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Comparative Study of Cooling under Shades of Some Forestry Tree Species with Respect to Ambient Temperatures

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Abstract

Trees create microclimate under their crowns in comparison to the outside ambient atmospheric temperature. Sun is the pivotal source of radiant energy reaching the earth atmosphere of which heat is more important than light. The radiant energy reaches the ground without any barricade whereas the tree crown impedes it in reaching the earth's surface. During the day, when insolation impinges on tree crown, a portion of it is reflected back to the space, other portion is absorbed by the canopy increasing the temperature of leaves and the remaining part reaches the ground penetrating through the crown. Thus, a significant coolness is experienced under the shade of trees in comparison to open sunshine, with qualitative variations. The cooling produced by trees under their shades varies with species to species due to variation in several anatomical, structural and physiological attributes of the species. Climate is changing more rapidly prominently due to human activities especially indiscriminate felling of trees and it is feared that it will create problems on availability of energy, water and food security. Economic value takes over ecological benefits in selection of species in plantation programmes and this might have been due to the lack of scientific data about varying effectiveness of ecological services bestowed by different species. In the present study, an endeavor has been made to understand as to how a tree is integrated to the effects on atmosphere and responses to changing conditions with respect to differential cooling produced by five selected forestry tree species belonging to different categories. Analysis of data has come out with gradation of the sample species in respect to their cooling effect in the atmosphere in terms of yearly, quarterly, monthly and diurnal basis.

Keywords

Solar Radiation, Ambient Temperature, Tree Crown, Tree Shade, Cooling, Bio-Physical Processes

1. Introduction

Trees create microclimate under their crowns in comparison to the outside ambient atmospheric temperature through certain biophysical processes such as interception to solar radiation by tree crowns, transpiration, photosynthesis, radiation etc. (Dimoudi & Nikolopoulou, 2003). Planting trees is recognized as an effective measure to reduce rate of climate change (Bravo et al., 2008). Tree plantations near and around buildings are being maintained to reduce temperature of walls as well as inside the buildings and thus lead to energy saving (Gómez-Baggethun & Barton, 2013; Takacs et al., 2014). Sun is the pivotal source of radiant energy reaching the earth atmosphere of which heat is more important than light. The radiant energy reaches the ground without any barricade whereas the tree crown or a forest canopy obstructs it in reaching the earth's surface (Campbell, 1977; Grace et al., 1980; Seth et al., 1967). Only about 30% - 40% of solar radiation reaches the ground in the cloudy, humid regions whereas 75% in cloud free arid areas (Kittredge, 1948). In fact, one usually experiences a significant coolness under the shade of trees in comparison to open sunshine, with qualitative variations. It is generally cooler under a sal (*Shorea robusta*) tree than under teak (*Tectona grandis*). Similarly, it is more comfortable under a deodar (*Cedrus deodara*) tree as compared to that under chirpine (*Pinus roxburghii*) etc. (Gupta et al., 2018).

The cooling produced by trees under their shades varies with species to species due to variation in several anatomical, structural and physiological attributes of the species. It largely depends on several physical attributes of the tree *viz.* size and denseness of tree crown; size, colour, roughness or smoothness and thickness of leaves in the crown; leaf contents, equilibrium temperature of leaves, etc. These attributes certainly affect the physiological functioning of tree species such as rate of transpiration, rate of photosynthesis, etc. (Lin & Lin, 2010). The atmospheric parameters such as temperature, wind speed, relative humidity also influence the cooling generated by a tree under its shade (Akbari et al., 1997; Kittredge, 1948). Some studies at Forest Research Institute, Dehradun, India also revealed that temperature in the morning was higher under plantations than in open whereas the temperature in the afternoon was lower under plantations than in open sunshine (Dabral & Nath, 1972). This state of temperature difference is also related to the height levels from the ground. Seth et al. (1967) revealed diurnal and seasonal variations in minimum and maximum temperatures in the open as well as under plantations. In the morning, the mean minimum temperature was lower for the entire year at 5 feet height from the ground under plantations as compared to open. In the afternoon, the ground level recorded maximum temperature in the open and minimum under forest for the entire year. However, Dabral (1961) working with a few forest species, has brought out that the diurnal fluctuations in temperature have been significantly higher in the open than under forest conditions, and that too, varied markedly with the type of plantations. In a dense forest at noon, the temperature is maximum on the upper reaches of the canopy whereas it is minimum at the ground surface and shows ∫ curve in between (Kittredge, 1948).

The climate change, popularly known as global warming is one of the most important issues facing the world community (Gupta, 2002). Climate is changing more rapidly than tend to occur naturally and it is feared that it will create problems on availability of energy, water and food security and may lead to violent situations (Marcott et al., 2013). The present rate of warming of atmosphere is reported to be 0.2 to 0.5 degree celsius per decade (Houghton et al., 2001). Emerging evidences in trends and intensity of weather events such as increasing number of hot days, decreasing number of cold days, shift in time of flowering and other phonological changes, more precipitation and floods, droughts etc. have been revealed (Melillo et al., 2014). Natural factors have always been the cause of climate change, which are still continuing. But, presently, the climate change is happening prominently due to human activities such as indiscriminate felling of trees, faulty land use pattern, urbanization and large scale constructions, uncontrolled transportation, industrial and electronic wastes, chemical pollutants etc. (Christidis et al., 2011).

During the past century, timber gained economic importance and indiscriminate felling of trees took place due to passionate advancement and impervious human attitude towards forest resources. Though this was supplemented by spate of plantation programmes yet economic value took over ecological benefits in selection of species for plantation and this might have been due to the lack of scientific data about varying effectiveness of ecological services bestowed by different species. In the present study, an endeavor has been made to study the differential cooling produced by different tree species by measuring the ambient temperatures and temperatures under the shades of trees.

2. Material and Methods

Selection of Sample Trees: Five sample trees, belonging to different categories-*viz*. Everegreen, Semi-deciduous and Deciduous, namely Kadam (*Anthocephalus chinensis* L.), Benjamin fig. (*Ficus benjamina* L.), Dhauri (*Lagerstroemia floribunda* L.), Mango (*Mangifera indica* L.), and Yellow Goldmohur (*Peltophorum africanum* L.) were selected in the premises of Forest Research Institute, Dehradun, India. Out of the selected species, two species belong to Evergreen, two species to Deciduous categories and there was available only one species, *A. chinensis* in the study area belonging to Semi-deciduous category. GPS locations of the sample trees were recorded with the help of GPS instrument, Oregon 650, Garmin. The detailed description about physiographic characteristics of the study area has been given in (Gupta & Singh, 2017). Because, isolated trees were required for the study and isolated trees of the sample species fulfilling the required criteria for selection were not available in numbers in the study area. Besides, a tree bears leaves with varying size, colour, number of open stomata on leaf epidermis etc. consequently different leaves show different physiological performances. Therefore, single trees with more number of measurements adopted for replications (Gupta et al., 2018). Because, all five sample trees were isolated and their GPS coordinates were recorded, marking of trees by making a ring around the trunk with paint or some other way was not considered necessary. Here, sizes and vigour of tree crowns which are species dependent characteristics are more important than diameter or age of trees for the present study. Therefore, average sized trees were selected as sample trees considering the criteria: 1) The sample trees exhibited regular and vigorous crowns without any abnormality and disease. 2) The sample trees were isolated and neither the sample trees overlapped other trees nor were overlapped by others, grown in the vicinity. 3) The sample trees covered different categories *viz.* evergreen, deciduous, and semi-deciduous. 4) The crown areas of the sample trees were sufficiently large so that temperatures at the reference or measuring points do not get affected by physical process of heat i.e. diffraction. 5) All the sample trees were of sufficient age having diameter classes beyond 60 - 70 cm. 6) There was no under storey growth.

Measurement of Temperatures: In order to determine the local cooling effect, it was very important to decide at what point of reference the temperatures in the sunshine and under the shade of crowns of trees be measured to determine temperature difference. During the day, when insolation impinges on tree canopy, a part of it is absorbed by the canopy increasing the air and leaf temperatures within the canopy and the other part reaches the ground penetrating through the canopy, which increases the temperature of soil surface. As the soil surface warms, it not only conducts heat deeper into the soil but also radiates into the air augmenting the air temperature above the ground surface. Thus, the air temperature at 1.5 m above the ground is affected utmost by the radiation reaching up to that level (Goulden et al., 2006; Mahrt et al., 2001; Stephen et al., 2015). Lin & Lin (2010) also chose 1.5 m above the ground as reference point to compare temperatures in the sun and inside the shade of tree canopies in their study. Therefore, in the present study, it was decided to measure temperatures at a 1.5 m above the ground in the sunshine as well as under tree shades of the sample trees. The Thermo Anemometer, AN 200, Extech was utilized for making the measurements of temperatures, which gives temperature and wind speed simultaneously. The procedure and precautions adopted during the exercise of measuring temperatures are described as: 1) The measurements of temperatures were made in the afternoon between 12:00 noon to 2:00 PM on a fair weather day 2) The measurements of temperatures were made twice each month, after a gap of about 15 days, depending upon the weather conditions. 3) Measurements of temperatures were recorded on saturation for a time of not less than 10 seconds. 4) Temperature measurements have been recorded under mild wind speed conditions, either at same wind speed or at a variation range of not more than 1 km/hr. 5) Three measurements of temperatures, in the sunshine and under the shade of tree crowns, were made on a day. The averages of all six readings, thus obtained in the sunshine as well as under tree shades in every month were utilized to obtain the temperature difference and for the purpose of analysis of data. The measurements were made from October 2015 to September 2016. But, in case of deciduous tree species *viz. L. floribunda* and *P. africanum*, measurements have been considered for analysis only in crown bearing condition of the trees. Thus, averages of ambient temperatures, temperatures under shades of the sample trees and cooling produced by trees along with Pearson correlation between ambient temperatures and the cooling produced by trees and standard error (SEM) in cooling were computed as given in Table 1. Regression analysis has

Table 1. Species wise temperatures, cooling and analytical parameters in different months.

Species	Particulars	Month											
		Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16
M. indica	Ambient Temp (˚C)	34.9	29.5	27.1	22.9	27.6	33.8	36.0	38.2	37.2	35.4	38.9	35.0
	Temp under Shade (˚C)	29.0	25.0	23.0	20.1	23.8	31.0	32.8	34.0	33.2	32.3	34.1	30.4
	Cooling (˚C)	5.9	4.5	4.1	2.8	3.8	2.8	3.2	4.2	4.0	3.1	4.8	4.6
	Pearson Correlation	0.98	0.86	0.27	0.92	0.22	0.71	0.79	0.89	0.84	0.55	0.54	0.91
	Standard Error	0.30	0.16	0.47	0.43	0.20	0.17	0.22	0.28	0.25	0.20	0.31	0.38
F. benjamina	Ambient Temp (˚C)	33.3	*29.9*	26.5	22.5	27.8	33.6	36.1	38.6	38.3	35.1	38.7	34.8
	Temp under Shade (˚C)	27.7	25.8	22.7	20.0	24.3	31.1	33.4	35.0	33.8	31.0	32.6	29.6
	Cooling (˚C)	5.6	4.1	3.8	2.5	3.5	2.5	2.7	3.6	4.5	4.1	6.1	5.2
	Pearson Correlation	0.38	0.88	0.09	0.94	0.51	0.55	0.84	0.98	0.58	0.79	0.87	0.71
	Standard Error	0.70	0.28	0.38	0.23	0.23	0.10	0.17	0.27	0.13	0.08	0.33	0.16
A. chinensis	Ambient Temp (˚C)	34.8	29.8	24.2	22.1	30.6	30.9	36.8	37.6	36.4	35.1	38.0	34.5
	Temp under Shade (˚C)	29.7	26.0	21.7	20.2	27.5	29.6	35.1	34.8	33.1	31.2	32.8	29.7
	Cooling (˚C)	5.1	3.8	2.5	1.9	3.1	1.3	1.7	2.8	3.3	3.9	5.2	4.8
	Pearson Correlation	0.95	0.72	0.18	0.67	0.88	0.11	0.98	0.54	0.58	0.21	0.99	0.29
	Standard Error	0.37	0.30	0.08	0.26	0.20	0.07	0.31	0.07	0.08	0.20	0.51	0.07
P. africanum	Ambient Temp (˚C)	34.0	29.4	25.8	22.6	29.2	31.2	34.6	37.6	37.2	35.4	38.8	34.5
	Temp under Shade (˚C)	28.9	25.8	22.5	21.2	28.3	30.6	32.0	34.3	33.5	32.0	33.7	29.9
	Cooling (˚C)	5.1	3.6	3.3	1.4	0.9	0.6	2.6	3.3	3.9	3.4	5.1	4.6
	Pearson Correlation	0.34	0.90	0.75	0.98	0.59	0.86	0.82	0.98	0.93	0.86	0.86	0.59
	Standard Error	0.23	0.14	0.53	0.56	0.11	0.16	0.11	0.41	0.22	0.08	0.57	0.18
L. floribunda	Ambient Temp (˚C)	32.7	30.6	24.7	22.6	27.7	31.6	36.0	37.7	37.8	35.0	38.1	34.6
	Temp under Shade (˚C)	29.1	27.2	22.2	20.7	25.2	30.3	34.7	37.3	34.8	32.6	33.8	31.0
	Cooling (˚C)	3.6	3.4	2.5	1.9	2.5	1.3	1.3	0.4	3.0	2.4	4.3	3.6
	Pearson Correlation	0.53	0.97	0.90	0.99	0.20	0.71	0.97	0.71	0.09	0.69	0.79	0.47
	Standard Error	0.10	0.36	0.18	0.41	0.18	0.19	0.16	0.03	0.22	0.10	0.22	0.09

been carried out to work out correlation between ambient temperature and cooling produced by trees under their shades for collation in different ways through applying appropriate statistical methods with the help of computer, windows version 10, Microsoft Office Excel 2007.

To study diurnal variation in cooling effect of the selected sample tree species, the measurements were made on three different days in the months of September and October 2016 because crowns of trees were complete in shape, size and vigour in this period. The measurements were made between 8 - 10 AM, 10 - 12 AM, 12 - 2 PM, 2 - 4 PM and 4 - 6 PM. The averages of all the measurements at time were considered for analysis of variation in cooling generated by the sample tree species.

3. Results and Discussion

3.1. Ambient Temperature and Cooling

The cooling produced by the sample tree species under their shades in comparison to the ambient temperatures varied from 2.8˚C to 5.9˚C for *M. indica*, followed by 2.5˚C to 6.1˚C for *F. benjamina*, 2.6˚C to 5.1˚C for *P. africanum*, 1.3˚C to 5.2˚C for *A. chinensis* whereas 1.3˚C to 4.3˚C for *L. floribunda* was the least effective during the entire study period. But, for deciduous tree *viz. P. africanum* and *L. floribunda*, including values of ambient temperature and cooling during leaflessness also, these came out as 1) from 0.6˚C to 5.1˚C for *P. africanum* and 2) from 0.4 ˚C to 4.3˚C for *L. floribunda*. The results of the present study are commensurate to the findings by Abdel-Aziz (2014) who disclosed that temperature reduction under tree shades varied from 1˚C to 5˚C whereas Lin & Lin (2010) found temperature reduction from 0.64˚C to 2.52˚C. This disparity in temperature reduction or cooling produced by tree crowns under their shades may certainly be correlated to the locality factors of the respective study areas along with variation in physical and physiological attributes of the tree species selected for the study. Obviously, there has been obtained an explicit variation in cooling produced by the respective sample tree species which is certainly related to difference in size and density of their crowns as well as other physical attributes of leaves present in the crowns of trees. Factually, crown of a tree establishes interaction between the terrestrial environment and the atmosphere and is responsible for regulation of various bio-physiological processes such as interception to solar radiation and precipitation as well as photosynthesis, transpiration, respiration (Sellers, 1987). It obstructs the flow of solar energy and exhibits physiological performance, which produces cooling in the atmosphere. The denseness of crown is very much dependent on rate of leaf shedding and growth of crown after emergence of new leaves, which is variable with time due to the phenomenon of leaf shedding and emergence of new leaves. *M. indica* and *F. benjamina*, being evergreen species, shed their leaves slowly from March to June during which denseness of crown decreases though they renewed their leaves through out the year (Luna, 2005). On the other hand, *A. chinensis*, being semi-deciduous species, exhibited leaf shedding in March-April 2016 along with simultaneous sprouting of new leaves. *L. floribunda* commenced leaf shedding in February and continued by the end of April 2016 and new leaves emerged in June 2016. *P. africanum* exhibited drastic leaf shedding in January 2016 and the tree became leafless by the end of first fortnight and remained in this condition for a longer duration, and rapid crown development took place after emergence of new leaves in April 2016. Thus, *M. indica* has been the most effective in producing cooling for a larger portion of the year followed by *F. benjamina* and *P. africanum*, *A. chinensis* and *L. floribunda* has been least effective in producing cooling. Lin & Lin (2010) elicited that leaf colour, foliage density, leaf thickness, and leaf texture are effective parameters in producing cooling, which are species dependent attributes and might have certainly played their role in producing cooling.

Due to great variation in recorded data on account of changing crown conditions, for the entire study period, all the recorded measurements of ambient temperatures have been grouped into the class-intervals of 15 - 20, 20 - 25, 25 - 30, 30 - 35, 35 - 40, and 40 - 45 degrees with corresponding values of temperatures under shades of trees and averages determined in every class-interval for every species as presented in **Table 2**. On analyzing these data, *M. indica* has been found most effective species in yielding coolness under its shade in comparison to the ambient temperature for most part of the year followed by *F. benjamina*, *P. africanum*, *A. chinensis* and *L. floribunda* has come out the least effective of all the five selected species under study as depicted in **Figure 1**. The equation between cooling (Δt) produced by the respective trees and the ambient temperature (T) for the respective trees have been furnished as follows:

$$\Delta t = a\,T + b$$

where, a = 0.129, b = −0.315 for *M. indica*; a = 0.111, b = 0.127 for *F. benjamina*; a = 0.118, b = −0.605 for *A. chinensis*; a = 0.114, b = 0.925 for *L. floribunda* and a = 0.137, b = − 1.107 for *P. africanum*.

Explicitly, cooling generated by tree crowns under their shades have been positively correlated to ambient temperatures for all the sample tree species. Evidently, the correlation has been very high but not significant at 95% level of confidence for all the sample tree species since for *M. indica* ($R^2 = 0.87$, $p = 0.71$), *F. benjamina* ($R^2 = 0.80$, $p = 0.89$), *A. chinensis* ($R^2 = 0.97$, $p = 0.15$), *L. floribunda* ($R^2 = 0.90$, $p = 0.25$) and *P. africanum* ($R^2 = 0.91$, $p = 0.28$). This might have been due to reason that several other parameters related to the atmosphere along with physical and physiological characteristics of the sample tree species also play their role in cooling produced by them.

3.2. Quarterly Analysis of Cooling Effect

Because the sample trees belonged to different categories *viz.* evergreen, deciduous and semi-deciduous and their time of leaf shedding as well as duration of leaflessness were different. Besides, heavy destruction of leaves was also experienced

Table 2. Species wise ambient temperatures and cooling with class interval for the entire study period.

S No	Name of Species	Temp (˚C)	Class-intervals					
			15 - 20	20 - 25	25 - 30	30 - 35	35 - 40	40 - 45
1	*A. chinensis*	Ambient Temp	18.9	22.9	28.0	33.2	37.0	-
		Temp. in Shade	17.4	20.6	25.4	29.8	33.3	-
		Cooling	1.5	2.3	2.6	3.4	3.7	-
2	*F. benjamina*	Ambient Temp	19.7	22.4	27.1	32.8	36.9	40.4
		Temp. in Shade	17.8	19.8	23.6	28.3	32.8	36.2
		Cooling	1.9	2.6	3.5	4.5	4.1	4.2
3	*L. floribunda*	Ambient Temp	19.1	23.2	27.2	32.9	37.5	-
		Temp. in Shade	18.1	21.0	25.1	30.2	35.0	-
		Cooling	1.0	2.2	2.1	2.7	2.5	-
4	*M. indica*	Ambient Temp	19.5	22.2	27.4	32.4	36.9	40.3
		Temp. in Shade	17.8	19.4	23.6	28.4	32.9	35.3
		Cooling	1.7	2.8	3.8	4.0	4.0	5.0
5	*P. africanum*	Ambient Temp	19.1	24.3	27.7	32.9	36.9	40.4
		Temp. in Shade	19.0	22.2	25.4	29.8	32.9	35.8
		Cooling	0.1	2.1	2.3	3.1	4.0	4.6

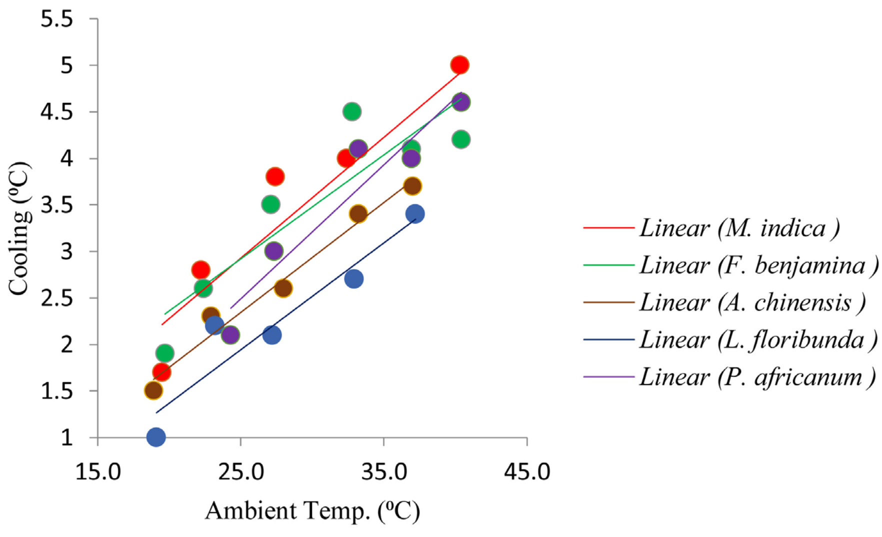

Figure 1. Graphical presentation of species wise relationship between temperatures and cooling.

in *M. indica* during fruit harvesting in July 2016. The data have, therefore, been analyzed quarterly to collate the status of cooling effect generated by different sample tree species in different quarters of the year, results of which are described as follows:

➢ In the quarter October 2015 to December 2015, the crowns of the sample trees were in complete shape and size without any abnormality. *M. indica* tree have been found the most effective followed by *F. benjamina*, and *P. africanum* whereas *A. chinensis* behaved inconsistently and *L. floribunda* the least effective, during this period as elucidated by **Figure 2(a)**.

- In the quarter January 2016 to March 2016, there occurred drastic leaf shedding in *P. africanum* during January and the tree became leafless by the end of the first fortnight of the month and remained leafless till the end of March. *L. floribunda* started to shed its leaves in February and continued during the entire quarter. *A. chinensis* also exhibited leaf shedding in the month of March. Thus, *M. indica* elucidated highest cooling in comparison to other sample trees followed by *F. benjamina*, *A. chinensis* and *L. floribunda* as depicted in **Figure 2(b)** whereas *P. africanum* have shown negligible cooling effect. During this period, the magnitude of cooling has been very low for all the sample tree species on account of lower atmospheric temperature.
- During the period of April 2016 to June 2016, *P. africanum* exhibited emergence of new leaves followed by rapid development of the crown whereas *A. chinensis* continued leaf shedding till the month of April along with simultaneous sprouting of new leaves. *L. floribunda* became leafless by the end of April and new leaves emerged in the month of June. *M. indica* and *F. benjamina* also showed normal leaf shedding. Thus, *M. indica* continued to demonstrate its highest effectiveness in yielding cooling followed by *P. africanum*, *F. benjamina*, *A. chinensis* and *L. floribunda* remained least effective during this quarter as illustrated in **Figure 2(c)**.
- Between July 2016 to September 2016, crown development occurred in all the sample trees except *M. indica*. There witnessed a heavy destruction of leaves in *M. indica* tree in the month of July due to fruit harvesting resulting in fall in LAI. Thus, *M. indica* which exhibited highest cooling effect of all the sample trees during the previous three quarters, have been found better only to *L. floribunda*. During this period, *F. benjamina* came out as the most effective followed by *A. chinensis*, *P. africanum* and *L. floribunda* remained the least effective species, in yielding cooling under their shades. The results have been displayed graphically by **Figure 2(d)**. Here, it will not be impertinent to hope that if heavy destruction of leaves in *M. indica* had not taken place it would have continued to demonstrate its greatest cooling effect during this period too.

3.3. Diurnal Variation in Cooling

The values of ambient temperatures, the temperatures under shades as well as cooling produced by the respective sample trees in respect to diurnal variation have been shown in **Table 3**. Explicitly, cooling produced by all the sample tree species have been highest in the afternoon between 12 Noon to 2 PM whereas lowest in the morning between 8 to 10 AM or may be earlier too. When insolation strikes the crown of a tree, it is distributed in three ways. Firstly, a portion is

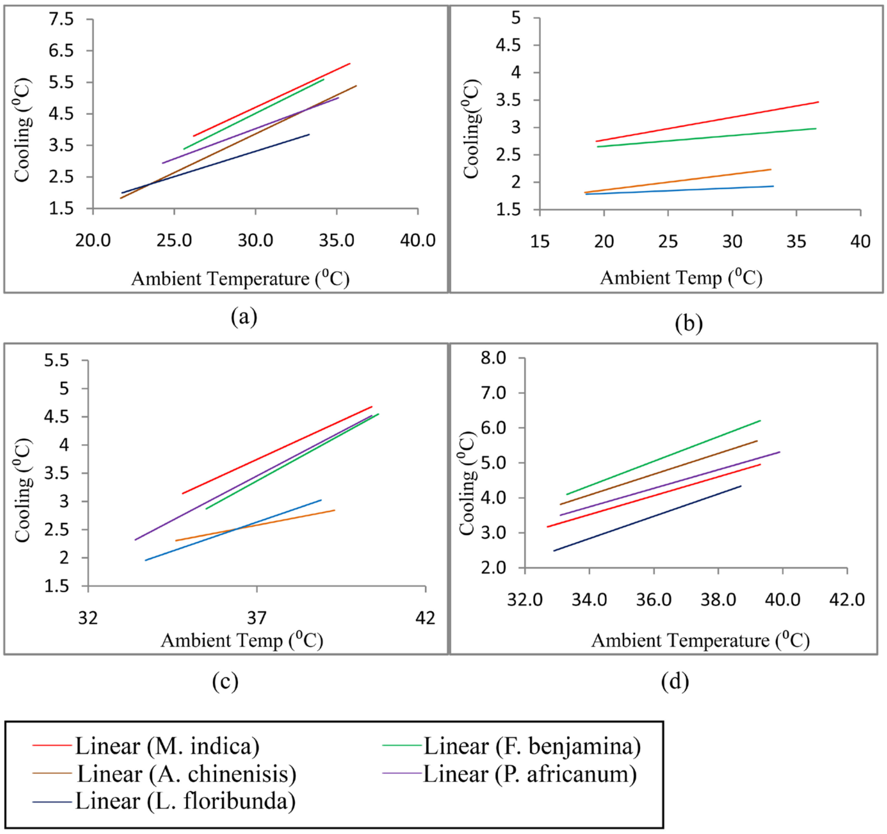

Figure 2. Cooling effect of sample tree species in different quarters of the year. (a) October - December 2015; (b) January - March 2016; (c) April - June 2016; (d) July - September 2016.

Table 3. Diurnal variation in ambient temperature and cooling produced by different sample tree species.

S. No.	Name of Species	Temperature (˚C)	Time Interval				
			8 - 10 AM	10 - 12 AM	12 noon - 2 PM	2 - 4 PM	4 - 6 PM
1	*A. chinensis*	Ambient Temp.	27.5	32.6	35.4	34.3	32.6
		Cooling	1.7	3.2	4.3	3.6	2.4
2	*F. benjamina*	Ambient Temp.	28.7	33.5	35.4	33.8	30.2
		Cooling	1.9	4.2	4.7	3.7	2.2
3	*L. floribunda*	Ambient Temp.	27.8	32.8	35.3	34.1	31.9
		Cooling	1.0	2.4	3.5	2.4	1.5
4	*M. indica*	Ambient Temp.	28.8	33.5	35.3	33.8	30.4
		Cooling	2.1	3.8	4.5	3.6	2.2
5	*P. africanum*	Ambient Temp.	28.2	33.0	35.4	33.3	32.1
		Cooling	2.0	3.7	4.5	2.9	2.2

reflected back to the atmosphere by the crown. Secondly, some portion is absorbed by leaves, which is utilized in metabolic functions of leaves and increase their temperature. Thirdly, the remaining portion is able to reach beneath the crown penetrating it through a series of reflective functions of different leaves in the crown. Thus, a very little solar energy is able to reach beneath the crown, which results in decrease in air temperature under the shade of tree crown in comparison to open area (Kittredge, 1948). In case of study of diurnal variation in cooling and ambient temperatures, the results presented in **Figure 3** reveal that the cooling generated under the crowns of sample trees as well as ambient temperatures have been minimum in the morning and gradually increased with time. Both of these culminated in the afternoon between 12 Noon - 2 PM in case of all the sample tree species and started to fall afterwards. The results obtained in the present study have been commensurate to the results found by Dabral & Nath (1972) and Dabral et al. (1969). The sizes and denseness of crowns of the sample trees as well as impact of seasonal variations have remained constant during determination of diurnal variation in cooling. The cooling, therefore, generated by trees may effectively be treated related to the ambient temperature since other physical attributes are constant and physiological performances of trees are temperature dependent.

But, it is also opined that, though cooling produced by sample trees has been positively correlated to ambient temperature yet high ambient temperature directly can not produce more cooling under shades of trees because it is not the temperature which produces cooling. It is due to performance by tree crown in respect to certain functions leading to cooling effect. More pertinently, as the ambient temperature increases it leads to augmented performance by tree crown in respect to obstruction of larger quantum of insolation reaching beneath the crowns, increased rate of transpiration and photosynthesis, which result in more cooling benefits under tree shade.

3.4. Monthly Variation in Cooling

In case of monthly variations in cooling produced by the sample trees, there has

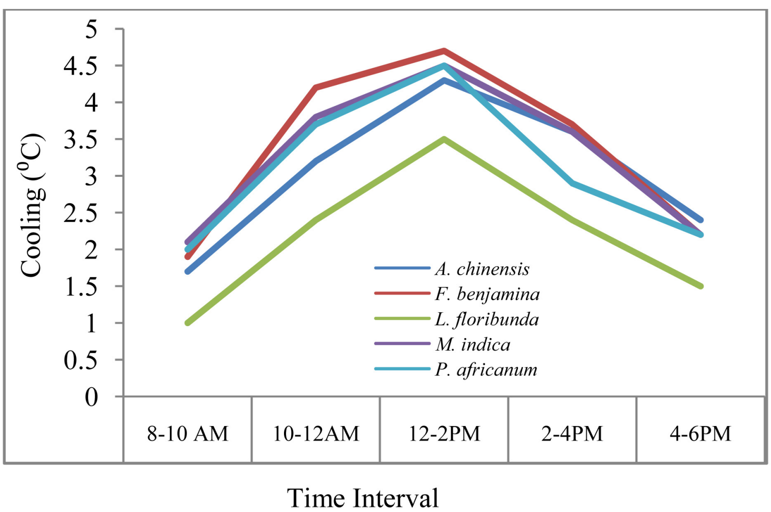

Figure 3. Diurnal variation in cooling effect of different sample species.

witnessed an irregular behavior in respect of cooling produced by the sample trees as demonstrated in **Figure 4**, which would have certainly been on account of changing conditions of their crowns due to varying time of leaf shedding as well as duration of leaflessness of different sample tree species. Thus, *M. indica* an*d F. benjamina,* being evergreen species, exhibited different trend whereas *A. chinensis*, *P. africanum* and *L. floribunda* performed peculiarly for the entire year due to their deciduous and semi-deciduous nature. *M. indica* tree indicated highest effectiveness in producing cooling in comparison to other sample trees from October 2015 to June 2016. There was observed a continuous fall in Leaf Area Index (LAI) from March 2016, which might have been mainly due to the two reasons—Firstly, due to leaf fall by natural processes of ageing and senescence and secondly, due to increase in weight of fruits which would have resulted in bending of branches, more towards vertical. Furthermore, there was a drastic fall in leaf area index on account of heavy destruction of leaves in July 2016 during fruit harvesting due to which tree crown became sparse resulting in more insolation reaching the ground surface penetrating through the crown. Consequently, *M. indica* exhibited a radical fall in cooling comparatively to other sample trees except *L. floribunda*. During this period, *F. benjamina* displayed highest cooling because there was not any sudden change in the physique of its crown. *P. africanum* was found least effective of all the selected trees in producing cooling from January to March 2016 due to drastic leaf fall in January and the tree remained leafless during this period. The nature of *A. chinensis* is semi-deciduous, leaf fall took place in March - April 2016 but due to sprouting of leaves simultaneously, it did not become leafless. Therefore, *A. chinensis* was found less effective in producing cooling of all the selected trees except *L. floribunda* during April - June 2016. Though the ambient temperatures began and continued to increase after the month of January 2016 yet cooling effect produced

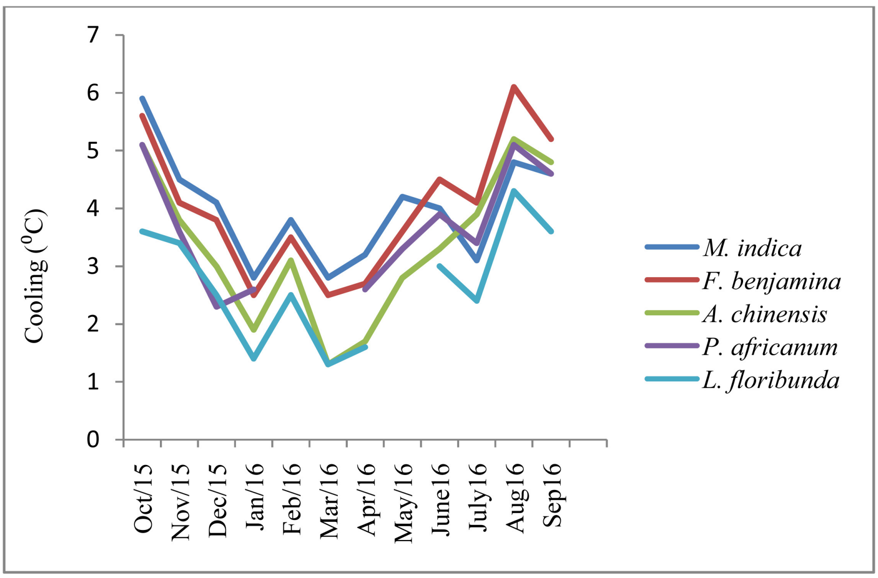

Figure 4. Monthly variation in cooling produced by different sample tree species.

by all the sample trees has been higher in the month of February 2016 in comparison to March 2016 and April 2016 except in case of *P. africanum* which was leafless. This is certainly beyond any scientific explanation and might have been due to the vagary of atmosphere.

It has also been revealed by the study that cooling produced by all the sample trees have been markedly higher in the months of October 2015, August 2016 and September 2016 in comparison to other months of the year despite ambient temperatures during these months were not higher than in the months of April 2016 to June 2016. This might have been due to the following reasons:

- The size and vigour of crowns of the trees are prominently larger in these months comparative to other months of the year due to various atmospheric conditions favourable to tree growth. This restricts the biggest amount of solar energy to reach beneath the tree crown resulting in more temperature reduction under the shade of the tree, during these months.
- During these months, atmosphere remains heavy on account of greater relative humidity, which would have restricted the lateral movement of air at higher temperature in open sunshine and at lower temperature under tree shade resulting in more cooling whereas the lateral movement of such air would have resulted in lowering the cooling during summer season.
- During these months, more water particles exist in the atmosphere due to high relative humidity. Thus, high relative humidity along with high temperature outside tree crown eventuates in conversion of these water particles into water vapour consuming latent heat and temperature of water vapour continues afterwards up to saturation point. But, this phenomenon may or may not happen and, if happens, it will certainly be less effective due to lower temperature under tree shade. It is well known too that warmer air contains more water vapour than cooled air (Larcher, 1995). This facilitates more temperature difference between ambient atmospheric temperature and the temperature under the shade of tree crown.
- When solar energy (photons) reaches the earth's atmosphere, some of the solar energy goes back to the space after collision of photons with particulate matter present in the atmosphere and the rest reaches the ground. But, after the rains, the level of presence of particulate matter in the atmosphere reduces to minimum during these months. Consequently, more solar radiation reaches the ground leading to higher ambient temperature and more cooling is produced under the tree crown.
- It is widely accepted that the rate of physiological functions, transpiration in particular, is higher after rains on account of removal of dust particles present on leaves as well as cleanliness of stomata (Kramer & Boyer, 1995; Larcher, 1995). Since transpiration is a continuous process and stomata normally exist on the ventral side of leaf, to keep the leaf temperature at equilibrium it takes heat from the immediate environment of the leaf, which results in reduction in air temperature under the shade of tree crown. Thus,

more transpiration by tree crown implies more reduction in air temperature inside the shade of the crown and consequently more cooling is produced by tree crown during these months.

The size of leaves in the crown also play an important role since larger size leaves provide more surface area and more number of stomata for transpiration and photosynthesis as well as more obstruction to solar radiation reaching beneath the crown resulting in more cooling produced under its shade (Esau, 1969). It could be easily identified ocularly that *P. africanum* had largest size leaves of all the sample trees followed by *A. chinensis, L. floribunda, M. indica* and *F. benjamina*. The sizes of leaves of different sample trees were differentiated with the help of Senior Plant Scientists. But, denseness of the crown is not only a function of leaf size and the number on leaves per unit volume of the crown also plays an efficient role in its denseness.

Smoothness or roughness of leaves in the crown is also significant because smooth leaves reflect more solar radiation than rough leaves whereas rough leaves provide larger surface area and more number of stomata resulting in higher rate of transpiration and photosynthesis. It could be recognized by rubbing the leaves with hand that leaves of *F. benjamina* were smoothest of all the sample trees followed by *A. chinensis, L. floribunda, P. africanum* and *M. indica*. The smoothness or roughness of leaves of different sample trees was differentiated with the help of Senior Plant Scientists. Though colour of leaves in the crown of tree also have some effect in cooling because light colour leaves reflect whereas dark colour leaves absorb more solar radiation yet Lin & Lin (2010) disclosed that colour of leaves has least effect on cooling produced by crown of trees. Therefore, this aspect was not covered in the present study due to certain reasons.

4. Conclusion

Thus, on the basis of the present study, it comes out that evergreen species such as *M. indica* and *F. benjamina* are preferred for plantation especially on sites where people want coolness under shades of trees during summers because these species provide shade in abundance with higher cooling experience during summers. *A. chinensis*, the semi-deciduous species may also be selected since it also provides shade during summers. But, *L. floribunda* species is not preferable because it not only remains leafless during summer season but produces least cooling effect whereas *P. africanum* is worth selecting species since the pace of crown development is fast after emergence of new leaves in April and produces comparatively better coolness under its shade during hot weather.

Though the natural factors are not feasible to check yet anthropogenic causes are manageable. To raise and develop plantations with ecologically more valuable species will certainly be beneficial to mitigate global warming. It is imperative to identify ecologically more valuable species for this purpose. Further investigation is required to undertake studies on trees to understand as to how a tree, through its physical presence and functions, is integrated to the effects on atmosphere and responses to changing conditions.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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