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COMPARATIVE EVALUATION OF VERTICAL GARDEN GROWN FOLIAGE ORNAMENTALS UNDER SHADE CONDITIONS OF PERENNIAL PLANT CANOPIES

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ABSTRACT

Vertical gardens are an effective solution for urban greening, particularly in areas where horizontal space is limited. The present study evaluated the growth and physiological performance of seven ornamental plant species under different light environments to identify their suitability for vertical garden systems. Significant differences were observed among species, growing environments and their interactions. Growth attributes, intercellular CO_2 concentration and chlorophyll content varied considerably across treatments, reflecting species specific adaptation to different microclimates. Among the evaluated plants, *Nephrolepis exaltata*, *Tradescantia pallida* and *Billbergia nutans* exhibited superior performance, demonstrating good adaptability and physiological efficiency under favourable light conditions. These findings suggest that careful selection of ornamental species based on their light requirements can enhance the aesthetic value, sustainability and functional performance of vertical garden systems.

***Key words*:** Vertical garden, Ornamental foliage plants, Light, Intercellular CO_2, Chlorophyll content.

Introduction

Rapid increase in the population density has resulted in urbanization and congestion in cities, thereby reducing the availability of horizontal space for greenery and landscaping. Vertical gardening and green wall systems provide an effective approach to harness limited urban space by establishing vegetation on vertical space. The concept of vertical greening has historical dates back about 2,500 years to the Hanging Gardens of Babylon (Shaikh *et al.*, 2015), while the modern vertical garden system was pioneered by French botanist 'Patrick Blanc', who developed soil-less plant-growing systems for vertical space. Green walls can be established on both exterior and interior walls and contribute to urban greening, aesthetic improvement and environmental sustainability. Ornamental plants are particularly valued for their attractive foliage, diverse forms and colours, while, also supporting urban biodiversity and improving the psychological quality of built environments.

Indoor vertical greenery can also contribute to improved indoor and urban environmental conditions. Since, people spend a considerable proportion of their time inside buildings, maintaining good indoor environmental quality is important. Indoor plants can help to alleviate certain problems associated with indoor environments, while vertical gardens can contribute to air-quality improvement, reduction of urban heat-island effects and reduction of heat and noise (Abdou, 2021; Kumar, 2023). Green facades additionally provide insulation to buildings by reducing direct solar radiation and mitigates indoor micro climate. (Sathien *et al.*, 2013; Rakhshandehroo *et al.*, 2015).

Light is one of the major environmental factors determining the successful growth and development of vertical gardens and broadly classified into sun or shade loving plants (Cuzzuol and Milanez, 2012). Light serves as the primary energy source for photosynthesis and influences the structure and functioning of the photosynthetic apparatus. Photosynthetic responses differ considerably between plants adapted to high or low light environments (Boardman, 1977; Ojanguren *et al.*, 2013; Valladares and Niinemets, 2008; Li *et al.*, 2014). Improper illumination may hamper the ATP production, carbon fixation and carbohydrate synthesis, ultimately reducing plant growth (Shao *et al.*, 2014). Hence, proper selection of shade-tolerant ornamental species is essential for successful indoor vertical gardening.

The successful establishment of any vertical garden mainly depends on growing factors like- media, nutrition, humidity, shade tolerance and light intensities. A majority of plant species were highly influenced by light and selection of plants based on the prevailing light conditions is quiet necessary for the successful formation of vertical garden. The present study investigates the growth and development of different plant species at under different light levels under perennial plant canopies for the successful vertical garden deployment.

Materials and Methods

Experimental site and climatic conditions

Experiment was carried out at College of Horticulture, Anantharajupeta, which falls under fourth agro-climatic zone that is Southern Plateau and hills region of India and Southern Agro climatic zone of Andhra Pradesh at an elevation of 162 (531 feet) MSL above lying between the 13º59' North latitude and 79º19' East longitude.

Experimental Design and Layout

Factorial Completely Randomized Design (FCRD) design has been used with 2 factors with 49 interactions and with 3 replications. The vertical stand frame size is 7×4 ft. with 5 columns and 7 rows. And the size of plant pots used are of 6.5 inches diameter (polypropylene).

Experimental details

The media of the experimental site is the mixture of garden soil and cocopeat in 1:1 ratio. Seven species of one month old rooted, were transplanted into a 6.5 inches diameter plant pots. Irrigation was provided based on the moisture status of the media.

Observations recorded

Morphological parameters like plant spread, leaf length and number of leaves per plant were recorded at 120 DAP. Intercellular CO_2 concentration was measured using LCi-SD portable photosynthetic system, *i.e.*, Infra-red gas analyser (IRGA). The total chlorophyll content in the leaves of plants was analysed by Arnon (1949) DMSO procedure.

Table 1: Treatment details.

Factor 1: (P) Ornamental plants	**Factor 2: (L) Locations**
P_1-*Aglaonema commutatum*	L_1 - Indoor condition (Control)
P_2-*Billbergia nutans*	L_2 - College portico
P_3-*Tradescantia pallida*	L_3 - Neem tree plantation
P_4-*Syngonium podophyllum*	L_4-Mango orchard
P_5-*Philodendron birkin*	L_5-Jack fruit tree plantation
P_6-*Peperomia* spp.	L_6-Oil Palm plantation
P_7-*Nephrolepis exaltata*	L_7 - Cocoa-coconut plantation

Results and Discussion

Plant Spread (cm²)

Significant differences were obtained in all the plant species and locations with respect to plant spread. Among the plant species *Tradescantia pallida* recorded the highest plant spread (291.61 cm^2), whereas, in locations, college portico showed highest plant spread (204.09 cm^2). In interaction, *Tradescantia pallida* at college portico showed significantly higher plant spread (497.68 cm^2).

Tradescantia pallida possess creeping and scrambling growth with rapid lateral shoot production (Ravi and Karuppaiah, 2025) and this might have increased the plant spread. Patil *et al.*, (2020) reported that plant spread and vegetative growth in ornamental species are optimized under moderate shade levels (40–60% light penetration), with severe reductions observed under both full sunlight and dense shade conditions.

Leaf length (cm)

Among all the plant species the highest leaf length (23.43 cm) was observed in *Nephrolepsis exaltata* and regarding location college portico recorded the maximum leaf length (15.33 cm), *Nephrolepsis exaltata* grown under college portico (34.10 cm) recorded maximum leaf length.

Most of the fern species requires diffused light conditions with low temperatures and high relative humidity. Providing these conditions might have increased the leaf length in *Nephrolepsis exaltata* with increased fronds length (Erwin *et al.*, 1989). The superior leaf elongation of *Nephrolepis exaltata* may be attributed to its fast-growing nature and sustained frond development, as reported by Pereira *et al.*, (2013). Similar effects of light intensity on leaf length were reported by Sood and Bhatia (2023) and Silalahi and Murni (2023).

Table 2: Effect of Location, Plant and their interaction to various shade and light levels under perennial plant canopies in response to growth parameters.

Plant Spread (cm^2)								
	L_1	L_2	L_3	L_4	L_5	L_6	L_7	Mean
P_1	271.77	175.98	58.40	215.39	77.65	39.16	31.01	124.19
P_2	138.37	151.07	242.92	146.22	141.10	230.08	138.21	169.71
P_3	95.05	497.68	279.98	375.67	341.57	306.46	144.85	291.61
P_4	54.21	144.11	123.46	60.41	14.73	54.49	26.10	68.21
P_5	20.55	112.43	72.97	84.74	45.16	18.13	74.77	61.25
P_6	63.25	42.84	174.23	87.18	51.12	159.44	34.65	87.53
P_7	48.89	304.52	132.82	280.01	55.13	262.28	63.84	163.93
Mean	98.87	204.09	154.97	178.52	103.78	152.86	73.35	
Source	P		L		P×L			
SEm±	0.995		0.995		0.632			
CD @5%	2.797		2.797		7.399			
Leaf Length (cm)								
	L_1	L_2	L_3	L_4	L_5	L_6	L_7	Mean
P_1	18.50	11.63	15.33	17.33	15.13	16.23	13.01	15.31
P_2	20.53	17.76	25.70	24.53	12.17	26.13	21.66	21.21
P_3	10.53	11.73	10.73	9.07	12.43	10.27	9.73	10.64
P_4	8.77	10.90	8.20	8.03	8.86	8.90	5.46	8.45
P_5	7.30	10.33	7.23	5.76	7.76	5.13	4.63	6.88
P_6	8.97	10.83	6.03	8.80	7.56	5.57	3.93	7.38
P_7	28.60	34.10	22.53	32.06	16.13	20.86	9.70	23.43
Mean	14.74	15.33	13.68	15.08	11.43	13.30	9.73	
Source	P		L		P×L			
SEm±	0.087		0.087		0.23			
CD @5%	0.244		0.244		0.646			
Number of leaves plant^{-1}								
	L_1	L_2	L_3	L_4	L_5	L_6	L_7	Mean
P_1	3.67	3.33	2.33	3.67	3.00	2.00	1.33	2.76
P_2	7.00	10.33	13.67	10.33	9.67	11.33	11.67	10.57
P_3	4.67	34.67	16.33	28.67	24.00	19.67	16.00	20.57
P_4	3.67	9.33	7.33	5.00	1.67	4.00	2.67	4.81
P_5	3.00	6.33	7.67	6.67	4.33	2.00	6.33	5.19
P_6	5.67	3.00	17.00	6.00	3.33	6.33	1.00	6.05
P_7	1.33	8.00	3.33	5.67	1.67	4.33	3.00	3.91
Mean	4.14	10.71	9.67	9.43	6.81	7.10	6.00	
Source	P		L		P×L			
SEm±	0.703		0.703		1.859			
CD @5%	1.975		1.975		5.226			

Number of leaves plant^{-1}

In all the plant species studied, maximum leaf number was observed in *Tradescantia pallida* (20.57), while in the locations, plants under college portico showed higher leaf number (10.71). In the interaction effect *Tradescantia pallida* grown at the college portico showed more number of leaves per plant (34.67).

Tradescantia pallida consistently produced the highest leaf count due to its vigorous growth habit and also shows tolerance to microclimatic fluctuations and ability to sustain continuous leaf initiation, unlike slower-growing ornamentals that prioritize leaf longevity over rapid proliferation (Ramesh kumar, 2018; Gautam *et al*., 2021; Ravi and Karuppaiah, 2025).

Intercellular CO_2 concentration (µmol CO_2 mol^{-1})

Significant differences were noted in intercellular CO_2 concentration in different species and locations. Among the plant species, highest intercellular CO_2 concentration (360.1 µmol CO_2 mol^{-1}) was observed *Billbergia nutans*. In locations, maximum intercellular CO_2 concentration (355.3 µmol CO_2 mol^{-1}) was recorded at *college portico. As an interaction, Billbergia nutans* grown under *college portico (*398.4 µmol CO_2 mol^{-1}) resulted highest intercellular CO_2 concentration.

Environmental conditions also influenced Ci, with moderately shaded locations such as the college portico and jackfruit plantation generally exhibiting higher values.

The variation in intercellular CO_2 concentration (Ci) among the ornamental species was primarily associated with differences in photosynthetic pathway, stomatal regulation and CO_2 assimilation capacity. Among all the species, *Billbergia nutans* consistently recorded the highest Ci, which may be attributed to its bromeliad physiology and characteristic Crassulacean Acid Metabolism (CAM). In CAM plants, nocturnal CO_2 fixation into malic acid followed by daytime decarboxylation increases the internal CO_2 concentration during Phase III of the CAM cycle, thereby reducing photorespiration and improving water-use efficiency (Gottlinger and Lohaus, 2020; Hermide *et al*., 2020).

Table 3: Effect of Location, Plant and their interaction to various shade and light levels under perennial plant canopies in response to physiological and biochemical parameters.

	Intercellular CO_2 concentration (µmol CO_2 mol^{-1})								Total chlorophyll content (mg g^{-1})							
	L_1	L_2	L_3	L_4	L_5	L_6	L_7	Mean	L_1	L_2	L_3	L_4	L_5	L_6	L_7	Mean
P_1	265.3	362.3	292.3	321.3	196.3	253.1	175.1	266.6	10.30	8.11	8.67	6.90	8.43	8.27	1.80	7.50
P_2	362.3	398.4	385.5	392.7	349.3	355.7	277.0	360.1	3.13	5.30	7.39	6.34	6.50	6.02	6.26	5.85
P_3	282.0	336.0	288.3	321.3	238.5	271.7	238.0	282.3	10.68	7.39	10.04	8.11	9.47	9.07	6.10	8.69
P_4	261.3	293.4	268.6	269.4	230.7	257.6	204.3	255.0	3.13	8.92	5.30	9.31	2.81	3.05	3.53	5.15
P_5	288.4	356.4	321.3	330.6	271.7	282.4	231.4	297.4	3.69	14.05	9.23	3.69	12.89	7.87	7.07	8.36
P_6	317.3	351.6	337.3	344.7	308.7	315.7	286.4	323.1	3.21	2.25	7.87	8.83	3.45	6.90	1.85	4.91
P_7	284.3	388.7	304.7	384.7	260.3	281.7	233.3	305.4	10.60	14.78	11.24	23.36	10.60	11.24	14.46	13.75
Mean	294.4	355.3	314.0	337.8	265.1	288.3	235.1		6.39	8.68	8.53	9.51	7.74	7.49	5.87	
Source	P		L		P×L				P		L		P×L			
SEm±	1.741		1.741		4.606				0.038		0.038		0.101			
CD@5%	4.887		4.887		12.931				0.107		0.107		0.282			

Total Chlorophyll content (mg g^{-1})

The maximum total chlorophyll concentration (13.74 mg g^{-1}) was recorded in *Nephrolepsis exaltata*, with respect to locations, under mango orchard recorded highest total chlorophyll content (9.51 mg g^{-1}). In interaction, *Nephrolepsis exaltata* under mango orchard (23.36 mg g^{-1}) resulted maximum total chlorophyll content.

The variation in total chlorophyll content among the evaluated foliage plants may be attributed to species-specific differences in photosynthetic adaptation and pigment regulation under different light environments. Shade-adapted plants generally maintain higher chlorophyll concentrations to maximize light capture under limited irradiance, whereas, excessive light can induce chlorophyll degradation or down-regulation as a protective mechanism against photoinhibition and oxidative stress. Moderate shade conditions under the mango plantation and college portico helped maintain higher chlorophyll content (Chen *et al.*, 2003; Naveena *et al.*, 2019; Seltsam and Owen, 2022). The adverse effects of high irradiance and temperature on chlorophyll stability and pigment degradation have also been documented by Boardman (1977).

Conclusion

At partial shade conditions *i.e*, college portico and under mango orchard *Tradescantia pallida, Nephrolepis exaltata, Billbergia nutans recorded* highest plant spread and number of leaves, leaf length and total chlorophyll content, intercellular CO_2 concentration respectively. The findings signify the importance of species selection for maintaining healthy and sustainable vertical greenery, as plant growth, physiological performance and overall adaptability are strongly influenced by the prevailing light environment and microclimatic conditions.

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