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Seasonal Photosynthesis Variations of Dominant Tree Species Used in Different Urban Landscapes

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Photosynthesis is the only natural process that converts photon energy into chemical energy, and it is responsible for 90–95% of plant biomass accumulation and hence growth. Environmental factors such as light, temperature, and CO_2 concentration in the atmosphere are major factors that influence photosynthesis, and excess of these can cause stress on plants. The photosynthetic response of tree species is found to vary to these factors. Therefore, the photosynthetic response of tree species can be a good indicator to assess these environmental factors that are changing due to urbanization and can be used to mitigate these factors as well by cultivating suitable tree species. The present study provides information on the seasonal variations in photosynthetic activity in six tree species. In the present study during the month of May (late summer to early monsoon) most of the tree species showed higher photosynthetic rates. It is also noticed that transpiration rate and water use efficiency was more in the month of May compared to other months. An increase in net photosynthesis and transpiration is observed among the tree species under high rainfall conditions 285.2 mm. It is also observed that photosynthesis decreased where the evaporative demand is very high.

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1. INTRODUCTION

The changes in climate at a global scale are predicted to have serious implications, especially in tropical countries in terms of increased natural perturbations that influence food security, health, and the environment. By the end of this century, average global temperatures are predicted to rise by 1.8–4.0°C [1]. The rate of respiration and photosynthetic capacity of leaves are two gas exchange traits that are temperature sensitive [2,3]. In recent decades, there has been a significant increase in studies to understand the pros and cons of global warming on photosynthesis [4,5].

Plants have many complex mechanisms that allow them to adapt to environmental conditions and survive despite the impacts of various stressors. Photosynthetic activity, as one of the most important metabolic processes, is a good indicator for the assessment of the influence of various unfavorable environmental conditions on their physiological condition and development in the terrestrial habitat [6,7]. Photosynthetically active radiation (PAR) is referred to as solar radiation with a wavelength between 400 and 700 nm [8,9]. Radiation absorption is carried out by the photosynthetic pigments chlorophyll and carotenoids, which are found in light-harvesting complexes (LHCs). They only expend a portion of the energy they have gathered. Some of it is released as chlorophyll fluorescence or lost as heat. The Kautsky kinetics is used to describe the induction of chlorophyll fluorescence [10]. Fluorescence is emitted by chloroplasts and is connected to all other physiological and metabolic activities taking place inside the plant cell. Therefore, any environmental change that has an impact on these processes will likewise have an impact on photosynthesis [11,12]. Typically, topographic differences in species composition and tree growth are observed. A slope's topography affects a variety of environmental factors, such as the chemical composition of the soil, its moisture regime, and how it is exposed to weather and sunlight. The connection between various environmental factors and the development or physiology of trees has been the subject of numerous studies [13], but little is known about how topographic position affects plant photosynthetic activity in actual field conditions.

Photosynthesis is the mechanism that takes place naturally which converts photon energy into chemical energy and it is responsible for 90–95% of plant biomass accumulation [14]. About 40% of a plant's dry mass consists of carbon which is fixed only through photosynthesis. The net photosynthetic rate is often influenced by environmental factors such as irradiance, temperature, and water supply, and also by leaf age, leaf position, and leaf developmental stage [15,16,17]. Trees act as a CO_2 sink which captures carbon from the atmosphere and stores the same in the form of biomass while releasing oxygen to the air through the process of photosynthesis [18]. Conservation and restoration of green spaces comprising trees, therefore, is an important approach to improving the environmental quality which plays a very important role in sustaining a clean environment not only by sequestering atmospheric carbon and releasing oxygen.

The present study explains the seasonal variations in the photosynthetic capacity of six tree species grown under controlled conditions which were investigated in this research to clarify the impact of summer, winter, and rainy seasons on the photosynthetic activity of plants.

2. METHODOLOGY

In the present study sapling of tree species namely *Grevillea robusta, Spathodea campanulata, Swietenia mahagoni, Bauhinia purpurea, Pongamia pinnata,* and *Peltophorum pterocarpum* were grown under controlled conditions in the greenhouse facility of the Department of Forestry & Environment Sciences, University of Agricultural Sciences, GKVK, Bengaluru, Karnataka, India. One-year-old saplings were planted in grow bags with a capacity to hold 25kg of the potting mixture. The recommended package of practices was followed and 10 seedlings each from six species were planted and irrigated every day twice during the summer months and once in the rainy season. The saplings were allowed to stabilize for one month after transplanting before recording the observations. Various physiological parameters like Photosynthetic rate, Transpiration and Water use efficiency were assessed periodically. The six species studied in this experiment are the dominant tree species out of 44 tree species present across the urban landscapes of

Bengaluru as avenue trees, in the parks, lakes, and home gardens.

2.1 Climate and Weather Conditions

University of Agricultural Sciences, Bangalore, is located at 13^0 05" N latitude and 77^0 34" E longitude and an altitude of 924 meters. The annual rainfall ranges from 528 mm to 1374.4 mm with a mean of 915.8 mm.

The weather parameters of different seasons were procured from the Department of Agrometeorology, University of Agricultural Sciences, Bangalore, Karnataka. The rainfall during the first three months of the study period (from February to April) was negligible and for the rest of the three months, it was almost uniform. Rainfall had no much effect on the plants used in this study as they were irrigated but influenced the surrounding temperature (Table 1). The influence of the rainfall is the moisture of the air that controls the opening and closing of stomata. The maximum temperature varied from 27.30 to 33.50ºC and the minimum temperature varied from 16 to 20.10^0C during the study period (Table 1).

2.2 Photosynthesis Measurements

Measurements of photosynthesis and allied parameters were made simultaneously using a portable photosynthesis system (CIRAS-3, PP-Systems, USA). Photosynthesis was measured on fully matured and well-exposed, at monthly intervals for a period of six months from February 2022 to July 2022. The measurements were made from 09:00 AM–12:00 PM in the second week of every month. Five to six observations per plant were recorded from 10 plants each and the average is presented as the photosynthetic rate for a given month of a species. The other related parameters that were simultaneously recorded are stomatal conductance, transpiration rate, and water use efficiency.

2.3 Data Analysis

The variation in the photosynthesis among the tree species and over time was analyzed based on the Analysis of Variance Technique (single-factor analysis) using the EXCEL-STAT statistical package and Pearson correlations among photosynthesis, transpiration, water efficient were used.

3. RESULTS

A significant difference in photosynthetic rate was observed among the tree species as well as with time over months (Table 2). In the month of February *Grevillea robusta was* found to have the highest photosynthetic rate followed by *Bauhinia purpurea*, *Pongamia pinnata* , *Peltophorum pterocarpum*, *Swietenia mahagoni* and the lowest photosynthetic rate was observed in *Spathodea campanulata* (Table 2). Similarly, in the month of March and April *Bauhinia, purpurea* was found to have the highest photosynthetic rate whereas, *Swietenia mahagoni* and *Peltophorum pterocarpum* had the lowest photosynthetic rate. In the month of May, June, and July Grevillea*ea robusta was* found to have the highest photosynthetic rate although, *Peltophorum pterocarpum* showed the lowest photosynthetic rate in the month of May and *Spathodea campanulata* showed the lowest photosynthetic rate in the month of June and July. The photosynthetic ability of dominant tree species may be found to be good.

Table 1. Distribution of rainfall (mm), maximum temperature, and minimum temperature during the experimental period

Months (2022)	Minimum Temperature (^{0}C)	Maximum Temperature (^{0}C)	Rainfall (mm)
February	16.0	29.3	0.01
March	18.3	32.0	0.60
April	20.1	33.5	64.8
May	19.4	29.5	285.2
June	19.0	28.9	216.8
July	18.7	27.3	149.8
Mean	18.58	30.08	119.53

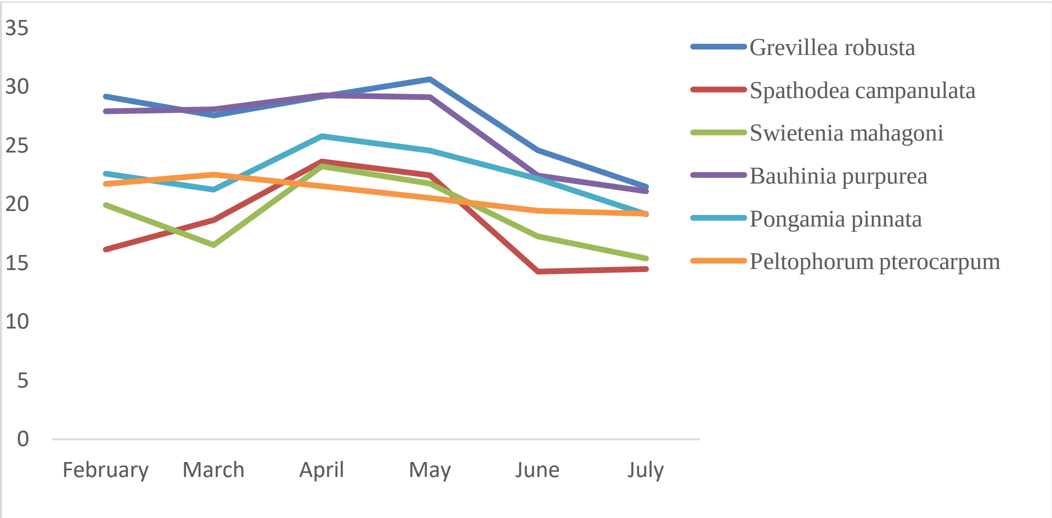

Fig. 1. Photosynthetic rate of six tree species

Table 2. Average monthly response of Photosynthesis rate (μmol CO_2 m^{-2} s^{-1}) of six tree species

Species	Months						
	February	March	April	May	June	July	Mean
Grevillea robusta	29.18	27.58	29.18	30.64	24.60	21.50	27.11
Spathodea campanulata	16.15	18.66	23.66	22.47	14.28	14.50	18.37
Swietenia mahagoni	19.94	16.55	23.24	21.78	17.28	15.40	19.03
Bauhinia purpurea	27.92	28.08	29.30	29.13	22.44	21.11	26.28
Pongamia pinnata	22.62	21.26	25.81	24.57	22.18	19.15	22.58
Peltophorum pterocarpum	21.74	22.54	21.54	20.53	19.45	19.22	20.83
SEM	2.105	1.698	1.609	1.556	1.727	1.604	
CD (<0.05)	6.717	5.42	5.135	4.966	5.513	NS	

Note: NS - Non Significant

Photosynthesis on six tree species in different seasons in the months of April and May (early monsoon season) all tree species showed a higher photosynthetic rate as compared to June and July (in February and March this happened too). *Grevillea robusta* was found to have the highest photosynthetic rate in the month of May and the lowest photosynthetic rate was observed in the month of July and no much difference was found in the month of summer (April) and winter (February) (Table 2). The same trend was followed in the rest of the species where the highest photosynthetic rate was observed in the early rainy season and the lowest was in July. The photosynthetic rates especially during the summer months, (drought period) indicate the drought tolerance of these species provided with irrigation, which is very significant considering the poor management practices these species provided.

The results are reiterated from the transpiration rates (Table 4). There is a significant difference in the transpiration rate among the tree species except in the month of July. In the month of February *Grevillea robusta* recorded the highest transpiration rate at followed by *Bauhinia purpurea at*, *Peltophorum pterocarpum*, *Spathodea campanulata Swietenia mahagoni* and the lowest transpiration rate was observed in *Pongamia pinnata*. Similarly in the month of March, *Bauhinia purpurea* and *Spathodea campanulata* had the highest transpiration rate and *Swietenia mahagoni* had the lowest transpiration rate. Similarly, *Spathodea campanulata* in the month of April, *Grevilleaa robusta* in the month of May, *Peltophorum pterocarpum* in June, and *Pongamia pinnata* in July showed the maximum transpiration rate. Likewise, *Pongamia pinnata* in the month of April and May, *Swietenia mahagoni* in June, and *Spathodea campanulata* in July showed the lowest transpiration rate. It can be observed that transpiration rates are complementary with the photosynthetic rates because both these functions are correlated.

Table 3. Pearson correlations among photosynthesis, transpiration, water efficient

Species	Corr Pearson		
	Photosy x Trans	Photosy x water effic	Trans x water effic
Grevillea robusta	0.851976217	0.493089	0.567483
Spathodea campanulata	0.971320381	0.975663	0.959073
Swietenia mahagoni	0.886871327	0.88639	0.875932
Bauhinia purpurea	0.659087038	0.441274	0.765072
Pongamia pinnata	-0.136066037	0.980682	0.002283
Peltophorum pterocarpum	-0.345227192	0.324642	-0.40456

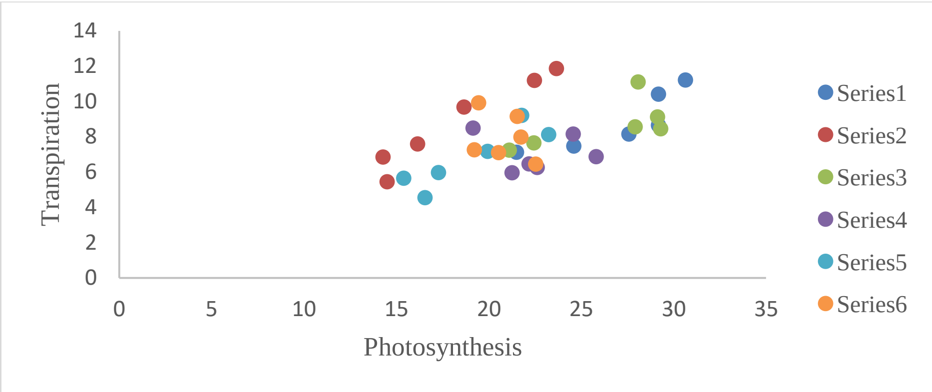

Fig. 2. Photosynthesis and transpiration rates

Table 4. Changes in the transpiration rates over time (mmol H_2O m^{-2} s^{-1}) among six dominant tree species of urban landscapes

Species	Months						
	February	March	April	May	June	July	Mean
Gravillea robusta	10.41	8.15	8.65	11.21	7.47	7.12	8.83
Spathodea campanulata	7.59	9.68	11.86	11.19	6.85	5.45	8.77
Swietenia mahagoni	7.17	4.55	8.12	9.21	5.97	5.65	6.77
Bauhinia purpurea	8.56	11.10	8.45	9.12	7.65	7.24	8.68
Pongamia pinnata	6.26	5.96	6.87	8.15	6.46	8.49	7.03
Peltophorum pterocarpum	7.98	6.45	9.15	7.10	9.92	7.26	7.97
SEM	0.799	0.867	0.615	0.738	0.676	0.349	
CD (<0.05)	NS	2.767	1.962	2.354	2.158	1.114	

Note: NS- Non Significant

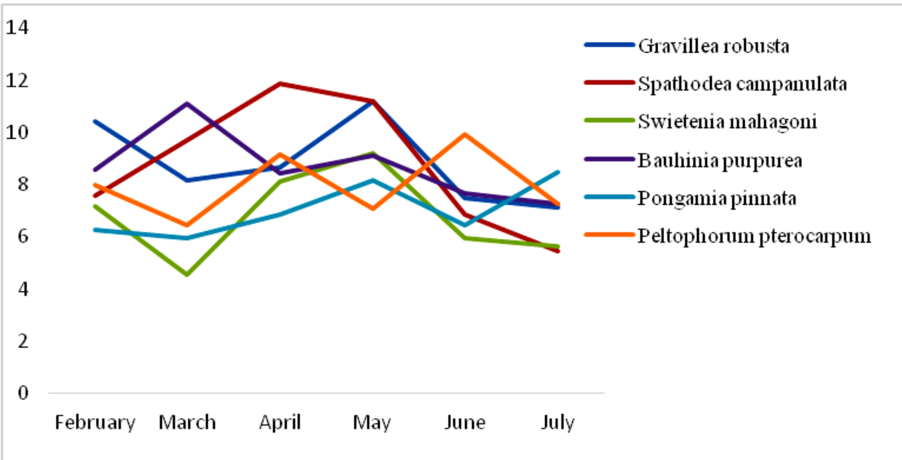

Fig. 3. Transpiration rate of six tree species

Table 5. Average monthly response of Water Use Efficiency (WUE) mmol CO_2/mol H_2O of six tree species

Species	Months						
	February	March	April	May	June	July	Mean
Gravillea robusta	2.50	2.42	2.50	3.86	3.24	2.00	2.67
Spathodea campanulata	2.27	3.64	4.70	4.19	2.26	2.29	3.22
Swietenia mahagoni	3.30	3.25	4.55	4.82	3.3	2.98	3.70
Bauhinia purpurea	2.05	5.09	2.53	5.08	2.07	2.77	3.26
Pongamia pinnata	3.66	2.96	5.51	5.26	3.93	2.24	3.92
Peltophorum pterocarpum	2.92	5.29	3.12	4.7	4.03	2.85	3.81
SEM	0.407	0.366	0.494	0.3	0.517	0.42	
CD (<0.05)	NS	1.169	1.578	NS	NS	NS	

Note: NS- Non Significant

It is noticed that in the month of April (Late summer) and May (Early rainy season), all tree species had a higher transpiration rate compared to June and July except for *Pongamia pinnata*, which showed more transpiration rate in July. *Grevillea robusta was* found to have the highest transpiration rate of 11.21 µmol H_2O m^{-2} s^{-1} in the month of May and the lowest transpiration rate was observed in the month of July at 7.12 µmol H_2O m^{-2} s^{-1} and no much difference was found during summer months (Table 4). The same trend was followed in the rest of the species where the highest transpiration rate was observed in the early rainy season and the lowest was in the month of July.

A significant difference in the WUE was found in the month of March and April whereas, remaining months there was no difference among the tree species were noticed (Tabel 4). In the month of February, April and May *Pongamia pinnata* found to have the highest WUE likewise *Peltophorum pterocarpum* in the month of March and June, and *Swietenia mahagoni* in the month of July had a higher WUE (Table 5). *Spathodea campanulata* recorded lower WUE in the month of February, while *Grevillea robusta* in the month of March, April, and May, *Bauhinia purpurea* in the month of June, and *Pongamia pinnata* in the month of July had a lower WUE among all the species. The WUE in the month of April and May was found to be highest as compared to other months. Since photosynthesis and transpiration are correlated, WUE depends on the efficiency with which carbon is assimilated to a unit of transpiration.

4. DISCUSSION

In the present study, it was found that six tree species growing in the temperatures range of 19.4 - 29.5 ^{0}C. Temperatures showed variation in the photosynthetic rates with a maximum rate recorded in the month of May (Table 1). The temperature range reported here is shown to be the optimal range for other tree species [19,20,21]. The temperatures around 40^{0}C are shown to reduce the photosynthetic rates critically because the process of photosynthesis is a chain of biochemical reactions in which many enzymes are involved. These enzymes are highly temperature sensitive and get denatured at higher temperatures. One of the studies found that plants growing at 8^{0}C to 30^{0}C showed similar gross leaf photosynthetic rates when measured at ambient temperatures [22]. When plants were incubated at temperatures 20^{0}C higher than ambient, the leaf photosynthetic rates increased to essentially the same value, irrespective of growth or measurement temperature. To better understand the effects of temperature on photosynthesis it is important to know the effect of temperature on the enzymes involved in photosynthesis. Enzymes may be affected a great deal by temperature. If the temperature is too low or too high the enzymes may move around too slowly to meet the substrate and for a reaction to occur. These findings suggest that temperature is an important factor in determining leaf photosynthetic potential in many terrestrial trees [23,24]. The different effects of temperature history on short-term photosynthesis in terrestrial species may be due to the lack of stomata and the rapid temperature equilibration of leaves with the surrounding environmental conditions [22].

Photosynthesis is particularly sensitive to moisture stress because the stomata will tend to close to conserve water as the soil water status decreases [25]. Indeed, stomatal regulation is vital in maintaining the hydraulic status of the plant [26]. In the present study during the month of May (late summer to early monsoon) all the tree species showed higher photosynthetic rates (Table 2). This is because, during the month of May, the study area received more rainfall as compared previous months (Table 1) as it alleviates the moisture stress the plant was under. So, from this study, it is also noticed that transpiration rate and WUE were found more in the month of May compared to other months (Tables 4 & 5).

Here it used the average of the photosynthesis, transpiration, water efficient with minimal, maximal temperature, and rainfall.

Table 6. Pearson correlation result

	Corr Pearson
phot_aver x MinTemp	0.201035
phot_aver x Rainfall	0.733883
phot_aver x MaxTemp	-0.11138
trans_aver x MinTemp	0.322865
trans_aver x Rainfall	0.511619
trans_aver x MaxTemp	0.224934
Wateff_aver x MinTemp	0.529999
Wateff_aver x Rainfall	0.52509
wateff_aver x MaxTemp	0.349276

A decrease in the net photosynthesis rate and transpiration is usually observed in plants under low rainfall conditions [27,28,29] and is also observed in environments where the evaporative demand is very high [30]. The present study observed that the tree species showed a photosynthetic depression at fewer rainfall events. According to a study, the depression of photosynthesis during dry days or non-rainy days probably results from too much light during this period, which can inhibit photosynthesis [31]. Other possible causes of depression at less rainfall include an increase in the atmospheric vapor pressure deficit [32,33,34] and high temperature [35,36]. The closure of stomata during the event may also decrease the intercellular CO_2 concentration, inhibiting photosynthesis [29]. Thus, the effective regulation of the stomatal aperture is a critical plant functional attribute of plants for optimal development of plants.

The ratio between carbon assimilation and the output of water by transpiration results in water use efficiency [37]. The WUE, therefore, indicates the efficiency of carbon assimilation taking place to the unit amount of water lost in the transpiration. Most often WUE is attributed to a higher rate of photosynthesis [38] and not a lower transpiration rate [39]. Hence, Photosynthesis, transpiration, and WUE are interdependent and extreme environmental conditions, such as high temperatures, rainfall, and drought, can affect photosynthetic activity and WUE in plants [31]. Therefore, these or any one of these can be good indicators of a plant's performance under stressful conditions [40].

5. CONCLUSION

This study provides an understanding of how photosynthetic activities in trees occur over time. Photosynthesis among the tree species was found to be highest in *Grevellia robusta* and in *Spathodea campanulate* and was least in *Bauhinia purpurea*. Among the six-tree species *Grevillea robusta* recorded the highest photosynthetic rates in pre and post-monsoon seasons too. The highest rate of photosynthesis was observed in the month of May among all the species during which plants experienced a minimum temperature of 19.4^0C and a maximum of 29.5^0C and received a rainfall of 285.2 mm after a prolonged dry spell of the previous months and continuous irrigation. Though the plants were watered and not subject to moisture stress during the experimental period the surrounding environment prevailed during the experimental period has created atmospheric stress for the plants. Transpiration most often changes in tune with photosynthesis. However, the WUE indicates the efficiency with which photosynthesis operates in relation to transpiration. These findings suggest that all these species have considerably good photosynthetic ability to sustain atmospheric stress and grow.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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