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Sustainable agricultural practices: investigating the impact of microalgae use on green plant (Lettuce, Basil, Mint, Green Tatsoi and Chervil) development in soilless agriculture

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Abstract
The increasing global population and environmental degradation make agricultural sustainability essential. Soilless farming and microalgae usage are innovative and environmentally friendly approaches in this field. Soilless farming grows plants using water and nutrient solutions, reducing water consumption while enhancing yield and quality. Microalgae serve as biological fertilizers, decreasing the need for chemical fertilizers and minimizing environmental impact. This study evaluates the potential of organic fertilizers in soilless farming by examining the effects of different microalgae concentrations on plant size and leaf development. Today, combating climate change and promoting sustainable agricultural practices are becoming increasingly important. In this context, zero-waste approaches and the use of organic materials as plant nutrients contribute to environmental sustainability and offer an effective strategy in the fight against climate change. The research findings indicate a significant increase in growth (45% and 30%) and leaf development (35% and 30%) in lettuce *(Lactuca sativa)* and basil *(Ocimum basilicum)* seedlings. However, the effects were more limited in mint *(Mentha spicata)* and green tatsoi *(Brassica rapa* subsp. *Narinosa)* seedlings. A slight growth increase (22%) was observed in chervil *(Anthriscus cerefolium)* seedlings. These results highlight the varying responses of different plant species to microalgae applications and emphasize the importance of determining the optimal concentration for plant species to maximize benefits.
Keywords: Soilles farming, Microalgae, *Chlorella vulgaris*, Sustainability, Biological fertilize

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INTRODUCTION

The rapid increase in the world population, especially in the 21st century, has brought significant challenges in agricultural production and food security. It is projected that the global population will reach 9.1 billion by 2050, which increases the pressure on existing agricultural systems. Traditional farming methods threaten environmental sustainability due to the intensive use of chemical fertilizers and pesticides, leading to long-term soil degradation. Meeting the growing demand for food while adopting sustainable agricultural practices has become one of the greatest challenges of our time. In this context, alternative methods such as soilless agriculture provide a significant opportunity to reduce environmental impacts and enhance agricultural productivity (Alexandratos & Bruinsma, 2012).

The rapid growth of the global population and the impact of economic development are expected to increase food demand by 70% to 100% by 2050 (Fukase & Martin, 2020). This raises serious concerns about whether existing resources will be sufficient to meet future food needs. The scarcity of natural resources, particularly land and water, is one of the main factors threatening the sustainability of agricultural production. In this context, water scarcity has a direct impact on agricultural production and poses a significant threat to food security (Yuan et al., 2024).

Therefore, it is essential to quickly implement policies and actions that mitigate the effects of climate change. This includes the development of crop varieties resistant to sudden changes in temperature and rainfall, as well as the adoption of biological and sustainable agricultural methods. The use of biofertilizers and biopesticides can reduce dependence on chemical fertilizers and pesticides, lowering greenhouse gas emissions and reducing environmental pollution. Chemical fertilizers play a vital role in sustaining soil fertility and boosting crop yields in modern intensive farming However, their large-scale production and continuous application have led to several significant issues (Shahid et al., 2024). Long-term reliance on chemical fertilizers not only degrades soil quality but also triggers various environmental problems, such as nutrient runoff, pollution of surface and groundwater, eutrophication, greenhouse gas emissions, and the decline of aquatic biodiversity (Chandini et al., 2019; Zhang et al., 2024). Consequently, adopting organic and biofertilizers has become essential to mitigate the environmental challenges linked to chemical fertilizer use in agriculture.Additionally, the resilience of crops can be enhanced by employing different planting techniques and crop types (Furtak & Wolińska, 2023).

Soilless agriculture is defined as an innovative production technique that meets the nutritional needs of plants without relying on soil, utilizing water and nutrient solutions. This system directly supplies nutrients and water to the plant root zone, ensuring the optimal uptake of all necessary elements. One of the most significant advantages of soilless agriculture is its ability to reduce the risk of pest and disease spread while improving the efficiency of water and nutrient use. Additionally, these systems save both land and water, creating a more sustainable agricultural model (Savvas et al., 2013).

Soilless agriculture offers numerous benefits not only for environmental sustainability but also in terms of economic advantages and product quality (Ayele et al., 2025; Mir et al., 2022). Particularly in regions with limited water resources, this method reduces production costs by conserving water. Additionally, soilless farming systems enable year-round production, minimizing the adverse effects of climate change (Yavuz et al., 2023). The controlled environmental conditions provided by these systems—such as optimal temperature, humidity, and light levels—allow for higher yield and quality (Fussy & Papenbrock, 2022).

The most common applications include hydroponic, aquaponic, and aeroponic systems (Shrouf, 2017). The advantages of soilless farming include reduced water and fertilizer usage, lower disease risk, increased productivity, and prevention of soil fatigue. However, these systems also have disadvantages, such as high initial costs, the need for skilled labor, and the requirement for continuous monitoring. Soilless farming offers an important alternative for sustainable food production, particularly in regions facing water and soil scarcity, and can play a key role in shaping agricultural production in the future.

The use of microalgae in soilless farming systems presents a sustainable approach. Utilizing microalgae as organic fertilizers can reduce the reliance on chemical fertilizers, thereby minimizing environmental impact (Renganathan et al., 2024). Microalgae support plant growth by producing plant growth-promoting hormones and biostimulants, enhancing both development and productivity (Parmar et al., 2023). Furthermore, they optimize nutrient cycling, ensuring more efficient uptake of essential nutrients by plants. Certain microalgae species enhance soil organic carbon levels by capturing atmospheric carbon dioxide (CO_2) and utilizing it through photosynthesis to produce nutrient-rich biomass. This process helps mitigate the greenhouse effect, global warming, and climate change. Additionally, microalgal biomass can sequester other greenhouse gases, such as nitrous oxide, further contributing to climate change mitigation (Zhang et al., 2024).

In recent years, regulatory frameworks have increasingly emphasized sustainability in agricultural systems, including soilless cultivation methods. The European Union, through its Green Deal and Farm to Fork Strategy, encourages innovative practices that reduce environmental impacts and enhance resource efficiency. Similarly, in the United States, the USDA and FDA have introduced guidelines addressing sustainable practices in controlled-environment agriculture. Although regulatory approaches vary across regions, they commonly aim to ensure food safety, environmental protection, and economic viability. Considering legal aspects, even at a basic level, can support the alignment of research and practice with broader policy objectives (Boros et al., 2025; Steines et al., 2024). Interest in sustainable agricultural practices has been increasing in Turkey, with soilless cultivation gaining particular attention. The Ministry of Agriculture and Forestry promotes sustainability through regulations such as the "Good Agricultural Practices" and "Organic Agriculture" directives, which aim to reduce environmental impact and ensure efficient resource use. Although there is currently no comprehensive and up-to-date legislation specifically focused on soilless agriculture, related frameworks—such as controlled environment agriculture, plant nutrition regulations, and production permits—form the basis of the legal landscape in this field. In line with Turkey's 2023 Agricultural Vision and its commitment to sustainable development goals, strengthening the legal support for soilless farming offers significant environmental and economic opportunities. Therefore, incorporating legal perspectives into future research may facilitate better alignment with policy development and implementation.

This study aims to examine the effects of using *Chlorella vulgaris* microalgae as organic fertilizers in soilless farming systems on plant growth. Experiments conducted on various green plant species such as lettuce, mint, and basil will evaluate the impact of these materials on plant development. The study seeks to contribute to the advancement of sustainable agricultural practices and the widespread adoption of soilless farming systems. By offering sustainable and efficient solutions for agricultural production in the future, the research aims to enhance food security. The use of microalgae as organic fertilizers can enable more efficient utilization of natural resources, providing a long-term solution for agricultural production.

MATERIAL ve METHODS

In this study, pure cultures of *Chlorella vulgaris* was used. The algal cultures were sourced from the Hacettepe University laboratory. To cultivate the algae, BBM (Bold's Basal Medium) culture medium was prepared using laboratory-grade chemicals. BBM contains precise concentrations of the following compounds: $NaNO_3$, $CaCl_2{\cdot}2H_2O$, $MgSO_4{\cdot}7H_2O$, K_2HPO_4, NaCl, Na_2EDTA, KOH, $FeSO_4{\cdot}7H_2O$, H_3BO_3, $ZnSO_4{\cdot}7H_2O$, $MnCl_2{\cdot}4H_2O$, MoO_3, $CuSO_4{\cdot}5H_2O$, and $Ca(NO_3)_2{\cdot}6H_2O$. During inoculation, an algae-to-medium ratio of 1:10 was maintained. The cultivation of algal cultures was carried out in the ESCO AC2-4E8 Biological Safety Cabinet within the laboratory. Freshly cultivated cultures were then transferred to an orbital shaker inside an air-conditioned cabinet, where they were exposed to LED panel modules emitting red and blue light optimized for algal growth. For optimal growth, a Photosynthetic Photon Flux Density (PPFD) value nearly 700 µmol/m²/s has been utilized, providing the ideal light intensity to support photosynthetic activity and rapid growth in fast-growing algae species. The cultivation conditions were set at 120 rpm, a temperature of 28°C and 45% humidity (Poleko KK 240 INOX climate chamber and Infors/HT orbital shaker system).

In the study, two different growing media, both suitable for soilless agriculture and easily accessible, were selected: perlite, an inorganic material, and cocopeat, an organic material. Perlite is notable for its lightweight structure and excellent drainage properties, while coco peat stands out for its high water retention capacity. The solid growing medium used in the study consisted of a mixture of 80% cocopeat and 20% perlite. Coco peat is a natural material derived from the processing of coconut husks and has a remarkably high water retention capacity, capable of absorbing 8–9 times its weight in water. Due to this property, it is widely used in soilless agriculture. Its natural pH level allows plants to easily absorb essential nutrients, positively influencing plant growth. Perlite, on the other hand, offers excellent drainage and aeration properties, enhancing oxygen uptake by the roots while ensuring the efficient utilization of water and nutrients (Fazlil Ilahi & Ahmad, 2017; Mohammadi Ghehsareh et al., 2011).

The growth of lettuce *(Lactuca sativa)*, basil *(Ocimum basilicum)*, mint *(Mentha spicata)*, chervil *(Anthriscus cerefolium)* and green tatsoi *(Brassica rapa* subsp. *Narinosa)* plants in different growing media using soilless agriculture methods was examined. The seedlings were transferred to hydroponic medium from beginning November to ending of December 2024, nearly 60 days. An experimental design with 2 replicates and 5 plants per replicate was used in each solid aggregat medium. 15 ml of irrigation water was provided per day. As a nutrient supplement, microalgae-based biofertilizer feeding was applied to the seedlings once a week at different doses (0.2, 0.3, 0.5 and 0.75 mg mL^{-1}).

(1) Control: Fresh media + Plant
(2) 0.2 mg mL^{-1} microalgae + Media + Plant
(3) 0.5 mg mL^{-1} microalgae + Media + Plant
(4) 0.75 mg mL^{-1} microalgae + Media + Plant

One plant from each replicate was reserved as a control, and it was only watered (Figure 1). In this way, the effects of different media on plant development were compared, and the potential benefits of microalgae supplementation were examined.

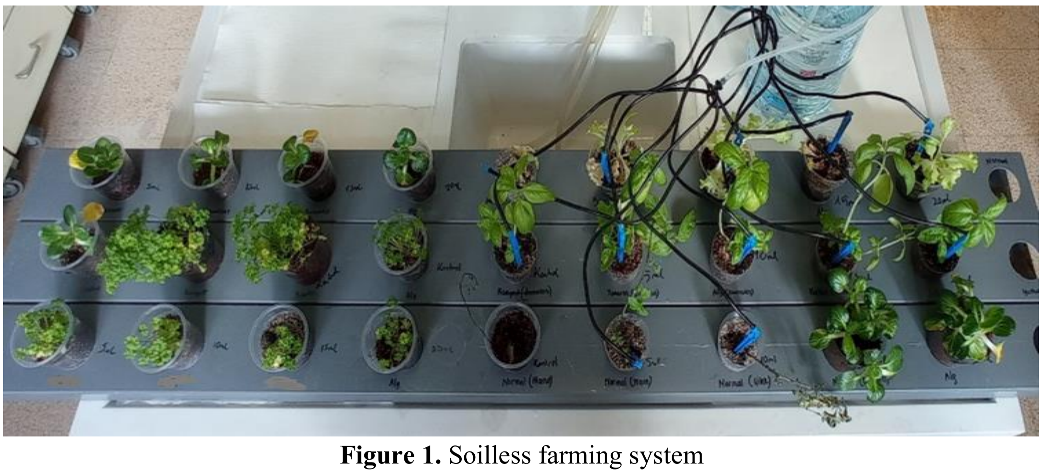

Figure 1. Soilless farming system

RESULTS AND DISCUSSION

The effect of microalgae supplementation varies depending on the plant species and the applied dose. The minimum, maximum, and average measured seedling heights are shown in the Figure 2. In lettuce seedlings, a 0.3 mg mL^{-1} microalgae resulted in the highest growth, allowing the seedlings to reach a height of 11 cm. In contrast, seedlings receiving 0,75 mg mL^{-1} ml of microalgae remained shorter at 10.5 cm, while those in the control group measured 7.8 cm. These data indicate that the optimal microalgae dose for lettuce seedlings is 0,3 mg mL^{-1}.

For basil seedlings, the most effective result was observed with a 0.5 mg mL^{-1} microalgae supplement, leading to a height of 17 cm. Seedlings given 5 ml remained the shortest at 13 cm, while those in the control group measured 11.9 cm. These findings suggest that the optimal microalgae dose for basil seedlings is 0.3 mg mL^{-1}.

In mint seedlings, the effect of microalgae supplementation was more limited. Seedlings receiving 0.2mgmL^{-1} of microalgae reached the highest height at 19 cm, while those in the control group measured 17 cm. These results suggest that microalgae application has a minimal effect on mint seedlings.

For green tatsoi seedlings, microalgae supplementation was found to be ineffective. The applied microalgae concentrations did not produce a significant growth difference compared to the control group. This indicates that microalgae application does not result in significant growth for green tatsoi seedlings.

In chervil seedlings, a 0.5 mg mL^{-1} microalgae supplement resulted in the highest growth, with seedlings reaching 4.9 cm. Seedlings receiving 0.2 mg mL^{-1} remained the shortest at 4.2 cm, while those in the control group measured 4.4 cm. These findings suggest that the optimal microalgae dose for chervil seedlings is 0.5 mg mL^{-1}.

While significant growth increases were observed in lettuce and basil seedlings, the effects were more limited in mint and green tatsoi seedlings. In chervil seedlings, a slight growth increase was observed. These findings indicate that the effect of microalgae supplementation on plant growth depends on the plant species and the determination of the appropriate dose.

Furthermore, the results suggest that while microalgae can act as an effective biofertilizer for certain plant species, its impact is not universal. The varying responses among different seedlings highlight the importance of species-specific optimization when using microalgae as a growth enhancer. Additionally, excessive microalgae supplementation may not always lead to greater growth, as seen in the lettuce seedlings where higher doses resulted in reduced height. This emphasizes the need for careful dose selection to maximize the benefits of microalgae application.

Overall, these findings contribute to a better understanding of how microalgae supplements can be integrated into plant cultivation strategies. Further studies exploring the long-term effects, nutrient uptake mechanisms, and interactions with soil microbiota could provide deeper insights into the potential of microalgae in sustainable agriculture.

The species- and dose-dependent effects of microalgae supplementation on plant growth can be attributed to several physiological and biochemical factors. Microalgae such as *Chlorella vulgaris* and *Scenedesmus sp.* are known to be rich in proteins, amino acids, phytohormones (e.g., indole-3-acetic acid [IAA]), vitamins, and micronutrients, all of which can promote plant growth (Renuka et al., 2013; Win et al., 2018). However, the degree to which plants can absorb and utilize these compounds varies among species, depending on their specific nutrient uptake mechanisms, root architecture, and growth stage (Ronga et al., 2019). In lettuce and basil seedlings, where significant growth improvements were observed, the applied doses of microalgae may have matched the optimal nutritional needs of these plants, particularly in terms of phytohormonal stimulation and nitrogen supplementation (Kumar et al., 2022). On the other hand, in mint and green tatsoi seedlings, the limited or negligible response could indicate either a lower sensitivity to the bioactive compounds in microalgae or possible nutrient saturation, where additional inputs do not translate into further growth (Sharma et al., 2014). Furthermore, the observation that higher doses (e.g., 0.75 mg mL^{-1} in lettuce) resulted in reduced growth suggests that excessive microalgae supplementation may lead to nutrient imbalances or osmotic stress, which can inhibit seedling development (Fiorentino et al., 2025). This aligns with findings from previous studies that emphasized the importance of dose optimization when using microalgae-based biofertilizers. The slight increase observed in chervil also underscores that not all species respond equally to biofertilizer input, and that certain species may require a more tailored approach. These species-specific responses highlight the importance of optimizing both the type and concentration of microalgae supplements to maximize their benefits.

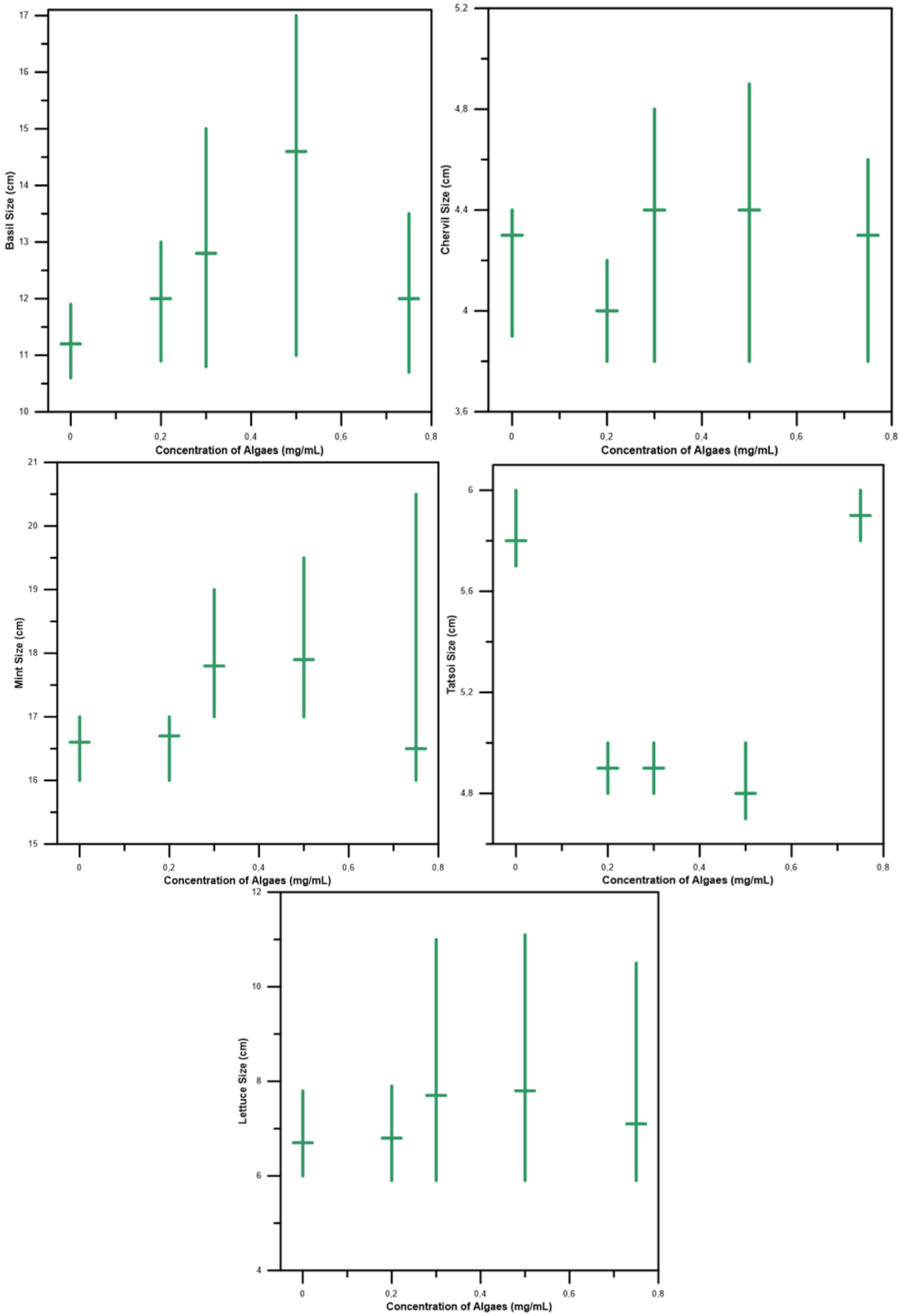

Figure 2. Effect of different concentrations of algal density on green plants height (Basil, chervil, mint, lettuce, tatsoi)

The effect of microalgae application on the number of leaves also varies depending on the plant species and the applied concentration (Figure 3). In experiments conducted on lettuce plants, a 0.3 mg mL^{-1} microalgae application resulted in the highest leaf increase, leading to the formation of 14 leaves per seedling. In contrast, seedlings treated with 0.75 mg mL^{-1} of microalgae had 10 leaves, while those in the control group had 9 leaves. These findings indicate that a 0.3 mg mL^{-1} microalgae application is the most effective dose for lettuce, whereas 0.75 mg mL^{-1} does not provide a significant difference compared to the control group.

In studies on basil plants, a 0.5 mg mL^{-1} microalgae application led to the highest increase, with seedlings developing 39 leaves. Seedlings treated with 0.3 mg mL^{-1} had 37 leaves, while the lowest leaf count was recorded at 0.2 and 0.75 mg mL^{-1} concentrations. The control group had 23 leaves. These results suggest that 0.5 mg mL^{-1} is the optimal microalgae dose for basil plants.

For mint plants, seedlings treated with 0.2 mg mL^{-1} of microalgae developed 10 leaves, while those in the control group had 8 leaves. These findings indicate that while microalgae application does not cause a significant increase in leaf production for mint plants, it has a slight positive effect.

Experiments on green tatsoi plants showed that microalgae concentrations did not lead to a significant leaf increase compared to the control group. This suggests that microalgae application does not have a meaningful impact on green tatsoi plants therefore, it has not been provided in the graphs.

In chervil plants, a 0.3 mg mL^{-1} microalgae application resulted in the highest leaf increase, while the lowest leaf count was observed in seedlings treated with 0.2 mg mL^{-1} of microalgae. These findings suggest that while microalgae supplementation provides a slight benefit for chervil plants, the most effective concentration is 0.3 mg mL^{-1}.

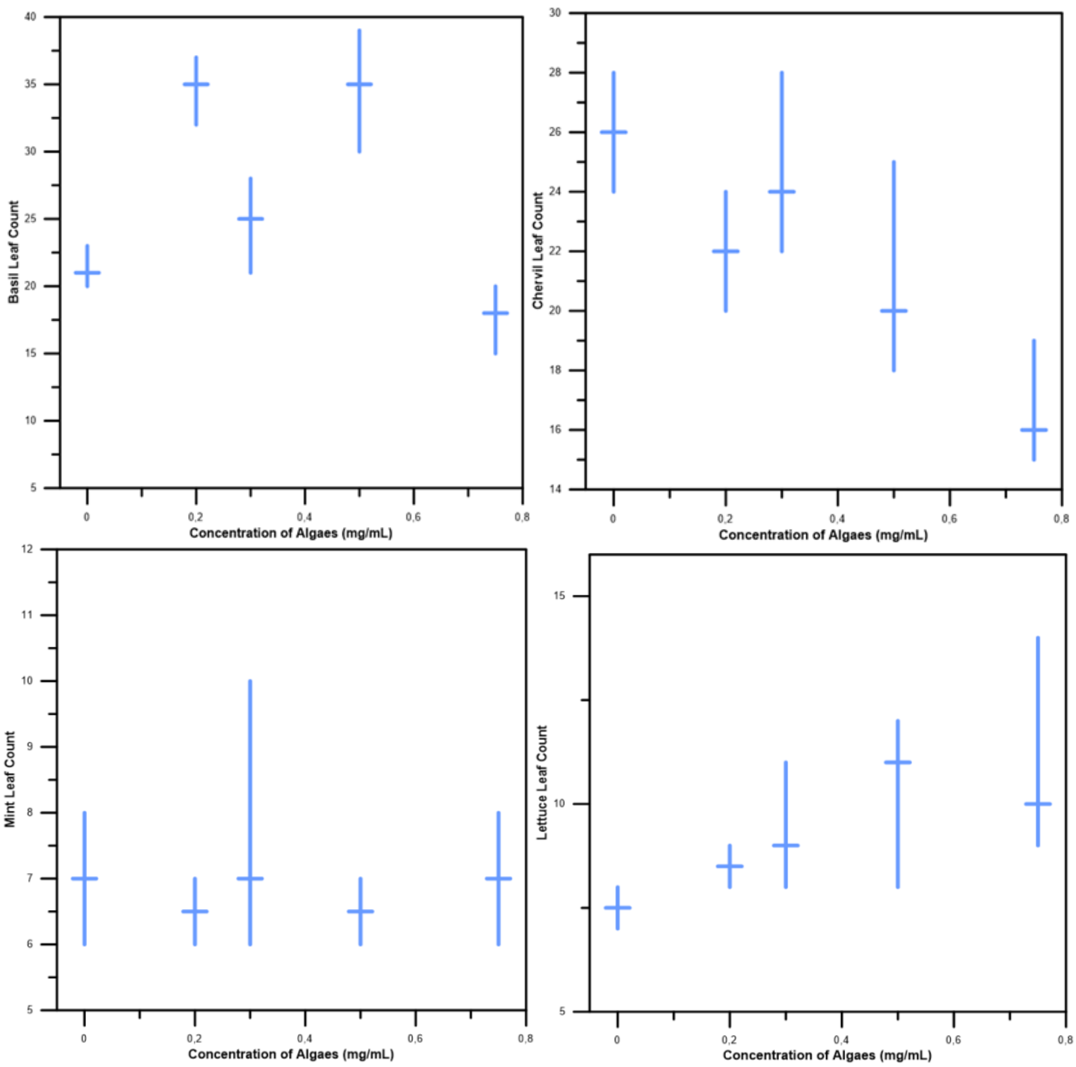

Figure 3. Effect of different concentrations of algal density on green plants leafs number (Basil, chervil, mint, lettuce)

The differences observed in leaf production in response to microalgae application could be due to several factors (Gonçalves et al., 2023). For example, the varying effects of microalgae on different plant species might be influenced by species-specific nutrient requirements, growth habits, or photosynthetic efficiency (Salah et al., 2023). Lettuce and basil, which showed significant increases in leaf count, may be more responsive to the added nutrients from the microalgae or have a higher photosynthetic capacity, allowing them to utilize the applied microalgae more effectively. On the other hand, mint and green tatsoi, which showed minimal response, may have different nutrient uptake mechanisms, or their growth may be more influenced by other environmental factors such as light intensity or soil composition, which were not controlled in the experiment. These differences highlight the need for a more thorough investigation into the physiological and environmental factors that govern plant responses to microalgae applications (Melo et al., 2022).

CONCLUSION

This research evaluates the potential of organic fertilizers in soilless agriculture by examining the effects of different microalgae concentrations on plant size and leaf development. Today, combating climate change and promoting sustainable agricultural practices are becoming increasingly important. In this context, zero-waste approaches and the use of organic matter as plant nutrients contribute to environmental sustainability and provide an effective strategy in the fight against climate change. Soilless agriculture, which includes techniques such as hydroponics and aeroponics, is gaining significant attention as a viable solution to conventional farming methods. This is due to its potential to conserve water, reduce land use, and promote more efficient nutrient uptake by plants. Today, combating climate change and promoting sustainable agricultural practices are becoming increasingly important as the global population continues to rise, placing additional pressure on agricultural systems. In this context, zero-waste approaches, such as recycling organic waste into microalgae biomass, and the use of organic matter as plant nutrients, contribute significantly to environmental sustainability. By utilizing microalgae as biofertilizers, we can reduce reliance on synthetic fertilizers, which often have detrimental environmental impacts (Nur et al., 2025). Moreover, these organic fertilizers provide essential nutrients to plants, improving their growth potential while minimizing soil degradation and water pollution, thus providing an effective strategy in the fight against climate change.

The findings of this study reveal that microalgae supplementation positively influenced lettuce and basil seedlings, resulting in notable improvements in plant height and leaf development. These results are consistent with prior studies that report enhanced root and shoot biomass, chlorophyll content, and nutrient uptake in leafy greens treated with microalgae-based fertilizers (Spolaore et al., 2006). In contrast, mint and green tatsoi seedlings demonstrated a more limited response, which may be attributed to species-specific physiological traits, root morphology, or differing nutrient demands (González et al., 2022). A slight increase in growth was also observed in parsley seedlings, suggesting a moderate responsiveness to microalgae supplementation.

These varied responses underscore the importance of optimizing both the dosage and the formulation of microalgae biofertilizers according to plant species. Over-application can lead to nutrient imbalances or osmotic stress, while under-application may result in suboptimal growth effects (Pekkoh et al., 2024). Therefore, species-specific trials are essential to develop effective guidelines for microalgae use in soilless systems.

In summary, this research highlights the dual environmental and agronomic benefits of integrating microalgae into sustainable soilless agriculture. It emphasizes the need for targeted application strategies based on plant-specific responses, ultimately contributing to resource-efficient and climate-smart farming systems.

Compliance with Ethical Standards
Peer-review
Externally peer-reviewed.
Declaration of Interests
The authors of the article declare that there is no conflict of interest among them.
Author contribution
The authors declare that they have contributed equally to the article.

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