, Yaacob JS (2023) From waste to wealth: Significant potential of oil palm kernel-derived biochar as alternative substrate for production of red lettuce (*Lactuca sativa* L.) with high bioactive metabolites content in NFT hydroponic system. *Sustain Chem Pharm* 34:101167. https://doi.org/10.1016/j.scp.2023.101167

Ngo PT, Rumpel C, Doan TT, Jouquet P (2012) The effect of earthworms on carbon storage and soil organic matter composition in tropical soil amended with compost and vermicompost. *Soil Biol Biochem* 50:214–220. https://doi.org/10.1016/j.soilbio.2012.02.037

Ngo PT, Rumpel C, Ngo QA, Alexis M, Vargas GV, Gil M Mora, Dela L, Dang DK, Jouquet P (2013) Biological and chemical reactivity and phosphorus forms of buffalo manure compost, vermicompost and their mixture with biochar. *Bioresour Technol* 148:401–407. https://doi.org/10.1016/j.biortech.2013.08.098

Nguyen NT, Mcinturf SA, Mendoza-cozatl DG (2016) Hydroponics: a versatile system to study nutrient allocation and plant responses to nutrient availability and exposure to toxic elements. *J Vis Exp* 8:1–9. https://doi.org/10.3791/54317

Nigussie A, Bruun S, Neergaard A de, Kuyper TW (2017) Earthworms change the quantity and composition of dissolved organic carbon and reduce greenhouse gas emissions during composting. *Waste Manag* 62:43–51. https://doi.org/10.1016/j.wasman.2017.02.009

Nigussie A, Kuyper TW, Bruun S, Neergaard A de (2016) Vermicomposting as a technology for reducing nitrogen losses and greenhouse gas emissions from small-scale composting. *J Clean Prod* 139:429–439. https://doi.org/10.1016/j.jclepro.2016.08.058

Oliveira TJSS, Oliveira CE, da S, Jalal A, Gato TMB, Rauf K, Moreira V, et al. (2023) Inoculation reduces nitrate accumulation and increases growth and nutrient accumulation in hydroponic arugula. *Sci Hortic* 320:112213. https://doi.org/10.1016/j.scienta.2023.112213

Parthasarathi K, Balamurugan M, Prashija KV, Jayanthi L, Ameer BS (2016) Potential of *Perionyx excavatus* (Perrier) in lignocellulosic solid waste management and quality vermifertilizer production for soil health. *Int J Recycl Org Waste Agricul* 5 (1): 65–86. https://doi.org/10.1007/s40093-016-0118-6

Parthasarathy P, Narayanan SK (2014) Effect of hydrothermal carbonization reaction parameters on. *Environmental Progress & Sustainable Energy* 33 (3): 676–680. https://doi.org/10.1002/ep.12100

Pathma J, Sakthivel N (2016) Microbial diversity of vermicompost bacteria that exhibit useful agricultural traits and waste management potential. *SpringerPlus* 1 (1): 1–19. https://doi.org/10.1007/s40093-016-0118-6

Pattillo D Allen, Hager JV, Cline DJ, Roy LA, Hanson TR (2022) System design and production practices of aquaponic stakeholders. *PLOS ONE* 17 (4): e0266475. https://doi.org/10.1371/journal.pone.0266475

Pattnaik S, Reddy MV (2009) Nutrient status of vermicompost of urban green waste processed by three earthworm species - *Eisenia fetida, Eudrilus eugeniae*, and *Perionyx excavatus*. *Appl Environ Soil Sci* 2010:1–13. https://doi.org/10.1155/2010/967526

Pomoni DI, Koukou MK, Vrachopoulos MG, Vasiliadis L (2023) A review of hydroponics and conventional agriculture based on energy and water consumption, environmental impact, and land use. *Energies* 16 (4): 1690. https://doi.org/10.3390/en16041690

Pramanik P, Ghosh GK, Chung YR (2010) Changes in nutrient content, enzymatic activities and microbial properties of lateritic soil due to application of different vermicomposts: a comparative study of ergosterol and chitin to determine fungal biomass in soil. *Soil Use Manag* 26 (4): 508–515. https://doi.org/10.1111/j.1475-2743.2010.00304.x

Preite L, Solari F, Vignali G (2023) Technologies to optimize the water consumption in agriculture: a systematic review. *Sustainability* 15 (5975): 28. https://doi.org/10.3390/su15075975

Putra PA, Yuliando H (2015) Soilless culture system to support water use efficiency and product quality: a Review. *Agric Sci Procedia* 3:283–288. https://doi.org/10.1016/j.aaspro.2015.01.054

Rajkhowa DJ, Sarma AK, Bhattacharyya PN, Mahanta K (2019) Bioconversion of agricultural waste and its efficient utilization in the hilly ecosystem of Northeast India. *Int J Recycl Org Waste Agricul* 8:11–20. https://doi.org/10.1007/s40093-019-0253-y

Ramnarain YI, Ansari AA, Ori L (2019) Vermicomposting of different organic materials using the epigeic earthworm *Eisenia foetida*. *Int J Recycl Org Waste Agricul* 8 (1): 23–36. https://doi.org/10.1007/s40093-018-0225-7

Ravindran B, Lee SR, Chang SW, Nguyen DD, Chung WJ, Balasubramanian B, Mupambwa HA, Arasu MV, Al-Dhabi NA, Sekaran G (2019) Positive effects of compost and vermicompost produced from tannery waste-animal fleshing on the growth and yield of commercial crop-tomato (*Lycopersicon esculentum* L.) plant. *J Environ Manage* 234:154–158. https://doi.org/10.1016/j.jenvman.2018.12.100

Ravindran B, Mnkeni PNS (2016) Bio-optimization of the carbon-to-nitrogen ratio for efficient vermicomposting of chicken manure and waste paper using *Eisenia fetida*. *Environ Sci Pollut Res* 23 (17): 16965–16976. https://doi.org/10.1007/s11356-016-6873-0

Raza ST, Zhu B, Yao Z, Wu J, Chen Z, Ali Z, Tang JT (2023) Impacts of vermicompost application on crop yield, ammonia volatilization and greenhouse gases emission on upland in Southwest China. *Sci Total Environ* 860:160479. https://doi.org/10.1016/j.scitotenv.2022.160479

Rehman S, Castro F De, Aprile A, Benedetti M, Fanizzi FP (2023) Vermicompost: enhancing plant growth and combating abiotic and biotic stress. *Agronomy* 13 (4): 1134. https://doi.org/10.3390/agronomy13041134

Rekha GS, Kaleena PK, Elumalai D, Srikumaran MP, Maheswari VN (2018) Effects of vermicompost and plant growth enhancers on the exo-morphological features of *Capsicum annum* (Linn.) Hepper. *Int J Recycl Org Waste Agricul* 7 (1): 83–88. https://doi.org/10.1007/s40093-017-0191-5

Rini J, Deepthi MP, Saminathan K, Narendhirakannan RT, Karmegam N, Kathireswari P (2020) Nutrient recovery and vermicompost production from livestock solid wastes with epigeic earthworms. *Bioresour Technol* 313:123690. https://doi.org/10.1016/j.biortech.2020.123690

Sattolo TMS, Mariano E, Boschiero BN, Otto R (2017) Effects of vermicompost and plant growth enhancers on the exo-morphological features of *Capsicum annum* (Linn.) Hepper. *Agric Ecosyst Environ* 247:63–74. https://doi.org/10.1016/j.agee.2017.06.005

Savvas D, Gianquinto G, Tuzel Y, Gruda N (2013) Soilless culture. In: Good agricultural practices for greenhouse vegetable crops-Principles for Mediterranean climate areas. Food / Agriculture Organization of The United Nations. Rome.

Savvas D, Gruda N (2018) Application of soilless culture technologies in the modern greenhouse industry-a review. *Eur J Hortic Sci* 83 (5): 280–293. https://doi.org/10.17660/eJHS.2018/83.5.2

Scaglia B, Nunes RR, Rezende MOO, Tambone F, Adani F (2016) Investigating organic molecules responsible of auxin-like activity of humic acid fraction extracted from vermicompost. *Sci Total Environ* 562:289–295. https://doi.org/10.1016/j.scitotenv.2016.03.212

Sharma D, Prasad R, Patel B, Parashar CK (2022) Biotransformation of sludges from dairy and sugarcane industries through vermicomposting using the epigeic earthworm *Eisenia fetida*. *Int J Recycl Org Waste Agricul* 11 (2): 165–175. https://doi.org/10.30486/IJROWA.2021.1922034.1196

Sharma N, Acharya S, Kumar K, Singh N, Chaurasia OP (2018) Hydroponics as an advanced technique for vegetable production: an overview. *J Soil Water Conserv* 17 (4): 364. https://doi.org/10.5958/2455-7145.2018.00056.5

Singh A, Singh GS (2017) Vermicomposting: A sustainable tool for environmental equilibria. *Environmental Quality Management* 27 (1): 23–40. https://doi.org/10.1002/tqem.21509

Singh J, Kaur A, Vig A, Rup PJ (2010) Role of Eisenia fetida in rapid recycling of nutrients from bio sludge of beverage industry. *Ecotoxicol Environ Saf* 73 (3): 430–435. https://doi.org/10.1016/J.ECOENV.2009.08.019

Singh RP, Singh P, Araujo ASF, Hakimi IM, Sulaiman O (2011) Management of urban solid waste: Vermicomposting a sustainable option. *Resour Conserv Recycl* 55 (7): 719–729. https://doi.org/10.1016/J.RESCONREC.2011.02.005

Singh S, Bhat SA, Singh J, Kaur R, Vig AP (2017) Earthworms converting milk processing industry sludge into biomanure. *Open Waste Manag J* 10 (1): 30–40. https://doi.org/10.2174/1876400201710010030

Soni A, Patil D, Argade K (2016) Municipal solid waste management. *Procedia Environ Sci* 35:119–126. https://doi.org/10.1016/j.proenv.2016.07.057

Soobhany N, Gunasee S, Rago YP, Joyram H, Raghoo P, Mohee R, Garg VK (2017) Spectroscopic, thermogravimetric and structural characterization analyses for comparing municipal solid waste composts and vermicomposts stability and maturity. *Bioresour Technol* 236:11–19. https://doi.org/10.1016/j.biortech.2017.03.161

Soobhany N, Mohee R, Garg VK (2015a) Comparative assessment of heavy metals content during the composting and vermicomposting of municipal solid waste employing *Eudrilus eugeniae*. *Waste Manag* 39:130–145. https://doi.org/10.1016/j.wasman.2015.02.003

——— (2015b) Recovery of nutrient from municipal solid waste by composting and vermicomposting using earthworm *Eudrilus eugeniae*. *J Environ Chem Eng* 3 (4): 2931–2942. https://doi.org/10.1016/j.jece.2015.10.025

Subhash KM, Rajiv P, Rajeshwari S, Venckatesh R (2015) Spectroscopic analysis of vermicompost for determination of nutritional quality. *Spectrochim Acta Part A Mol Biomol Spectrosc* 135:252–255. https://doi.org/10.1016/J.SAA.2014.07.011

Suleiman H, Rorat A, Grobelak A, Grosser A, Milczarek M, Piytycz B, Kacprzak M, Vandenbulcke F (2017) Determination of the performance of vermicomposting process applied to sewage sludge by monitoring of the compost quality and immune responses in three earthworm species: *Eisenia fetida, Eisenia andrei and Dendrobaena veneta*. *Bioresour Technol* 241:103–112. https://doi.org/10.1016/j.biortech.2017.05.104

Suthar S (2009) Vermicomposting of vegetable-market solid waste using *Eisenia fetida*: Impact of bulking material on earthworm growth and decomposition rate. *Ecol Eng* 35 (5): 914–920. https://doi.org/10.1016/j.ecoleng.2008.12.019

Syarifinnur S, Nuraini Y, Prasetya B (2022) Effect of application compost and vermicompost from market waste on soil chemical properties and plant growth. *J Degrad Min Lands Manag* 9 (2): 3379–3386. https://doi.org/10.15243/jdmlm.2022.092.3379

Syarifinnur S, Nuraini Y, Prasetya B, Handayanto E (2023) Comparing compost and vermicompost produced from market organic waste. *Int J Recycl Org waste Agricul* 12 (3): 279–289. https://doi.org/10.30486/ijrowa.2022.1944251.1368

——— (2020) Effectiveness of compost and vermicompost from market organic waste to improve soil chemical properties. *IOP Conference Series: Materials Science and Engineering* 980:012068. https://doi.org/10.1088/1757-899X/980/1/012068

Thomas P, Knox OGG, Powell JR, Sindel B (2023) The Hydroponic rockwool root microbiome: Under control or underutilised?. *Microorganisms* 11:836. https://doi.org/10.3390/microorganisms11040835

Vandam DA, Anderson T, Villiers DDe, Timmons MB (2017) Growth and tissue elemental composition response of Spinach (*Spinacia oleracea*) to hydroponic and aquaponic water quality conditions. *Horticulturae* 3:32. https://doi.org/10.3390/horticulturae3020032

Varma VS, Kalamdhad AS, Khwairkpam M (2016) Feasibility of *Eudrilus eugeniae* and *Perionyx excavatus* in vermicomposting of water hyacinth. *Ecol Eng* 94:127–135. https://doi.org/10.1016/j.ecoleng.2016.05.058

Velazquez-Gonzalez RS, Garcia AL, Ventura-Zapata E, Barceinas-Sanchez JDO, Sosa-Savedra JC (2022) A Review on hydroponics and the technologies associated for medium and small scale operations. *Agriculture* 12 (5): 1–21. https://doi.org/10.3390/agriculture12050646

Verma S, Babu A, Patel A, Kumar SS, Swayamprbha PS, Verma S, Singh J, et al. (2018) Significance of vermiwash on crop production: a review. *J Pharmacogn Phytochem* 7 (2): 297–301.

Villar I, Alves D, Perez-Diaz D, Mato S (2016) Changes in microbial dynamics during vermicomposting of fresh and composted sewage sludge. *Waste Manag* 48:409–417. https://doi.org/10.1016/j.wasman.2015.10.011

Vinci G, Ruggieri R, Ruggeri M, Prencipe SA (2023) Rice production chain: Environmental and social impact assessment-a review. *Agriculture* 13 (2): 340. https://doi.org/10.3390/agriculture13020340

Vyas P, Sharma S, Gupta J (2022) Vermicomposting with microbial amendment: implications for bioremediation of industrial and agricultural waste. *Biotechnologia* 103 (2): 203–215. https://doi.org/10.5114/bta.2022.116213

Wagner AO, Prem EM, Markt R, Kaufmann R, Illmer P (2019) Biotechnology for biofuels formation of phenylacetic acid and phenylpropionic acid under different overload conditions during mesophilic and thermophilic anaerobic digestion. *Biotechnol Biofuels* 12 (26): 1–24. https://doi.org/10.1186/s13068-019-1370-6

Wang D, Shi Q, Wang X, Wei M, Hu J, Liu J, Yang F (2010) Influence of cow manure vermicompost on the growth, metabolite contents, and antioxidant activities of Chinese cabbage (*Brassica campestris ssp. chinensis)*. *Biol Fertil Soils* 46 (7): 689–696. https://doi.org/10.1007/s00374-010-0473-9

Wang F, Wang X, Song N (2021) Biochar and vermicompost improve the soil properties and the yield and quality of cucumber (*Cucumis sativus* L.) grown in plastic shed soil continuously cropped for different years. *Agric Ecosyst Environ* 315:107425. https://doi.org/10.1016/j.agee.2021.107425

Wang QY, Zhao MR, Wang JQ, Hu BY, Chen QJ, Qin Y, Zhang GQ (2023) Effects of microbial inoculants on agronomic characters, physicochemical properties and nutritional qualities of lettuce and celery in hydroponic cultivation. *Sci Hortic* 320:112202. https://doi.org/10.1016/j.scienta.2023.112202

Wang S, Adekunle A, Raghavan V (2022) Exploring the integration of bioelectrochemical systems and hydroponics: possibilities, challenges, and innovations. *J Clean Prod* 366:132855. https://doi.org/10.1016/j.jclepro.2022.132855

Wani KA, Mamta, Rao RJ (2013) Bioconversion of garden waste, kitchen waste and cow dung into value- added products using earthworm *Eisenia fetida*. *Saudi J Biologic Sci* 20:149–154. https://doi.org/10.1016/j.sjbs.2013.01.001

Wiegmann ME, Zhao K, Hube S, Ge L, Lisak G, Wu B (2023) Integrating gravity-driven ceramic membrane filtration with hydroponic system for nutrient recovery from primary municipal wastewater. *J Environ Sci,* https://doi.org/10.1016/j.jes.2023.06.008

Wu D, Feng Y, Xue L, Liu M, Yang B, Hu F, Yang L (2019) Biochar combined with vermicompost increases crop production while reducing ammonia and nitrous oxide emissions from a paddy soil. *Pedosphere* 29 (1): 82–94. https://doi.org/10.1016/S1002-0160(18)60050-5

Xiao Z, Liu M, Jiang L, Chen X, Griffiths BS, Li H, Hu F (2016) Vermicompost increases defence against root-knot nematode (*Meloidogyne incognita*) in tomato plants. *Appl Soil Ecol* 105:177–186. https://doi.org/10.1016/j.apsoil.2016.04.003

Xu B, Wang F, Zhang Q, Lan Q, Liu C, Guo X, Cai Q, Chen Y, Wang G, Ding J (2018) Ecotoxicology and environmental safety influence of iron plaque on the uptake and accumulation of chromium by rice (*Oryza sativa* L .) seedlings: Insights from hydroponic and soil cultivation. *Ecot Envir Safet* 162:51–58. https://doi.org/10.1016/j.ecoenv.2018.06.063

Yadav P, Samadder SR (2018) A critical review of the life cycle assessment studies on solid waste management in Asian countries. *J Clean Prod* 185:492–515. https://doi.org/10.1016/j.jclepro.2018.02.298

Yadav S, Parveen K (2023) Influence of vermicompost derived from rice straw, neem leaves, and cow dung on plant growth parameters of *Solanum lycopersicum* (Tomato). *Indian J Sci Technol* 16:989–997. https://doi.org/10.17485/IJST/v16i13.2307

Yang ZY, Wang XJ, Cao Y, Dong QE, Tong JY, Mau MH (2023) Vermicomposting of *Pleurotus eryngii* spent mushroom substrates and the possible mechanisms of vermicompost suppressing nematode disease caused by *Meloidogyne incognita*. *Heliyon* 9 (4): 1–11. https://doi.org/10.1016/j.heliyon.2023.e15111

Yasmin N, Jamuda M, Panda AK, Samal K, Nayak JK (2022) Emission of greenhouse gases (GHGs) during composting and vermicomposting: measurement, mitigation, and perspectives. *Energ Nex* 7:100092. https://doi.org/10.1016/j.nexus.2022.100092

Yuvaraj A, Thangaraj R, Ravindran B, Chang SW, Karmegam N (2021) Centrality of cattle solid wastes in vermicomposting technology – a cleaner resource recovery and biowaste recycling option for agricultural and environmental sustainability. *Environ Pollut* 268:115688. https://doi.org/10.1016/j.envpol.2020.115688

Zeljkovic S Cavar, Aucique-Perez CE, Stefelova N, Diego N De (2022) Optimizing growing conditions for hydroponic farming of selected medicinal and aromatic plants. *Food Chem* 375:131845. https://doi.org/0.1016/j.foodchem.2021.131845

Zhang H, Asutosh A, Hu W (2018) Implementing vertical farming at university scale to promote sustainable communities: a feasibility analysis. *Sustainability* 10 (12): 4429. https://doi.org/10.3390/su10124429

Zulhipri Z, Erdawati E, Purwanto A (2021) Development of technology vermicompost production for the coffee plant Industry. *J Phys: Conference Series* 1876:012020. https://doi.org/10.1088/1742-6596/1876/1/012020

Zziwa A, Jjagwe J, Kizito S, Kabenge I, Komakech AJ, Kayondo H (2021) Nutrient recovery from pineapple waste through controlled batch and continuous vermicomposting systems. *J Environ Manage* 279:111784. https://doi.org/10.1016/j.jenvman.2020.111784