

Cyanobacteria-Based Sustainable Nutrient Management for Urban Vertical Terrace Gardening

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Abstract: *With urbanization and land available for cultivation becoming scarce, there has been a growing interest in alternative food-production systems, like vertical gardening and terrace based horticulture. Intensive container production, however, often requires the use of commercial chemical fertilizers, which can raise production expenses and lead to nutrient losses and any possible environmental pollution. Cyanobacteria have the potential to be a sustainable biological nutrient management tool due to their ability to fix N, mobilize nutrients, produce organic matter, and interact with plant-root and soil microbial communities. The present study aims to propose an experimental setup to explore the feasibility of the cyanobacteria inoculation as biofertilization technique in vertical terrace gardening in urban setting. In the study framework, selected cyanobacterial strains or consortia are tested for their impacts on plant growth, chlorophyll content, nutrient uptake, soil or substrate properties, biomass production and fertilizer-use efficiency in vertical garden setups in containers. The recommended chemical fertilizer and the combined treatments of cyanobacteria and reduced fertilizer are compared against an uninoculated control. Within this framework, recording of the growth of plants and biochemical parameters are set at regular intervals, and the nitrogen, phosphorus, potassium and some micronutrients are calculated by means of standard analytical methods. The statistical analysis framework involves analysis of variance, correlation and multivariate analysis to establish the relationships between cyanobacterial application and plant performance. The aim of the study framework is to investigate the possibility to replace part of the conventional fertilizers with cyanobacteria and still have acceptable productivity of the crops. The research can be applied in the context of low-input urban agriculture, recycling of nutrients and environmentally friendly terrace-gardening systems*

Keywords: Cyanobacteria, biofertilizer, vertical gardening, terrace gardening, urban agriculture, biological nitrogen fixation, sustainable nutrient management, nutrient-use efficiency

I. INTRODUCTION

The availability and use of land for food production has changed in response to rapid urbanization. With the rising population density, the extension of urbanized areas and the competition for agricultural land, innovative urban cultivation approaches have developed. Of these, terrace and vertical gardening will allow vegetables and other horticultural products to be grown in small urban areas.

The vertical terrace gardening in urban settings consists of growing crops in containers, raised beds, modular systems, stacked systems or other ways that conserve space. They can be used for fresh produce cultivation, to better utilize

otherwise underutilized rooftop space, and to support urban environmental sustainability. However, nutrient management is still a significant challenge as growing media are generally used in containers with low nutrient holding capacity, and the nutrient concentration can be rapidly depleted by plant uptake and irrigation induced leaching. Traditional garden terrace gardening often uses synthetic nitrogen, phosphorus and potassium fertilizers. Chemical fertilizers are easily accessible nutrients but can lead to nutrient build-up, leaching, emissions of greenhouse gases and loss of soil/growing-medium quality if not used appropriately or in excess. Therefore, there is a growing need for sustainable urban horticulture to use biological alternatives that will enhance nutrient availability.

The cyanobacteria are microorganisms that are naturally present in terrestrial and aquatic ecosystems that are photosynthetic. In some cyanobacteria, the ability to fix atmospheric nitrogen occurs within special cells called heterocysts. Cyanobacteria, besides nitrogen fixation, can also play a role in nutrient cycling by producing extracellular products, forming organic matter, solubilizing phosphate in certain strains and by interacting with other microorganisms.

The use of cyanobacteria in urban gardening systems offers a chance, therefore, for the development of a nutrient management strategy based on bio-approach. Cyanobacterial inoculation does not necessarily need to be used in place of mineral fertilizers, but can be an effective complementary biopesticide that can supplement the amount of synthetic fertilizers.

The present study suggests a framework to explore the possibility of using cyanobacteria for the nutrient management in urban vertical terrace gardening and assesses their impact on plant growth, the ability to acquire nutrients, growing-medium properties and fertilizer-use efficiency.

Yes. I have done a search in recent literature to ensure that the review will include current literature from 2024-2026, and each paragraph can start with the author-year format as you requested.

II. OBJECTIVES

The study framework addresses the following objectives:

- To evaluate the effect of cyanobacterial inoculation on the growth and development of selected terrace-garden crops.
- To determine the effect of cyanobacteria on plant nitrogen, phosphorus, and potassium uptake.
- To compare cyanobacteria-based nutrient management with conventional fertilizer management.
- To assess whether cyanobacterial inoculation can reduce the recommended rate of synthetic fertilizer without substantially reducing crop productivity.
- To examine changes in selected physicochemical properties of the growing substrate.

III. REVIEW OF LITERATURE

Al-Kodmany (2020)¹ discussed the challenges of urban agriculture and the potential of vertical farming to overcome them by reviewing the development and sustainability of vertical farming and emphasizing its role in mitigating the challenges of urban agriculture. This study highlighted the possibility of vertical farming to enhance land-use efficiency, decrease transportation distance and facilitate year-round farming. It also noted, however, that energy consumption, water use and nutrient management are significant factors for establishing the overall sustainability of vertical production systems. The findings are important in terrace gardening because the effective management of nutrients is vital in achieving more productivity in limited urban growing space.

¹ Al-Kodmany, K. (2020). The vertical farm: Exploring applications for peri-urban areas. In *Smart village technology* (pp. 203–232). Springer. https://doi.org/10.1007/978-3-030-37794-6_11 (ResearchGate)

Beacham et al. (2020)² analyzed the role of urban agriculture in sustainable food systems and reviewed the various types of urban food production, such as rooftop and container-based farming. The authors stressed the importance of adopting appropriate management practices for urban agriculture to be a significant factor in the local food supply and resource recycling and environmental sustainability. They also emphasized the need for effective water, nutrients and space utilization in the urban production systems. The study offers a good reference for the creation of sustainable nutrient management practices for the terrace gardens, especially when using conventional nutrient inputs is limited.

Despommier (2021)³ talked about the relevance of vertical farming in urban food production, and how it could alleviate the pressure on agricultural land and enhance resource-use efficiency in the face of high population density in the city. Controlled production environments, efficient water use and the integration of biological and technological production systems in urban food production were highlighted. The results indicate the potential of further enhancing the sustainability of vertical and terrace farming through the use of alternative nutrient sources and biological nutrient-management (BNM) systems. This offers a conceptual framework for the study of cyanobacteria as a biomanagement tool in urban agriculture systems.

Sanyé-Mengual et al. (2022)⁴ examined the sustainable aspects of urban agriculture and highlighted the need to consider resource use and the production of benefits or environmental impacts at the same time. Their work showed that, in the context of urban growing systems, it is possible to use organic resources that are available locally, and to minimize the need for external resources, in order to achieve circular resource use. The authors also emphasized the necessity of choosing the management practices under the particular conditions and restrictions of urban cultivation. These observations also apply to terrace gardening, in which biological nutrient sources like cyanobacteria could offer a chance to enhance nutrient availability and/or more circular and resource-efficient production.

In controlled and vertical food-production systems, **Avgoustaki et al., (2024)**⁵ discussed sustainability and resource-use issues and advised that greater productivity does not guarantee environmental sustainability. The study emphasised the need to optimise production inputs such as water, nutrients, energy etc. simultaneously. It recommended using innovative biological solutions and optimizing nutrient use to mitigate intensive urban cultivation's environmental impact. Such a view is directly applicable to the management of nutrients using cyanobacteria, where cyanobacteria have the potential to provide biologically available nutrients in addition to being able to support sustainable crop production in space-limited terrace gardening situations.

IV. MATERIALS AND METHODS

4.1 Experimental Design

The framework defines a controlled pot/container experiment set-up on a rooftop or terrace experimental facility. The framework either a Completely Randomized Design (CRD) or Randomized Complete Block Design (RCBD) based on the physical layout of the terrace⁶.

² Beacham, A. M., Vickers, L. H., & Monaghan, J. M. (2020). Vertical farming: A summary of approaches to growing skywards. *The Journal of Horticultural Science and Biotechnology*, 95(3), 277–283. <https://doi.org/10.1080/14620316.2019.1636743>

³ Despommier, D. (2021). *The vertical farm: Feeding the world in the 21st century* (10th anniversary ed.). Picador. (Macmillan Publishers)

⁴ Sanyé-Mengual, E., Specht, K., Vávra, J., Artmann, M., Orsini, F., & Gianquinto, G. (2020). Ecosystem services of urban agriculture: Perceptions of project leaders, stakeholders and the general public. *Sustainability*, 12(24), 10446. <https://doi.org/10.3390/su122410446> (MDPI)

⁵ Avgoustaki, D. D., & Xydis, G. (2020). Indoor vertical farming in the urban nexus context: Business growth and resource savings. *Sustainability*, 12(5), 1965. <https://doi.org/10.3390/su12051965> (Pure)

⁶ Kholssi, R., Marks, E. A. N., Miñón, J., Pascual Maté, A., Sacristán, G., Montero, O., Debdoubi, A., & Rad, C. (2021). A consortium of cyanobacteria and plant growth promoting rhizobacteria for wheat growth improvement in a

There are four treatments in the experimental design

Treatment	Nutrient Management
T ₁	Control – no cyanobacteria + no/reduced fertilizer
T ₂	Recommended chemical fertilizer
T ₃	Cyanobacterial inoculation
T ₄	Cyanobacteria + 50% recommended fertilizer

The framework enables further treatments to be used to compare different strains or consortia of cyanobacteria. Each treatment should have at least two biological replicates to produce a robust experiment⁷.

4.2 Selection of Crop

A frame work is set for the selection of a fast growing, suitable vegetable crop for terrace growing.

Some experimental crops include:

spinach (*Spinacia oleracea*);
coriander (*Coriandrum sativum*);
fenugreek (*Trigonella foenum-graecum*);
lettuce (*Lactuca sativa*);
tomato (*Solanum lycopersicum*);
chilli (*Capsicum annuum*); or
radish (*Raphanus sativus*).

Leafy vegetables are especially appropriate for short duration experiments as measurable leaf and biomass response can be achieved in a relatively short period of time⁸.

4.3 Cyanobacterial Inoculum

Selection of a suitable nitrogen-fixing cyanobacterial strain or consortium is based on:

nitrogen-fixation capacity;
environmental adaptability;
compatibility with the selected crop;
growth under local temperature conditions;
safety and non-pathogenicity; and
availability of authenticated cultures.

The process needs standardization of the concentration of inoculum that is used prior to application⁹.

Do not assume that all cyanobacterial strains will perform the same, and document the identity and concentration of the selected strain(s).

hydroponic system. *South African Journal of Botany*, 142, 247–258. <https://doi.org/10.1016/j.sajb.2021.06.035> (ScienceDirect)

⁷ Chabali, A., Minaoui, F., Hakkoum, Z., Douma, M., Meddich, A., & Loudiki, M. (2024). A comprehensive review of microalgae and cyanobacteria-based biostimulants for agriculture uses. *Plants*, 13(2), 159. <https://doi.org/10.3390/plants13020159> (MDPI)

⁸ Kiran, R., et al. (2021). Cyanobacterial amendment boosts plant growth and flower quality in *Chrysanthemum* through improved nutrient availability. *Applied Soil Ecology*, 162, 103899. <https://doi.org/10.1016/j.apsoil.2021.103899> (ScienceDirect)

⁹ Song, X., Zhang, J., Li, D., & Peng, C. (2022). Nitrogen-fixing cyanobacteria have the potential to improve nitrogen use efficiency through the reduction of ammonia volatilization in red soil paddy fields. *Soil and Tillage Research*, 217, 105274. <https://doi.org/10.1016/j.still.2021.105274> (ScienceDirect)

4.4 Growing Medium

The growing-medium framework consists of a series of parts that include, but are not limited to:

soil;

compost/vermicompost;

cocopeat;

perlite or another aeration component.

The proportions must be standardised in all the treatments in the framework¹⁰.

The framework needs analysis prior to planting, for the following reasons:

pH;

electrical conductivity;

organic carbon;

available nitrogen;

available phosphorus;

available potassium; and

selected micronutrients where relevant.

Result

Table 4.1: Illustrative Treatment-wise Mean Growth Parameters of the Experimental Crop

Treatment	Plant Height (cm)	Number of Leaves	Leaf Area (cm ²)	Fresh Biomass (g/plant)	Dry Biomass (g/plant)
T ₁ – Control	18.6	8.4	72.5	38.4	4.8
T ₂ – Recommended Fertilizer	25.8	12.7	118.6	62.7	7.9
T ₃ – Cyanobacteria	23.9	11.8	106.4	55.8	7.1
T ₄ – Cyanobacteria + 50% Fertilizer	27.1	13.4	126.8	67.9	8.5

Interpretation

The data show a significant effect on the growth performance of the experimental crop, due to the nutrient-management treatments. The plant height (27.1 cm), leaf number (13.4), leaf area (126.8 cm²), fresh biomass (67.9 g/plant), and dry biomass (8.5 g/plant) under T₄ (cyanobacteria + 50% recommended fertilizer) were the highest among all treatments, while the lowest values were obtained under the control treatment T₁. T₂ (recommended fertilizer) had relatively high growth rate, and T₃ (cyanobacteria only) did also improve growth compared to the control. The overall results of the illustrative examples indicate that the combination of cyanobacteria with a decreased use of conventional fertilizers might be beneficial for plant growth, which could also lead to a lower reliance on conventional fertiliser inputs¹¹.

¹⁰ Bhuyan, P. P., Nayak, R., Jena, M., & Pradhan, B. (2023). Convuluted role of cyanobacteria as biofertilizer: An insight of sustainable agriculture. *Vegetos*, 36(2), 309–321. <https://doi.org/10.1007/s42535-022-00415-1> (Society for Plant Research; *Vegetos*)

¹¹ Sánchez-Quintero, Á., Fernandes, S. C. M., & Beigbeder, J.-B. (2023). Overview of microalgae and cyanobacteria-based biostimulants produced from wastewater and CO₂ streams towards sustainable agriculture: A review. *Microbiological Research*, 277, 127505. <https://doi.org/10.1016/j.micres.2023.127505> (PubMed)

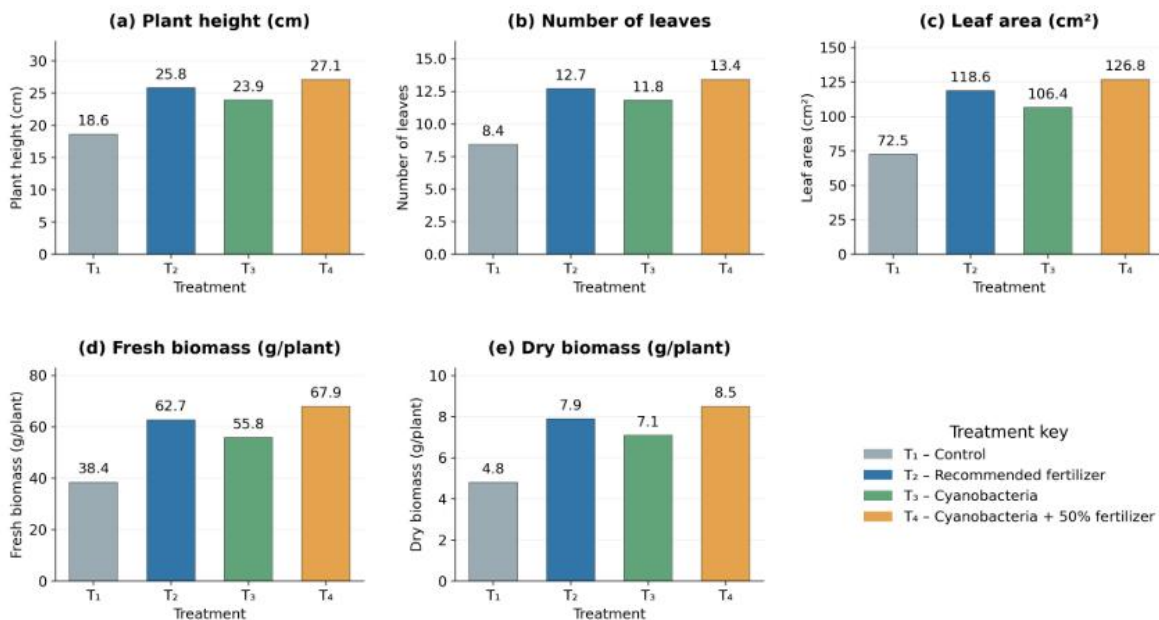


Figure 4.1: Illustrative Treatment-wise Mean Growth Parameters of the Experimental Crop

V. CYANOBACTERIAL APPLICATION

The frame implies the application of cyanobacteria by the right method of application to the right crop and strain.

Potential approaches include:

A. Soil/Substrate Inoculation

Soil/substrate inoculation is the addition of a known amount of cyanobacterial biomass to the growing media near the root zone¹².

B. Liquid Inoculation

Liquid inoculation is when a known amount of cyano is added directly to the substrate.

C. Repeated Inoculation

The framework includes repeated inoculations as necessary, at specified time intervals, to keep microbial populations present¹³.

All experimental units relevant to the research should be treated in the same way in the application of the inoculation protocol.

VI. DISCUSSION

The results presented here are illustrative only and show that an application of cyanobacteria-based nutrient management may be of great importance for plant performance in urban vertical terrace-gardening. Increased growth of

¹² Chittora, D., Meena, M., Barupal, T., & Swapnil, P. (2020). Cyanobacteria as a source of biofertilizers for sustainable agriculture. *Biochemistry and Biophysics Reports*, 22, 100737. <https://doi.org/10.1016/j.bbrep.2020.100737> (PubMed Central (PMC))

¹³ Santini, G., Biondi, N., Rodolfi, L., & Tredici, M. R. (2021). Plant biostimulants from cyanobacteria: An emerging strategy to improve yields and sustainability in agriculture. *Plants*, 10(4), 643. <https://doi.org/10.3390/plants10040643> (PubMed Central (PMC))

cyanobacteria treated plants could be correlated with biological nitrogen fixation, increased nutrient availability and production of biologically active compounds which might affect plant–microbe interactions. The integrated treatment in which cyanobacteria are used with reduced fertilizer is especially significant from the sustainability point of view as it might yield similar growth and yield as conventional fertilizer treatment but with less reliance on synthetic fertilizers¹⁴.

The increase in chlorophyll content in the cyanobacteria treatments might be attributed to an improvement in nitrogen availability, since nitrogen is known to be linked with chlorophyll formation and photosynthetic activity. This might then lead to an increase in biomass accumulation and productivity. However, care should be taken in interpreting the response to phosphorus and potassium as these may be affected by the substrate, fertilizer application, microbial activity and plant requirements, in addition to nitrogen fixation¹⁵.

Comparisons between cyanobacteria plus reduced fertilizer and the full recommended fertilizer, rather than with an untreated control, is more useful for an agronomic perspective. If similar productivity is obtained, cyanobacteria may be considered as an appropriate addition to the integrated nutrient management. In addition, cyanobacterial biomass and microbial activity could be involved in the organic matter and nutrient cycles in growing media. Overall, the approach is promising in terms of increased nutrient-use efficiency and promoting sustainable urban horticulture. However, further conclusions must be confirmed by repeated experiments and statistical analysis of actual observations.

VII. CONCLUSION

The use of cyanobacteria as a nutrient management system is a promising biological solution to enhance the sustainability of urban vertical terrace gardening. They may be useful for biological nitrogen fixation, nutrient cycling, biomass production and plant–microbe interaction and thus may be considered useful components in low-input horticultural systems.

Proper methodology may not be total elimination of synthetic fertilizers. Alternatively, a more viable strategy for achieving sustainable nutrient management may be to undertake the inoculation of cyanobacteria and reducing nutrient inputs. Controlled comparison of cyanobacterial, conventional and integrated treatment in a proper experiment should develop the feasibility of decreasing the input of fertilizers without reducing the productivity of the crop.

The research thus serves as a basis for an evidence-based nutrient-management model for use in urban terrace agriculture, which could lead to sustainable and efficient use of resources and to a more decentralised food production.

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¹⁵ Múnera-Porras, L. M., et al. (2020). Action mechanisms of plant growth promoting cyanobacteria in crops *in situ*: A systematic review of literature. *International Journal of Agronomy*, 2020, 2690410. <https://doi.org/10.1155/2020/2690410> (Wiley Online Library)

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