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Integrated Hydroponics-Microbial Electrochemical Technology (iHydroMET) is promising for Olericulture along with domestic wastewater management

Ravi K. Yadav, Siddharth, Sunil A. Patil

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Highlights

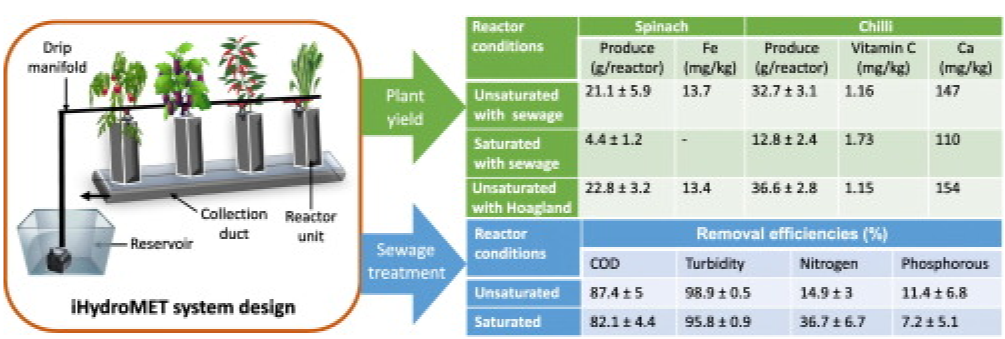
- iHydroMET design is suitable for Olericulture and domestic wastewater treatment.
- Water unsaturated and saturated reactors favor organics and N removal, respectively.
- Spinach and Chilli yields were~21 and 33 g/plant in unsaturated reactor conditions.

- Wastewater supports substantial vegetative growth but limited reproductive growth.
- Spinach or similar leafy greens can be grown readily in sewage-treating iHydroMET.

Abstract

Integrated Hydroponics-Microbial Electrochemical Technology (iHydroMET) has emerged as a promising decentralized option for efficient domestic wastewater management. Considering its intended application at households and the aim of offering useful plant cultivation options to the end users, this study focused on testing the Olericulture feasibility in sewage-treating iHydroMET design in wastewater-saturated (SW) and unsaturated (UW) reactor conditions. The systems operated outdoors in drip-hydroponics batch recirculation mode achieved efficient COD (87.4±5% and 82.1±4.4%) and turbidity (98.8±0.5% and 95.8±0.9%) but low total nitrogen (14.9±3% and 36.7±6.7%) removal in UW and SW conditions, respectively. Spinach and Chilli yield in UW and SW conditions were 21.1±5.9 and 4.4±1.2 g/plant and 32.7±3.1 and 12.8±2.4 g/plant, respectively. Chilli quality was compromised marginally in wastewater; however, Spinach yield was similar to that obtained in control with nutrient-rich Hoagland solution. These findings validate iHydroMET's benefits for growing leafy vegetables besides wastewater management at households.

Graphical abstract



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Introduction

Sustainable management of resources such as water, energy, and food is imperative to meet the increasing demand for these life-supporting essentials of the burgeoning human population. As per the latest report of the United Nations Educational, Scientific and Cultural Organization (UNESCO, 2021), around 2.2 billion, 789 million, and 2 billion people worldwide suffer due to a lack of safe drinking water, reliable electricity supply, and food security, respectively. This situation will worsen in the future if preventive and circumventing measures are not practiced, as highlighted in recent studies (de Amorim et al., 2018; Pastor et al., 2019). Strategies such as transitioning to renewable energy sources, technological advancement in energy management, and increasing the global energy networks like International Solar Alliance in the last decade have been impactful measures in ensuring global energy security (Gielen et al., 2019; Sayed et al., 2021). However, the challenge of water security and related food security is still persistent. According to the latest report of the Food and Agriculture Organization (FAO, 2020), nearly 3.2 billion and 1.2 billion people live in agricultural areas with high water shortages and severely water-constrained agricultural areas, respectively. Overusing freshwater in agriculture, about 72% of all water withdrawals as per the United Nations World Water Development Report 2021 (United Nations, 2021), is the primary cause of the water-stressed situation. Hence, traditional agriculture practices are not foreseen to be capable of feeding our world sustainably.

Drip irrigation and soil amendment using hydrogels (i.e., polymeric hydrophilic materials with high water holding capacity) approaches are some of the key interventions that emerged in the late 20th century to minimize the water requirement of the agriculture sector (Ahmed, 2015; Camp, 1998; Kaur et al., 2023). Another major intervention, Hydroponics, a plant cultivation technique in an aqueous nutrient medium, has emerged as a remarkable advancement in agriculture to overcome both land and freshwater shortage issues. However, the use of costly synthetic nutrient media in hydroponics cannot be considered a sustainable practice. It creates a need to explore alternative or unconventional nutrient media sources. On the other side, wastewater, which was long regarded as environmental waste, is now seen as an unconventional but promising sustainable source of water, energy, nutrients, and other recoverable by-products, as highlighted in the United Nations World Water Development Report (UNWWAP, 2017) (van der Hoek et al., 2016). In this context, wastewater hydroponics has emerged as a promising approach for horticulture plant cultivation and partial wastewater treatment (Cifuentes-Torres et al., 2021; Richa et al., 2020). This integration strategy helps not only to reduce the costs and energy input required for wastewater treatment but also cut off the cost of synthetic nutrient media by replacing it with wastewater, resulting in a win-win situation. It has been tested with partially treated, fully treated, and untreated wastewater as a source of nutrients and irrigation (Cifuentes-Torres et al., 2021; Richa et al., 2020; Worku et al., 2018; Yadav et al., 2020). Magwaza et al. summarized different types of hydroponic system designs, wastewater sources, substrates, and plants or crops tested in wastewater-based hydroponics (Magwaza et al., 2020a). Plants can uptake nutrients, toxic metals, and emerging contaminants (Cifuentes-Torres et al., 2021). Hence, the presence of trace metals and emerging contaminants in wastewater can establish the risk of bioaccumulation on human health (Prazeres et al., 2017). Domestic or residential wastewater typically does not contain toxic or heavy metals, banishing the possibility of health concerns and making it a potential wastewater source. The wastewater hydroponics approach can be a crucial asset to sustainable development plans by managing water and wastewater resources and generating alternate food production options. Hence, considerable efforts are made to make this integration more proficient in recovering resources like energy, water, and nutrients from wastewater.

Intending to provide a sustainable and economically feasible technological solution for domestic wastewater management and resource recovery at the household level, we reported a novel advancement in wastewater hydroponics by integrating it with an emerging microbial fuel cell (MFC), which is a type of microbial electrochemical technology (Yadav et al., 2020). The integrated Hydroponics-Microbial Electrochemical Technology (iHydroMET) is efficient for domestic wastewater treatment and recovery of reusable quality reclaimed water, plant biomass, and low amount of electricity (Yadav et al., 2023). Further optimization studies on the reactor design, bed matrix, and cathode placement improved the system performance considerably and validated its potential for efficient wastewater management at the point sources (Yadav et al., 2022). Considering its intended application at households, we tested the cultivation of aesthetic plants, namely *Cymbopogon citratus* (Lemongrass) and *Catharanthus roseus* (*Vinca rosea*) in earlier studies (Yadav et al., 2020, Yadav et al., 2022). The aim of offering useful plant options to the end users of technology led to the feasibility assessment of Olericulture plants cultivation under different conditions in the iHydroMET system design in this study. It focused mainly on testing the feasibility of cultivating different Olericulture plants, namely, Spinach, Chilli, Tomato, and Brinjal, in the iHydroMET system design and under different operation conditions for the sustainable management of resources like water, nutrients, and food at a household level. While monitoring plant growth and yield of selected plants, the domestic wastewater treatment performance was also assessed in water unsaturated and saturated reactor units of iHydroMET systems. The analysis of key nutritional elements besides the contamination of *E. coli* in the harvested Olericulture yield was finally performed to check the overall quality of the plant produce.

Section snippets

Domestic wastewater as a source of nutrient solution

The primary clarified domestic wastewater collected daily in the morning (around 9:30AM) from a sewage treatment plant (residential area of the IISER Mohali campus) was used throughout the study. No heavy or toxic metal contamination was found in the influent domestic wastewater (Supplementary materials). The Hoagland synthetic nutrient solution was used as a positive control in the study to compare the plant growth and yield with real domestic wastewater conditions. The calculations followed…

Wastewater treatment performance

The physicochemical characteristics of the domestic wastewater influent used during the whole study were: 7.3±0.1 pH, 3.1±0.3mg/L Dissolved oxygen, 0.9±0.1 mS Conductivity, 122±17.5 FNU Turbidity, 138±20mg/L BOD, 202±31mg/L COD, 38.2±2.5mg/L TN, 4.6±0.3mg/L TP, 1.2±0.4mg/L Nitrate-N, 0.5±0.4mg/L Nitrite-N, and 26.2±3.2mg/L Ammoniacal-N. The wastewater treatment performance in saturated and unsaturated reactor units of iHydroMET systems was compared based on…

Conclusion

This study confirms the applicability of the iHydroMET system design for Olericulture along with domestic wastewater treatment. The wastewater unsaturated and saturated reactor conditions in the systems favor efficient organics and nitrogen removal, respectively. Sufficient macronutrient availability ensures substantial vegetative growth, but the limited availability of micronutrients results in poor reproductive growth of tested plants in wastewater conditions. Spinach grew well among tested…

CRediT authorship contribution statement

Ravi K. Yadav: Conceptualization, Investigation, Methodology, Data curation, Formal analysis, Writing – original draft. **Siddharth:** Investigation, Methodology, Formal analysis. **Sunil A. Patil:** Conceptualization, Methodology, Writing – review & editing, Funding acquisition, Project administration.…

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Dr. Sunil A. Patil reports financial support was provided by Department of Science and Technology, India.…

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