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Studies for Determination of Air Pollution Tolerance Index of Ornamental Plant Species Grown in the Vertical Landscape System

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ABSTRACT: Air pollution in Cities and Metros across the world is a matter of global health concern. Poor air quality is associated with health problems throughout the world due to rapid urbanization and industrialization. Little relief is possible if we rely on ornamental plants which can mitigate air pollution. In the present era of rapid urbanization, the horizontal space left for outdoor gardens is very limited. Here comes the importance of vertical landscaping. Vertical green walls are aesthetically appealing, refresh the ambiance and improve the air quality. Vertical gardening expands the possibility of growing ornamental plants in a vertical space wherever space is a constraint. Smartly designing the available vertical spaces in balcony, terraces, sit outs and living rooms allows us to transform it into a beautiful and lush area perfect for relaxing. Plants in the vertical green walls can remove toxicants and obnoxious compounds from surrounding air, in addition to the basic photosynthesis. Relatively little is known, and limited studies have been carried out on the utilization of ornamentals in vertical gardens for curbing air pollution. The result of the present study shows that inclusion of ornamental plants having pollution mitigating ability in the vertical landscape plan will serve the dual purpose of making our living environment green and pollution free in the long run.

Keywords: APTI, Foliage ornamentals, Vertical farming

INTRODUCTION

The quality of human life is affected due to lack of vegetation coupled with air pollution in urban areas. Neglecting the air pollution makes the people prone to acute health risks like frequent illness, allergies, asthma, strokes, heart attacks, bronchial infection, dry eyes, sore throat, sinus, headache, cancer, cardiovascular emergencies, loss of concentration, nausea, dizziness, fatigue, skin and eye irritation, and many other ailments. The developing countries including India experienced a progressive degradation in air quality due to rapid development in industrial and urban sectors in the last three decades (Lindgren and Saravanakumar, 2009). A range of environmental toxins has been released into the atmosphere due to urbanisation and industrialization over the last 200 years (Chen *et al*., 2016). Ornamental plants are believed to be potential scavengers of obnoxious gases to improve the air quality. In the present era, the horizontal space left for outdoor gardens is very limited. Vertical landscaping is a relatively new concept of urban gardening which are suitable for small spaces, mostly for adorning the walls and roofs in various styles. This is a distinctive method of gardening by expanding the possibility of growing ornamental plants in a vertical space wherever space is a constraint. Vertical gardening allows ornamental plants to grow on walls and other non - horizontal surfaces. Vertical garden is the solution to implement beautiful plant in any location where there are no others places left for plants (Ankit, 2017). Plants in the vertical green wall systems can remove toxicants and obnoxious compounds from air, in addition to the basic photosynthesis that removes carbon dioxide and returns oxygen to the air. Air quality can be improved exponentially by the use of vertical green wall systems. Vertical green wall systems reduce dust levels, stabilize humidity and temperature, lower noise levels and provide a refreshing environment. The greenery in vertical landscaping systems provides a feeling of pleasure, calm and relief from stress. Thus, vertical landscaping system or green wall system which includes ornamental crops improves the wellbeing and performance / work productivity of people. The scientific information available is scanty or little on selection of suitable species of ornamental plant for improvement of air quality. Vanda *et al*., 2020 reported that APTI (Air pollution tolerance index) values can be used to select pollution tolerant species used for urban greening and/or selecting species for green belt development. With this background the present experiment was initiated with objectives to evaluate different ornamental plant species for their performance in the vertical landscape system and to estimate the Air Pollution Tolerance Index of different ornamental plant species used in vertical landscape system.

MATERIALS AND METHODS

The experiment was implemented at Floriculture Research Farm, Hadapsar farm, ICAR – Directorate of Floricultural Research, Pune. For setting up the experiment, a MS Steel Structure was fabricated to Support the Weight of the Vertical Garden Modules and Panels. The size of each fabricated structure was 150 cm X 120 cm (5 ft X 4 ft) – 20 sqft. After fabrication, the frames were attached to the structure. Size of the frame used was 18 inches height -45 cm and 6 inches width- 15 cm which could hold three detachable containers (pots) of size 5 inches. A total of 12 structures of 20 sq. ft were fabricated for conducting the experiment. Each fabricated structure could accommodate 24 sets of vertical garden frames which is sufficient for keeping 72 numbers of detachable pots of size 5 inches. The experiment was laid out in Randomized Block Design with 18 treatments and 3 replications. Each treatment consisted of 48 plants and 16 plants per replication. Eighteen different species of ornamental plants / treatments used in the experiment are

T_1: *Syngonium podophyllum* 'Berry Allusion' (Berry Allusion Nephthytis),
T_2: *Alternanthera* Green,
T_3: *Syngonium podophyllum* 'Strawberry Cream'(Strawberry Cream Arrowhead Vine),
T_4: *Pleomele reflexa*,
T_5: *Syngonium podophyllum* 'Bold Allusion'(Bold Allusion Nephthytis),
T_6: *Rhoeo discolor* (Moses in the cradle) Sitara Gold
T_7: *Syngonium podophyllum* 'Maria Allusion' (Maria Allusion Nephthytis),
T_8: *Peperomia obtusifolia variegata*
T_9: *Syngonium podophyllum* 'Pink Allusion' (Pink Allusion Nephthytis),
T_{10}: *Syngonium podophyllum* 'Cream Allusion' (Cream Allusion Nephthytis),
T_{11}: *Syngonium podophyllum* 'White Butterfly' (White Butterfly Arrowhead Vine),
T_{12}: *Alternanthera* White,
T_{13}: *Philodendron scandens green*
T_{14} : *Epipremnum aureum* (Golden money plant / Golden Pothos)
T_{15}: *Tradescantia spathaceae variegata*,
T_{16}: *Alternanthera* Red,
T_{17}: *Philodendron Imperial Green*,
T_{18}: *Chlorophytum comosum* green

were being evaluated under the study for estimation of air pollution tolerance index. The study was carried out for a period of one year. During the experimental period, several growth parameters such as Plant height, number of leaves, number of branches, stem girth, length of leaf with petiole, petiole length, leaf width and length of leaf without petiole were monitored at bimonthly intervals. Data recorded on various morphological parameters were statistically analyzed following the procedures as described by Panse and Sukhatme (1978). Biochemical parameters used for analysis of leaf samples for estimation of APTI are Relative water content of leaf, Leaf pH, Total Chlorophyll content and Ascorbic Acid Content. Care was taken to obtain leaf samples from the plants of uniform size and the leaf samples were taken in the morning (8:30-10:00 A.M) in triplicates.

1. Relative water content of leaf

It can be calculated using the formula: $RWC = [(FW-DW) / (TW-DW)] \times 100$

Where, FW = Fresh weight of leaf.
DW = Dry weight of leaf.
TW = Turgid weight of leaf.

Fresh weight of leaves was obtained by weighing the fresh leaves. The leaves were then immersed in water overnight (24 hour), blotted dry and then weighed to get the turgid weight. The leaves were then dried in hot oven drier to obtain the dry weight.

2. Total Chlorophyll content

0.5 g of fresh leaves were blended and then extracted with 10 ml of 80% acetone and left for 15 minutes. The liquid portion was centrifuged at 4000 rpm for 20 minutes. The supernatant was collected and adjusted to volume of 15ml by adding chilled acetone and then measured the absorbance at 645 nm and 663 nm using Spectrophotometer. The following calculations were performed to determine Total Chlorophyll content

Chlorophyll a = $(12.7 \times DX_{663} - 2.69 \times DX_{645}) \times (V/1000W)$ mg/g

Chlorophyll b = $(22.9 \times DX_{645} - 4.68 \times DX_{663}) \times (V/1000W)$ mg/g

Total Chlorophyll content = (Chlorophyll a + Chlorophyll b) mg/g

DX= Absorbance of the extract at the wavelength Xnm
V= Total volume of the chlorophyll solution (ml)
W= Weight of the tissue extract (g)

3. Ascorbic Acid Content

In this analysis, the method of Bajaj and Kaur (1981) was adopted. 1 g of fresh leaf samples was taken in a test tube, 4 mL of oxalic acid-EDTA extracting solution (5 g oxalic acid + 0.75 g EDTA in 1000 mL of distilled water) was added and then 1 mL of orthophosphoric acid followed by 1 mL of 5% sulfuric acid was added. To this mixture, 2 mL of 5% ammonium molybdate solution and 3 mL of water was added. The solution was allowed to rest for about 15 minutes at room temperature condition. After the incubation period, the absorbance was measured at 760 nm using a UV-Visible Spectrophotometer. The concentration of ascorbic acid in the samples was calculated from a standard ascorbic curve. For this, 0.1 to 0.8 mL aliquots of standard ascorbic acid solution were taken in a series of test tubes and chemicals was added as before. After the incubation period, absorbance was measured at 760 nm and the standard graph was prepared.

4. pH of leaf extract

Grind the leaf to paste and dissolve in distilled water, filter and measure the pH.

5. Air Pollution Tolerance Index (APTI):

The APTI value is calculated by adopting the formula;

APTI = {A (T + P) + R}/10

Where; A = Ascorbic acid content (mg/g).

T = Total chlorophyll content (mg/g)P = pH of the leaf extract..R = Relative leaf water content (%).

RESULTS AND DISCUSSION

Significant variation was noticed among different species of ornamental plants used in the present study for various morphological and leaf quality parameters and the data is presented in Table 1 – Table 6. Data was recorded on various morphological parameters at bimonthly intervals and analyzed statistically. Statistically significant variations in vegetative attributes were recorded. The desired characteristics for plants grown in vertical garden wall system should be dense, compact, well-formed, evergreen and slow growing in nature with healthy root system.

In the present study, out of the eighteen species evaluated for their vegetative characteristics, least plant height of 21.24 cm was observed in *Peperomia obtusifolia variegata* followed by *Rhoeo discolor* (23.93 cm), *Tradescantia spathaceae variegata* (25.95 cm), *Syngonium podophyllum* 'Cream Allusion' (26.2 cm) and *Syngonium podophyllum* 'Strawberry Cream' (26.39 cm). The maximum plant height was recorded in *Epipremnum aureum* (139 cm) followed by *Philodendron scandens* Imperial Green (116.7 cm). Since they were trailing and tall growing with fast growth, these species are not suitable for vertical landscaping. Longest (28.10 cm) and broadest (7.88 cm) leaves was observed in *Syngonium podophyllum* ‘White Butterfly’ (White Butterfly Arrowhead Vine) whereas, shortest (3.61 cm) and narrowest (1.39 cm) leaves were observed in *Alternanthera* Green. The covering percentage was observed maximum in *Syngonium podophyllum* 'Bold Allusion' which recorded the highest leaf area of 247.50 cm^2 followed by *Syngonium podophyllum* ‘White Butterfly' (223.50 cm^2). It is evident from the results that *Syngonium podophyllum* 'White Butterfly, ‘’Maria Allusion’, ‘Berry allusion’ and ‘Bold Allusion’ are promising in respect of growth and quality for vertical landscape system.

For the estimation of APTI which is one of the best indices to depict the tolerance and sensitivity of plant species to air pollution, total chlorophyll, ascorbic acid, pH and relative water content were taken into account. The results of each biochemical components and air pollution tolerance index are enumerated in Fig.1 to Fig. 6.

Table 1: Plant height of different ornamental plant species in the Vertical landscape system recorded at bimonthly intervals.

Treatments	2 MAP	4 MAP	6 MAP	8 MAP	10 MAP	12 MAP
T- 1 :*Syngonium podophyllum* ‘Berry Allusion’(Berry Allusion Nephthytis)	8.23	17.56	21.44	28.04	29.35	31.16
T – 2 :*Alternanthera* Green	15.64	24.89	25.66	29.53	30.13	32.00
T – 3 :*Syngonium podophyllum* 'Strawberry Cream'(Strawberry Cream Arrowhead Vine)	12.13	18.11	19.72	25.40	25.93	26.39
T – 4 :*Pleomele reflexa*	8.81	13.00	12.67	14.07	14.32	14.57
T- 5 :*Syngonium podophyllum* 'Bold Allusion'(Bold Allusion Nephthytis)	13.63	24.33	26.49	32.80	36.20	36.64
T- 6 :*Rhoeo discolor* (Moses in the cradle) Sitara Gold	11.82	18.21	22.94	23.43	23.51	23.93
T – 7 :*Syngonium podophyllum* 'Maria Allusion' (Maria Allusion Nephthytis)	7.77	20.89	24.11	30.59	31.56	32.58
T- 8 :*Peperomia obtusifolia variegata*	8.48	12.78	14.56	16.98	19.06	21.24
T- 9 :*Syngonium podophyllum* 'Pink Allusion' (Pink Allusion Nephthytis)	8.97	16.22	20.06	33.14	41.40	51.23
T- 10 :*Syngonium podophyllum* 'Cream Allusion' (Cream Allusion Nephthytis)	10.00	19.78	21.00	22.66	25.66	26.20
T- 11 :*Syngonium podophyllum* 'White Butterfly' (White Butterfly Arrowhead Vine)	8.76	18.61	24.50	30.82	31.17	34.21
T- 12 :*Alternanthera* White	10.63	18.39	20.11	27.78	29.72	33.35
T- 13 :*Philodendron scandens green*	8.39	32.33	54.66	95.43	108.90	116.73
T- 14 : *Epipremnum aureum* (Golden money plant (Golden Pothos)	8.78	45.83	67.11	104.84	125.68	139.04
T- 15 :*Tradescantia spathaceae variegata*	4.12	19.02	20.31	20.92	21.60	25.95
T-16 :*Alternanthera* Red	12.90	18.17	19.61	22.77	24.70	25.74
T – 17 :*Philodendron Imperial Green*	7.31	33.33	40.11	58.56	63.21	74.77
T – 18 :*Chlorophytum comosum* green	9.70	23.36	27.50	33.17	38.13	42.86
Sem±	1.67	1.35	3.35	4.47	6.35	6.79
CD(0.05)	5.03	4.06	10.05	13.41	19.05	20.36

Table 2: Number of leaves recorded in different ornamental plant species in the Vertical landscape system at bimonthly intervals.

Treatments	2 MAP	4 MAP	6 MAP	8 MAP	10 MAP	12 MAP
T- 1 :*Syngonium podophyllum* 'Berry Allusion'(Berry Allusion Nephthytis)	7.44	7.67	9.11	9.88	9.89	10.83
T – 2 :*Alternanthera* Green	41.56	48.33	71.89	75.39	77.61	89.22
T – 3 :*Syngonium podophyllum* 'Strawberry Cream'(Strawberry Cream Arrowhead Vine)	8.67	9.56	10.67	11.00	11.99	12.22
T – 4 :*Pleomele reflexa*	8.78	8.89	9.67	10.33	12.56	12.67
T- 5 :*Syngonium podophyllum* 'Bold Allusion'(Bold Allusion Nephthytis)	8.11	11.99	12.22	14.67	15.33	16.11
T- 6 :*Rhoeo discolor* (Moses in the cradle) Sitara Gold	15.44	17.78	19.78	22.11	28.79	41.89
T – 7 :*Syngonium podophyllum* 'Maria Allusion' (Maria Allusion Nephthytis)	6.67	9.00	11.44	13.22	15.56	16.00
T- 8 :*Peperomia obtusifolia variegata*	4.67	6.89	7.22	8.67	11.11	11.56
T- 9 :*Syngonium podophyllum* 'Pink Allusion' (Pink Allusion Nephthytis)	10.33	12.89	14.00	18.67	20.44	22.33
T- 10 :*Syngonium podophyllum* 'Cream Allusion' (Cream Allusion Nephthytis)	15.14	16.67	17.00	18.89	26.00	27.22
T- 11 :*Syngonium podophyllum* 'White Butterfly' (White Butterfly Arrowhead Vine)	11.22	13.11	14.56	18.22	21.06	21.11
T- 12 :*Alternanthera* White	24.33	29.22	34.89	38.11	41.17	82.00
T- 13 :*Philodendron scandens green*	6.72	13.89	18.11	23.22	27.67	27.89
T- 14 :*Epipremnum aureum* (Golden money plant (Golden Pothos)	5.89	12.11	17.00	20.89	21.11	23.83
T- 15 :*Tradescantia spathaceae variegata*	10.67	15.28	16.17	17.11	18.67	21.33
T-16 :*Alternanthera* Red	47.89	63.22	67.00	68.11	68.33	89.83
T – 17 :*Philodendron Imperial Green*	7.22	10.88	11.78	14.56	15.04	15.44
T – 18 :*Chlorophytum comosum* green	13.94	19.78	25.72	30.06	36.50	36.78
Sem$\pm$	2.17	1.91	9.05	9.58	5.73	7.33
CD(0.05)	6.51	5.73	27.14	28.75	17.19	21.99

Table 3: Leaf length (cm) in different ornamental plant species in the Vertical landscape system at bimonthly intervals.

Treatments	2 MAP	4 MAP	6 MAP	8 MAP	10 MAP	12 MAP
T- 1 :*Syngonium podophyllum* 'Berry Allusion'(Berry Allusion Nephthytis)	9.89	15.00	17.44	21.53	22.32	24.02
T – 2 :*Alternanthera* Green	2.23	2.52	3.06	3.22	3.50	3.61
T – 3 :*Syngonium podophyllum* 'Strawberry Cream'(Strawberry Cream Arrowhead Vine)	11.43	16.22	17.00	19.88	21.17	21.29
T – 4 :*Pleomele reflexa*	9.11	10.21	10.52	10.83	11.74	12.17
T- 5 :*Syngonium podophyllum* 'Bold Allusion'(Bold Allusion Nephthytis)	11.97	20.61	22.06	25.27	26.20	27.36
T- 6 :*Rhoeo discolor* (Moses in the cradle) Sitara Gold	8.79	10.69	13.72	14.09	14.89	15.31
T – 7 :*Syngonium podophyllum* 'Maria Allusion' (Maria Allusion Nephthytis)	11.11	18.56	20.72	24.27	24.92	25.34
T- 8 :*Peperomia obtusifolia variegata*	8.61	9.05	9.67	9.72	9.99	11.39
T- 9 :*Syngonium podophyllum* 'Pink Allusion' (Pink Allusion Nephthytis)	11.02	13.22	14.39	14.76	15.17	16.73
T- 10 :*Syngonium podophyllum* 'Cream Allusion' (Cream Allusion Nephthytis)	12.42	16.33	16.72	18.59	19.39	20.27
T- 11 :*Syngonium podophyllum* 'White Butterfly' (White Butterfly Arrowhead Vine)	11.00	15.00	19.50	22.33	24.26	28.10
T- 12 :*Alternanthera* White	3.200	4.22	4.48	4.57	4.92	5.39
T- 13 :*Philodendron scandens green*	11.22	12.50	13.44	14.94	15.00	15.57
T- 14 :*Epipremnum aureum* (Golden money plant (Golden Pothos)	13.58	14.54	14.83	14.88	15.10	15.78
T- 15 :*Tradescantia spathaceae variegata*	11.28	12.94	13.95	14.20	14.89	14.94
T-16 :*Alternanthera* Red	2.60	2.72	2.81	3.11	4.23	4.33
T – 17 :*Philodendron Imperial Green*	11.80	19.52	22.64	22.72	23.84	24.37
T – 18 :*Chlorophytum comosum* green	15.66	20.00	23.44	26.36	27.46	28.67
Sem$\pm$	0.59	0.79	0.97	1.21	2.02	1.26
CD(0.05)	1.79	2.39	2.89	3.63	6.07	3.77

Table 4: Stalk length of the leaf (cm) in different ornamental plants in the Vertical landscape system at bimonthly intervals.

Treatments	2 MAP	4 MAP	6 MAP	8 MAP	10 MAP	12 MAP
T- 1 :*Syngonium podophyllum* ‘Berry Allusion’(Berry Allusion Nephthytis)	3.44	8.50	10.44	12.94	13.02	15.34
T – 2 :*Alternanthera* Green	1.07	1.14	1.28	1.53	1.67	1.94
T – 3 :*Syngonium podophyllum* 'Strawberry Cream'(Strawberry Cream Arrowhead Vine)	5.84	9.28	10.56	12.17	12.18	13.67
T – 4 :*Pleomele reflexa*	0.40	0.50	0.53	0.73	0.76	0.89
T- 5 :*Syngonium podophyllum* 'Bold Allusion'(Bold Allusion Nephthytis)	5.33	11.17	14.00	14.96	17.34	18.16
T- 6 :*Rhoeo discolor* (Moses in the cradle) Sitara Gold	0.36	0.46	0.49	0.50	0.68	1.52
T – 7 :*Syngonium podophyllum* 'Maria Allusion' (Maria Allusion Nephthytis)	4.58	10.56	13.00	15.63	16.19	17.03
T- 8 :*Peperomia obtusifolia variegata*	1.61	1.93	1.98	2.11	2.44	2.63
T- 9 :*Syngonium podophyllum* 'Pink Allusion' (Pink Allusion Nephthytis)	4.28	6.89	7.37	7.72	7.80	9.24
T- 10 :*Syngonium podophyllum* 'Cream Allusion' (Cream Allusion Nephthytis)	6.22	9.72	10.33	10.59	10.74	12.08
T- 11 :*Syngonium podophyllum* 'White Butterfly' (White Butterfly Arrowhead Vine)	4.52	7.61	11.67	13.16	14.33	18.27
T- 12 :*Alternanthera* White	0.98	1.14	1.38	1.44	1.82	2.05
T- 13 :*Philodendron scandens green*	3.02	4.44	4.56	5.22	5.50	5.72
T- 14 :*Epipremnum aureum* (Golden money plant (Golden Pothos)	4.20	5.23	5.40	5.71	5.78	6.61
T- 15 :*Tradescantia spathaceae variegata*	0.32	0.37	0.49	0.50	0.75	0.80
T-16 :*Alternanthera* Red	1.21	1.38	1.39	1.45	1.72	1.89
T – 17 :*Philodendron Imperial Green*	3.69	5.41	8.28	8.70	9.27	11.34
T – 18 :*Chlorophytum comosum* green	0.41	0.48	0.50	0.51	0.62	0.63
Sem±	0.58	0.58	0.51	0.80	1.48	0.97
CD(0.05)	1.74	1.75	1.52	2.41	4.43	2.91

Table 5: Leaf width (cm)in different ornamental plant species in the Vertical landscape system at bimonthly intervals.

Treatments	2 MAP	4 MAP	6 MAP	8 MAP	10 MAP	12 MAP
T- 1 :*Syngonium podophyllum* ‘Berry Allusion’(Berry Allusion Nephthytis)	4.67	6.22	6.72	7.73	7.77	7.78
T – 2 :*Alternanthera* Green	0.88	0.95	0.97	1.24	1.38	1.39
T – 3 :*Syngonium podophyllum* 'Strawberry Cream'(Strawberry Cream Arrowhead Vine)	4.76	5.94	6.22	6.24	6.72	7.16
T – 4 :*Pleomele reflexa*	1.72	1.82	1.98	2.06	2.07	2.41
T- 5 :*Syngonium podophyllum* 'Bold Allusion'(Bold Allusion Nephthytis)	5.82	7.50	7.67	8.23	8.60	9.01
T- 6 :*Rhoeo discolor* (Moses in the cradle) Sitara Gold	2.06	2.06	2.08	2.57	2.58	2.79
T – 7 :*Syngonium podophyllum* 'Maria Allusion' (Maria Allusion Nephthytis)	5.11	6.56	6.94	7.82	7.91	7.98
T- 8 :*Peperomia obtusifolia variegata*	4.86	5.00	5.17	5.91	5.92	6.10
T- 9 :*Syngonium podophyllum* 'Pink Allusion' (Pink Allusion Nephthytis)	3.55	3.56	3.78	3.87	3.93	3.94
T- 10 :*Syngonium podophyllum* 'Cream Allusion' (Cream Allusion Nephthytis)	3.78	4.18	4.61	4.70	4.92	5.18
T- 11 :*Syngonium podophyllum* 'White Butterfly' (White Butterfly Arrowhead Vine)	4.67	5.44	6.44	7.13	7.29	7.88
T- 12 :*Alternanthera* White	1.03	1.23	1.39	1.47	1.81	1.84
T- 13 :*Philodendron scandens green*	4.66	4.83	5.44	5.80	5.81	6.27
T- 14 :*Epipremnum aureum* (Golden money plant (Golden Pothos)	5.42	5.78	5.89	6.93	6.94	7.32
T- 15 :*Tradescantia spathaceae variegata*	1.97	2.17	2.27	2.41	2.42	2.50
T-16 :*Alternanthera* Red	1.00	1.02	1.11	1.29	1.51	1.52
T – 17 :*Philodendron Imperial Green*	3.50	4.78	5.61	6.36	6.48	6.52
T – 18 :*Chlorophytum comosum* green	2.11	2.33	2.37	2.40	2.44	2.61
Sem±	0.31	0.21	0.32	0.43	0.29	0.36
CD(0.05)	0.93	0.63	0.96	1.29	0.88	1.09

Table 6: Leaf area in different ornamental plant species in the Vertical landscape system at bimonthly intervals.

Treatments	2 MAP	4 MAP	6 MAP	8 MAP	10 MAP	12 MAP
T- 1 :*Syngonium podophyllum* 'Berry Allusion'(Berry Allusion Nephthytis)	29.93	41.06	117.40	168.19	172.46	186.72
T – 2 :*Alternanthera* Green	2.11	2.23	2.26	3.09	3.12	4.02
T – 3 :*Syngonium podophyllum* 'Strawberry Cream'(Strawberry Cream Arrowhead Vine)	26.53	40.15	106.71	124.64	142.55	154.09
T – 4 :*Pleomelereflexa*	18.83	19.18	19.62	20.22	21.15	23.23
T- 5 :*Syngonium podophyllum* 'Bold Allusion'(Bold Allusion Nephthytis)	38.59	72.28	165.73	209.69	226.03	247.51
T- 6 :*Rhoeo discolor* (Moses in the cradle) Sitara Gold	20.02	23.23	28.41	34.31	37.90	39.78
T – 7 :*Syngonium podophyllum* 'Maria Allusion' (Maria Allusion Nephthytis)	33.95	49.07	144.12	192.98	199.17	199.18
T- 8 :*Peperomia obtusifolia variegata*	33.56	33.87	50.67	59.15	60.11	68.94
T- 9 :*Syngonium podophyllum* 'Pink Allusion' (Pink Allusion Nephthytis)	23.87	23.94	51.14	58.28	58.93	66.35
T- 10 :*Syngonium podophyllum* 'Cream Allusion' (Cream Allusion Nephthytis)	25.93	32.24	61.48	95.13	95.39	95.56
T- 11 :*Syngonium podophyllum* 'White Butterfly' (White Butterfly Arrowhead Vine)	29.90	39.29	128.77	172.25	180.49	223.51
T- 12 :*Alternanthera* White	3.31	5.68	5.93	6.14	6.69	6.86
T- 13 :*Philodendron scandens green*	38.45	38.84	73.33	87.23	87.51	97.79
T- 14 :*Epipremnum aureum* (Golden money plant (Golden Pothos)	50.84	51.75	93.21	100.67	105.42	109.27
T- 15 :*Tradescantia spathaceae variegata*	23.83	30.71	32.03	32.77	35.29	35.91
T-16 :*Alternanthera* Red	2.28	2.65	3.07	3.13	3.69	3.82
T – 17 :*Philodendron Imperial Green*	28.46	67.48	127.75	144.07	154.44	159.37
T – 18 :*Chlorophytum comosum* green	35.57	47.69	50.04	64.64	69.12	69.39
Sem±	3.49	3.59	8.81	14.65	16.88	12.15
CD(0.05)	10.49	10.79	26.42	43.95	50.63	36.44

Syngonium podophyllum 'Berry Allusion' (Berry Allusion Nephthytis)

Alternanthera Green

Syngonium podophyllum 'Strawberry Cream' (Strawberry Cream Arrowhead Vine)

Pleomele reflexa

Syngonium podophyllum 'Bold Allusion' (Bold Allusion Nephthytis)

Rhoeo discolor (Moses in the cradle) Sitara Gold

Syngonium podophyllum 'Maria Allusion'
(Maria Allusion Nephthytis),

Peperomia obtusifolia variegata

Syngonium podophyllum 'Pink Allusion'
(Pink Allusion Nephthytis),

Syngonium podophyllum 'Cream Allusion'
(Cream Allusion Nephthytis)

Syngonium podophyllum 'White Butterfly'
(White Butterfly Arrowhead Vine),

Alternanthera White

Philodendron scandens green

Epipremnum aureum
(Golden Pothos)

Philodendron Imperial Green

Alternanthera Red

Tradescantia spathaceae variegata

Chlorophytum comosum

A. pH of Leaf extract

pH of the leaf extract signifies the tolerant capacity of the species. Higher level of pH in leaf extract indicates that the plants are tolerant under polluted conditions. A higher level of leaf-extract pH was observed in *Syngonium podophyllum* 'Cream Allusion' (7.74) and *Syngonium podophyllum* 'Maria Allusion' (7.71) whereas least was observed in *Philodendron scandens* (5.37). Leaf extract pH on the higher side could provide tolerance in plants against pollutants. Singh and Verma (2007) have reported that plants with lower pH are more susceptible to air pollution than those with higher pH. Such a trend is established in the present study. Scholz and Reck (1977) have opined that in presence of an acidic pollutant, the leaf pH is lowered with a greater decline in sensitive species. A shift in cell sap pH towards the acid side in presence of an acidic pollutant might decrease the efficiency of conversion of hexose sugar to ascorbic acid. However, the reducing activity of ascorbic acid is pH dependent being more at higher and lesser at lower pH. Agrawal, 1988 hence reported that the leaf extract pH on the higher side gives tolerance to plants against pollution. Vanda *et al*., 2020 reported higher leaf pH in *Celtis occidentalis* than in *Tilia europaea* leaves. Higher values of these parameters generally indicate a higher tolerance for plants and the leaf pH influences the stomatal permeability of pollutants.

B. Relative water content (RWC)

Maximum relative water content was observed in species like *Peperomia obtusifolia variegata* (92.63 %), *Syngonium podophyllum* 'Maria Allusion' (89.28%) and 'Berry Allusion' (88.43 %). RWC is the water present in leaf relative to its full turgidity. The high RWC indicates the absence of cuticle or waxy layer in whereas less RWC is due to presence of waxy layer resulting in the decrease of water absorption in the cell sap. Singhare and Talpade (2013) reported that high water content within the plant body helps the plant to maintain its physiological balance under environmental stress condition such as exposure to air pollution. Relative Water Content (RWC) of a leaf is the water present in it relative to its full turgidity. RWC directly measures the water deficit in leaves. It indicates the capacity of the cell membrane to maintain its permeability under polluted conditions. Relative water content is associated with protoplasmic permeability in cells causes loss of water and dissolved nutrients, resulting in early senescence of leaves (Agrawal and Tiwari, 1997). The relative water content helps maintain physiological balance through increased transpiration rates (Vanda *et al.,* 2020). Therefore the plants with high relative water content under polluted conditions may be tolerant to pollutants.

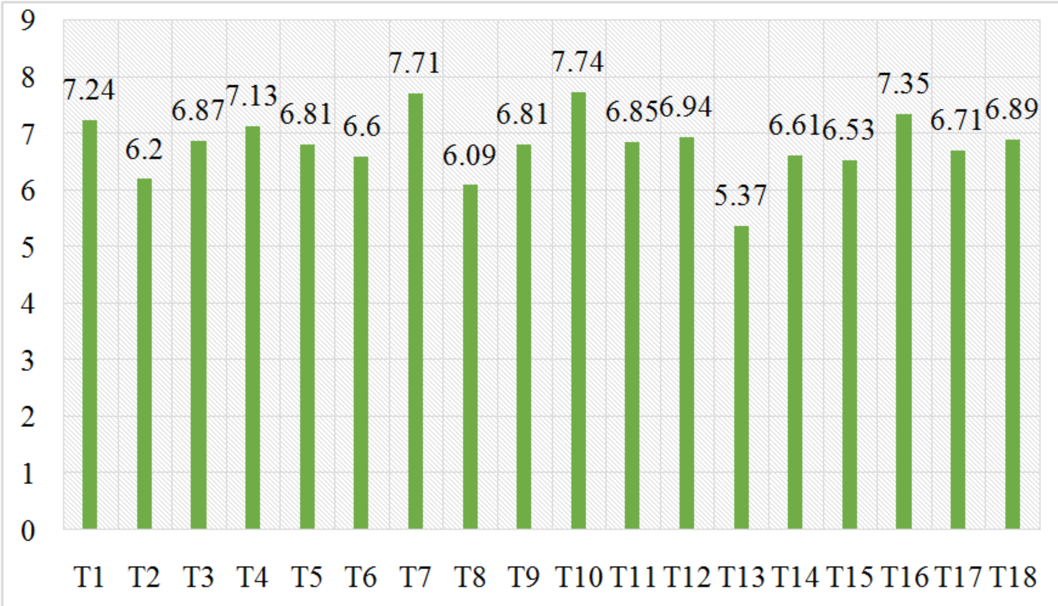

Fig. 1. pH of the leaf extract.

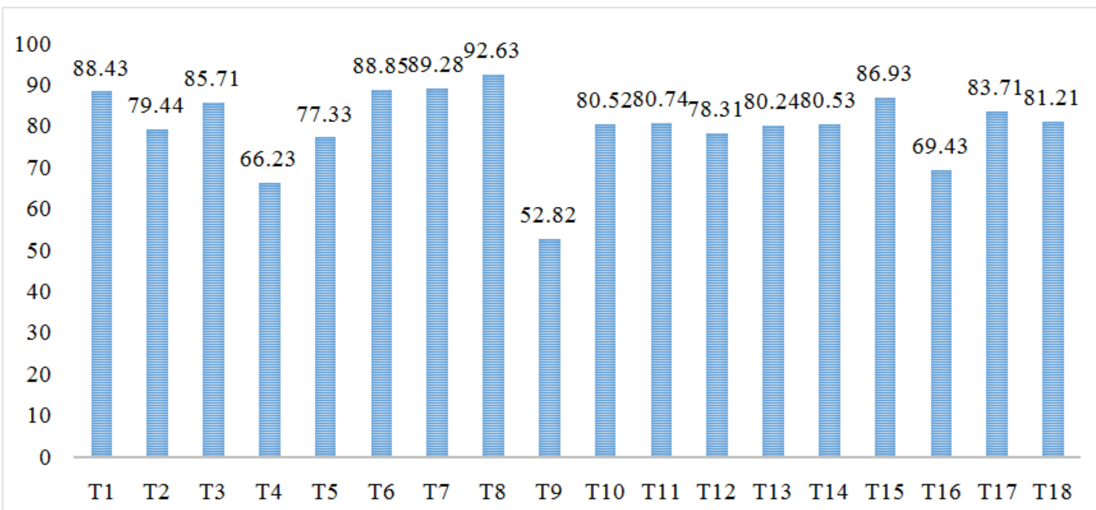

Fig. 2. Relative water content (RWC).

C. Ascorbic Acid (AA) Content

In the present study, content of ascorbic acid varied from 0.40 in *Philodendron scandens green* to 3.99 in *Peperomia obtusifolia.* Plants maintaining high AA under pollutant conditions are considered to be tolerant to air pollution. The higher content of ascorbic acid content is a sign of its tolerance against sulphur dioxide pollution (Varshney and Varshney, 1984; Chaudhary and Rao, 1977) Ascorbic acid, being a very important reducing agent, plays a vital role in cell wall synthesis, defense and cell division and influences the resistance of plants to adverse condition including air pollution (Conklin, 2001). Ascorbic acid, through its reducing power, protects chloroplasts against SO_2-induced H_2O_2, O_{2-} and OH accumulation, and thus protects the enzymes of the CO_2 fixation cycle and chlorophyll from inactivation. Its reducing power is directly proportional to its concentration. The reducing activity of ascorbic acid is pH dependent, being more at higher pH may increase the efficiency of conversion of hexose sugar to AA is related to the tolerance to pollution (Krishnaveni and Kiran Kumar, 2017). Together with leaf pH, it plays a significant role in determining the SO_2-sensitivity of plants (Chaudhary and Rao, 1977). Vanda *et al*., 2020 opined that Ascorbic acid protects the plant from oxidative compounds and is essential for several physiological mechanisms. Thus Ascorbic acid is a natural detoxicant, which may prevent the effects of air pollutants in the plant tissues. In the present study higher baseline levels of ascorbic acid content in the leaves of *Peperomia obtusifolia*, among the different ornamental plant species studied suggests its tolerance towards the pollutants. Lower ascorbic acid contents in the leaves of other plant species studied like *Philodendron scandens green* supports the sensitive nature of these plants towards pollutants.

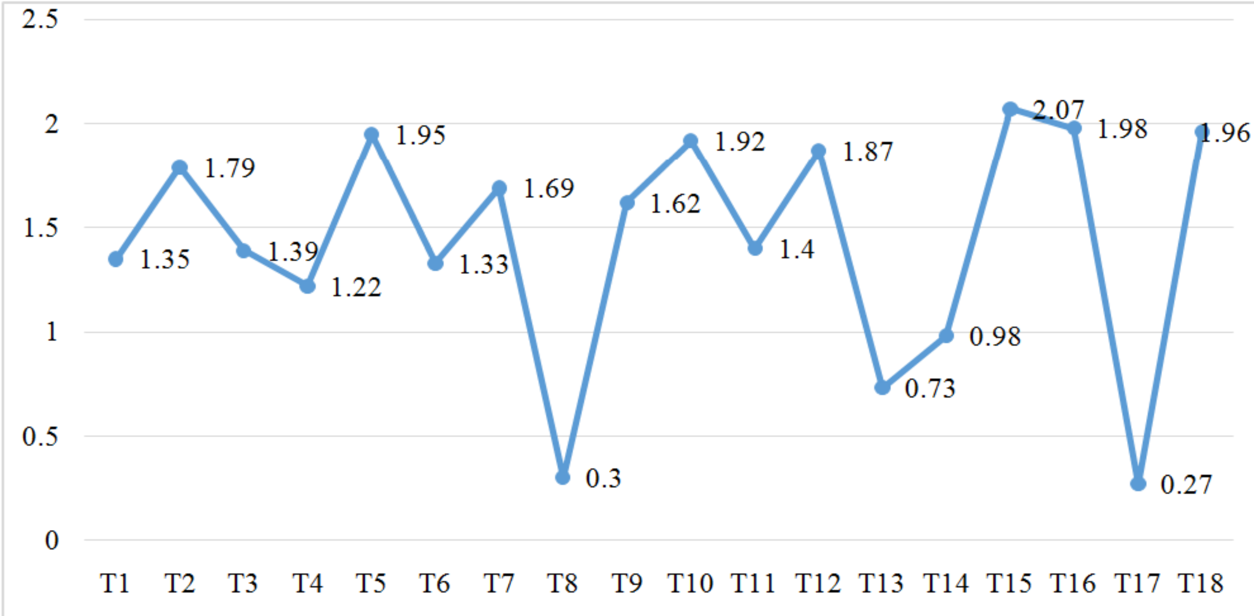

Fig. 3. Ascorbic Acid (AA) Content.

D. Total chlorophyll content

The tolerance of plants to any of the pollutant may be linked with synthesis or degradation of chlorophyll and those having high chlorophyll content under field conditions are generally tolerant to air pollutants. Highest total chlorophyll content was observed in *Syngonium podophyllum* 'Maria Allusion' (1.86 mg/g) and 'Pink Allusion' (1.83 mg/g) whereas lowest was observed in *Peperomia obtusifolia variegata* (0.08 mg/g). Sharma *et al.*, (2019) reported that total chlorophyll content of leaves has been used commonly for evaluation of the effect of air pollutants on photosynthesis rate in plant leaves. Chlorophyll content of plants signifies its photosynthetic activity as well as the growth and development of biomass (Jyothi and Jaya, 2010). It is well apparent that chlorophyll content of plants varies from species to species; age of leaf and also with the pollution level as well as with other biotic and abiotic conditions (Katiyar and Dubey, 2001). Ninave *et al*., 2001 reported that degradation of photosynthetic pigment has been widely used as an indication of air pollution. Present study revealed that chlorophyll content in all the ornamental plant species varies with the pollution status. It also varies with the tolerance as well as sensitivity of the plant species i.e. higher the sensitive nature of the plant species lowers the chlorophyll content.

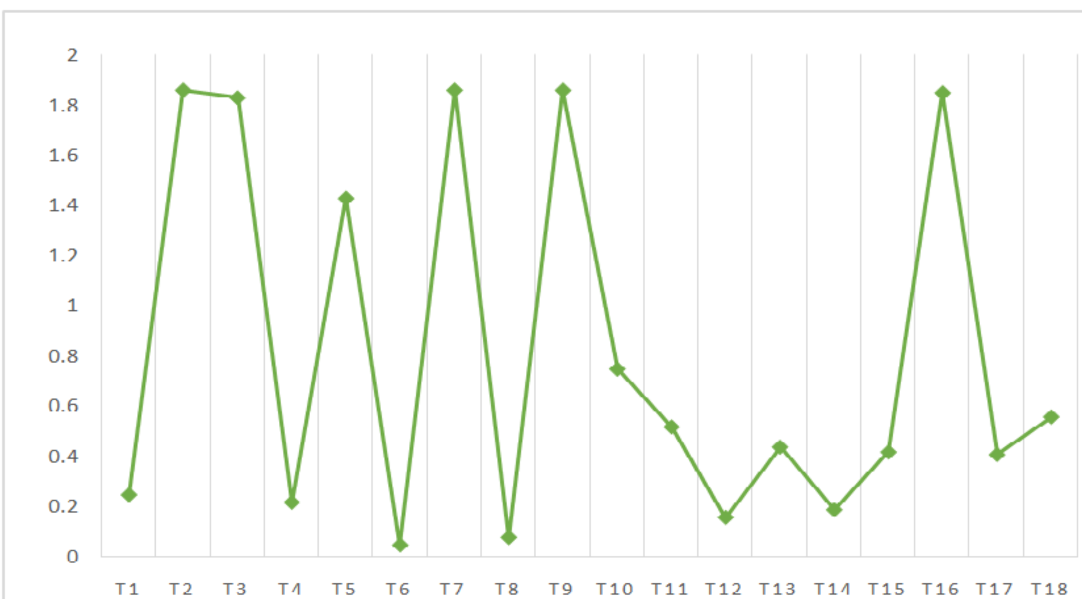

Fig. 4. Total chlorophyll content.

In the present study, higher baseline levels of total chlorophyll was observed in *Syngonium podophyllum ’*Maria Allusion’ and ‘Pink Allusion’ among the different ornamental plant species studied, and this higher levels of total chlorophyll observed may be due to its tolerance nature.

E. Air Pollution Tolerance Index

The results of air pollution tolerance index [APTI] calculated for each ornamental plant species studied is depicted in Fig. 5.

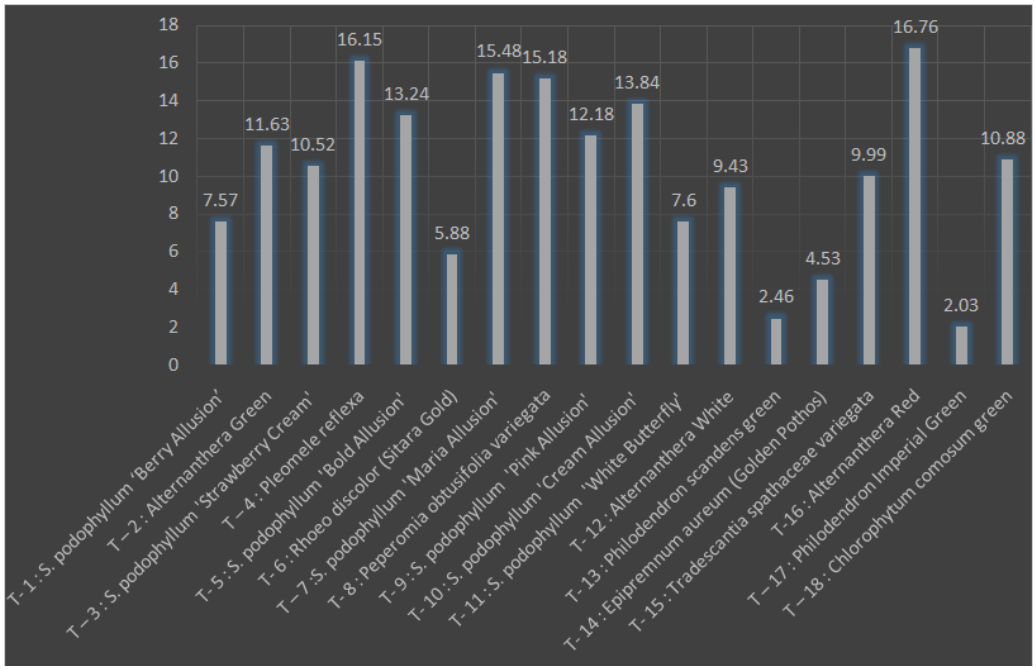

Fig. 5. Air Pollution Tolerance Index of different ornamental plant species used in the study.

Different ornamental plant species shows considerable variation in their susceptibility to air pollution. The plants with high and low APTI values can serve as tolerant and sensitive species respectively. In the present study, *Alternanthera Red* (16.76), *Pleomele reflexa* (16.15), *S. podophyllum ’Maria Allusion’* (15.48), *Peperomia obtusifolia variegata* (15.18), *S. podophyllum 'Cream Allusion* (13.84), *S. podophyllum 'Bold Allusion*‘(13.24), *S. podophyllum ’Pink Allusion’* (12.18), *Alternanthera Green (*11.63), *Chlorophytum comosum green* (10.88) and *S. podophyllum ’Strawberry Cream’* (10.52) were tolerant to air pollution. *Tradescantia spathaceae variegata* (9.99), *Alternanthera White*(9.43), *S. podophyllum ‘White Butterfly’* (7.6) *and S. podophyllum ‘Berry Allusion’* (7.57) were moderately tolerant species. The species like *Philodendron Imperial Green* (2.03), *Philodendron scandens green* (2.46), *Epipremnum aureum* (4.53) and *Rhoeo discolor* (5.88) were sensitive to air pollution.

In accordance with the research conducted by Zhang *et al*., (2016), not only do tolerant plants help attenuate air pollution, they also maintain the ecological balance, control soil erosion and improve the aesthetic aspects of polluted areas. The observations in the present study suggest that ornamental plants viz., *Alternanthera Red*, *Pleomele reflexa*, *S. podophyllum ’Maria Allusion’*, *Peperomia obtusifolia variegata*, *S. podophyllum 'Cream Allusion*, *S. podophyllum 'Bold Allusion'*, *S. podophyllum ’Pink Allusion’*, *Alternanthera Green*, *Chlorophytum comosum green* and *S. podophyllum ’Strawberry Cream’* have the potential to serve as excellent quantitative and qualitative indices of pollution. Plants clean the environment by soaking up gases and particulate count through leaves since leaves act as a persistent absorber whilst exposed to the polluted surroundings (Kumari and Deswal, 2017).

Among the different ornamental plant species selected for this study, the aforementioned tolerant plant species can effectively be used in the air pollution amelioration purposes through vertical landscaping. This is in line with the findings of Yomna *et al*., 2020 who opined that while not a substitute for recreational open spaces, a vertical garden strategy can constitute an alternative approach for increased urban residents’ contact with vegetation, which has been shown to be important to general psychological health. Present study shows that inclusion of ornamental plants with pollution mitigating ability in the landscape plan will serve the dual purpose of making the environment green and pollution free in the long run.

FUTURE SCOPE

It is essential to carry out this type of research on different species of ornamental plants in vertical gardening for better insight into the interactions and correlations between environmental pollution and various ecological, biochemical, and physiological parameters in urban environments.

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Conflict of Interest. The authors declare no conflict of interest.

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