Advancing Sustainable Controlled Environment Agriculture: Reuse of Septic Tank Effluent for Hydroponic

Mehedi Hasan & Nusrat Jahan

Department of Civil Engineering, Khulna University of Engineering & Technology (KUET), Khulna, Bangladesh.

DOI: https://doi.org/10.51244/IJRSI.2026.1309000299

Received: 08 October 2026; Accepted: 13 October 2026; Published: 26 October 2026

ABSTRACT

The increasing demand for sustainable food production and effective wastewater management has created opportunities for integrating resource recovery with controlled environment agriculture (CEA). Septic tank effluent contains high concentrations of nitrogen and phosphorus that could potentially serve as alternative nutrient sources for hydroponic crop production. However, elevated ammonium concentrations and other water quality limitations restrict its direct application. This study investigated the effectiveness of microalgae-based pretreatment of septic tank effluent for potential hydroponic reuse under three cultivation conditions: aeration, no aeration, and surface aeration. Six low-cost photobioreactors were constructed using locally available 8-L transparent water bottles and inoculated with a mixed microalgal culture dominated by Scenedesmus sp. and Chlorella sp. Microalgal growth, turbidity, pH, nutrient removal, and effluent quality were evaluated during a 10-day cultivation period. Surface aeration achieved the highest microalgal biomass concentration of approximately 4.7 g/L on Day 7, compared with 3.7 and 3.3 g/L under conventional aeration and no aeration, respectively. Conventional aeration demonstrated the highest ammonia-nitrogen removal efficiency (77%), reducing the initial concentration from 153.7 to 34.7 mg/L, followed by surface aeration (70%) and no aeration (43%). Surface aeration achieved the greatest total phosphorus reduction (approximately 79%) and the lowest final biochemical oxygen demand (7.2 mg/L). Although conventional aeration provided superior ammonia removal, its elevated final pH (9.31) may limit direct hydroponic application. Surface aeration produced a comparatively lower pH (8.45) and favorable overall effluent characteristics, suggesting its potential as a pretreatment approach. However, further pH adjustment, nutrient balancing, and water quality assessment are necessary before hydroponic reuse. These findings demonstrate the potential of integrating microalgae-based wastewater treatment with CEA to support nutrient recovery, wastewater reuse, and more resource-efficient food production.

Keywords: CEA, microalgae, hydroponic, wastewater, Septic effluent

INTRODUCTION

As the global population grows, food demand continues to increase. At the same time, traditional open-field agriculture is threatened by soil degradation, groundwater depletion, and more frequent extreme weather events (Dohlman et al., 2024). The FAO estimates that 75 billion tons of soil are lost annually worldwide, while major aquifers are being depleted. Given the challenges of land degradation, water scarcity, and climate change, the question becomes: how can we produce more food with fewer resources? One promising approach is Controlled Environment Agriculture (CEA).

CEA enables crop production in highly controlled environments such as greenhouses, allowing higher productivity on limited land while reducing dependence on weather conditions (Boyd et al., 2025). Compared with traditional open-field agriculture, CEA can improve resource-use efficiency through precise management of water, nutrients, and climate (Ahamed et al., 2019; Maureira et al., 2022). This helps conserve water, reduce food losses, and improve food system resilience under changing climate conditions.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue IX September 2026

Although CEA offers many advantages, its energy-intensive operations can pose challenges to achieving a low-carbon economy. Climate control, irrigation, nutrient management, and supplemental lighting can require substantial energy inputs, resulting in a relatively high carbon footprint compared with conventional agricultural systems (Soussi et al., 2025). Meanwhile, septic tank effluent may contain elevated nutrient concentrations and, without adequate treatment, may fail to meet regulatory discharge standards. Direct discharge into natural water bodies can contribute to eutrophication, while infiltration through soakage pits can transport nutrients into the subsurface environment, leading to nutrient accumulation in unsaturated soils or groundwater and potentially threatening ecological integrity and human health (Hasan et al., 2021). In this context, the present study explores the use of septic tank effluent as an alternative nutrient source for CEA. This approach has the potential to provide a dual benefit by recovering nutrients for crop production while addressing nutrient management challenges associated with septic effluent.

However, the direct use of septic tank effluent in CEA may be limited by its high ammonium concentration, which can adversely affect plant growth. Therefore, pretreatment is necessary before its application in hydroponic systems. Cultivating microalgae in septic effluent offers a potential pretreatment strategy for nutrient removal, as microalgae assimilate inorganic nitrogen and phosphorus for their growth (Khalekuzzaman et al., 2019). Furthermore, the resulting microalgal biomass can serve as a third-generation feedstock for biofuel production, providing an additional opportunity for resource recovery (Rawat et al., 2011).

To the best of the authors' knowledge, limited research has investigated the suitability of treated septic tank effluent for use in hydroponic systems. Therefore, this study evaluated the effectiveness of microalgae cultivation as a pretreatment approach for septic tank effluent and assessed the quality of the treated effluent for potential hydroponic applications. Also, the study aimed to identify suitable cultivation conditions for maximizing microalgal growth and nutrient removal from septic tank effluent. The findings may help determine the potential of microalgae-based treatment to recover nutrients from wastewater while improving effluent quality for reuse in CEA.

MATERIALS AND METHODS

Characteristics of Septic Tank Effluent

Septic tank effluent was collected from Amar Ekushey Hall at Khulna University of Engineering & Technology (KUET), Khulna, Bangladesh. The physicochemical properties such as pH, Oxidation Reduction Potential (ORP), Turbidity, Nitrite-N (NO_2-N), Nitrate-N (NO_3-N), Ammonia-N (NH_3-N), Total phosphorus (TP), and Biochemical Oxygen Demand (BOD) of the raw effluent were analyzed according to standard methods and depicted in **Table 1**. The value of total nitrogen and phosphorus suggested that the effluent is suitable for microalgae cultivation.

Table 1: Characteristics of septic tank effluent before microalgae cultivation.

Parameters	Unit	*Standard Methods (SM) of Analysis	Value
pH	--	SM 4500-H^+ B	7.57 ± 0.06
ORP	mV	SM 2580 B	19.7 ± 1.53
Turbidity	NTU	SM 2130 B	15.0 ± 2.00
NO_2-N	mg/l	SM 4500-NO_2^- B	0.01 ± 0.00
NO_3-N	mg/l	SM 4500-NO_3^- E	1.00 ± 0.03

NH_3-N	mg/l	ASTM D3590-17	153.7 ± 4.05
TP	mg/l	SM 4500-P E	7.87 ± 0.21
BOD	mg/l	SM 5210 B	68.7 ± 4.04

*Standard Methods for the Examination of Water and Wastewater (APHA-AWWA-WEF)

Photobioreactor Configuration

The cultivation of microalgae and harvesting are challenging steps and hot topics for researchers. The priority of this study was given to the cost-effectiveness of microalgae cultivation and harvesting technique. Hence, six (6) identical Photobioreactors (PBR-1 to PBR-6) were built in locally available 8 L drinking water bottles with dimensions: diameter of 150 mm and height of 460 mm. The water bottle was transparent enough to supply sufficient sunlight for microalgal biomass growth.

Microalgae Strains Selection

Each PBR was inoculated with 20 ml concentrated microalgal co-culture dominated by Scenedesmus sp. and Chlorella sp. to avoid the contamination risk of microalgal monoculture. These types of microalgal species have a high lipid content and outstanding ability to grow at higher saline prone zone, temperature, and illumination conditions (Khalekuzzaman et al., 2019). Since the study area (KUET campus) is located near the coastal region of Bangladesh having high salinity in supplied and ground water, these contribute salinity in domestic wastewater. The inoculum was characterized by proximate analysis according to standard methods and presented in **Table 2**.

Table 2: Inoculum Characterization.

Components	**Value**
Moisture (wt%)	90.40 ± 0.28
Total solids (wt%)	9.60 ± 0.15
Volatile solids (wt%)	8.40 ± 0.11
Ash content (wt%)	1.20 ± 0.08
Fixed carbon (wt%)	0.05 ± 0.01

Experimental setup

The experimental setup of the microalgae cultivation process was shown in **Figure 1** and noticed that the PBRs were in different cultivation conditions. The first two PBRs related to two headers (2 x 3 L/min) air pump (Venus aqua, China) to supply CO_2 through a 5 mm diameter air flow tube during the cultivation period of nine (9) days. A porous air stone diffuser was at the end of the air flow tube, which was approximately 2 cm above the bottom of the PBRs. The air pump was operated with a timer (Sino timer, China) that was programmed for 10 min/hour in the daytime (7:00 am to 19:00 pm). No air has been supplied into the PBR-3 and PBR-4 due to pH control of the culture medium. As the pH of the culture medium is maintained at an optimum range to offset the nutrients loss for extreme pH values. The rest of the two PBRs (PBR-5 and PBR-6) were in surface aeration condition during the entire cultivation period. All PBRs were set up at the rooftop in the Civil Engineering Department, KUET under a shed room where sunlight irradiation was available for the culture medium. The light intensity during morning, noon and afternoon were 95±25 μmoles/m^2/s, 101±38 μmoles/m^2/s and 24±6 μmoles/m^2/s, respectively.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue IX September 2026

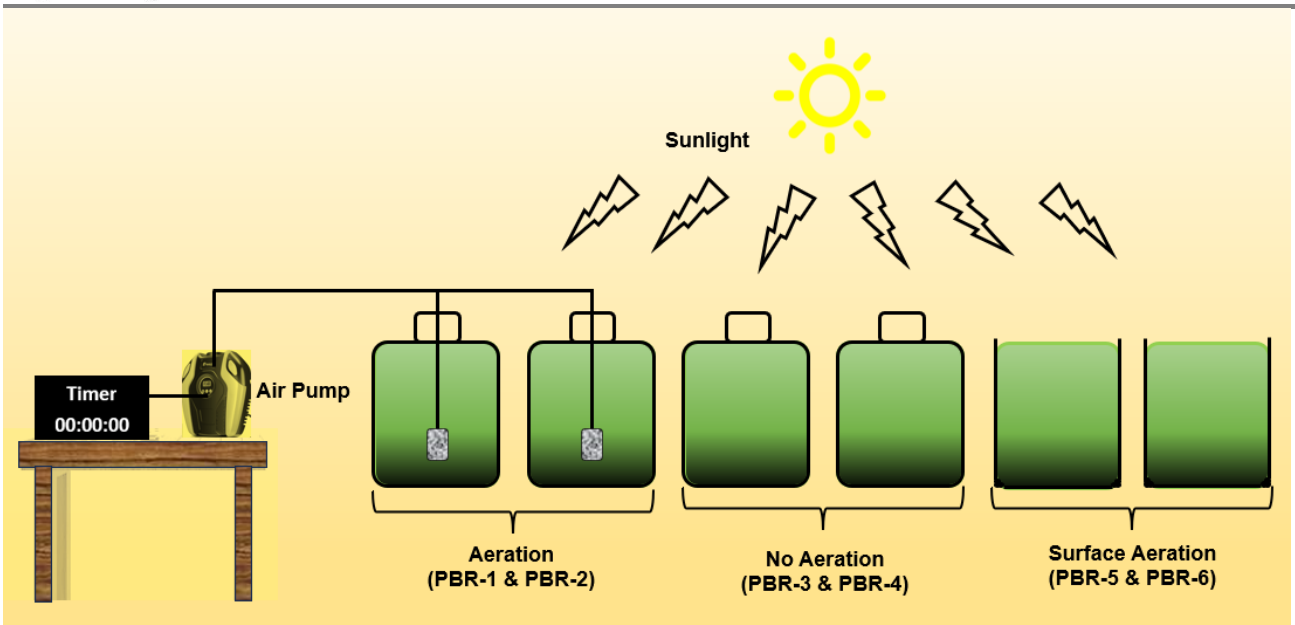


Figure 1: Experimental setup during microalgae cultivation process.

Microalgal Growth Kinetics

During the cultivation process, the following parameters such as pH, turbidity, and microalgae concentration were monitored daily to find out the biomass productivity and microalgal growth rate. The microalgae cell density in suspensions was observed at 680 nm wavelength using spectrophotometer (HACH DR 3900). The dry cell weight (DCW) method was used to calculate microalgae concentration. In this method, a linear relationship between the microalgae concentration (g/L) and absorbance (Abs) was developed for a particular strain following Eq.1.

$$\text{Microalgae concentration, X (g/L)} = 2.4407 * \text{Abs} - 0.0224\ ;\ \ R^2 = 0.9956 \qquad (1)$$

Natural coagulants such as Moringa oleifera was used for microalgae harvesting after cultivation. The details of microalgae harvesting technique were discussed in the author's previous study (Hasan et al., 2021). After harvesting, the treated effluent was analyzed for pH, ORP, Turbidity, NO_2-N, NO_3-N, NH_3-N, TP, and BOD.

RESULTS AND DISCUSSION

Microalgae biomass productivity

Figure 2 illustrates the variations in turbidity and microalgal concentration in septic tank effluent under three cultivation conditions: aeration, no aeration, and surface aeration. Turbidity increased gradually during the first two days, followed by a more pronounced increase between Days 3 and 7. This trend coincided with increasing microalgal concentrations, suggesting active microalgal growth during this period. Surface aeration exhibited the highest microalgal concentration, reaching approximately 4.7 g/L on Day 7, compared with approximately 3.7 g/L under aeration on Day 8 and 3.3 g/L under no aeration on Day 7. Similarly, surface aeration produced the highest turbidity, reaching approximately 350 NTU on Day 7, whereas the maximum turbidity under aeration and no aeration was approximately 280 NTU. These results suggest that surface aeration supported greater biomass accumulation under experimental conditions.

After reaching their respective peaks, microalgal concentrations declined. By Day 10, the concentrations had decreased to approximately 3.4, 2.6, and 3.6 g/L under aeration, no aeration, and surface aeration, respectively. Turbidity also decreased during the later cultivation period. These declines may reflect nutrient depletion, changes in culture conditions, cell aggregation or settling, and biomass decay (Shahid et al., 2020).

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue IX September 2026

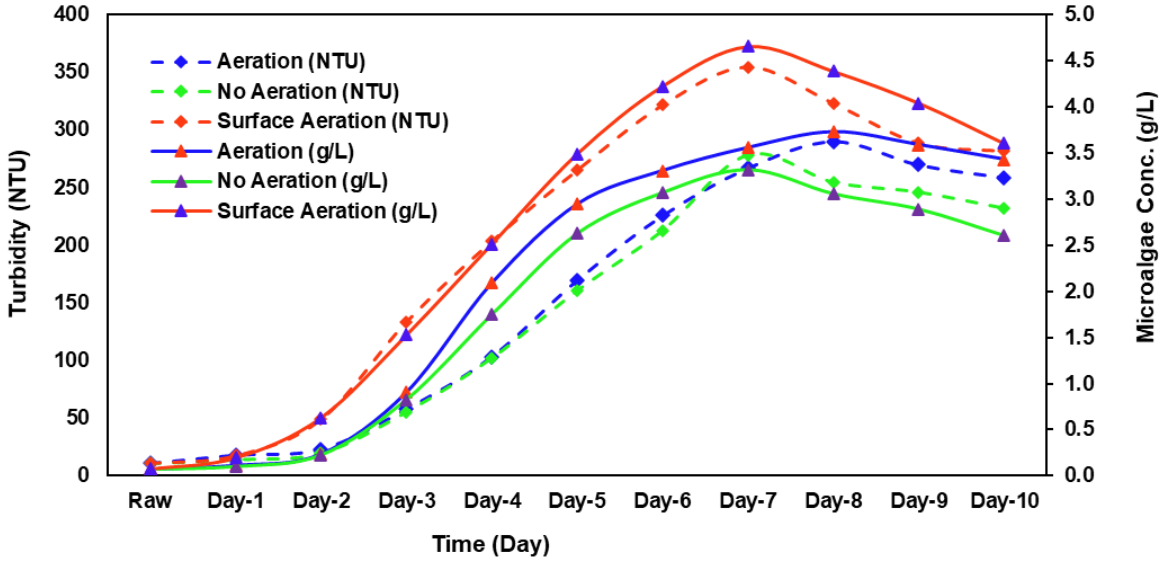


Figure 2: The microalgae concentration and turbidity during batch experiment in PBR.

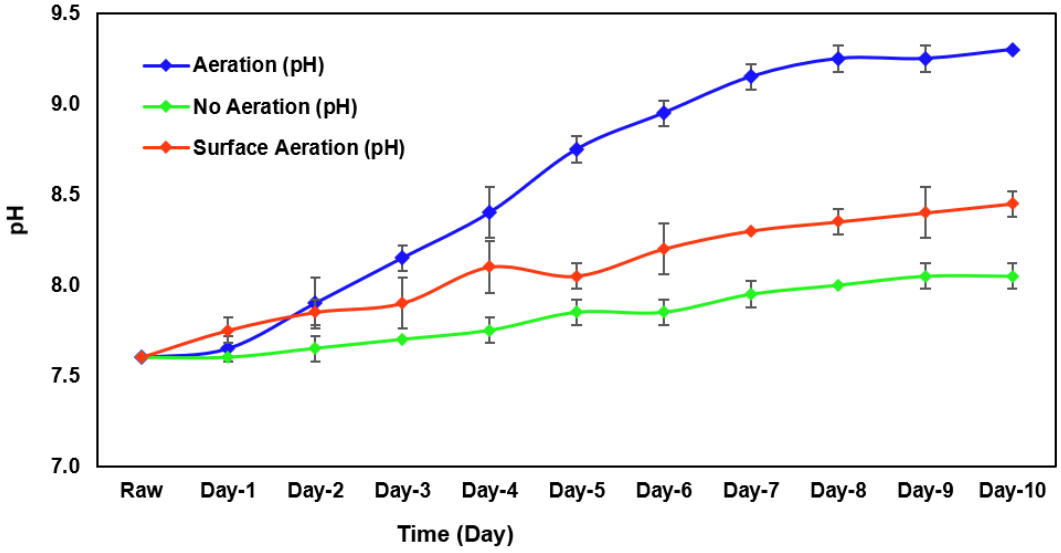


Figure 3: pH during the growing condition of microalgae.

The pH of the septic tank effluent increased under all three cultivation conditions over the 10-day experimental period, although the magnitude of the increase varied among treatments. The aeration treatment exhibited the greatest increase, with pH rising from approximately 7.6 in the raw effluent to 9.3 on Day 10. Surface aeration showed a moderate increase, reaching approximately 8.45, while the no-aeration treatment maintained the lowest pH, increasing gradually to approximately 8.05. The pH under aeration increased particularly rapidly between Days 2 and 7, whereas the other two treatments showed more gradual changes. These results indicate that aeration had a stronger influence on pH dynamics during microalgal cultivation than surface aeration or no aeration. The increase in pH may be associated with microalgal photosynthetic activity, which consumes dissolved CO_2 and reduces carbonic acid in the culture medium (Dammak et al., 2023). The relatively stable pH under no aeration may reflect lower gas exchange and differences in photosynthetic activity.

Nitrogen removal

Figure 4 illustrates the effects of different aeration conditions on ammonia (NH_3) concentration and removal efficiency during microalgae pretreatment. The initial NH_3 concentration was approximately 153 mg/L, which

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue IX September 2026

decreased to 35, 87, and 46 mg/L under conventional aeration, no aeration, and surface aeration, respectively. The highest ammonia removal efficiency (77%) was achieved under conventional aeration, followed by surface aeration (70%) and no aeration (43%). The higher removal efficiency under aerated conditions may be attributed to improved oxygen availability, which promotes microbial activity and facilitates the biological oxidation of ammonia through nitrification (Skouteris et al., 2020). In contrast, the lower removal efficiency observed without aeration may be associated with oxygen limitation, which restricts the activity of ammonia-oxidizing microorganisms. Surface aeration also reduced ammonia concentration, potentially because oxygen transfer at the air–water interface supported aerobic microbial processes (Dotro et al., 2011).

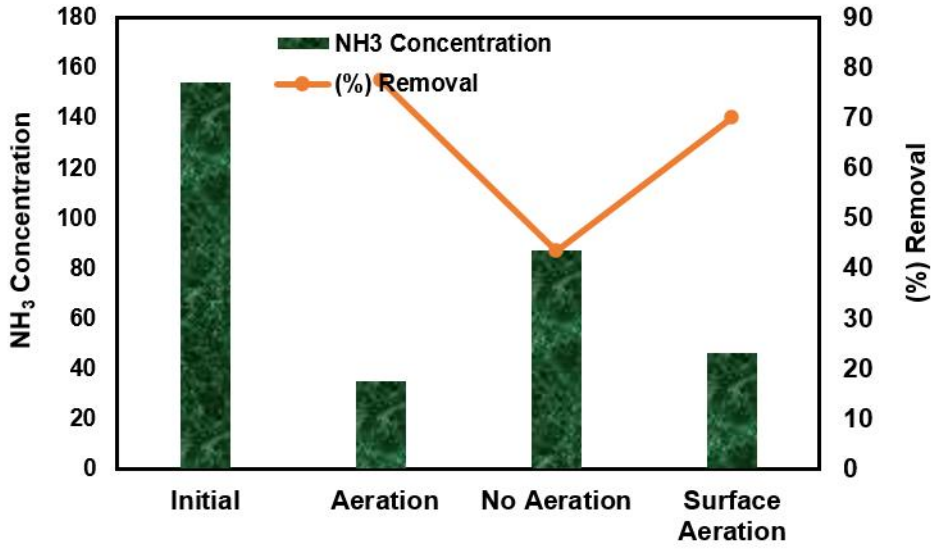


Figure 4: Ammonia concentration and removal after ten days of cultivation.

Water quality

The suitability of different pretreatment methods for hydroponic applications was evaluated based on the physicochemical characteristics of wastewater following microalgae cultivation (Table 3). Among the three treatments, conventional aeration resulted in the lowest NH_3-N concentration (34.7 ± 1.05 mg/L) and the highest NO_3-N concentration (36.80 ± 1.93 mg/L), suggesting enhanced nitrification under aerated conditions. Surface aeration also improved nitrogen quality, reducing NH_3-N to 46.2 ± 1.29 mg/L while increasing NO_3-N to 29.8 ± 1.41 mg/L. In contrast, the no-aeration treatment retained a substantially higher NH_3-N concentration (87.1 ± 1.77 mg/L), indicating its limited suitability for hydroponic reuse. Although conventional aeration demonstrated superior ammonia reduction, its elevated pH (9.31 ± 0.26) and turbidity (44.3 ± 2.43 NTU) may present challenges for direct application in hydroponic systems. Surface aeration produced a comparatively lower pH (8.45 ± 0.31), turbidity (30.1 ± 1.56 NTU), and BOD (7.2 ± 0.20 mg/L), suggesting a potentially more favorable overall water quality. However, the substantial reduction in total phosphorus to 1.69 ± 1.04 mg/L may necessitate nutrient supplementation to support optimal plant growth. Previous research has demonstrated the potential of treated wastewater as a nutrient source for hydroponic cultivation, although appropriate nutrient balance and water quality management remain essential (Magwaza et al., 2020).

Table 3: Characteristics of water quality after microalgae cultivation.

Parameters	Unit	Initial	Aeration	No Aeration	Surface Aeration
pH	--	7.57 ± 0.06	9.31 ± 0.26	8.05 ± 0.18	8.45 ± 0.31
Turbidity	NTU	15.0 ± 2.00	44.3 ± 2.43	25.9 ± 1.83	30.1 ± 1.56

NO_3-N	mg/l	1.00 ± 0.03	36.80 ± 1.93	1.32 ± 0.73	29.8 ± 1.41
NH_3-N	mg/l	153.7 ± 4.05	34.7 ± 1.05	87.1 ± 1.77	46.2 ± 1.29
TP	mg/l	7.87 ± 0.21	3.87 ± 0.12	6.71 ± 1.12	1.69 ± 1.04
BOD	mg/l	68.7 ± 4.04	8.5 ± .41	8.2 ± 0.23	7.2 ± 0.20

CONCLUSION

This study investigated the potential of microalgae cultivation as a low-cost pretreatment strategy for septic tank effluent, with the aim of recovering nutrients and improving water quality for potential reuse in hydroponic systems. The findings demonstrated that cultivation conditions substantially influenced microalgal biomass production, nutrient removal, and the physicochemical characteristics of the treated effluent. Among the three treatments, surface aeration supported the highest microalgal biomass concentration, reaching approximately 4.7 g/L on Day 7. In contrast, conventional aeration achieved the highest ammonia-nitrogen removal efficiency (77%), followed by surface aeration (70%) and no aeration (43%). Conventional aeration also resulted in the highest nitrate-nitrogen concentration (36.8 mg/L), suggesting greater conversion of ammonia to nitrate under aerated conditions. However, the final pH increased to 9.31, which may restrict its direct application in hydroponic systems. Surface aeration maintained a comparatively lower pH (8.45), achieved approximately 79% total phosphorus removal, and reduced biochemical oxygen demand from 68.7 to 7.2 mg/L. Although microalgae-based pretreatment substantially reduced ammonia and organic matter concentrations, the treated effluent did not fully meet the desired characteristics of a conventional hydroponic nutrient solution. The remaining ammonia concentration, elevated pH, and reduced phosphorus availability indicate that additional treatment, pH adjustment, and nutrient supplementation may be necessary. Furthermore, the suitability of the treated effluent for crop production requires experimental validation through plant growth trials and assessment of microbial safety and other relevant water quality parameters.

REFERENCES

1. Ahamed, M.S., Guo, H., Tanino, K., 2019. Energy saving techniques for reducing the heating cost of conventional greenhouses. Biosyst. Eng. 178, 9–33. https://doi.org/10.1016/j.biosystemseng.2018.10.017
2. Boyd, A.P., Zankowski, P., Wheeler, R., Stokes-Draut, J.R., Chudnovsky, Y., Ingram, D., Tijerina, M., Mickens, M., Steward, D., Armstrong, K., Boggs, A.S.P., Neely, B.A., Lunney, J.K., Luo, Y., 2025. Controlled environment agriculture: An opportunity to strengthen interagency research collaboration in the US government. PNAS Nexus 4, pgaf155. https://doi.org/10.1093/pnasnexus/pgaf155
3. Dammak, I., Fersi, M., Hachicha, R., Abdelkafi, S., 2023. Current Insights into Growing Microalgae for Municipal Wastewater Treatment and Biomass Generation. Resources 12, 119. https://doi.org/10.3390/resources12100119
4. Dohlman, E.N., Maguire, K., Davis, W.V., Husby, M., Bovay, J., Weber, C.E., Lee, Y., United States. Department of Agriculture.Economic Research Service, 2024. Trends, insights, and future prospects for production in controlled environment agriculture and agrivoltaics systems. Economic Research Service, U.S. Department of Agriculture, Washington, D.C. https://doi.org/10.32747/2024.8254671.ers
5. Dotro, G., Jefferson, B., Jones, M., Vale, P., Cartmell, E., Stephenson, T., 2011. A review of the impact and potential of intermittent aeration on continuous flow nitrifying activated sludge. Environ. Technol. 32, 1685–1697. https://doi.org/10.1080/09593330.2011.597783
6. Hasan, M., Khalekuzzaman, M., Hossain, N., Alamgir, M., 2021. Anaerobic digested effluent phycoremediation by microalgae co-culture and harvesting by Moringa oleifera as natural coagulant. J. Clean. Prod. 292, 126042. https://doi.org/10.1016/j.jclepro.2021.126042
7. Khalekuzzaman, M., Alamgir, M., Islam, M.B., Hasan, M., 2019. A simplistic approach of algal biofuels production from wastewater using a Hybrid Anaerobic Baffled Reactor and Photobioreactor (HABR-PBR) System. PLOS ONE 14, e0225458. https://doi.org/10.1371/journal.pone.0225458

8. Magwaza, S.T., Magwaza, L.S., Odindo, A.O., Mditshwa, A., 2020. Hydroponic technology as decentralised system for domestic wastewater treatment and vegetable production in urban agriculture: A review. Sci. Total Environ. 698, 134154. https://doi.org/10.1016/j.scitotenv.2019.134154
9. Maureira, F., Rajagopalan, K., Stöckle, C.O., 2022. Evaluating tomato production in open-field and high-tech greenhouse systems. J. Clean. Prod. 337, 130459. https://doi.org/10.1016/j.jclepro.2022.130459
10. Rawat, I., Ranjith Kumar, R., Mutanda, T., Bux, F., 2011. Dual role of microalgae: Phycoremediation of domestic wastewater and biomass production for sustainable biofuels production. Appl. Energy, Special Issue of Energy from algae: Current status and future trends 88, 3411–3424. https://doi.org/10.1016/j.apenergy.2010.11.025
11. Shahid, A., Malik, S., Zhu, H., Xu, J., Nawaz, M.Z., Nawaz, S., Asraful Alam, Md., Mehmood, M.A., 2020. Cultivating microalgae in wastewater for biomass production, pollutant removal, and atmospheric carbon mitigation; a review. Sci. Total Environ. 704, 135303. https://doi.org/10.1016/j.scitotenv.2019.135303
12. Skouteris, G., Rodriguez-Garcia, G., Reinecke, S.F., Hampel, U., 2020. The use of pure oxygen for aeration in aerobic wastewater treatment: A review of its potential and limitations. Bioresour. Technol. 312, 123595. https://doi.org/10.1016/j.biortech.2020.123595
13. Soussi, A., Zero, E., Ouammi, A., Zejli, D., Zahmoun, S., Sacile, R., 2025. Smart greenhouse farming: a review towards near zero energy consumption. Discov. Cities 2, 55. https://doi.org/10.1007/s44327-025-00096-w