

**VERTICAL FARMING MODULE FOR URBAN DWELLING
FOR LETTUCE CULTIVATION**

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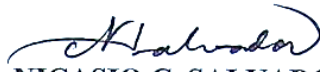
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(AB Structures and Environmental Engineering)

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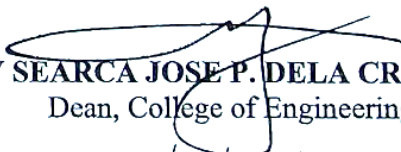

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DENCEL ASHIA M. FAJARDO

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ABSTRACT

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**VERTICAL FARMING MODULE FOR URBAN DWELLING FOR LETTUCE
CULTIVATION.**

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To address the food insecurity brought by diminishing areas for cultivation and limited water supply for production, vertical tower gardens (VTGs) aimed to increase the crop yield per unit area footprint. However, current designs of VTGs are fixed and suffered from several problems such as non-uniform light demonstration and water inefficiency. This study is conceptualized to address the above-mentioned problems and aimed to contribute in solving the food security issues. A rotating vertical module for lettuce production was designed and evaluated, with the aim to help urban dwellers and farmers produce more food per square meter of space. The nutrient solution utilized was Nutriblend A&B, purchased from Mikai Agri Trading, specifically formulated for lettuce cultivation. The water parameters for the nutrient solution were maintained as follows: the total dissolved solids (TDS) ranged from 800 ppm to 1000 ppm, the pH level was kept between 5.5 and 6.5, the electrical conductivity was maintained between 1.5 and 2.5 dS/m, and the temperature was controlled within a range of 22 to 31 degrees Celsius. Two factors are considered: the layer factor, consisting of the top (T1), middle (T2), and bottom layer (T3), and the irrigation factor, with irrigation frequencies of 20 minutes per hour (A1) and 15 minutes per hour (A2). The harvest period was set at 20 days after transplanting. The first run (A2) recorded a higher mean temperature of 28.2 degrees Celsius than the second run,

which had a mean temperature of 27.5 degrees Celsius. However, the humidity in the first run was lower than in the second run, with mean values of 68.5% and 71.4%, respectively. The gathered data were analyzed using analysis of variance and Tukey's test for comparison among means. The implementation of A1 within Vertical Farming Modules yielded favorable outcomes for parameters such as area (120.654 cm²), weight (23.875g), height (18.571cm), and leaf count (7 leaves), while A2 resulted in longer root length (9.105cm). Moreover, the layer factor significantly influenced the height, weight, and area, with notably larger values observed in the bottom and middle layers compared to the top layer, except for root length. The number of leaves did not show significant differences among the treatments. The inclusion of a rotational mechanism within the module is significant for efficiently dispersing sunlight, especially in instances where the module is situated in shaded areas. Vertical Farming Modules can grow significant quantities of lettuce within limited space when compared to traditional farming methods. Additionally, the researcher showcased the viability of lettuce thriving in indoor settings using vertical farming modules equipped with grow lights. However, further research is advised.

REFERENCES

- Abedin, T., Yamamoto, A., Hayashi, T., & Hosokawa, M. (2021). Drip fertigation enhances the growth of hydroponic lettuce (*Lactuca sativa*) using polyester fiber substrate. *Scientia Horticulturae*, 276. <https://doi.org/10.1016/j.scienta.2020.109604>
- Altiné. (2023, January 28). Drip System Hydroponics Pros and Cons (and how to avoid them). *Plants Heaven*. Retrieved March 27, 2023, from <https://plantsheaven.com/drip-system-hydroponics-pros-and-cons/>
- Ani, A., & Gopalakrishnan, P. (2020). Automated Hydroponic Drip Irrigation Using Big Data. 2020 Second International Conference on Inventive Research in Computing Applications (ICIRCA), 370–375. <https://doi.org/10.1109/ICIRCA48905.2020.9182908>
- Barnett, K. (2017, October 1). The many benefits of rockwool as a growing substrate for hydroponic systems. *LinkedIn*. <https://www.linkedin.com/pulse/many-benefits-rockwool-growing-substrate-hydroponic-systems-barnett#>
- Bavel, J. (2013). The world population explosion: causes, backgrounds and -projections for the future. *Facts, views & vision in ObGyn*. 5. 281-91.
- Bhattacharya, Nilanjan. (2017). Hydroponics: Producing plants In-vitro on artificial support medium. *International Journal of Scientific and Engineering Research*. 8. 224-229.
- Bláha, L. (2019). Importance of Root-Shoot ratio for crops production. *HSOA Journal of Agronomy and Agricultural Science*, 2(2), 1–7. <https://doi.org/10.24966/aas-8292/100012>
- Bravo, M.R. (2017). Urbanization in the Philippines and Its Influence on Agriculture. In: Yokohari, M., Murakami, A., Hara, Y., Tsuchiya, K. (eds) *Sustainable Landscape Planning in Selected Urban Regions*. Science for Sustainable Societies. Springer, Tokyo. https://doi.org/10.1007/978-4-431-56445-4_9
- Bussell, W. T., & Mckennie, S. (2004). Rockwool in horticulture, and its importance and sustainable use in New Zealand. *New Zealand Journal of Crop and Horticultural Science*, 32(1), 29–37. <https://doi.org/10.1080/01140671.2004.9514277>
- Chhetri, Sadhana & Dulal, Sushmita & Subba, Subhawana & Gurung, Kushal. (2022). Effect of different growing media on growth and yield of leafy vegetables in nutrient film technique hydroponics system. *Archives of Agriculture and Environmental Science*. 7. 12-19. [10.26832/24566632.2022.070103](https://doi.org/10.26832/24566632.2022.070103).

- Crops Statistics of the Philippines - National and Regional | Philippine Statistics Authority. (n.d.). Retrieved from <https://psa.gov.ph/content/crops-statistics-philippines-national-and-regional>
- Dayananda, H. (n.d.). Master thesis in Sustainable Development 2021/43 Examensarbete i Hållbar utveckling One Square Meter Yield: A Hydroponic System Design. Retrieved March 25, 2023, from <https://www.diva-portal.org/smash/get/diva2:1568472/FULLTEXT01.pdf>
- Development of an Indoor Hydroponic Tower for Urban Farming. (2018). Retrieved from DLSU: <https://www.dlsu.edu.ph/wp-content/uploads/pdf/conferences/ditech/proceedings/volume-3/paper-10.pdf>
- Dingre, S. K., Shinde, M. G., Pawar, D. D., & Kale, K. D. (2020, December 2). Performance of cabbage at different irrigation levels under drip and micro-sprinkler irrigation systems. Wiley Online Library. Retrieved April 6, 2023, from <https://onlinelibrary.wiley.com/doi/abs/10.1002/ird.2557>
- Domingues, D. S., Takahashi, H. W., Camara, C. A. P., & Nixdorf, S. L. (2012). Automated system developed to control pH and concentration of nutrient solution evaluated in hydroponic lettuce production. *Computers and Electronics in Agriculture*, 84, 53–61. <https://doi.org/10.1016/j.compag.2012.02>.
- DOST. (2022). Vegetable Growers in pantabangan. [dost.gov.ph](https://www.dost.gov.ph). <https://www.dost.gov.ph/knowledge-resources/databases.html>
- Dr. George P, George N. Hydroponics- (Soilless Cultivation of Plants) for Bioiversity Conservation. *Inte. Jour. of Mode. Tren.in Engi. and Scie.* 2016;3(6): 97-104
- Drost, D. (2020, April). Lettuce in the garden. digitalcommons.usu.edu. from https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1248&context=extension_curall
- Dunn, B. (2013). ResearchGate. Retrieved from *Hydroponics*: https://www.researchgate.net/publication/280235408_Hydroponics
- Falivene, S. (2005, June). Open Hydroponics: Risks and Opportunities http://www.arapahocitrus.com/files/OHS_Stage_Publications.pdf
- Fayed, M. (2020). Drip Irrigation Technology: Principles, Design, and Evaluation. *Technological and Modern Irrigation Environment in Egypt: Best Management Practices & Evaluation*, 275-303.

- Finding the Best Hydroponic Timers for your Hydroponic System. (2020). Retrieved from Sensorex: <https://sensorex.com/2022/02/28/best-hydroponic-timers/>
- Gerrewey, T., Boon, N., & Geelen, D. (2021). Vertical Farming: The Only Way Is Up? *Agronomy* 2022, Vol. 12, Page 2, 12(1), 2. <https://doi.org/10.3390/AGRONOMY12010002>
- Godin, R., & Broner, I. (2016, February 19). Micro-sprinkler irrigation for orchards - 4.703. CSU-Extension. Retrieved April 6, 2023, from <https://extension.colostate.edu/topic-areas/agriculture/micro-sprinkler-irrigation-for-orchards-4-703/>
- Gonzaga, Zenaida & Fuentes, Lou & Capuno, Othello & Rom, Jessie & Gorme, Ana & Dimabuyu, Hubert & Lusanta, Dhenber & McDougall, Sandra & Goldwater, Adam & Rogers, Gordon. (2017). Growth and yield of different leaf-type lettuce cultivars grown in protected and open field cultivation. *Annals of Tropical Research*. 100-107. 10.32945/atr39sb7.2017.
- Grigas, A., Kemzūraitė, A., & Steponavičius, D. (2019). Hydroponic devices for green fodder production: a review. In *Rural development 2019: research and innovation for bioeconomy (RD2019) [elektroninis išteklius]: 9th international scientific conference, September 26-28, 2019, Agriculture Academy of Vytautas Magnus University*. Akademija: Agriculture Academy of Vytautas Magnus University.
- Gumisiriza, M. S., Kabirizi, J. M. L., Mugerwa, M., Ndakidemi, P. A., & Mbega, E. R. (2022). Can soilless farming feed urban East Africa? An assessment of the benefits and challenges of hydroponics in Uganda and Tanzania. *Environmental Challenges*, 6, 100413. <https://doi.org/10.1016/J.ENVC.2021.100413>
- Isabel Luna Maldonado, A., Mariana Márquez Reyes, J., Flores Breceda, H., Rodríguez Fuentes, H., Antonio Vidales Contreras, J., & Luna Maldonado, U. (2020). Automation and Robotics Used in Hydroponic System. In *Urban Horticulture - Necessity of the Future*. <https://doi.org/10.5772/intechopen.90438>
- Jain, R., & Janakiram, T. (2016). Vertical Gardening: A new concept of modern era. https://www.researchgate.net/profile/Ritu-Jain-17/publication/295646943_Vertikal_Gardening_A_New_Concept_of_Modern_Era/links/56cc380208ae5488f0dcebce/Vertical-Gardening-A-New-Concept-of-Modern-Era.pdf?origin=publication_detail

- J, Faheemah., & A, Dr. J. Dhanaseely. (2018). Smart Plant Growth on Hydroponics using Rain Water Harvesting. *International Journal of Trend in Scientific Research and Development*, Volume-2(Issue-3), 1928–1931. <https://doi.org/10.31142/ijtsrd11488>
- Jose, D. C. (2018). Lettuce Production Guide. library.buplant.da.gov.ph. <https://library.buplant.da.gov.ph/images/1640931738Lettuce%20Production%20Guide.pdf>
- Kaiser, C. and Ernst, E. (2016). Matt Ernst. Retrieved from <https://www.uky.edu/ccd/sites/www.uky.edu.ccd/files/hydrolettuce.pdf>
- King, J. (2020). Nutrient Delivery System Basics. Retrieved from [growlink](http://growlink.com): <https://blog.growlink.com/nutrient-delivery-system>
- Kumar, S., Singh, M., Yadav, K. K., & Singh, P. K. (2021, October). Opportunities and constraints in hydroponic crop production systems: A Review. *Environment Conservation Journal*. Retrieved March 28, 2023, from <https://journal.envirocnj.in/index.php/ecj/article/view/828>
- Macwan, Jemima & Pandya, Dhruv & Mankad, Archana & Pandya, Himanshu. (2021). Review on soilless method: Hydroponics. 11. 37122-371273
- Mansuroglu G.S. Bozkurt S. Kara M. Telli S. (2010) The effects of nitrogen forms and rates under different irrigation levels on yield and plant growth of lettuce. *Journal of Cell and Plant Sciences*, 1(1): 33–40.
- Midmore, D., & Deng-Lin, W. (1999, April 1). Work that water! hydroponics made easy. *Waterlines*. Retrieved March 27, 2023, from <https://practicalactionpublishing.com/article/754/work-that-water-hydroponics-made-easy>
- Muhammad, S., Hamidona, M. H., Mahadia, R., Aziza, A., & Ahamedb, T. (2019, December). Design and development of smart vertical garden system for urban agriculture initiative in Malaysia. *ResearchGate*. https://www.researchgate.net/publication/338221991_design_and_development_of_smart_vertical_garden_system_for_urban_agriculture_initiative_in_Malaysia
- Niu, G., & Masabni, J. (2022). Hydroponics. *Plant Factory Basics, Applications and Advances*, 153–166. <https://doi.org/10.1016/B978-0-323-85152-7.00023-9>

- Palm, H. W., Knaus, U., Appelbaum, S., Goddek, S., Strauch, S. M., Vermeulen, T., ... & Kotzen, B. (2018). Towards commercial aquaponics: a review of systems, designs, scales and nomenclature. *Aquaculture international*, 26(3), 813-842.
- Poliquit, D. E., & Jorge, S. (2019). Growth and Yield of Lettuce (*Lactuca sativa* L.) as Influenced by the Residual Effects of Guano-Char. *Asia Pacific Journal of Multidisciplinary Research*, 7(2), 73–77.
- Purba, Jhon & Parmila, I & Dadi, Wayan. (2021). Effect of Soilless Media (Hydroponic) on Growth and Yield of Two Varieties of Lettuce. *Agricultural Science*. 4. 154-165.
- Resh, Dr. Howard. (2023). Hydroponic lettuce production. Howard Resh Hydroponic Services. Retrieved April 8, 2023, from <https://howardresh.com/dr-howard-resh-hydroponic-services/hydroponic-lettuce-production>
- Rahman, J., Quamruzzaman, M., Ali, M., Ahmed, S., Chawdhery, A., & Sarkar, D. (2017, December). The effects of irrigation timing on growth, yield, and physiological traits of hydroponic lettuce. *researchgate*. https://www.researchgate.net/publication/322925802_The_effects_of_irrigation_timing_on_growth_yield_and_physiological_traits_of_hydroponic_lettuce
- Robinson, B. (2019). What are hydroponic systems and how do they work? *FreshWater Systems*. Retrieved March 27, 2023, from <https://www.freshwatersystems.com/blogs/blog/what-are-hydroponic-systems>
- Rowse, H. R. (1974). The effect of irrigation on the length, weight, and diameter of lettuce roots. *Plant and Soil*, 40(2), 381–391. <https://doi.org/10.1007/bf00011520>
- Sharma, N., Acharya, S., Kumar, K., Singh, N., & Chaurasia, O. P. (2018). Hydroponics as an advanced technique for vegetable production: An overview. *Journal of Soil and Water Conservation*, 17(4), 364. <https://doi.org/10.5958/2455-7145.2018.00056.5>
- Shrestha, A., & Dunn, B. (2010, March 1). Hydroponics. Retrieved April 8, 2023, from <https://shareok.org/handle/11244/50283>
- Siregar, R. R. A., Seminar, K. B., Wahjuni, S., & Santosa, E. (2022). Vertical Farming Perspectives in Support of Precision Agriculture Using Artificial Intelligence: A Review. *Computers* 2022, Vol. 11, Page 135, 11(9), 135. <https://doi.org/10.3390/COMPUTERS11090135>
- Stephens, O. (2021). How Big of a Reservoir Do Hydroponics Need? Retrieved from *The Hydroponics Planet*: <https://thehydroponicsplanet.com/how-big-of-a-reservoir-do-hydroponics-need/>

- Storey, A. (2016). Sizing a Pump for Hydroponics or. Retrieved from Upstart Farmers: https://csdt.org/culture/engineeredecosystems/resources/upstartfarmers.com_Sizing_a_Pump.pdf
- Sulit, M. F., Cinense, M. M., & Agulto, I. C. (2023, October). Rootzone cooling, water productivity and economics of intensified vertical grown red butterhead lettuce (*Lactuca sativa* Linn). Food Research. <https://www.myfoodresearch.com/>
- Trejo-Téllez, Libia Iris & Gómez-Merino, Fernando. (2012). Nutrient Solutions for Hydroponic Systems. 10.5772/37578.