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Analysis of Leaf Area Index of Shade Trees and Its Relationship with the Discomfort Index: A Case Study at the University of Mataram Campus

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Abstract: The development of shade trees on the Mataram University campus is intended to maintain environmental comfort, as well as add beauty. The microclimate softening function of trees is largely determined by the density of their canopies, known as the leaf area index (LAI). Various LAI measurement methods have been developed, which are generally more suitable for assessing tree productivity but less valid for assessing the ability to soften the microclimate or decrease the discomfort index (DI). This study was conducted to analyze the distribution of LAI of shade trees and their relationship with the DI on the Mataram University campus. To obtain a more valid LAI value, the leaf area variable measured was the leaf area forming the canopy, replacing the leaf area on the canopy surface, as was done in previous studies. Microclimate variables measured to determine the discomfort index (DI) were air temperature and relative humidity. The results showed that the LAI of 108 trees (33 species) spread across 9 zones within the Mataram University campus ranges from 1.2630 (very small category) to 9.6735 (very large category). The DI values under the canopy of trees ranged from 23.225 (quite comfortable category) to 26.869 (somewhat comfortable category). The relationship between LAI of shade trees and DI on the campus of Mataram University was linear and negative, with the resulting regression equation being y = 28.1204-0.4749x. If LAI increased, then DI tended to decrease; conversely, if DI increased, then LAI tended to decrease. The function of campus trees in softening the microclimate can be enhanced by improving their LAI.

Keywords: Comfort; Leaf Area; Tree Canopy.

Introduction

The presence of trees in a public area, apart from increasing property and aesthetic values, can also add ecological value by softening the microclimate, which can help prevent an increase in the thermal discomfort index (DI). As part of the green open space, the shade trees on the Mataram University campus, which have been developed to date, are intended not only to maintain environmental comfort but also to enhance the beauty of the campus. The microclimate softening function of shade trees depends on the shape, size and leaf density of their canopy. The level of leaf density in a tree canopy is determined by the ratio of the canopy leaf area to the land area under the canopy, known as the leaf area index (LAI). Various methods of measuring LAI have been developed, from direct methods to indirect methods, which are basically used to calculate the ratio of the leaf area of the canopy surface to the land area under the canopy [1,2], which is more suitable for assessing tree productivity but less valid for assessing the ability to soften the microclimate [3,4].

To increase the validity of the LAI value of trees, especially in order to assess the ability of trees to soften the microclimate or reduce DI, the canopy surface area variable needs to be replaced with the leaf area variable that forms the canopy, which describes the total area of all leaves that form the canopy. The microclimate softening function of all the leaves that form the canopy occurs mainly through physical processes, namely absorbing more heat from the environment and reflecting less heat to the environment, resulting in a decrease in the heat of the surrounding environment [5], in addition to the microclimate softening also occurring through physiological processes, namely photosynthesis, especially by the leaves on the canopy surface that receive direct sunlight [6]. The reduction in environmental heat due to the absorption of environmental heat by all the leaves forming the canopy is much greater than the reduction in environmental heat due to photosynthesis activity, which only occurs in the leaves on the surface of the canopy or leaves exposed to direct sunlight [7]. That is why assessing the ability of trees to soften the microclimate is more valid when using the leaf area variable of all the leaves that form the canopy, rather than just the leaves on the surface of the canopy or those exposed to direct sunlight. This conceptual building is considered the novelty of this research. Based on the proposed concept building, it can be further assumed that LAI measured based on the area of all leaves forming the canopy has a negative linear regression relationship with the thermal discomfort index. Meanwhile, LAI, based solely on leaf area on the canopy surface, a previous concept, will remain valid when used to assess tree productivity (not to assess the ability of DI reduction), as used in previous research in the fields of agriculture and forestry. This affirmation is crucial in avoiding misconceptions when determining the method of measuring vegetation LAI.

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Measuring the LAI of shade trees in public areas is crucial because it not only relates to the function of leaves as part of the growth process, but also relates to their role in softening the microclimate through important processes such as environmental heat absorption, light interception, photosynthesis, and transpiration [8]. Thus, there is another important reason to know the LAI of shade trees, namely, to make it easier for managers to monitor the health of the shade trees. Trees with an LAI below the moderate category (low leaf density) can be considered unhealthy. Low leaf density can be caused by impaired leaf growth (the rate of leaf growth is lower than the rate of leaf loss) [9].

Based on the background of the problem above, this research was conducted with the aim of determining the distribution of LAI (based on the total area of all leaves forming the canopy) of shade trees on the Mataram University campus and its relationship with the distribution of DI values in the Mataram University campus.

Research Methods

This study was planned according to a non-experimental research design, namely exploring LAI data without treatment from shade trees and microclimate data to determine the thermal discomfort index on the Mataram University campus. The research was conducted in stages, which included determining the sample area and selecting sample trees or observation points, data collection, and data analysis. The general flowchart of the research is shown in Figure 1.

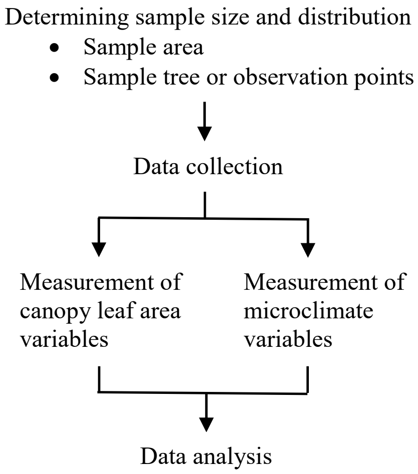

Figure 1. Workflow chart of research on the relationship between tree leaf area index and discomfort index on the Mataram University campus.

Sampling of Sites and Trees

The sample area or sites were determined using the purposive sampling method, adapted from [10, 11], which involved selecting green open areas with adequate and uniform tree density, resulting in nine zones within the Mataram University campus. The sample trees, which also serve as microclimate observation points, were selected using the quaternary method, adapted from [12, 13, 14] (Figure 2). This method involves taking three-quarter points in each zone, resulting in 12 trees or 12 observation points per zone. Thus, a total of 108 trees or points were observed on the Mataram University campus in this study. Before being observed, specimens of important organs, such as leaves, flowers, fruit, and branching systems, were taken from each sample tree in the form of herbaria and photographs for the purpose of species identification in the laboratory. Identification of tree species was carried out using the flora species determination book from [15].

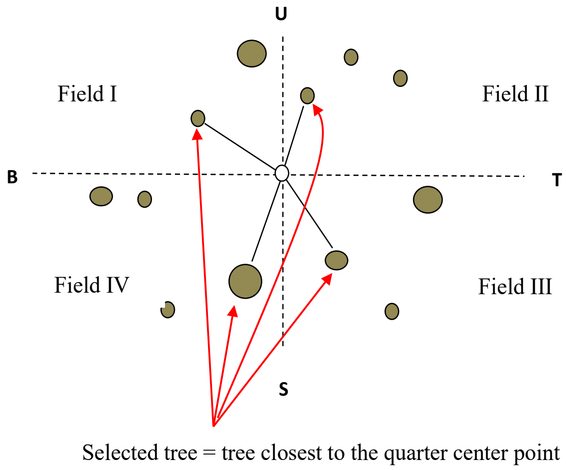

Figure 2. Scheme for determining tree samples using the quarter method

Data Collection Procedures

Leaf area index (LAI)

Data collection on sample tree variables to determine the leaf area index was carried out using tree variable measurement techniques and calculations adapted from [16]. The tree variables in question include the length (l) and width (w) of a single leaf to determine the single leaf area (SLA) (3 replications per tree), the distance between leaves (DL) (3 replications per tree), 3 duets of canopy diameter (D), and tall of canopy (TC) (Figure 3).

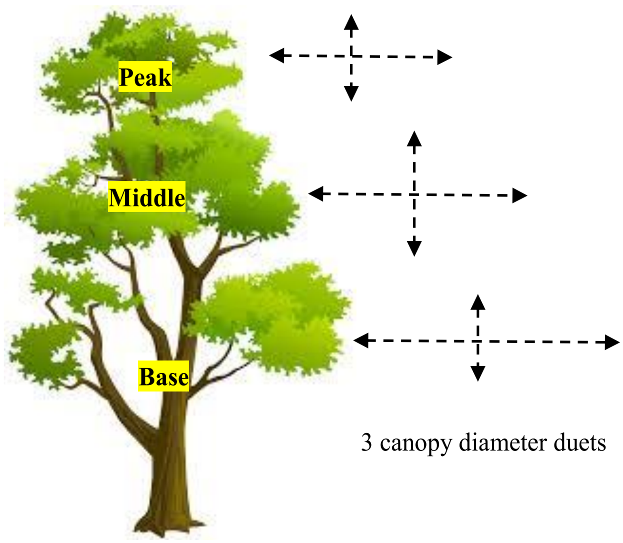

Figure 3. Schematic of measuring three tree canopy diameters duets

Leaf area index (LAI) was calculated using a formula adapted from [17] (Equation 1):

$$LAI = TAL/LA \ldots\ldots\ldots\ldots (1)$$

Information:

LAI = Leaf area index
TAL = Total area of all individual leaves
LA = Land area covered by canopy
TAL = ILA x N
ILA = Individual leaf area (cm^2)
0.75 x (w x l)
w = Leaf width (cm)
l = Leaf length (cm)
N = The total number of leaves in the canopy
VC/SL
VC = Volume of the canopy (cm^3)
D^2 x 1/3 T
D = Diameter of the canopy (Average of the 3 diameter duets)
T = Tall of canopy
SL = Space between leaves (cm^3)
ILA x DL
DL = Distance between leaves (cm)
$ILA^{1/2}$

Discomfort index (DI)

The microclimate variables observed to determine the thermal discomfort index were air temperature and relative humidity. These measurements were taken on a sunny day at a height of 1.5 m above the ground within the area of each tree sample unit. Each sample tree used for observing microclimate variables was identical to the one used for observing leaf area index variables. This microclimate data represents the average of 4 replicates, specifically, microclimate data collected at 4 points within the radius of the sample tree canopy circle. Distribution of measurement points for each tree sample area using a schematic design adapted from [18, 19] (Figure 4).

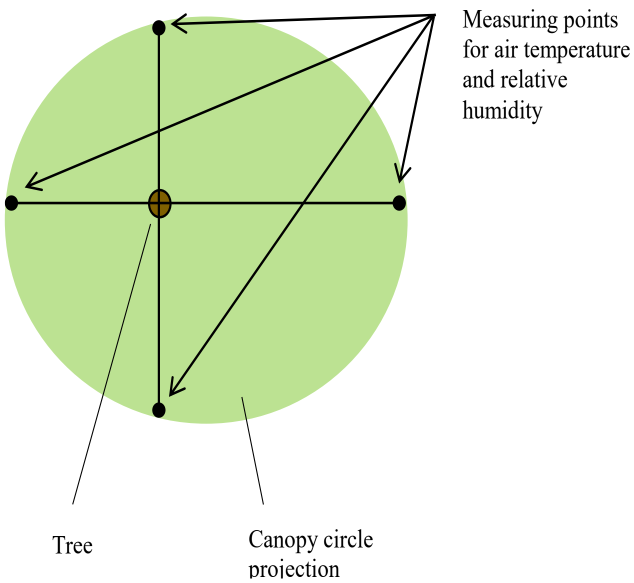

Figure 4 Schematic of measuring air temperature and humidity under the canopy of the sample tree

The temperature and humidity data from each tree sample unit area are then calculated to determine the thermal discomfort index (DI) using a formula that has been used by [21], as follows (Equation 2):

$$DI = T - 0.55\,(1 - 0.01\,RH)(T - 14.5) \ldots\ldots\ldots (2)$$

Information:

DI = Discomfort Index
T = Absolute value of air temperature OC
RH = Absolute value of air relative humidity

Data Analysis

Distribution of leaf area index

Leaf area index data from all sample trees were classified quarterly (Q) into 5 classes (Table 1).

Table 1. LAI classification into 5 categories

LAI value range	Category
Q0 ≤ LAI < Q1	Very small
Q1 ≤ LAI < Q2	Small
Q2 ≤ LAI < Q3	Medium
Q3 ≤ LAI < Q4	Large
LAI ≥ Q4	Very large

Distribution of discomfort index

Discomfort index data from all observation points are grouped into 5 categories according to criteria adjusted from [22], as follows (Table 2):

Table 2. Criteria for levels and categories of discomfort

Expression	Category	DI (°C)
No discomfort	Comfortable	< 21
Discomfort is felt by < 50% of the population	Quite comfortable	21 - 24
Discomfort is felt by > 50% of the population	Somewhat comfortable	24 - 27
Discomfort is felt by the majority of the population	Less comfortable	27 - 29
Discomfort is felt by all	Not comfortable	29 - 32
Medical alarm stages	Dangerous	> 32

Relationship between LAI and DI

The data pairs of shade tree leaf area index and environmental discomfort index from all observation points were statistically processed, using linear regression analysis to determine the regression relationship between the shade tree leaf area index as an independent variable (x) and the discomfort index as a dependent variable (y).

Results and Discussion

A total of 108 sample trees (33 species identified), spread across 9 zones within the University of Mataram campus, were observed, and the leaf area index of these trees ranged from 1.2630 (very small category) to 9.6735 (very large category) (Tables 3 and 4).

In Table 3, it can be seen that the number of trees observed for each species varied, but the number of trees for each zone was consistent, at 12 trees. This was a consequence of the sampling results using the quaternary method. The sampling results also showed that the distribution of shade trees varies among species. Some species are found only in certain zones, such as *Cassia grandis*, *C. siamea*, and *Ficus carica* in zone 3, *Diospyros celebica* and *Morinda citrifolia* in zone 2, and *Polyalthia longifolia* in zone 4. However, there are also tree species that can always be found in every observation zone, such as *Albizia saman*. Meanwhile, in Table 4 it can be seen that trees of the same species do not always have LAI values in the same category, even though LAI is greatly influenced by genetic factors. Although LAI vegetation is basically genetic, it can also be influenced by environmental factors. [20, 23]. For this reason, vegetation maintenance is crucial for enhancing the LAI of vegetation.

Table 3. List of local names and tree species observed on the Mataram University campus.

No.	Local names and species of trees	Cs	N
1	Akasia (*Acacia auriculiformis*)	*Aa*	2
2	Angsana (*Pterocarpus indicus*)*	*Pi*	3
3	Asam (*Tamarindus indica*)*	*Ti*	3
4	Baujan (*Albizia saman*)*	*As*	12
5	Beringin (*Ficus benyamina*)	*Fb*	2
6	Behonia (*Bauhinia purpurea*)	*Bp*	2
7	Bungur (*Lagerstroemia speciosa*)	*Ls*	2
8	Cemara (*Araucaria heteropylla*)	*Ah*	2
9	Dadap merah (*Erythrina variegata)*	*Ev*	2
10	Flamboyan (*Delonix regia*)*	*Dr*	3
11	Glodogan (*Polyalthia longifolia*)	*Pl*	1
12	Jati (*Tectona grandis*)	*Tg*	7
13	Johar (*Cassia siamea*)*	*Cs*	1
14	Johar Pink (*C. grandis*)	*Cg*	1
15	Kenari (*Canarium commune*)*	*cc*	2
16	Ketapang (*Terminalia catappa*)	*Tc*	5
17	Ketapang Kencana (*T. mantaly*)	*Tm*	2
18	Ki Kencrut (*Spathodea campanulata*)*	*Sc*	3
19	Mahoni (*Swietenia mahogani*)*	*Sm*	8
20	Mangga (*Mangifera indica*)	*Mi*	3
21	Mengkudu (*Morinda citrifolia*)	*Mc*	2
22	Nyamplung (*Calophyllum inophyllum*)	*Ci*	3
23	Pohon ara (*Ficus carica*)	*Fc*	1
24	Pohon eboni (Diospyros celebica)	*Dc*	1
25	Pohon Pulai (*Alstonia scholaris*)	*Als*	2
26	Pohon Saga (*Adenanthera pavonina*)*	*Ap*	5
27	Pohon salam (*Syzygium polyanthum*)	*Sp*	1
28	Pohon trengguli (*Cassia fistula*)*	*Cf*	4
29	Sawo kecik (*Manilkara kauki*)	*Mk*	3
30	Sengon (*Albizzia chinensis*)*	*Ac*	4
31	Tanjung (*Mimusops elengi*)	*Me*	9
32	Waringin (*Ficus rumphii*)	*Fr*	3
33	Waru (*Hibiscus tiliaceus*)	*Ht*	4
	Total number of trees observed		108

Cs = Code of species

Table 4. Distribution of leaf area index of 108 trees (33 species) in nine zones on the Mataram University campus

No.	Cs	Zones								
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	*Aa*			4.52		4.56				
2	*Pi*	5.41			7.37	7.29				
3	*Ti*		8.33			8,27		8.68		
4	*As*	8.2; 8.01	7.84	8.24	8.43	8.41	8.73	8.35	8.73	8.3;8.31;8.43
5	*Fb*							9.57	9.14	
6	*Bp*						2.37			1.66
7	*Ls*		5.44							5.74
8	*Ah*		7.72	6.89						
9	*Ev*								6.41	6.56
10	*Dr*							8.08	8,82; 8.74	
11	*Pl*				9.67					
12	*Tg*	6.7	6.11		6.37; 6.50	6.55	6.43	6.42		
13	*Cs*			5.73						
14	*Cg*			5.23						
15	*cc*		6.17	5.74						
16	*Tc*	5.17		5.16		5.2				5.18; 5.38
17	*Tm*	3.15	4.2							
18	*Sc*	6.88			6.76	6.6				
19	*Sm*	6.06			5.92	5.84	5.02	6.02	6,41: 6.66	6.46
20	*Mi*					7.3		7.11	7.39	
21	*Mc*		1.27						1.26	
22	*Ci*	5.11	5.43	5.1						

23	*Fc*			4.71							
24	*Dc*		7.57								
25	*Als*				3.6						2.82
26	*Ap*	6.69	6.87		6.98	7.27	7.01; 6.77				
27	*Sp*			6.75							
28	*Cf*		6.39		6.45		6.57	6.77			
29	*Mk*	5.98		5.89			6.57				
30	*Ac*				6.94		6.72	6.83		7.02	
31	*Me*	8.16		8.41	7.28	7.38	7.31	7.33		7.37	7,05; 7.17
32	*Fr*					5.61	5.08	5.71			
33	*Ht*				6.56		6.48	6.67		7.21	

Cs: Code of species

Based on the quarterly (Q) classification, the LAI values of all observed trees were divided into 5 levels or categories (Table 5).

Table 5. Results of the quarterly (Q) classification of LAI values from 108 trees observed on the Mataram University campus.

LAI Value Range	Category
1.2630 ≤ LAI < 5.7396	Very small
5.7396 ≤ LAI < 6.6810	Small
6.6810 ≤ LAI < 7.3736	Medium
7.3736 ≤ LAI < 9,6735	Large
LAI ≥ 9.6735	Very large

Of all the sample trees observed, the number of trees with LAI values in the very small, small, medium, large and very large categories were 28 (25.93%), 26 (24.07%), 27 (25%), 26 (24.07%) and 1 (0.93%), respectively (Figure 5).

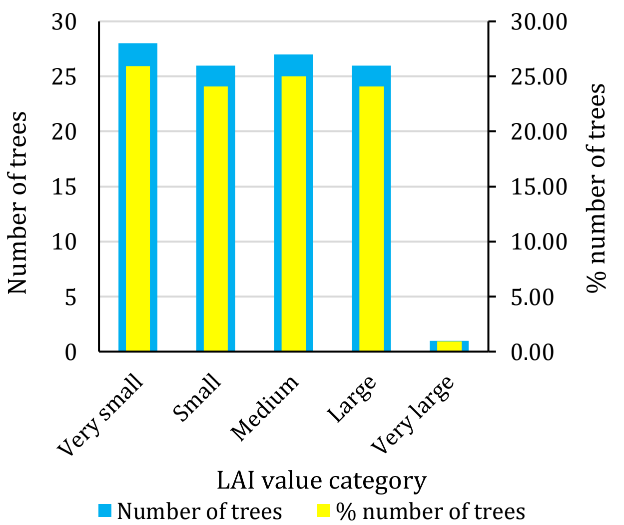

Figure 5. The number of trees according to the LAI category on the Mataram University campus

Small and very small leaf area indexes are mostly found in tree species that have large single leaves but with low leaf density, meaning the distance between leaves is larger than the size of the leaves themselves. Large leaf area indexes are generally found in trees that have small, single leaves but with high density, that is, the distance between the leaves is smaller than the size of the leaves themselves. Large LAI values are also common in compound-leaf or doubly compound-leaf trees, which have very high leaflet density, increasing the total leaf surface area. However, some compound-leaf trees also have small or even very small LAI values. This is usually caused by low compound leaf density or the distance between compound leaves being much larger than the size of the compound leaves themselves. This confirms the hypothesis of a previous study conducted by [23], namely that not all types of compound-leafed trees have a large leaf area index, which may be caused by the low density between compound leaves, even though the density between leaflets is high. Leaf density, leaflet density and compound leaf density are genetic, but especially for the density of single leaves and compound leaf density, they can be influenced by environmental and care factors [24].

The environmental discomfort index (DI) under the canopy of shade trees observed on the Mataram University campus ranges from 23.22500 (Class b or discomfort category felt by < 50% of the population or can also be called the fairly comfortable category) to 26.86900 (Class c or discomfort category felt by > 50% of the population or can also be called the somewhat comfortable category). Of the 108 observation points under the canopy of the sample tree, 22 (20.37%) observation points showed DI values of 23.22 to 23.87 in the fairly comfortable category, and 86 (79.63%) showed DI values of 24.02 to 26.87 in the somewhat comfortable category (Table 6).

Table 6. Distribution of the discomfort index (DI) at 108 points under shade trees on the Mataram University campus.

Number of points (trees)	Quite comfortable (23,22 - 23,87)	Rather comfortable (24,02 - 26,87)
(n)	22	86
(%)	20,37037037	79,62962963

The absence of DI values in the comfortable category in all observation areas in the Mataram University campus environment is likely due to the observation being carried out in the middle of the day, when the sunlight intensity is high to very high (11.00 to 13.00), where the air temperature is in the range above the low category, namely 27.9 to 29.2°C. and the relative humidity ranges from 65 to 78%, which falls within the high humidity category.

In general, low temperatures in tropical areas are cooler than the annual average. On the campus of Malang State University, temperatures range from 26°C (in the low temperature range) to 28°C (in the moderate temperature range). Some studies also consider temperatures below 26°C as a low temperature category for human activity in tropical climates. Meanwhile, moderate temperatures in the tropics refer to the average temperature typically found in the region throughout the year. The average normal temperature in Indonesia is 26.42°C, which is considered moderate. Temperatures above this range increase energy consumption for cooling and affect occupant productivity. Relative humidity above 60% is considered high. Excessively humid air can prevent sweat from evaporating, making the body feel hotter and stickier, which can lead to discomfort. The ideal relative humidity range for human comfort and health is between 40% and 60%. [25,26].

Thermal comfort levels are also influenced by other environmental factors, such as direct sunlight exposure, wind speed and direction, activity, and clothing. Sunlight intensity has a significant relationship with environmental heat, and the mechanisms by which solar intensity influences DI values include surface heating, heat radiation, air temperature, and relative humidity. Intense sunlight can heat the Earth's surface, which then radiates heat into the atmosphere. This can increase ambient temperatures. Intense sunlight can also emit heat radiation, contributing to increased environmental temperatures. High sunlight intensity can increase air temperature, especially during the day. Intense sunlight can also affect air humidity by increasing water evaporation from the Earth's surface. Thus, sunlight intensity plays a significant role in determining environmental temperature and heat. Wind speed can also affect the process of evaporation and body cooling, thereby affecting thermal comfort [27,28].

Visualization of the relationship between the leaf area index and the discomfort index under the canopy of each tree from all the trees observed on the Mataram University campus can be seen in Figure 6.

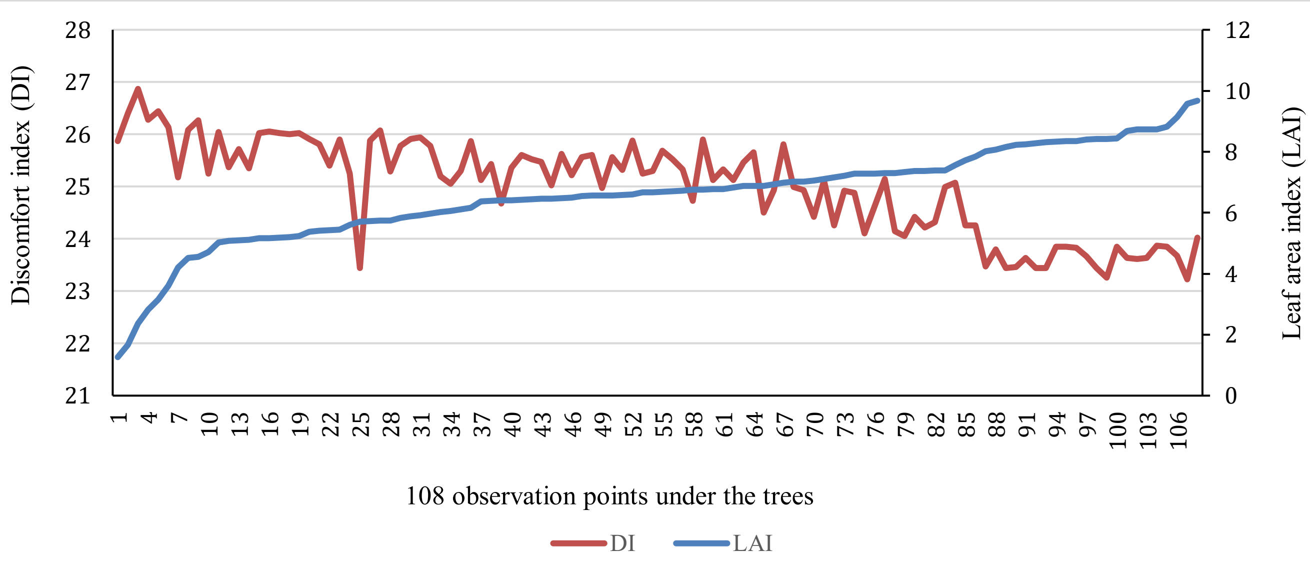

Figure 6. Visualization of the relationship between the distribution of tree leaf area index and discomfort index on the Mataram University campus (Information for tree species codes can be seen in Table 3).

The figure shows that the change in LAI is in the opposite trend to DI. An increase in LAI was accompanied by a decrease in DI, or vice versa. The results of the regression analysis show that the relationship between LAI and DI under the tree canopy on the campus of the University of Mataram was significant, with F count (204.8150) > F table (1.6420E-26) and the relationship was negative, with the coefficient of the variable x = -0.4749 and the form of the relationship was linear, with Regression Statistics for Adjusted R Square (0.6557) > Standard Error (0.5297). The conclusions drawn from the regression analysis results above were in accordance with the criteria used by [29, 30]. The resulting regression equations, LAI (x) and DI (y), are as follows (Equation 3):

$$y = 28.1204 - 0.4749x \quad \text{........ (3)}$$

Information:
x = leaf area index
y = discomfort index

The regression coefficient of -0.4749 can be interpreted as meaning that a one-unit increase in LAI (x) will result in a 0.4749-unit decrease in DI (y), assuming that all other variables remain constant. The constant value of 28.1204 indicates that if LAI (x) equals 0 (zero), then DI (y) will also equal 28.1204.

In an environmental context, the results of this regression analysis suggest that increasing the LAI can help mitigate discomfort caused by high air temperatures and suboptimal relative humidity. It can also be stated that the LAI value of trees reflects their ability to moderate the microclimate, namely by lowering air temperature through carbon dioxide absorption and oxygen release through photosynthesis and optimizing humidity through evapotranspiration [31,32]. LAI describes the total surface area of a single leaf as a whole, not only providing a physical shade function during hot, scorching days but also serving a physiological function of reducing environmental heat, namely reducing CO_2 gas in the environment through photosynthesis activities. Reducing CO2, the primary greenhouse gas, can further lower the heat or air temperature in the environment [33]. Photosynthesis also produces oxygen; besides providing a fresh impression for respiration, it can also reduce air pressure caused by other gases, such as water vapor pressure or relative humidity of the air. The result of a decrease in air temperature and a decrease in air pressure is equivalent to a decrease in the discomfort index [34]. The availability of LAI data and their relationship to DI in a public area will make it easier for managers to improve the microclimate softening function of trees and monitor their health.

Conclusion

The leaf area index (LAI) of 108 trees (33 species) on the Mataram University campus ranged from 1.2630 (very small category) to 9.6735 (very large category). The discomfort index (DI) values under the tree canopy ranged from 23.23 (quite comfortable category) to 26.87 (somewhat comfortable category). The relationship between the LAI of shade trees and DI on the Mataram University campus was linear and negative, with the resulting regression equation being y = 28.1204 - 0.4749x. If the LAI increases, the DI tends to decrease, and vice versa.

Author's Contribution

Conceptualization, S; methodology, S, SS; software, LMAD, RNR; formal analysis, LMAD, S; investigation, FAG, LMAD, RNR, S, SS; data curation, S, RNR; writing—original draft preparation, S, NRN; writing—review and editing, SS; visualization, LMAD; supervision, SS; project administration, FAG, RNR; funding acquisition, RNR,S. All authors have read and agreed to the published version of the manuscript.

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