

# Performance of fruiting vegetables and leafy vegetables in vertical farming

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## Abstract

Cultivable land is shrinking day by day in urban areas and the population in urban regions is increasing rapidly, according to United Nations estimate the total world population will be doubled by the year 2050 accounting for 80% of the total population in urban areas. With increasing population and decreasing cultivable land in urban areas, production of fresh vegetables will be a serious issue. Vertical farming is a soilless technology of growing plants that serves as an alternative for cultivating fresh vegetables in a limited land area. The present study was carried out to standardize a vertical farming structure and an operating protocol for production of tropical fruiting vegetables *viz.*, tomato, chilli, brinjal and leafy vegetables *viz.*, palak, amaranthus, mint. A vertical farming structure made of 4 inch PVC pipe was used in the study and 3 inch net pots were used for growing plants and coir-pith was used as growing media. The experiment was laid out in Complete Randomized Design (CRD) with four replications. The observations on physiological parameters (leaf chlorophyll content, leaf area index), plant growth attributes (specific leaf area, relative growth rate, net assimilation rate) and quality parameters (nutrient content of leaves) of fruiting vegetable and leafy vegetable were assessed. Physiological parameters such as leaf chlorophyll content was the highest (1.30 mg/g) in palak plants and the brinjal plants recorded the maximum (0.97) leaf area index, with more flowers and fruits compared to tomato and chilli which had less flowers and fruits. Plant growth attributes like specific leaf area was the highest (6.73 cm<sup>2</sup>g<sup>-1</sup>) in brinjal, the highest net assimilation rate was recorded in mint (0.12 g g<sup>-1</sup>day<sup>-1</sup>) and brinjal recorded the highest relative growth rate (0.15 g g<sup>-1</sup>day<sup>-1</sup>). The tomato grown in vertical structure had the highest nitrogen (2.70 %) and potassium (2.93 %) content in the leaves, whereas palak recorded the highest phosphorus content (0.56 %), quality parameters like Ca (10.47%), Mg (3.36%) and protein content (3.61 mg/g) of leaves were found to be the highest in amaranthus leaves.

**Keywords:** Vertical farming, urban / terrace farm, fruiting and leafy vegetables, nutritious

## Introduction

Total world population is increasing at a rapid rate and as urbanization is also increasing year by year. United Nations has estimated that the population living in urban areas will be doubled by the year 2050, which will be 80% of the total world population which will be around 6.5 billion. Urban areas contribute more than 70 percent of the total global CO<sub>2</sub> emissions, which will result in pollution and ill effects, thus food security will be a major thrust in urban areas. As population in urban areas is increasing availability of fresh fruits and vegetables will be a serious issue and production of fresh vegetables through conventional farming will be difficult in urban areas due to less fertile soil and non-cultivable land (Zareba *et al.* 2021).

Innovative methods of farming is gaining importance and has a great scope in the future vertical farming is one such technology of cultivating fresh vegetables which involves soilless cultivation. Vertical farming is not a very new technology. An American geologist Gilbert Ellis Bailey coined the term “Vertical farming” in the year 1915. This indicates that the scientists / researchers were looking into this kind of cultivation since then. Vertical farming is a technique of growing fresh vegetables that incorporates soilless agriculture, and it is getting popular and has huge future potential. Scientists and researchers are investigating this type of agriculture for adopting by urban dwellers. Though the word is not new to the world, very few people are aware of this type of farming, and even fewer have used it to grow fresh food.

People in metropolitan cities in developing nations like India are dependent on adjacent rural areas for fresh veggies, which lead to problems like price swings, quality issues and many more. In this scenario, metropolitan residents should be prepared to grow their own food. However, due to rising land prices and scarcity of agricultural land in urban areas, conventional farming will be challenging. However, rooftop and terrace farming are always good alternatives. Rooftop/ terrace farming is also considered as “zero-acreage farming”, as they are characterized by non-use of land. Vertical farming or rooftop farming will serve as a source of cultivation of fresh vegetables in urban areas. Vertical farming otherwise soilless cultivation, where growing media is used instead of soil in order to give support to plants and nutrients will be supplied through nutrient solutions. From a small rooftop to enormous commercial buildings, vertical farming is practiced in a wide range of configurations. Technologies including hydroponics, aeroponics, and aquaponics are used in vertical farming. In order to serve fresh food to the urban dweller’s, present study carried out to produce fresh tropical fruit vegetables *viz.*, tomato, brinjal, chilli and leafy vegetables *viz.*, palak, amaranthus, mint.

## 1. Materials used

### 1.1. Crops

Tropical fruiting vegetables like tomato, chilli, brinjal and leafy vegetables like palak, amaranthus, mint were used in this study.

### 1.2. Vertical structure

The crop was raised in a vertical farming structure having 92 cells. The structure was made of 4 inch PVC pipe and fertigation was given through a 40W submersible pump, which was regulated by a timer connected to monitor the pump, timer was set to run for 30 minutes every day and 3 inch net pots were placed in the 92 cells for growing plants.

### 1.3. Water

The water used in this study was taken from a reverse osmosis unit which had a TDS range of 40–50ppm, pH range of 6.5-7.0 and EC range of 0.4 - 0.5 dSm<sup>-1</sup>.

### 1.4. Growing media

Coirpith was used as growing media. The compressed coirpith slabs which had low EC level was used in the study.

### 1.5. pH, EC and TDS meter

Hand held digital pH, EC and TDS meters were used to measure the pH, EC and TDS of the nutrient solution.

### 1.6. Location

The study was conducted at the Western block farm of Horticultural College and Research Institute, TNAU, Periyakulam, Theni, Tamil Nadu, India, which is situated at a latitude of 10<sup>o</sup>.13<sup>o</sup>N, longitude of 77<sup>o</sup>.59<sup>o</sup>E and altitude of 289m above MSL. It is situated on the National Highway (NH45B) between Dindigul and Theni.

## 2. Methods adopted

### 2.1. Experimental details

**Crops:** Tomato, chilli, brinjal, palak, amaranthus and mint

**Design:** Completely randomized design (CRD)

**No. of Treatments:** 06

**No. of Replications:** 04

### 2.2. Calibration of vertical farming structure

The existing vertical structure made of 4 inch PVC pipe was taken for the study. The structure was cleaned and the pipes were connected by applying PVC gum. A 30 liters water tub was taken and kept under the vertical structure which was used as nutrient tank. A submersible motor of 40 watt capacity was kept in the tub to pump the nutrient solution periodically. The drip laterals were connected with submersible motor and the excess nutrient drained back to the nutrient reservoir through a drip lateral.

### 2.3. Cultural Practices

#### 2.3.1. Preparation of growing media

The compressed coirpith slab of 5 kg was taken and soaked in water overnight and then excess water was squeezed and removed before filling net pots.

#### 2.3.2. Sowing / Planting

The coirpith with optimum moisture was taken to fill 3 inch net pots. For sowing of palak and amaranthus seeds, coirpith was filled in the net pots then seeds were sown and seeds were closed with the coirpith. Mint nodal cuttings were taken and the cuttings were planted first in the net pots half filled with coirpith. The seedlings of tomato, chilli and brinjal were taken and kept in the middle of the net pots and half filled with moist coirpith. All the seed sown and planted cuttings and seedlings net pots were kept in the cells of vertical structure.

#### 2.3.3. Nutrient preparations

**Nutrient A:** Nutrient A contained nitrates, 50g of calcium nitrate will be taken and potassium nitrate 50g were weighed and taken, 1000 ml of distilled water was taken in a beaker, then both the minerals were added and mixed.

**Nutrient B:** Nutrient B contained magnesium sulphate and micronutrient mixture. 50g each salt will be taken in a beaker 1000 ml of distil water is taken and both salts were mixed.

Both Nutrient A and B solution were used as stock. Initially 1000 ml of reverse osmosis water was taken and then 50 ml of nutrient solution was added and mixed thoroughly. Then 50 ml of nutrient solution B was added and mixed, this nutrient mix was added slowly to the fertigation tank by checking the TDS of the nutrient reservoir.

#### 2.3.4. Fertigation schedule

A timer was fixed to the fertigation schedule and the timer was set to it switch on the pump every day for 30 minutes. Nutrient reservoir was cleaned every 10 days and nutrients were added from the stock solutions A and B TDS maintained at a range of 300 ppm.

### 3. Observations recorded

Observations were recorded such as chlorophyll content, leaf area index, specific leaf area, net assimilation rate, relative growth rate, nitrogen, phosphorous, potassium, calcium, magnesium and protein content of leaves were analysed and the data recorded showed significant difference among the treatments.

### 4. Results and discussion

#### 4.1. Chlorophyll content (mg/g)

The chlorophyll content in leaves is directly related with the photosynthetic tools. As a result, it offers important information about the photosynthetic capacity. The chlorophyll content of vegetables grown in vertical structure showed significant differences for treatments (Fig. 1). The palak plants grown in vertical structure recorded the highest chlorophyll content (1.30 mg/g), followed by mint (0.84 mg/g) and the lowest chlorophyll content was recorded in tomato (0.25 mg/g). Parallel result outcomes were found by Coronel *et al.* (2008) plants with sufficient nutrients (nitrogen, magnesium, iron, and manganese) have greater chlorophyll contents, which were directly related to the performance of the photosynthetic rate. Similar outcomes were obtained by Rincón Castillo and Ligarreto (2010) who stated that the minimum chlorophyll content of the plant may indicate the scarcity of nutrient content.

#### 4.2. Leaf area index

Leaf area index (LAI) is an important parameter in physiological activity, as it measures the photosynthetically active area and it also links with the canopy structure. This parameter shows significant variation among the treatments (Table 1&2). The tomato plants grown in vertical structure recorded the highest LAD (3.70) at 90 DAP and the minimum LAD (0.76) was recorded at 30 DAP. The chilli plants grown in vertical structure recorded the highest LAD (2.80) at 90 DAP and the lowest LAD (0.68) recorded at 30 DAP. The brinjal plants grown in vertical structure recorded the highest LAD (5.27) at 90 DAP and the minimum LAD (1.63) was recorded at 30 DAP. Among fruiting vegetables, grown in vertical structure the brinjal plants recorded the maximum leaf area duration of 5.27, followed by tomato (3.70) and chilli (2.80). The palak plants grown in vertical structure recorded the highest LAD (2.06) at 45 DAP and the lowest LAD (0.72) at 15 DAP. The amaranthus plants recorded the highest LAD (1.27) at 45 DAP and the lowest LAD (0.32) was recorded at 15 DAP. The mint plants grown in vertical structure recorded the maximum LAD (9.81) at 45 DAP and lowest LAD (4.15) was recorded at 15 DAP. Among leafy vegetables, mint recorded the highest leaf area duration (9.81), followed by palak (2.06) and amaranthus (1.27). (Melgarejo *et al.* 2007) stated that leaf area index (LAI) depends on temperature, nutrition, radiation interception and water availability. Similar results on LAI were found by Ogunlela *et al.* (2005) in okra that increased leaf area index was based on nutrients released by fertilizer which improved the availability and their uptake had a stimulative effect on LAI. Less number of leaves on plants reduced the photosynthesis and leaf area index consequently, vegetative biomass and yield. The results of Cantliffe *et al.* (2007) in strawberry are in line with this hypothesis.

#### 4.3. Specific leaf area (cm<sup>2</sup>g<sup>-1</sup>)

The specific leaf area (SLA) is an important growth attribute in this study that showed significant variation among the treatments (Table 3&4). The tomato plants grown in vertical structure recorded the highest SLA (3.12 cm<sup>2</sup>g<sup>-1</sup>) at 90 DAP and the minimum SLA (1.66 cm<sup>2</sup>g<sup>-1</sup>) was recorded at 30 DAP. The chilli plants grown in vertical structure recorded the highest SLA (1.89 cm<sup>2</sup>g<sup>-1</sup>) at 90 DAP and the lowest SLA (1.32 cm<sup>2</sup>g<sup>-1</sup>) recorded at 30 DAP. The brinjal plants grown in vertical structure recorded the highest SLA (6.73 cm<sup>2</sup>g<sup>-1</sup>) at 90 DAP and the minimum SLA (3.20 cm<sup>2</sup>g<sup>-1</sup>) was recorded at 30 DAP. Among fruiting vegetables, the brinjal plants recorded the maximum specific leaf area of 6.73 cm<sup>2</sup>g<sup>-1</sup>, followed by tomato (3.12 cm<sup>2</sup>g<sup>-1</sup>) and chilli (1.89 cm<sup>2</sup>g<sup>-1</sup>). The palak plants grown in vertical structure recorded the highest SLA (6.71 cm<sup>2</sup>g<sup>-1</sup>) at 45 DAP and the lowest SLA (4.12 cm<sup>2</sup>g<sup>-1</sup>) at 15 DAP. The amaranthus plants recorded the highest SLA (4.77 cm<sup>2</sup>g<sup>-1</sup>) at 45 DAP and the lowest SLA (3.12 cm<sup>2</sup>g<sup>-1</sup>) was recorded at 15 DAP. The mint grown in vertical structure recorded the maximum SLA (2.12 cm<sup>2</sup>g<sup>-1</sup>) at 45 DAP and lowest SLA (1.35 cm<sup>2</sup>g<sup>-1</sup>) was recorded at 15 DAP. Among leafy vegetables, the palak plants recorded the highest specific leaf area (6.71 cm<sup>2</sup>g<sup>-1</sup>), followed by amaranthus (4.77 cm<sup>2</sup>g<sup>-1</sup>) and mint (2.12 cm<sup>2</sup>g<sup>-1</sup>). These results are similar with the findings of Björkman and Holmgren (1963) and Wolff and Colman (1990) who found that shade plays a major role in specific leaf area.

#### 4.4. Net assimilation rate ( $\text{g g}^{-1}\text{day}^{-1}$ )

Net assimilation rate is an important plant growth parameter which directly affects the plant photosynthetic process. Crops grown in vertical structure showed different net assimilation rates. Net assimilation rate is an important plant growth parameter which directly affects the plant photosynthetic process. Crops grown in vertical structure showed different net assimilation rates (Fig. 2). Among them mint recorded the maximum net assimilation rate ( $0.12 \text{ g g}^{-1}\text{day}^{-1}$ ) followed by brinjal ( $0.088 \text{ g g}^{-1}\text{day}^{-1}$ ) and amaranthus ( $0.081 \text{ g g}^{-1}\text{day}^{-1}$ ). The chilli grown in vertical structure recorded the minimum net assimilation rate ( $0.010 \text{ g g}^{-1}\text{day}^{-1}$ ). According to the findings of Hunt *et al.*, (2002), NAR is directly influenced by the plant's internal metabolism as well as its area, age, and arrangement of the leaves. Similar results are affirmed by Gonzales *et al.* (2015) in *Brassica napus* and Hammad *et al.* (2019) in Broccoli, which stated that the decrease in NAR was due to the supply of photo assimilate towards the vegetative growth.

#### 4.5. Relative growth rate ( $\text{g g}^{-1}\text{day}^{-1}$ )

Relative growth rate is an important parameter recorded in this study. The data recorded showed significant variation among the treatments (Fig. 2). Among different crops raised in vertical structure, the brinjal plants recorded the highest RGR ( $0.15 \text{ g g}^{-1}\text{day}^{-1}$ ), followed by chilli and tomato ( $0.13 \text{ g g}^{-1}\text{day}^{-1}$ ), the lowest relative growth was recorded in amaranthus ( $0.01 \text{ g g}^{-1}\text{day}^{-1}$ ). Grime and Hunt (1975) concluded that due to high RGR, a plant will increase its size rapidly and as a result it occupies larger space, both above and below ground.

#### 4.6. Quality parameters

Quality parameters like nitrogen, phosphorous, potassium, calcium, magnesium and protein content of leaves were analysed and the data recorded showed significant difference among the treatments. The data recorded are elucidated (Fig. 3).

The quality parameters analysed are the nutrient content present in leaves of the plants grown in vertical structure. Each crop had variable nutrient contents. The tomato grown in vertical structure had the highest nitrogen (2.70 %) and potassium (2.93 %) content in the leaves, palak recorded the highest content of phosphorus (0.56 %). Quality attributes like Ca, Mg and protein content of leaves were found highest in amaranthus plants (*i.e.*) calcium content (10.47 %), magnesium content (3.67 %) and protein content of 3.61 mg/g. The results of this study is in line with the findings of Li *et al.* (2018) who revealed that the NPK content of lettuce leaves were found maximum in hydroponic growing media which is significantly different than the substrate media. Rouphael *et al.* (2004) concluded that zucchini plants grown in soilless culture had a higher content of N, Mg, Na, Fe, Cu, Mn, Zn than those grown in soil.

#### Conclusion

Vertical farming is a novel technology and the technique employed in this study are simple, easily adaptable with low running cost. With all these credits, this technology will be helpful in future with problematic soil and where land area is scarce. Thus, this study clearly depicts that the Vertical farming system for fruit vegetable and leafy vegetable production, elucidates that among fruiting vegetable brinjal performed the best and among leafy vegetables mint and palak performed the best by considering the physiological parameters, plant growth attributes and quality parameters. Therefore, vertical farming can be recommended for rooftop / terrace farming to fulfill the requirement of fresh vegetables in urban areas.

**Table 1. Leaf area index recorded for fruit vegetables**

Leaf area index			
DAP	Tomato	Chilli	Brinjal
30 DAP	0.43	0.11	0.89
60 DAP	0.47	0.13	0.91
90 DAP	0.51	0.12	0.97
<b>Mean</b>	<b>0.47</b>	<b>0.12</b>	<b>0.92</b>
<b>SE (d)</b>	<b>0.009</b>	<b>0.002</b>	<b>0.019</b>
<b>CD (0.05)</b>	<b>0.021</b>	<b>0.004</b>	<b>0.041</b>

**Table 2. Leaf area index recorded for leafy vegetables**

Leaf area index			
DAP	Palak	Amaranthus	Mint
15 DAP	0.21	0.13	0.09
30 DAP	0.27	0.15	0.11
45 DAP	0.26	0.14	0.10
<b>Mean</b>	<b>0.25</b>	<b>0.14</b>	<b>0.10</b>
<b>SE (d)</b>	<b>0.002</b>	<b>0.003</b>	<b>0.002</b>
<b>CD (0.05)</b>	<b>0.005</b>	<b>0.007</b>	<b>0.003</b>

Table 3. Specific leaf area recorded for fruit vegetables

Specific leaf area (cm <sup>2</sup> g <sup>-1</sup> )			
DAP	Tomato	Chilli	Brinjal
30 DAP	1.66	1.32	3.20
60 DAP	2.56	1.65	5.10
90 DAP	3.12	1.89	6.73
<b>Mean</b>	<b>2.44</b>	<b>1.62</b>	<b>5.01</b>
<b>SE (d)</b>	<b>0.03</b>	<b>0.03</b>	<b>0.04</b>
<b>CD (0.05)</b>	<b>0.06</b>	<b>0.07</b>	<b>0.10</b>

Table 4. Specific leaf area recorded for leafy vegetables

Specific leaf area (cm <sup>2</sup> g <sup>-1</sup> )			
DAP	Palak	Amaranthus	Mint
15 DAP	4.12	3.12	1.35
30 DAP	5.80	4.26	2.40
45 DAP	6.71	4.77	2.12
<b>Mean</b>	<b>5.54</b>	<b>4.05</b>	<b>1.95</b>
<b>SE (d)</b>	<b>0.10</b>	<b>0.05</b>	<b>0.02</b>
<b>CD (0.05)</b>	<b>0.22</b>	<b>0.12</b>	<b>0.04</b>

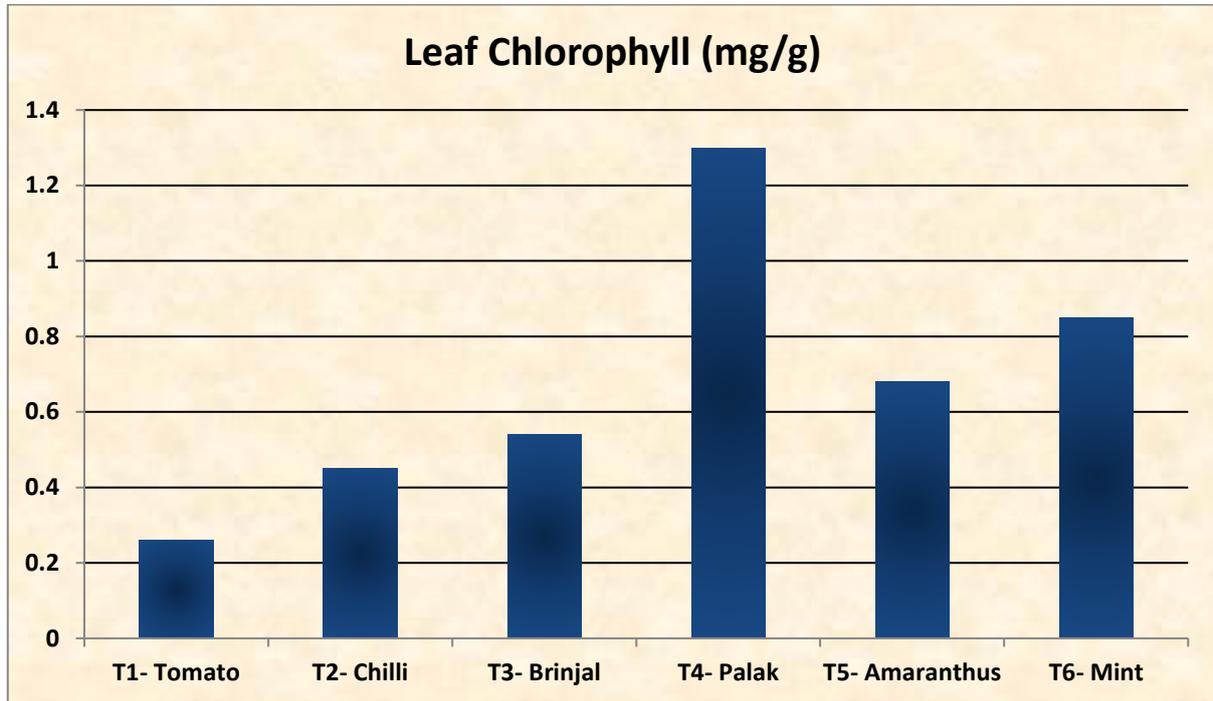


Fig. 1. Leaf chlorophyll content of crops grown in vertical structure

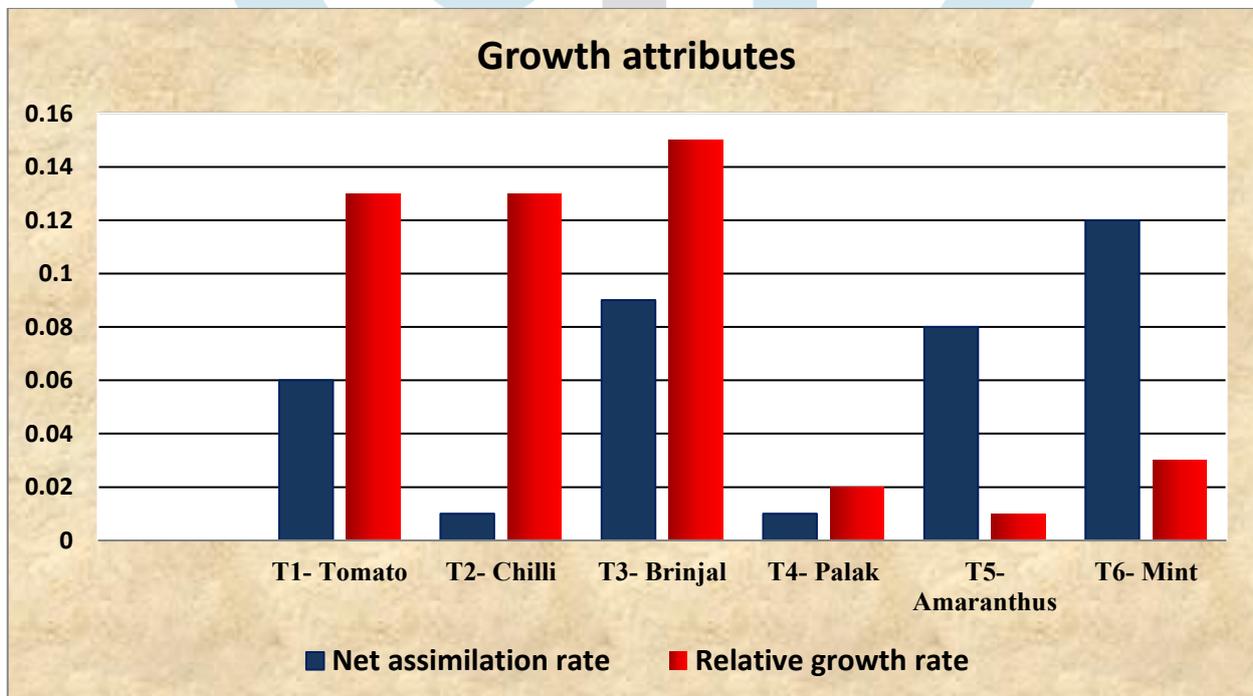


Fig. 2. Net assimilation rate and Relative growth rate of crops in vertical structure

**Vertical structure used in this study**



**Brinjal vegetative & flowering stage**



**Fruiting (Brinjal, Tomato, Chilli) and Leafy vegetable (Palak, Mint, Amaranthus) production in Vertical structure**



**Tomato**

**Brinjal**



**Chilli**



### Leafy Vegetables



### References

1. Björkman, Olle, and Paul Holmgren. 1963. "Adaptability of the photosynthetic apparatus to light intensity in ecotypes from exposed and shaded habitats." *Physiologia plantarum* 16 (4):889-914.
2. Cantliffe, Daniel J, Javier Z Castellanos, and Ashwin V Paranjpe. 2007. "Yield and quality of greenhouse-grown strawberries as affected by nitrogen level in coco coir and pine bark media." *Proceedings of the Florida State Horticultural Society*.
3. Coronel, G, M Chang, and A Rodríguez-Delfín. 2008. "Nitrate reductase activity and chlorophyll content in lettuce plants grown hydroponically and organically." *International Symposium on Soilless Culture and Hydroponics* 843.
4. Gonzales, Leif Marvin R, Ramonita A Caralde, and Maita L Aban. 2015. "Response of Pechay (*Brassica napus* L.) to different levels of compost fertilizer." *International Journal of Scientific Research Publications* 5 (2):1-4.
5. Grime, JP, and Roderick Hunt. 1975. "Relative growth-rate: its range and adaptive significance in a local flora." *The Journal of Ecology*:393-422.
6. Hammad, Hameed Salih, Ahmed Amir Murad Al-Mandalawi, and Ghassan Jaafar Hamdi. 2019. "Effect of manure on growth and yield of broccoli." *International Journal of Vegetable Science* 25 (4):400-406.
7. Hunt, R, DR Causton, B Shipley, and AP Askew. 2002. "A modern tool for classical plant growth analysis." *Annals of botany* 90 (4):485-488.
8. Li, Qiansheng, Xiaoqiang Li, Bin Tang, and Mengmeng Gu. 2018. "Growth responses and root characteristics of lettuce grown in aeroponics, hydroponics, and substrate culture." *Horticulturae* 4 (4):35.
9. Melgarejo, P, JJ Martínez, Fca Hernández, DM Salazar, and R Martínez. 2007. "Preliminary results on fig soil-less culture." *Scientia horticulturae* 111 (3):255-259.
10. Ogunlela, Vincent B, Michael T Masarirambi, and Stanley M Makuza. 2005. "Effect of cattle manure application on pod yield and yield indices of okra (*Abelmoschus esculentus* L. Moench) in semi-arid and subtropical environment." *Journal of Food, Agriculture and Environment* 3 (1):125-129.

11. Rincón Castillo, Á, and Gustavo Adolfo Ligarreto. 2010. "Relationship between leaf nitrogen and chlorophyll content in corn found in pastures in the Llanos Foothills of Colombia." *Revista Corpoica-Ciencia y Tecnologia Agropecuarias* 11 (2):122-128.
12. Roupael, Y, G Colla, A Battistelli, S Moscatello, S Proietti, and E Rea. 2004. "Yield, water requirement, nutrient uptake and fruit quality of zucchini squash grown in soil and closed soilless culture." *The Journal of Horticultural Science Biotechnology* 79 (3):423-430.
13. Wolff, Xenia Y, and Robert R. Coltman. 1990. "Productivity of eight leafy vegetable crops grown under shade in Hawaii." *Journal of the American Society for Horticultural Science* 115 (1):182-188.
14. Zaręba, A., Krzemińska, A., & Kozik, R. (2021). Urban Vertical Farming as an Example of Nature-Based Solutions Supporting a Healthy Society Living in the Urban Environment. *Resources*, 10(11), 109.

