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Assessment of vertical hydroponic structures compared to planting in soil under different light conditions

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The aim of this research was to evaluate the performance of small-scale vertical hydroponic structures compared to indoor planting in soil under different light conditions. Fordhook Giant Swiss chard (*Spinacea oleracea*) was grown for 2 cropping seasons. It was hypothesized that there would be no significant difference in the biometric attributes of the plants grown hydroponically and those grown in soil under different light conditions. Plants grown hydroponically had a significantly higher relative growth rate than plants grown in soil (0.090 $g.g^{-1}.day^{-1}$ vs 0.080 $g.g^{-1}.day^{-1}$ in cropping season one (CS1), and 0.085 $g.g^{-1}.day^{-1}$ vs 0.079 $g.g^{-1}.day^{-1}$ in CS2), $p = 0.030$ in CS1 and $p = 0.011$ in CS2. There was a statistically significant difference between the total leaf area per plant of plants grown hydroponically and those grown in soil (1 263.39 vs 914.32 mm^2 in CS1 and 1 286.98 vs 896.63 mm^2 in CS2), $p < 0.01$ in both cropping seasons. The results indicate that small-scale vertical hydroponic structures can be used as an applicable alternative to conventional potting systems in indoor planting. The study has contributed new quantitative information about the performance of vertical hydroponic structures, which may aid potential farmers in decision making.

Key words: Vertical farming, hydroponics, indoor farming, grow lights, relative growth rates.

INTRODUCTION

It is projected that by the year 2050, there will be a global population of over 9 billion (Gu et al., 2021). It is further estimated that food production will need to be increased by 70% to adequately meet the food requirements of this population. To achieve this, current food production rates will have to be doubled (Pawlak and Kolodziejczak, 2020).

However, achieving this goal will be challenging due to several drivers, such as spikes in population numbers, arable land limitations, and climate change, among others, impacting and continuing to impact food production. Therefore, there exists a need for high-yielding food production methods that are sustainable as well. Consequently, there is an increased focus on

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developing technologies that move agriculture away from traditional practices towards smart agricultural practices (Abbasi et al., 2022). The concept of using the vertical plane for food production is an example of the application of such technologies. Vertical farming is defined as a method of farming where plants are cultivated through multilayer production to increase the yield obtained per surface area. It is practiced in soilless media under controlled environmental conditions. Vertical farming can be conducted in plant factories or shipping containers that are fitted with artificial light, greenhouses, existing buildings, and new buildings specifically designed for indoor farming (Gerrewey et al., 2022; Goh et al., 2023).

The aim of the research was to evaluate the performance of small-scale vertical hydroponic structures compared to growth of plants in soil in plant pots that were exposed to different light conditions. The growth parameters that were evaluated were the plant dry weights mean total leaf areas per plant, relative growth rates, and the leaf area indices. The objectives of the study were:

a) To compare the growth parameters of plants grown in vertical hydroponic structures under sunlight and Light Emitting Diode (LED) grow lights to that of soil grown plants in plant pots under sunlight and under LED grow lights for two nutrient concentration levels, and
b) To determine the difference between biometric attributes of plants grown hydroponically under LED grow lights and those grown hydroponically under sunlight.

LED grow lights were selected because they are lightweight, have low energy consumption, and emit minimal heat compared to conventional indoor grow lights (Landi et al., 2020). Two null hypotheses were posited. The first hypothesized that there would not be a significant difference between the plant growth parameters of Fordhook Giant Swiss chard (*Spinacea oleracea*) grown in vertical hydroponic structures under LED grow lights and sunlight, compared to those grown in soil in plant pots under LED grow lights and sunlight for the two nutrient concentration levels. The second hypothesized that the biometric attributes of plants grown in vertical hydroponic structures under LED grow lights and those grown in vertical hydroponic structures under sunlight would not be significantly different from each other.

MATERIALS AND METHODS

The hydroponic system was designed as a vertical column to optimize space utilization. Fordhook giant Swiss chard was selected for its nutrient richness and adaptability to various hydroponic setups (Parkell, 2016). The study was carried out at the Ukulinga Research Farm located in Mkhondeni, Pietermaritzburg, within the Engineering Practical's Laboratory. Two growing periods were established for the trials. The first trial commenced in February and concluded in March 2020, while the second trial began in October and concluded in November 2020.

Experimental design

A complete randomized block design was utilized, incorporating three experimental factors with two levels each. The primary factor was the type of growing method, with levels being plant growth in vertical hydroponic structures versus plant growth in soil in plant pots. The type of grow light provided constituted the first sub-factor, with levels being artificial light versus sunlight. A light intensity of 260 $\mu mol.m^{-2}.s^{-1}$ was selected for the experiment, maintaining a photoperiod of 18 h (Kang et al., 2013). Red/blue LED grow lights were chosen in a 4:1 ratio to supply light within the photosynthetically active radiation range. The blue light's wavelength ranged from 450 to 470 nm, while the red light's wavelength ranged from 650 to 670 nm. The second sub-factor was the nutrient solution concentration, with the first concentration level (C1) at 1.4 $g.l^{-1}$ and the second concentration level (C2) at 1.9 $g.l^{-1}$ (Kumari et al., 2018). These concentrations were selected to investigate potential differences across different concentration levels in the growing method and light treatments. Each treatment had four replications. Fordhook Giant Swiss Chard (*S. oleracea*) was cultivated from the seedling stage. For the soil treatment, plant pots were utilized, and Gromor potting soil served as the growing medium (Amelework et al., 2016). Each light treatment comprised 160 plant pots, with one seedling per pot. Eighty plants were irrigated with C1, and the other eighty were irrigated with C2 within the two light treatments. The pots were labeled to differentiate between the two concentrations and were randomly placed. The pots occupied 5 m^2 in each light treatment. Although temperature and relative humidity sensors were installed for the experiment, it was discovered during data collection that the sensors had malfunctioned, rendering the collected data unusable.

In the hydroponic treatment, polyvinyl chloride (PVC) pipes were utilized to contain the plants. Each pipe measured 1200 mm in length with a diameter of 110 mm and accommodated twenty plants. Holes were created in the pipes to accommodate the plants, and fifty ml net pots were employed to secure each plant within the holes, with one plant per net pot. Expanded clay pebbles were used as a growing medium to anchor the plants within the net pots. The PVC pipes were affixed to a metal frame, with two frames in total, each supporting 160 plants; one frame was placed under the grow light treatment, and the other under sunlight. Half of the plants in each light treatment received irrigation with C1, while the other half received irrigation with C2. Nutrient solution was delivered to the plants through micro-sprayers attached to a 20 mm pipe connected to a reservoir containing the nutrient solution. Gutter pipes facilitated the recirculation of the nutrient solution back to the reservoir. A 1,200 $L.h^{-1}$, 2 m submersible pump facilitated the recirculation of the nutrient solution throughout the hydroponic system. Figure 1 provides a rough sketch of the hydroponic structures employed, although the sketch.

Fertigation and irrigation

Stark Aryes Nutrifeed (Xego et al., 2016) was selected as the nutrient solution due to its suitability for hydroponic systems and potting soil. The nutrient solution comprised the following macronutrients: Potassium (13%), Sulphur (7.5%), Calcium (7.0%), Nitrogen (6.5%), Phosphorus (2.7%), and Magnesium (2.2%). Additionally, it contained micronutrients such as Molybdenum, Boron, Iron, Copper, Sulphur, Zinc, and Manganese. Upon transplanting the seedlings, Trichoderma was introduced into the nutrient solution to safeguard against diseases commonly affecting leafy vegetables, including wilting and leaf spot (Bhale et al., 2012). Pest control was managed by biweekly application of diatomaceous

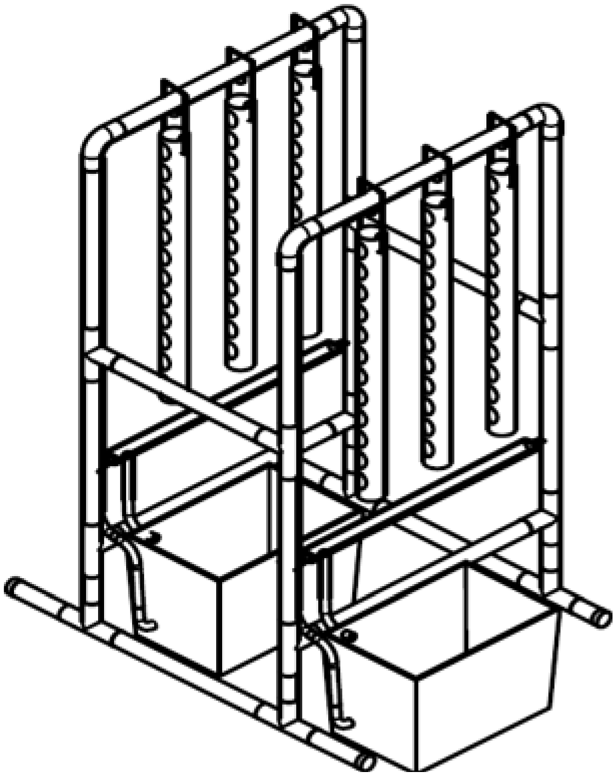

Figure 1. Sketch of the hydroponic structure (not to scale).

earth coating on the plant leaves to deter infestations by pests like thrips and aphids (Buss and Brown, 2006). For soil-grown plants, irrigation requirements were determined using the Irrigation Design Manual (Burger et al., 2003), indicating a need for 5 mm of water every three days, with nutrient solution application occurring every second watering. To ensure appropriate soil moisture levels, a TEROS 21 soil water potential meter (METER Group, Inc. USA) with ± 10% accuracy (Eliades et al., 2018) was utilized alongside a Decagon ProCheck readout device (Bart et al., 2015). In the hydroponic treatment, the nutrient solution was refreshed weekly to prevent salt precipitation from clogging the pumps. An ECO Testr EC meter (Eutech Instruments, Singapore) with ± 1% accuracy (Stanley et al., 2014) was employed to maintain the electrical conductivity (EC) of the hydroponic solution between 1.5 and 2.5 dS.m^{-1} (Kumari et al., 2018). If the EC value exceeded the recommended range, the solution was diluted with water, while additional nutrient solution was added if the EC value dropped below the specified range. pH levels were also monitored and adjusted to stay within the optimal range of 5.5 to 6.5 for chard grown in hydroponic systems (Sardare and Admane, 2013), with pH up or pH down solutions added as needed to maintain the desired pH levels.

Data collection

Data collection was conducted through destructive sampling, occurring once every two weeks. From each treatment, three plants were randomly chosen. Biometric measurements included leaf area as well as fresh and dry weights of roots, stems, and leaves. For soil-grown plants, roots were washed to remove soil and ensure accurate weights. Leaf area was determined using the Leaf-IT application with a ± 0.5% accuracy (Schrader et al., 2017). The weights of various plant components were measured using the Kern-SOHN ALS250-4A analytical balance. Subsequently, the plants were dried in an oven dryer at 65°C for 24 h to obtain dry weights.

Data analysis

Plant growth analysis measures, such as leaf area indices and relative growth rates, were derived from the biometric attributes following methods described by Hunt (1990). The leaf area index (LAI) illustrates the relationship between the total plant leaf area and the area of the soil surface. A LAI greater than 1 indicates efficient utilization of solar energy, whereas a value less than 1 suggests that some solar energy is wasted on the soil or weeds (Winch, 2007). LAI is calculated using Equation 1 as outlined by Hunt (1990).

$$\bar{L} = \frac{\frac{L_{A1}}{P_1} + \frac{L_{A2}}{P_2}}{2} \tag{1}$$

where $\bar{L}$ is the average leaf area index [unitless], L_{An} average leaf area at time n [mm^2], and P_n is the average total ground area upon which the plant stands at time n [mm^2].

The plant relative growth rate (RGR) is the rate at which new dry mass accumulates for each unit of existing dry mass (Lowry and Smith, 2018). Hoffmann and Poorter (2002) distinguished RGR as the most important growth characterisation parameter. RGR is determined using Equation 2 (Hunt, 1990).

Table 1. The mean growth parameters in cropping season one (CS1) and two (CS2) of plants grown in vertical hydroponic structures and in soil in plant pots.

Parameter		CS1			CS2		
		Vertical hydroponics	Soil	Probability	Vertical hydroponics	Soil	Probability
Mean growth	Relative growth rate ($g.g^{-1}.day^{-1}$)	0.0903	0.0803	< 0.05	0.0853	0.0790	< 0.05
	Total plant dry weight (g)	19.00	12.53	< 0.01	19.42	14.52	< 0.01
	Total leaf area per plant (mm^2)	1 263.39	914.32	< 0.01	1 286.98	896.63	<0.01
	Leaf area index	5.59	4.06	< 0.01	5.69	3.95	< 0.01

$$\bar{R} = \frac{\log_e W_2 - \log_e W_1}{T_2 - T_1}$$

$\bar{R}$ is the average relative growth rate [$g.g^{-1}.week^{-1}$], W_n is the total dry weight per plant at time n [g], and T_n is the time of harvest [week].

An analysis of variation (ANOVA) at a 95% confidence interval using IBM SPSS Statistics 26 (Dytham, 2011) was used to conduct statistical analysis of the results of two cropping seasons. The analysis was conducted by comparing the dry weight, leaf area, LAI, and RGR values of the different treatments and determining whether a significant difference existed amongst them. Once a significant difference was established, pairwise comparisons were then used to establish between which treatments the significant difference existed.

RESULTS AND DISCUSSION

This part of the study presents the plant growth rates derived from plant biometric measurements. Plant dry weights were utilized in the analysis involving plant weights. Classical approach equations described by Hunt (1990) were employed to conduct plant growth analysis, encompassing relative growth rate, total leaf area per plant, leaf area index, and total plant dry weight. Statistical analysis was performed using analysis of variance (ANOVA) in IBM SPSS Statistics 26 (Dytham, 2011) to analyze the results across two cropping seasons (Feb-March and Oct-Nov). A three-way ANOVA was utilized to examine interactions among the plant growing method, light provision, and nutrient solution concentration for various plant variables, as detailed in the subsequent analyses. The nutrient solution concentration levels did not yield a significant effect on the plant growth parameters, implying that the interpretations of the study results are applicable across recommended nutrient solution concentration levels.

The effect of the growing method on plant growth parameters

The type of growing method demonstrated a significant effect ($P<0.01$) on the plant growth parameters assessed in the study. The mean growth parameters of plants grown in vertical hydroponic structures and those grown in potting soil, along with the corresponding probability values, are summarized in Table 1 for both cropping seasons. Plants grown in vertical hydroponic structures exhibited significantly higher mean total plant dry weights, mean total leaf areas per plant, and LAIs compared to those grown in potting soil ($P<0.01$). This difference can be attributed to the significantly higher RGR observed in plants grown in vertical hydroponic structures compared to those grown in soil in plant pots. Consequently, plants grown in vertical hydroponic structures developed at a significantly faster rate despite both treatments receiving the same nutrient solution at identical concentrations. This finding aligns with reports by Gruda (2019), suggesting that the use of inert artificial growing media in hydroponics enhances nutrient use efficiency in plants.

Gashgari et al. (2018) also reported similar results, indicating that plants grown hydroponically exhibit significantly higher growth rates than those grown in soil. Kang et al. (2020) attributed this outcome to the higher photosynthetic rates and increased partitioning of photosynthates to above-ground plant matter in hydroponically grown plants compared to soil-grown plants. In hydroponic systems, nutrients are supplied directly to the roots through continuous contact with the nutrient solution, leading to enhanced plant growth and development (Sardare and Admane, 2013). However, a meta-analysis conducted by Goh et al. (2023) produced mixed results. While certain crops such as anise, badian, fennel, coriander, chillies and peppers, and cucumbers and gherkins exhibited higher yields under hydroponic production, others like cabbages, lettuce, spinach, tomatoes, and other vegetables showed higher yields under conventional agriculture.

The combined effect of growing method and LED grow lights on plant growth parameters

The LED grow lights exerted a significant effect ($P< 0.05$) on plant growth parameters, leading to significantly higher values for both plants cultivated in vertical hydroponic structures and those grown in soil in plant

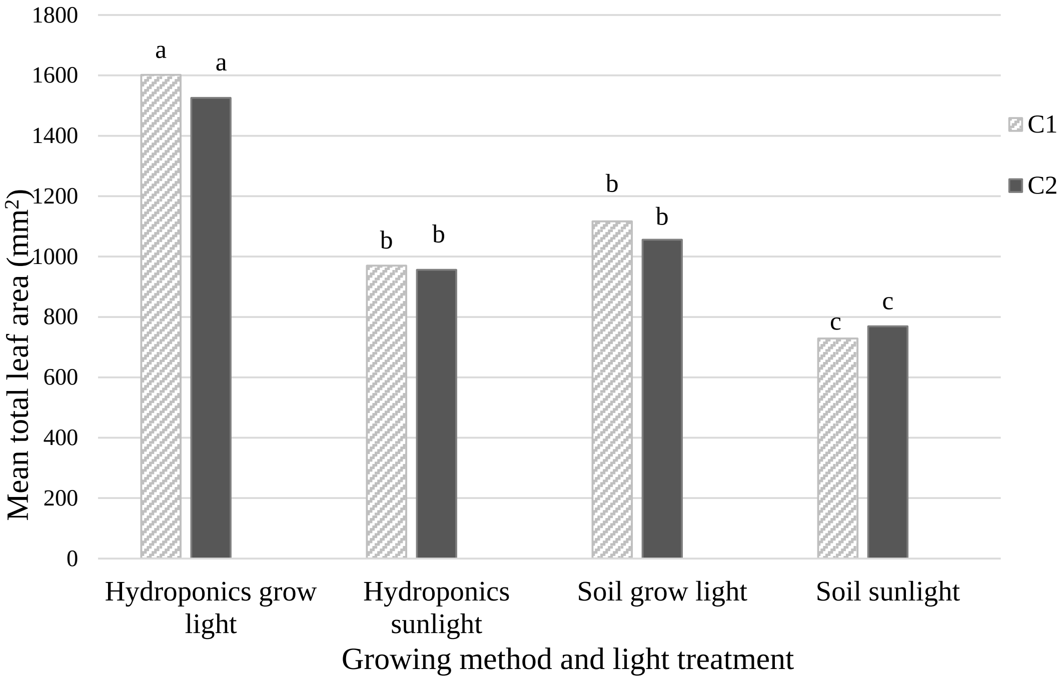

Figure 2. The mean total leaf area per plant (mm^2) in the first cropping season. Similar letters indicate no significant difference between treatments for a 95% confidence interval. C1 and C2 indicate the nutrient concentration levels.

pots. This enhancement can be attributed to the improved photosynthetic capacity facilitated by LED grow lights (Li et al., 2019). Interestingly, the disparity in biometric attributes between plants grown under LED grow lights and those under sunlight was more pronounced in the vertical hydroponic treatment compared to the soil treatment. This trend is evident in the mean total leaf areas per plant graphs (Figures 2 and 3) and the mean total dry weights per plant graphs (Figures 4 and 5). Such findings suggest that hydroponically grown plants make more efficient use of artificial grow lights, resulting in higher plant production compared to soil-grown plants. Consequently, in plant production scenarios utilizing artificial grow lights, hydroponic systems offer a viable alternative to soil growth for achieving optimal plant development.

An intriguing discovery was that the biometric attributes of plants grown in vertical hydroponic structures under sunlight were not significantly different from those grown in soil under LED grow lights. This similarity arose because the difference in RGRs between these two treatments was not statistically significant. The mean growth parameters of plants grown in vertical hydroponic structures under sunlight and in soil under LED grow lights, along with their corresponding probability values, are summarized in Table 2 for both cropping seasons. This outcome suggests that cultivating plants hydroponically under sufficient sunlight is statistically comparable to integrating LED grow lights into soil farming within controlled environments. Such a finding holds significance, as artificial grow lights have been identified as one of the primary energy consumers in controlled environmental agriculture (CEA). This discovery can guide farmers in decision-making processes. For example, small-scale vertical hydroponic systems could replace soil-based CEA systems where sunlight is supplemented with artificial grow lights during dark hours. This finding is particularly crucial because small-scale vertical hydroponic systems can operate using low-energy-consuming low-pressure pumps, such as submersible fountain pumps.

Comparison of growth parameters of plants grown hydroponically under different light treatments

The plants cultivated hydroponically under LED grow lights exhibited the highest mean total leaf areas per plant, as depicted in Figures 1 and 2. The mean total leaf areas per plant of plants grown in vertical hydroponic structures under LED grow lights were significantly greater than those under sunlight ($p < 0.01$ in both cropping seasons). Similarly, plants grown hydroponically under LED grow lights displayed the highest mean total dry weights per plant, as illustrated in Figures 3 and 4. The mean total dry weights per plant of plants grown in vertical hydroponic structures under LED grow lights were significantly higher than those under sunlight (p <

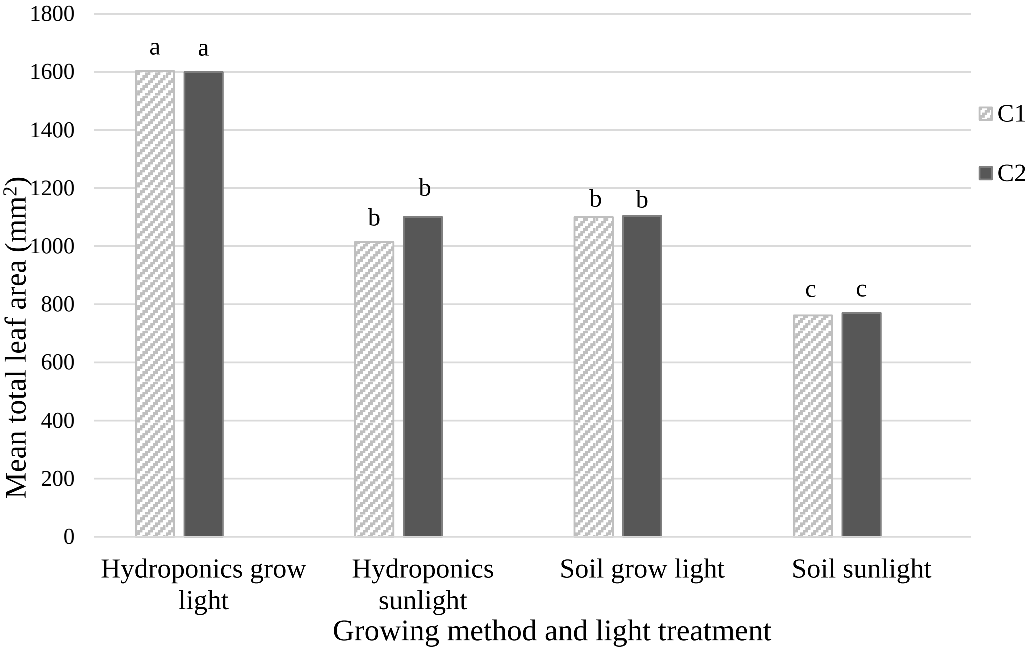

Figure 3. The mean total leaf area per plant (mm^2) in the second cropping season. Similar letters indicate no significant difference between treatments for a 95% confidence interval. C1 and C2 indicate the nutrient concentration levels.

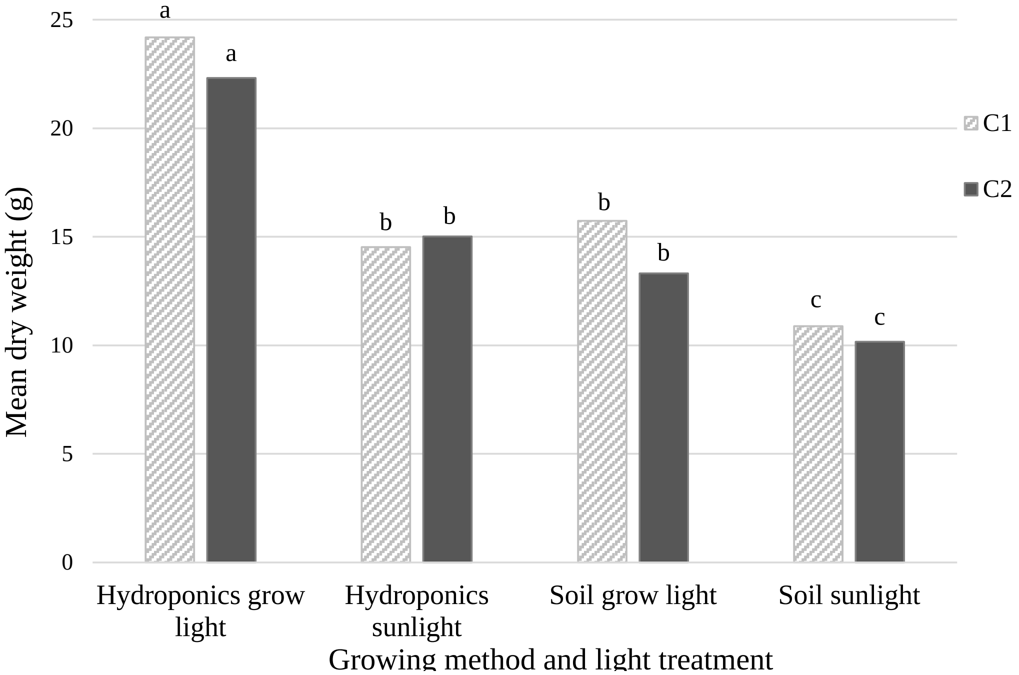

Figure 4. The mean total plant dry weight in the first cropping season. Similar letters indicate no significant difference between treatments for a 95% confidence interval. C1 and C2 indicate the nutrient concentration levels.

0.0005 in both cropping seasons). The observed significant differences in the biometric attributes of plants grown in vertical hydroponic structures under different light treatments were attributed to the effects of LED grow lights. As previously mentioned, LED grow lights enhanced the plants' photosynthetic capacity (Li et al.,

Table 2. The mean growth parameters in cropping season one (CS1) and two (CS2) of plants grown in vertical hydroponic structures and in soil in plant pots.

Parameter		CS1			CS2		
		VHSL	SGL	Probability	VHSL	SGL	Probability
Mean growth	Relative growth rate (g.g^{-1}.day^{-1})	0.0848	0.0842	0.910	0.0793	0.0818	0.463
	Total plant dry weight (g)	14.77	14.53	0.892	14.65	16.24	0.380
	Total leaf area per plant (mm^2)	963.19	1086.27	0.063	1006.25	1029.78	0.763
	Leaf area index	4.13	4.81	0.053	4.45	4.56	0.757

VHSL: Vertical hydroponics under sunlight, SGL: soil-grown plants under LED grow lights.

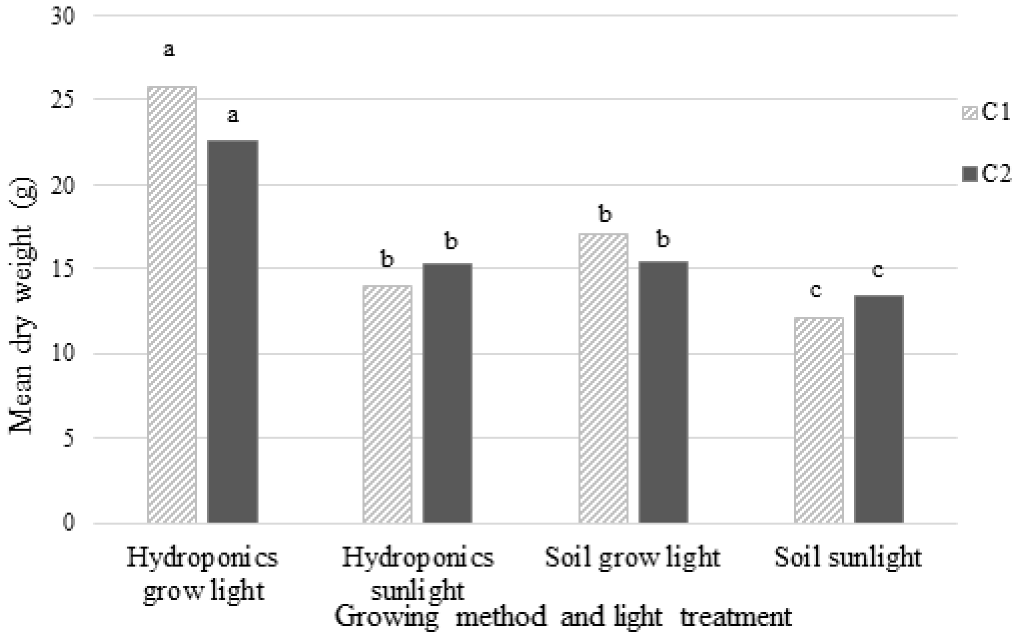

Figure 5. The mean total plant dry weight in the second cropping season. Similar letters indicate no significant difference between treatments for a 95% confidence interval. C1 and C2 indicate the nutrient concentration levels.

2019) and provided controlled radiation. The vertical hydroponic system under LED grow lights received consistent radiation unaffected by external factors such as weather or atmospheric particles, unlike the system under solar radiation. Therefore, a hydroponic system under LED grow lights can be expected to yield uniform and consistent results across different planting cycles, independent of atmospheric conditions.

CONCLUSIONS AND RECOMMENDATIONS

The research aimed to assess the performance of small-scale vertical farming structures compared to soil farming. Based on the analysis of plant biometric attributes, it can be concluded that small-scale vertical hydroponic structures offer a viable alternative to potted soil plant production. The findings indicate that growing plants in vertical hydroponic structures significantly enhances plant development. Moreover, plants grown in vertical hydroponic structures appear to utilize radiation from LED grow lights more efficiently and productively than those grown in soil. Therefore, the null hypotheses were rejected for these treatments, as the results disproved them. However, it was found that growing plants hydroponically under sunlight is statistically equivalent to growing plants in soil under LED grow lights. Hence, the null hypothesis held true for these treatments.

Although the study demonstrated the viability of small-scale vertical hydroponic structures, the current design has limitations in accommodating a diverse range of plants suitable for hydroponic cultivation. Nonetheless, further research opportunities exist to explore and compare different designs of small-scale vertical hydroponic structures to offer diverse alternatives for various farming setups. Additionally, to assess the practicality of replacing soil-based planting in CEA setups using hydroponics, further investigation is warranted. Such research could compare the resource use efficiencies of the two systems to determine whether hydroponic systems under sunlight would be more sustainable.

This study contributes to filling the gap in the literature regarding quantitative information on the performance of small-scale vertical hydroponic structures compared to conventional farming methods. Given the challenges associated with large-scale vertical farming, the study underscores that, whether under artificial or natural radiation, small-scale vertical hydroponic structures yield larger plants than soil-based methods. These results serve as a foundation for future research endeavors exploring vertical hydroponic plant production systems.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

Abbasi R, Martinez P, Ahmad R (2022). The digitization of agricultural industry – a systematic literature review on agriculture 4.0. Smart Agricultural Technology 2:100042.

Amelework A, Laing M, Shimelis H (2016). Evaluation of effective gametocides for selective induction of male sterility in sorghum. Czech Journal of Genetics and Plant Breeding 52:163-170.

Bart D, Davenport T, Carpenter Q (2015). Stress and land-use legacies alter the relationship between invasive-and native-plant richness. Journal of Vegetation Science 26(1):80-88.

Bhale UN, Ambuse MG, Chatage VS, Rajkonda JN (2012). Bioefficacy of Trichoderma isolates against pathogenic fungi inciting spinach (*Spinacea oleracea* L.). Journal of Biopesticides 5(2):222.

Burger J, Heyns P, Hoffman E, Kleynhans E, Koegelenberg F, Lategan M, Mulder D, Smal H, Stimie C, Uys W, van der Merve F, van der Stoep I, Viljoen P (2003). Irrigation Design Manual. Agricultural Research Council - Institute for Agricultural Engineering, Pretoria, South Africa.

Buss E, Brown S (2006). Natural Products for Insect Management. University of Florida. Available at: https://www.researchgate.net/profile/Eileen_Buss/publication/237391484_Natural_Products_for_Insect_Pest_Management1/links/00b4952a5dbef7e2b4000000.pdf.

Dytham C (2011). Choosing and Using Statistics: A Biologist's Guide. Wiley-Black, West Sussex, United Kingdom.

Eliades M, Bruggeman A, Djuma H, Lubczynski MW (2018). Tree water dynamics in a semi-arid, Pinus brutia forest. Water 10(8):1039.

Gashgari R, Alharbi K, Mughrbil K, Jan A, Glolam A (2018). Comparison between growing plants in hydroponic system and soil based system. Proceedings of the 4th World Congress on Mechanical, Chemical, and Material Engineering, ICMIE Madrid, Spain pp. 1-7.

Gerrewey VT, Boon N, Geelen D (2022). Vertical farming: The only way is up? Agronomy 12(1):2-17.

Goh YS, Hum YC, Lee YL, Lai KW, Yap WS, Tee YK (2023). A meta-analysis: Food production and vegetable crop yields of hydroponics. Scientia Horticulturae 321:112339.

Gruda NS (2019). Increasing sustainability of growing media constituents and stand-alone substrates in soilless culture systems. Agronomy 9(6):298.

Gu D, Andreev K, Dupre ME (2021). Major trends in population growth around the world. China CDC Wkly 3(28):604-613.

Hunt R (1990). Basic Growth Analysis Plant growth for beginners. Unwin Hyman Ltd, London, UK.

Kang DI, Hu J, Li Y, Jeong BR (2020). Growth, productivity, and quality of strawberry as affected by propagation method and cultivation system. Protected Horticulture and Plant Factory 29(4):326-336.

Kang JH, Krishnakumar S, Atulba SLS, Jeong BR, Hwang SJ (2013). Light intensity and photoperiod influence the growth and development of hydroponically grown leaf lettuce in a closed-type plant factory system. Horticulture, Environment, and Biotechnology 54:501-509.

Kumari S, Pradhan P, Yadav R, Kumar S (2018). Hydroponic techniques: A soilless cultivation in agriculture. Journal of Pharmacognosy and Phytochemistry 7(1S):1886-1891.

Landi M, Zivcak M, Sytar O, Brestic M, Allakhverdiev SI (2020). Plasticity of photosynthetic processes and the accumulation of secondary metabolites in plants in response to monochromatic light environments: A review. Biochima et Biophysica Acta (BBA) - Bioenergetics 1861(2):148131.

Li Q, Liu Y, Tian S, Liang Z, Li S, Li Y, Wei M, Zhang D (2019). Effect of supplemental lighting on water transport, photosynthetic carbon gain and water use efficiency in greenhouse tomato. Scientia Horticulturae 256:108630.

Parkell NB, Hochmuth RC, Laughlin WL (2016). Leafy Greens in Hydroponics and Protected Culture in Florida. Institute of Food and Agricultural Sciences. Gainesville, USA. Available at: https://growables.com/information/documents/HydroLeafyGreenUF.pdf

Pawlak K, Kołodziejczak M (2020). The Role of Agriculture in Ensuring Food Security in Developing Countries: Considerations in the Context of the Problem of Sustainable Food Production. Sustainability 12(13):5488.

Sardare MD, Admane SV (2013). A review on plant without soil-hydroponics. International Journal of Research in Engineering and Technology 2(3):299-304.

Schrader J, Pillar G, Kreft HH (2017). Leaf-IT: An Android application for measuring leaf area. Ecology and Evolution 7(2):9731-9738.

Stanley JN, Lamb DW, Falzon G, Schneider DA (2014). Apparent electrical conductivity (ECa) as a surrogate for neutron probe counts to measure soil moisture content in heavy clay soils (Vertosols). Soil Research 52(4):373-378.

Winch T (2007). Growing Food a Guide to Food Production. Springer, Dordrecht, Netherlands.

Xego S, Kambizi L, Nchu F (2016). Threatened medicinal plants of South Africa: case of the family Hyacinthaceae. African Journal of traditional, complementary and alternative medicines 13(3):169-180.