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Urban household vegetable production through the use of a developed vertical garden

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Abstract

Recent trends in agricultural production aimed at ensuring adequate food production if not properly checked can result in the depletion of major factors of agricultural production, especially agricultural lands. Though agroecological methods of farming, which are readily being adopted by farmers, are a sure way to ensure sustainable production, constant efforts must be geared towards innovative methods of production. Vertical farming, a method for reducing land required for agricultural production, offers hopefully a sustainable food production method. However, this technology tends to be costly and technologically beyond the operation of the average person. This hinders the full potential of adopting vertical gardens in most homes in urban settings where agricultural lands are gradually becoming scarce due to urbanization. This project is on the premise that if the vertical garden concept can be made efficient but low-tech and easily affordable, it can offer most urban households a good quality supply of vegetables. As such the project has developed a low-cost self-watering vertical garden which was evaluated with lettuce (*lactuta sativa*) as the test crop. The lettuce showed good growth parameters for the properties measured and attained a fresh weight of 12.78 g at harvest. The system has a capital outlay of GH¢ 1,056.00 (≈ US $ 200.00) with a payback period of eight production cycles and offers total land savings of 70 %. The study further evaluated different growing mediums (biochar, poultry manure, biochar and poultry manure) respectively mixed with soil and garden soil within the vertical garden and found that the growth medium with poultry manure gave the best growth values.

Keywords: vertical garden, self-watering, low technology, affordable, growth medium

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Introduction

Due to factors like climate change and declining soil fertility, relying on traditional agriculture to pave the way for balancing the demand-supply equation for food appears to be an unreliable endeavor. This is because a 70% increase in food production is necessary to fulfil the demands of the expanding world population, which is projected to reach 9.15 billion people in 2050, posing a threat to the agricultural sector (Bendorf, 2010; Natsheh et al., 2021).

Conservation agriculture promotes production practices to guarantee output is maximized without excessively destroying the current ecosystem. About 70% of the water used for irrigation in agriculture already comes from aquifers and rivers, while fertilizer use is expected to increase (FAO, 2020). One method for addressing some of the disadvantages of traditional agriculture is to increase a particular land area's production through vertical farming. Utilizing aeroponic, aquaponic, and hydroponic processes requires less soil or entirely substitutes soil as the growing medium, consuming less energy, water (about 1% of the water needed in conventional agriculture), and synthetic fertilizer inputs (Al-Kodmany, 2018; Hovhannisyan & Devadoss, 2020). There are many different types of vertical gardens, and the production process incorporates technology at different levels.

Research indicates that growing lettuce in contaminated water degrades the quality of the lettuce head that is produced (Abdulai et al., 2017) but one of the main crops consumed in Ghana is lettuce. Hence, growing lettuce in the home using a vertical garden will be a healthier option as well as reducing demand for produce while yet providing household nutrition security towards the attainment of SDG goals 1 and 2. The technological gap, rather than the system's cost, is the main obstacle to the adoption of existing vertical garden technologies in homes (Kalantari et al., 2017). Therefore, reducing the vertical garden's technological requirements is necessary without losing its fundamental ideas. Hence this project aims to develop a self-watering Vertical Garden that is as low-tech as possible, cost-effective, and with few user-maintenance procedures as possible.

Material and Methods

The vertical garden system design was purely a prototype for evaluation before the design was finalized, hence, the dimensions were determined by the number of lettuce seeds to be cultivated. This design was adopted by applying knowledge from review works and logical reasoning based on existing modules. The system was built with locally accessible materials and is primarily concerned with long-term usability, affordability, and a self-watering (wicking) system. It also features a growing trough made from plywood fastened with white glue, and nails; a supporting A-frame made from wood; a drip irrigation system; and growing mediums (biochar, poultry manure, biochar and poultry manure) respectively mixed with soil and garden soil. The weight of the trough depends on its size and the amount of soil it will hold in total.

The trough sizes were replicated twice to determine the optimum depth of soil to use so it had dimensions of 110 cm in length x 20 cm in width. The trough sizes varied according to soil depths, levels 1, 2, 3, and 4 (Fig. 1; counting from the bottom upwards) had soil depths of 3, 6, 9 and 12cm, respectively. After the first experiment, different growing mediums (biochar, poultry manure, biochar and poultry manure) respectively mixed with soil and garden soil were varied while a constant depth of 12cm (determined from experiment one) was maintained. The structure was designed to support both the volume of growing material and the weight of the troughs. It was also constructed at a 45°angle to take up as little space as possible. A CAD (Computer Aided Drawing) representation of the design was made and proper stress analysis was done to ensure the system was safe before it was fabricated.

The experiments to evaluate the designed vertical garden was set up at the University of Ghana Farms (5.6506^{o} N, 0.1962^{o}W). The vertical garden was mounted under a screen house to ensure that the crop will only use the water supplied during the period of the experiment. A complete block design was used for the experiment and each trough served as an experimental block where the experimental crop, iceberg (crisp head) lettuce with an ideal germination temperature that ranges from 15° C – 20° C (Jagdish, 2020; Dorvlo et al., 2021) with a daily water requirement of about 3.9mm/day (Martin et al., 2009) was grown.

The data collected from the experimental crop were plant height, PH; leaf area index, LAI; the number of leaves, NL; chlorophyll content, CC; water level, WL; stem diameter, SD; root length, RL; wet weight, WW and dry weight, DW of the lettuce. The data collected during the experiment were statistically analyzed using the ANOVA test at a 95% confidence level to determine any significant difference in the measured parameters for each block.

Results and Discussion

Using the experimental crop lettuce, the impacts of diverse soil mediums and the design of varying depths of trough utilized for crop (*lactuca sativa*) growth were investigated (Fig. 1). The collected result (plant height, PH; leaf area index, LAI; the number of leaves, NL; chlorophyll content, CC; water level, WL; stem diameter, SD; root length, RL; wet weight, WW and dry weight, DW) of the lettuce (Table 1 and Fig. 2) were evaluated to see if there was a statistically significant change in the crop's growth parameter. Though there were observed differences within the mean values obtained for the growth parameters, the variance analysis at a 95% confidence interval showed no statistically significant variance in the means.

Table 1. Mean data collected on the growth parameters.

Parameter	Depth of Soil Medium			
	TH10	TH13	TH16	TH19
Fresh Weight (FW)	-	9.510 ± 0.500	6.577 ± 0.386	12.667 ± 0.210
Dry Weight (DW)	0.233 ± 0.015	0.263 ± 0.025	0.553 ± 0.049	1.157 ± 0.064
Stem Diameter (SD)	-	3.400 ± 0.100	3.833 ± 0.153	4.033 ± 0.015
Root Length (RL)	-	7.707 ± 0.263	7.740 ± 0.191	5.073 ± 0.042

(Source: Dorvlo et al, 2021)

Fig. 1. Final design of VG for local manufacture and use. (Source: Dorvlo et al, 2021)

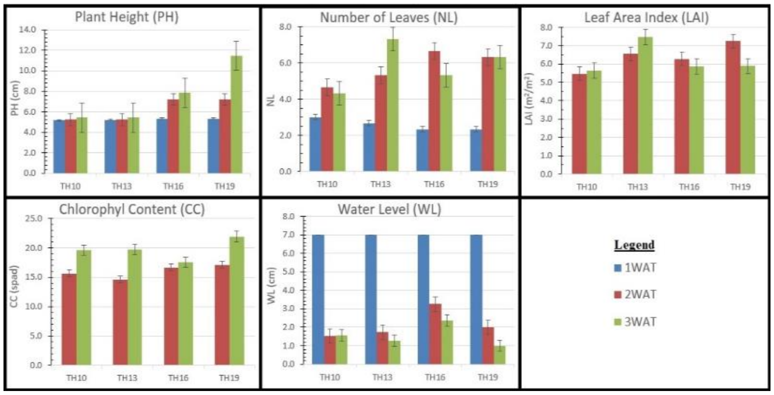

Fig. 2. Bar graphs for data collected on lettuce grown in the VG (WAT = week(s) after transplanting). (Source: Dorvlo et al, 2021)

The tallest bunch was in the 19cm trough depth with its growing medium as a mix of garden soil and poultry manure. The system provides a land savings of 70% since the total land required to set up the system was 2.25m^2 (1.5m x 1.5m) and it can be produced at a cost of GH₵1056.00 (≈ the US $ 200.00). This offers a very low-tech and affordable vertical garden design that can easily be deployed in homes to provide sustainable and consistent good-quality vegetables. The system has a pay-back period of 8 production cycles (when a constant market price is assumed) as shown in

Table 2 and can stand for two calendar years before any major maintenance and repair will be required.

Table 2. Payback period for the vertical garden.

Production Cycle	0	1	2	3	4	5	6	7	8	9	10
Net Profit (GH¢)	-1056	-926	-796	-666	-536	-406	-276	-146	-16	114	244

(Source: Dorvlo et al, 2021)

Conclusions and Outlook

The study developed a simple, low-tech vertical garden with self-watering (wicking) system capabilities, and it varied the soil depths to determine the optimum depth to use for future design implementation. Since the experimental data obtained showed that the 19cm trough depth (with the mix of soil and poultry manure of a depth of 12cm) showed the best result in plant growth, these parameters will be suitable for the final design of the vertical garden for leafy green vegetables or shallow root crops. More research and testing on the wicking material of the water delivery system and the uniformity of water distribution with the VG will likely be necessary for the effective self-watering system, given that the crop depends on water to acquire market fresh weight. Also, a microbiological quality test should be conducted on the vegetables to prevent spoilage and maintain food safety.

References

Abdulai, J., Nimoh, F., Darko-Koomson, S., & Kassoh, K. F. S. (2017). Performance of Vegetable Production and Marketing in Peri-Urban Kumasi, Ghana. *Journal of Agricultural Science*, *9*(3), 202. https://doi.org/10.5539/jas.v9n3p202

Al-Kodmany, K. (2018). The vertical farm: A review of developments and implications for the vertical city. *Buildings*, *8*(2). https://doi.org/10.3390/buildings8020024

Bendorf, A. (2010). World Population Trends Towards 2050 and Beyond. *Strategic Analysis Paper*, *February*.

Dorvlo, S. Y., Nyanteh, H. A., Aziato, E. K. S., Ninson, D., Dazugo, E., & Quaye, D. (2021). Effect of different soil depths on selected lettuce (Lactuca sativa) growth parameters in a developed self-watering vertical garden. *Research on Crops*, *22*(4), 907–912. https://doi.org/10.31830/2348-7542.2021.148

FAO. (2020). World fertilizer trends and outlook to 2022. In *World fertilizer trends and outlook to 2022*. https://doi.org/10.4060/ca6746en

Hovhannisyan, V., & Devadoss, S. (2020). Effects of urbanization on food demand in China. *Empirical Economics*, *58*(2), 699–721. https://doi.org/10.1007/s00181-018-1526-4

Jagdish. (2020). *Lettuce Seed Germination, Period, Temperature, Process | Gardening Tips*. https://gardeningtips.in/lettuce-seed-germination-period-temperature-process

Kalantari, F., Mohd Tahir, O., Mahmoudi Lahijani, A., & Kalantari, S. (2017). A Review of Vertical Farming Technology: A Guide for Implementation of Building Integrated Agriculture in Cities. *Advanced Engineering Forum*, *24*(October), 76–91. https://doi.org/10.4028/www.scientific.net/aef.24.76

Martin, E., Slack, D. C., & Pegelow, E. (2009). Water use in vegetables— western head lettuce. *Arizona Water Series*, *26*, 2.

Natsheh, B., Abu-Khalaf, N., & Abubaker, S. (2021). Evaluating cauliflower (Brassica oleracea) production under different fertilizer systems. *Research on Crops*, *22*(3), 556–563. https://doi.org/10.31830/2348-7542.2021.103