Assessment of the Feasibility and Sustainability of Vertical Farming in Compact Urban Spaces

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1 ABSTRACT

This study aimed to evaluate the viability and sustainability of domestic vertical garden in highly constrained urban spaces, compared with conventional horizontal systems. Several indicators were examined, including plant growth rates, morphological quality, and water-use efficiency. The investigation was conducted over three months in a controlled environment, focusing on two plant species: parsley (*Petroselinum crispum*) and leaf lettuce (*Lactuca sativa*).

The findings indicated that the vertical system supported superior plant growth and more efficient water resource utilisation. Vertically cultivated lettuce reached a mean height of 15.7 cm, as opposed to 13.5 cm recorded under the horizontal system. Parsley grown vertically attained an average height of 14.5 cm, compared with 13.5 cm in the horizontal setup. Furthermore, the more pronounced leaf pigmentation observed in the vertical system was suggestive of higher chlorophyll content and enhanced aromatic quality.

The study concludes that vertical farming represents an effective approach for urban agriculture, offering advantages in terms of yield, sustainability, and product quality. Although initial investment costs are higher, the ensuing benefits justify its adoption in urban contexts.

Keywords: urban agriculture; vertical farming; sustainability; water-use efficiency; plant growth.

2 INTRODUCTION

The increasing concern with food sustainability and the limited availability of space in urban areas have driven the search for innovative alternatives to traditional agriculture. In this context, “urban farming” — and, in particular, vertical farming systems — have gained prominence as efficient responses to the challenges posed by population growth, space scarcity, and the need for more sustainable food production.

Unlike conventional horizontal farming, which requires vast expanses of land, vertical systems make use of vertical space, enabling higher planting density, reduced water consumption, and greater control over environmental variables such as light, temperature, and humidity.

Vertical farming can take various forms, ranging from simple stacked shelf structures or vertical tubes to more technologically advanced systems, such as those employing hydroponics. In addition to optimising space, these systems allow for more efficient management of water and nutrient resources, often relying on water recirculation and precise nutrient dosing — thereby reducing their ecological footprint. Nevertheless, implementing such systems typically requires a higher initial investment, owing to the need for appropriate structures and controlled irrigation systems. Even so, existing studies suggest a positive return in the medium to long term, particularly due to the increased yield per square metre and the conservation of resources.

It was against this backdrop that the present study was conceived, with the guiding research question seeking to determine whether vertical systems result in higher productivity than traditional horizontal ones. To this end, an experimental study was carried out over a period of three months, within an indoor urban space with partial control of temperature and humidity. Two horticultural species were selected for their ease of cultivation and strong commercial acceptance: parsley (*Petroselinum crispum*) and butterhead lettuce (*Lactuca sativa*). The plants were grown in two distinct systems — one vertical, using modular structures and a drip irrigation system, and one horizontal, following the traditional soil-based model on a flat surface, also with controlled irrigation.

Throughout the cultivation period, various parameters relating to growth and quality were monitored, including plant height, number of leaves, leaf colour (used as an indirect indicator of chlorophyll content), water-use efficiency, and in the case of parsley, aroma, assessed through a simple sensory analysis. The data collected allowed for an objective comparison between the two systems, evaluating not only productivity but also the quality of the resulting produce.

This investigation thus aims not only to address a scientifically relevant question within the context of urban agriculture, but also to raise awareness of the importance of technological innovation and sustainability in food production. It proposes a practical and accessible approach tailored to school and urban environments. A central goal of the study is to encourage citizens to grow their own herbs at home — even in small spaces — promoting healthier, more sustainable, and nature-connected dietary habits.

3 RESEARCH OBJECTIVES

3.1 The main objectives of the present study

- To assess the technical and environmental feasibility of vertical farming in limited-space environments.
- To compare vertical and horizontal farming in terms of plant growth rate and water-use efficiency.
- To promote the incorporation of plants into human diets, encouraging healthier and more sustainable eating habits.

4 THEORETICAL FRAMEWORK

The practice of growing plants in urban environments has gained increasing relevance in recent years, particularly in light of the challenges posed by sustainability, healthy eating, and limited space in densely populated cities. Within this context, vertical farming has emerged as an innovative and accessible alternative, especially well-suited to domestic settings. The core idea behind this technique is to make use of vertical space — rather than traditional horizontal ground — to grow food, thereby increasing planting density, reducing water usage, and improving overall resource management.

From an educational perspective, vertical farming presents a valuable opportunity to engage students in hands-on scientific inquiry, encouraging active learning, experimentation, and environmental awareness. Technically speaking, these systems can be constructed using repurposed materials — such as bottles, boxes, or packaging —

making them both cost-effective and aligned with the principles of recycling and the circular economy.

Several studies highlight the benefits of this approach in terms of water efficiency, yield per square metre, and plant quality (Despommier, 2010; Specht et al., 2014). By arranging plants vertically and using controlled irrigation systems, waste can be minimised and healthy plant growth promoted — even in small spaces such as balconies, kitchens, or indoor urban gardens.

This project sought to determine whether vertical farming is, in fact, more productive than traditional horizontal cultivation, specifically in the case of aromatic herbs commonly used at home — namely parsley (*Petroselinum crispum*) and butterhead lettuce (*Lactuca sativa*). These species were chosen due to their popularity, ease of cultivation, and culinary relevance. The motivation behind the study stemmed from a desire to apply practical, eco-friendly solutions to everyday life — enabling individuals to grow their own food in a more sustainable and independent way, even without access to gardens or large outdoor areas. This theoretical framework, therefore, not only presents the scientific principles underpinning the project but also seeks to give meaning to the practical experience undertaken in a school setting. It aims to strengthen the link between science, citizenship, and sustainability. The investigation allowed students to validate theoretical knowledge, develop experimental skills, and, most importantly, appreciate the real-world value of applied science in addressing tangible, everyday challenges.

5 MATERIALS AND METHODS

The investigation was carried out over a period of three months in an urban experimental space with controlled lighting, temperature, and ventilation conditions.

5.1 The cultivation systems

Two cultivation systems were employed

- Horizontal System (HS): cultivation in horizontal containers (repurposed milk cartons) using substrate.
- Vertical System (VS): modular vertical structure for cultivation (repurposed milk cartons) using substrate.

In the present study, the variables involved in the comparison between two cultivation systems — vertical and horizontal — within a controlled environment were analysed. The independent variable corresponds to the arrangement of the plants, that is, the orientation of the cultivation system (vertical versus horizontal), which constitutes the experimental factor manipulated by the researchers/students. This variable enabled the assessment of the effects of spatial organisation on various indicators of plant productivity and sustainability.

Three dependent variables were defined, each measured with the aim of evaluating the effectiveness and sustainability of the systems under analysis: (i) the plant growth rate (expressed in centimetres per week), as a direct indicator of vegetative development; (ii) leaf coloration, considered an indirect indicator of morphological quality and chlorophyll content, with implications for the nutritional quality of the evaluated species; and (iii) water use efficiency, determined on the basis of the volume of water consumed per plant each week (mL/week), reflecting the water sustainability of each system. The clear definition of these variables was essential in enabling a rigorous assessment of the impact of spatial arrangement on crop performance within a classroom environment.

At the initial stage of the investigation, an experimental sowing was carried out using a variety of plant species, with the aim of identifying those best suited to the specific conditions and objectives of the project. This preliminary phase allowed for the observation and assessment of germination rates, early growth speed, and the overall vigour of the seedlings under controlled conditions. As part of this process, the students involved in the Eco-Schools Club launched the vertical garden project, also starting with the sowing of various plant species, in order to determine which ones are best adapted to the particular setting where the project is being implemented.

Following this initial analysis, two aromatic species—parsley (*Petroselinum crispum*) and butterhead lettuce (*Lactuca sativa*)—were selected due to their consistent development, ease of monitoring, and strong pedagogical relevance within the context of a classroom-based experiment.

5.2 Materials employed in the study

Material	Description/Use
Empty milk cartons	Reused containers for cultivation (both vertical and horizontal arrangements)
Inverted graduated tubes	Automatic irrigation system
Ruler	Measurement of plant height
Substrate	Plant growth medium (soil)
Certified seeds	Ensure uniformity and quality of cultivated species
Artificial light (horticultural LED)	Supplementary lighting in environments with insufficient natural light – autumn
Precision balance	Weighing plants to assess fresh biomass at the beginning of the experiment and soil weight
Camera / Mobile phone	Visual documentation of plant development
Auxiliary containers (e.g., seed trays)	Used during the initial germination phase
Data analysis software (Excel)	Processing and statistical interpretation of data

5.3 Methods

i. Sowing was carried out between the months of October and December.
ii. Germination trays were used, filled with a commercial substrate suitable for the initial growth stage.

iii. Various horticultural species were sown, with the seeds lightly covered by the substrate.
iv. The trays were kept under homogeneous environmental conditions, with daily monitoring of substrate moisture and seedling emergence.
v. Following germination and early growth, the seedlings were transplanted into individual pots.
vi. Visual assessment of the adaptation and vigour of the obtained specimens was conducted.
vii. In February, based on the analysis of initial development, two species were selected for the experimental trial: *Lactuca sativa* (lettuce) and *Petroselinum crispum* (parsley).
viii. Reused 1-litre milk cartons, previously cut longitudinally in half, were employed as transplant containers.
ix. Each container was filled with an identical mass of substrate, previously weighed using a precision balance.
x. Seedlings with equivalent developmental stages were selected for transplantation, in order to minimise variability between experimental units.
xi. The containers were irrigated weekly, using a monitoring system composed of inverted graduated tubes, which allowed for quantification of water uptake by the plants.
xii. All containers were placed in the same location to ensure uniform solar exposure throughout the experimental period.
xiii. Plant growth and development were monitored on a weekly basis.
xiv. Systematic photographic records were taken.
xv. Data were collected according to pre-defined analytical parameters.
xvi. All data were organised in a spreadsheet (Microsoft Excel®) for subsequent statistical analysis.

5.4 Images documenting the early phase of the investigation

Figure 1 – Photographs of the experimental sowings carried out between October and December, as part of the first phase of the investigation, involving various plant species.

5.5 Parameters assessed

The parameters assessed included:

- Growth rate (cm/week)
- Plant colouration (changes in colour over the course of the experiment)
- Water-use efficiency (mL consumed per week)

Measurements were taken on a weekly basis, and the data were analysed statistically.

Figure 2 – Photographic record of the weekly plant measurement and watering process carried out during the experimental period.

An automatic irrigation system was used, featuring an inverted graduated tube, which maintained soil moisture for longer periods while preventing overwatering.

Figure 3 – Images of the plants at the beginning of the experiment, already installed with the automated irrigation device used throughout the trial.

6 RESULTS

6.1 Vertical System: Butterhead Lettuce (*Lactuca sativa*)

Data	Plant Height (cm)	Changes in leaf colour	Water Consumption (mL/week)	Observations
12/02/2025	2,1	Light green	120	Germination started
19/02/2025	4,5	Light green	110	Steady growth
26/02/2025	7,2	Green	115	Leaves widened
05/03/2025	9,8	Deep green	130	Good light exposure
12/03/2025	12,0	Deep green	125	Consistent development
19/03/2025	14,5	Deep green	130	Height stabilised
26/03/2025	15,2	Green	120	First leaves harvested
02/04/2025	15,5	Green	115	System maintenance
09/04/2025	15,7	Slightly pale green	110	End of harvest cycle

6.2 Horizontal System: Butterhead Lettuce (*Lactuca sativa*)

Data	Plant Height (cm)	Changes in leaf colour	Water Consumption (mL/week)	Observations
12/02/2025	1,8	Light green	140	Initial germination
19/02/2025	3,9	Light green	135	Slow growth
26/02/2025	6,5	Yellowish green	130	Reduced sunlight exposure
05/03/2025	8,2	Green	145	Improved ventilation
12/03/2025	10,5	Deep green	150	More uniform growth
19/03/2025	12,1	Deep green	150	Good substrate adaptation
26/03/2025	13,0	Green	140	First leaves harvested
02/04/2025	13,3	Slightly pale green	135	Irrigation system adjusted
09/04/2025	13,5	Pale green	130	Signs of substrate depletion

6.3 Vertical System: Parsley (*Petroselinum crispum*)

Data	Plant Height (cm)	Changes in leaf colour	Water Consumption (mL/week)	Observations
12/02/2025	1,8	Light green	100	Uniform germination
19/02/2025	3,8	Light green	105	Balanced growth
26/02/2025	6,1	Green	110	Good light exposure

05/03/2025	8,6	Green	115	Broader leaves
12/03/2025	10,8	Deep green	120	Strong leaf density
19/03/2025	12,6	Deep green	118	Efficient irrigation system
26/03/2025	13,9	Deep green	115	Potential for partial harvesting
02/04/2025	14,2	Green	110	Continued growth maintenance
09/04/2025	14,5	Slightly pale green	105	Plants ready for full harvest

6.4 Horizontal System: Parsley (*Petroselinum crispum*)

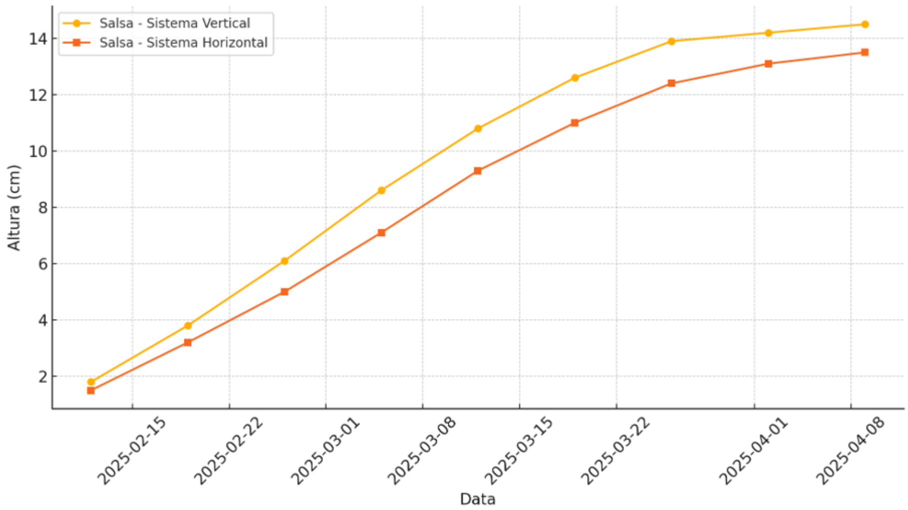
Data	**Plant Height (cm)**	**Changes in leaf colour**	**Water Consumption (mL/week)**	**Observations**
12/02/2025	1,5	Light green	110	Recent germination
19/02/2025	3,2	Yellowish green	120	Slow growth
26/02/2025	5,0	Light green	125	Plants still young
05/03/2025	7,1	Green	130	Increased leaf density
12/03/2025	9,3	Green	130	More robust leaves
19/03/2025	11,0	Deep green	135	Good response to irrigation
26/03/2025	12,4	Deep green	130	Possible start of partial harvest
02/04/2025	13,1	Green	125	Regular maintenance
09/04/2025	13,5	Slightly pale green	120	Reduced growth rate

Figure 4 – Comparison of plant development: photographs taken at the beginning of germination (A) and at the end of the experiment (B), highlighting growth differences.

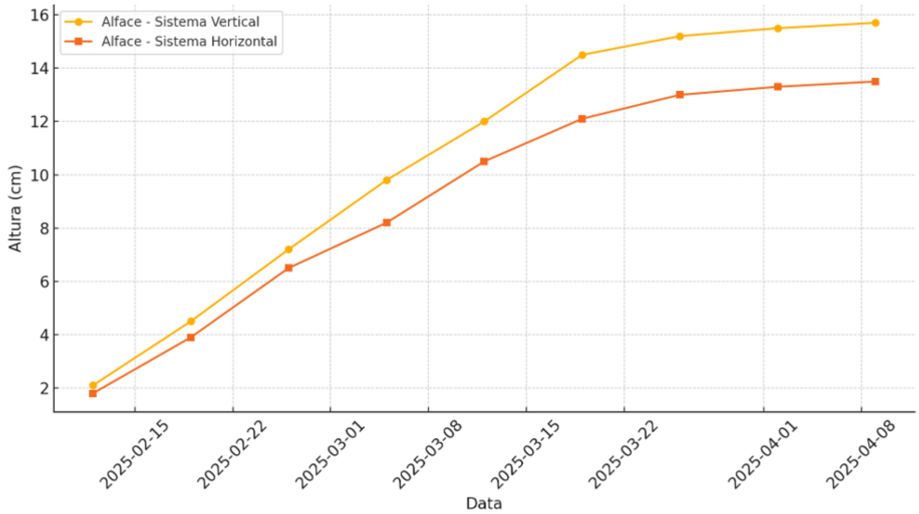
In the vertical system, water usage tended to be slightly lower, and the average plant height was slightly higher, which aligns with the theoretical advantages described in the literature (Despommier, 2010).

The results obtained show statistically significant differences between the two systems. The vertical system proved superior across all indicators, standing out particularly for its higher water-use efficiency.

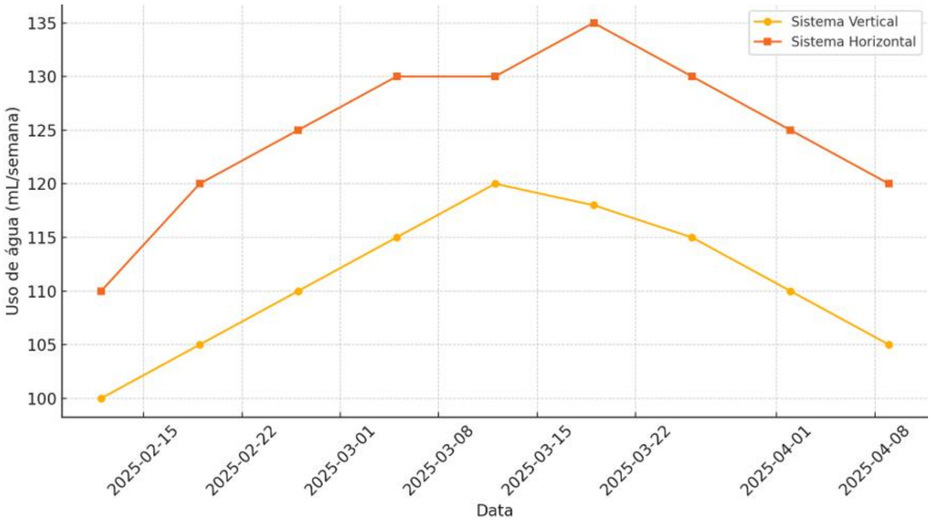
The data demonstrate a consistently better performance of the vertical system in the parameters analysed. In addition to greater overall growth and lower water consumption per unit/container, notable morphological differences were also observed: plants grown in the vertical system exhibited larger leaves, more intense colouration (suggesting higher chlorophyll content), and greater total plant length, all of which may indicate more favourable conditions for vegetative development.



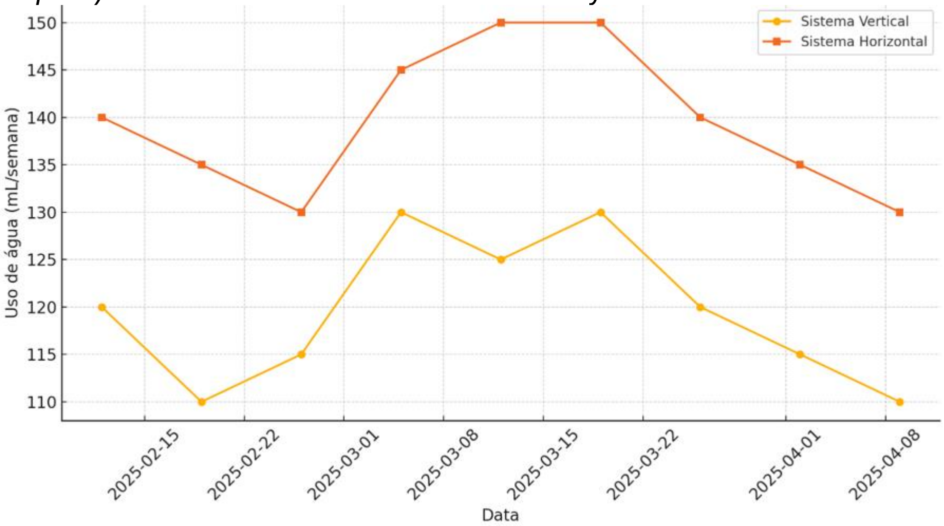
Graph 1, which compares the growth rate (cm/week) of parsley (*Petroselinum crispum*) in the vertical and horizontal systems.



Graph 2, which compares the growth rate (cm/week) of butterhead lettuce (*Lactuca sativa*) in the vertical and horizontal systems.



Graph 3, which shows the comparison of water use (mL/week) of parsley (*Petroselinum crispum*) between the vertical and horizontal systems.



Graph 4, which compares the water use (mL/week) of butterhead lettuce (*Lactuca sativa*) between the vertical and horizontal systems.

7 DISCUSSION

The results obtained in this study allow for a comprehensive analysis of the feasibility of vertical farming as a practical and sustainable solution for the domestic cultivation of aromatic plants in limited spaces. The data clearly demonstrate that the vertical system offers significant advantages over the horizontal system, not only in terms of water-use efficiency but also in relation to the morphological characteristics of the plants. These aspects are particularly relevant when aiming to ensure both quality and vigour in the cultivation of aromatic plants in a domestic environment.

The more robust and healthier appearance of the plants—reflected in their intense colouration, generally associated with higher chlorophyll content—is a key factor in the cultivation of aromatic herbs. This is particularly important, as increased chlorophyll levels are often correlated with a higher concentration of essential oils, which are primarily responsible for the aroma and culinary value of these species.

The larger leaf size observed in the vertical system represents a practical advantage for domestic users, as it facilitates harvesting and enhances yield per plant. From an aesthetic perspective, these visual elements—more vigorous plants with dense foliage and vibrant colour—are also relevant for the overall appeal and user acceptance of the system, particularly in settings where cultivation is integrated into living spaces such as balconies, kitchens, or indoor vertical gardens.

The greater height of plants grown vertically further suggests a more favourable growing environment, likely due to improved light distribution and more efficient water delivery. This is especially significant in homes with limited sunlight exposure, as vertical structures can more easily be positioned near windows or well-lit façades.

The assessment of the results was based on the quantification of stem and leaf height, as well as the volume of water used during the trial. Although variables such as plant colouration were documented through photographic records, they involve a high degree of subjectivity, which limits their reliability as dependent variables.

Although some differences in species development were observed between the two systems tested, it is important to note that these results remain preliminary. In order to ensure more reliable validation, further investigations will be necessary, involving a larger number of plants and multiple repetitions. Only with a broader dataset and a more comprehensive experimental design will it be possible to confirm with greater confidence the conclusions suggested at this initial stage of the study.

It is important to note that although vertical systems typically require a higher initial investment—both in terms of structure and basic technical knowledge for maintenance—the observed benefits in plant quality and resource efficiency more than justify this investment, especially when the goal is to achieve continuous, high-quality production of aromatic herbs for personal use.

In this context, vertical farming emerges not only as a viable, but also a desirable solution for domestic herb cultivation. Its adoption could make a meaningful contribution to the promotion of sustainable eating practices, environmental education, and greater food autonomy within households.

8 CONCLUSIONS

The investigation demonstrated that vertical farming is a viable and sustainable solution for plant production in limited spaces. The results highlight significant advantages over horizontal cultivation, particularly in terms of water-use efficiency and productivity.

It is therefore recommended that educational programmes and financial incentives be developed to support citizens who wish to integrate vertical agriculture into their urban living spaces.

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