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Heat Reduction Capacity of Street Trees in the Municipalities of Los Baños and Bay, Philippines

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Abstract. Background: This study compared the phenotypic traits and microclimate parameters of street trees as affected by species origin (native [N] vs. non-native [NN]) and location (inside vs. outside the University of the Philippines, Los Baños [UPLB]). Methods: Tree traits were counted and measured using a meter tape and a range finder, while microclimates (air temperature, relative humidity, heat index, light intensity) under tree canopies and adjacent exposed areas were gathered using a multifunctional environmental meter and a light meter. Results: T-test analysis revealed that tree traits differed significantly but not in terms of microclimate, except for crown-shaded light intensity, with NN trees showing a significant reduction compared to N trees. Meanwhile, tree traits as affected by location showed significant variation only in the number of major branches, with trees outside UPLB registering more branches than the other location. Moreover, multiple linear regression indicated which part of the trees had a strong influence on crown-shaded microclimate, while results of correlation analysis showed that phenotypic traits, except for the relationship between total height and crown traits, regardless of their species' origin, were significant, positive, and strongly correlated. Conclusion: T-test analysis highlighted that street trees in solitary and/or small aggregates tend to enhance the production of protective (e.g., leaves) rather than productive (e.g., stems) traits, while correlation analysis suggested that interventions (e.g., pruning) could improve the trees' crown-shaded microclimate condition. These findings could provide technical guidance for a more sound decision for the inclusion or removal of street trees in urban areas.

Keywords. Crown-Shaded; Microclimate; Mitigation Effect; Protective Traits.

INTRODUCTION

The expanding urbanization from flatlands to mountainous regions, coupled with increasing population and intensified effect of climate change, is gradually changing the urban forest dynamic and drastically aggravating the existing microclimate in many urban landscapes, including the Philippines (FAO 2018; Pataki et al. 2021; Kennedy 2024). Apart from their ability to improve the safety and well-being of the urban community, street trees can enhance the landscape's aesthetic beauty. For example, studies have proved that street trees can increase the monetary value of properties, significantly reduce the urban temperatures, and improve the safety of bicyclists and vehicle drivers (Nowak and Dwyer 2000; Eisenman et al. 2021; Ettinger et al. 2024). However, these urban areas are generally problematic for trees due to their extreme microclimate conditions (Edmondson et al. 2016; Lüttge and Buckeridge 2023). Such a condition affects the trees' overall health and structural conditions as well as their heat reduction ability to provide the optimum thermal comfort needed by urban communities (Winbourne et al. 2020; Lüttge and Buckeridge 2023; Ettinger et al. 2024).

While modern technology (e.g., air conditioning, improved health systems) could improve the health and living conditions in urban areas, many believe that the presence of trees and other vegetation is still the most appropriate action and offers a more sustainable solution (United Nations 2021). Numerous studies have been reported regarding specific tree mechanisms or processes that influence the microclimate related to their physical and physiological traits. The cooling ability of urban trees can be determined by understanding the joint influence of shading (physical influence) and transpiration (physiological influence) (Winbourne et al. 2020). However, understanding the influence of trees' physiological cooling requires complex, more sophisticated, and expensive tools; hence, few studies have been done to understand this aspect.

Nonetheless, several studies have proved the relevance of studying the physical traits of trees to understand their heat reduction abilities. For instance, tree size, canopy density, and leaf area index (LAI) are some of the most well-studied traits of trees that are capable of mitigating the urban heat island (UHI) effect (Akbari et al. 2001; Zheng et al. 2018; Rahman et al. 2020). The bigger the size of a tree, the greater the number of branches, twigs, and leaves, which apparently may provide better shade and intercept sunlight before it warms the building (Akbari et al. 2001; Zheng et al. 2018). Additionally, the denser the tree canopy, the more it can reduce the glare and block the diffuse light from the sky and surrounding surfaces by altering terrestrial radiation and ultimately reducing the ground surface temperature (Akbari et al. 2001; Zheng et al. 2018). Moreover, trees with higher LAI help reduce the mean radiant temperature or the sum of all short-wave and long-wave radiation fluxes received by the body by controlling the sun's radiant fluxes (Winbourne et al. 2020; Guo et al. 2023). These observations indicate that since different trees have different genetic quality and capability to influence the climate variability, more investigations are needed to understand the physical mechanisms of street trees that influence the microclimate, especially in the Philippines (Zobel and Talbert 2003; Gilman and Sadowski 2007).

The intensified effect of extreme weather conditions has resulted in more frequent and increasing temperatures, particularly in urban areas. This led to several studies to clearly understand the natural mechanisms of trees to mitigate the microclimate, such as air temperature, heat index, relative humidity, and light intensity (Akbari et al. 2001; Zheng et al. 2018; Helletsgruber et al. 2020; Rahman et al. 2020; Winbourne et al. 2020; Cheung et al. 2021; Feng et al. 2023; Guo et al. 2023; Sharmin et al. 2023). Understanding trees' physical mechanisms that influence the microclimate is important, as their effect could either be positive or negative. For instance, while trees can mitigate the UHI by providing shade during the day, they may also retain the heat at night by restricting the movement of warm air, particularly in areas with more towering commercial buildings (Armson et al. 2012; Edmondson et al. 2016). These findings emphasize the need for more investigations to determine the most appropriate arboricultural treatments and identify the best species for street trees to positively regulate the microclimate conditions in the built environment. Additionally, since tropical trees are genetically and phenotypically more diverse compared to temperate species, determining their ability to influence the microclimate, particularly in the country, is therefore timely and necessary (Lugo and Brown 1991; Zobel and Talbert 2003). Unfortunately, while several related studies have been done in other countries, very few or none have attempted to determine the heat reduction capacity of street trees in the Philippines.

The relatively high species diversity of tropical tree species in many Asian countries provides a range of species for urban greenery to achieve a greener urban landscape and to address the effects of climate change (e.g., elevated carbon dioxide, UHI, etc.)(Kjelgren et al. 2011). Apart from interspecies competition for water and nutrients, improper species mixture and closer space tree planting may increase the occurrence of pests and diseases. Therefore, species selection is crucial in any tree planting activities, particularly in a more stressful urban environment (Zobel and Talbert 2003; Gilman and Sadowski 2007; Kjelgren et al. 2011). These observations should be considered as an increasing interest in the inclusion of native species as street trees to enhance the thermal comfort in various tropical countries has been recognized (Thaiutsa et al. 2008; Nagendra and Gopal 2010; Kjelgren et al. 2011; Valle 2018; Jayasooriya et al. 2024). While native species have greater species compatibility than the non-natives in general, there are indications that the latter have the capability of maximizing their cooling ability through high transpiration rates and are less prone to their reduction (Arcos-Lebert et al. 2021; Sashua-Bar et al. 2023; Alonzo et al. 2025). Since species diversity and vegetative configuration (e.g., planting spacing and multilayered planting designs combining trees, shrubs, and grasses) have been significantly influencing the cooling ability of trees in the urban landscape, the heat reduction capacity of native and non-native species as street trees is worth investigating (Duncan et al. 2019; Jayasinghe et al. 2024).

The study would like to test the hypothesis that native (N) and non-native (NN) forest tree species are similar with regard to their morphological traits and influence on microclimate conditions when used as street trees in the municipalities of Los Baños and Bay, Philippines. To test this hypothesis, the study

Figure 1. Location of the municipalities of Los Baños and Bay. Reprinted from Piñon et al. (2024).

was carried out to determine the heat reduction capacity of street trees in the subject municipalities as affected by species' origin and locational variability.

MATERIALS AND METHODS

Description of the Study Site

All activities in this study were undertaken in portions of Los Baños and Bay municipalities in Laguna province (Figure 1). These municipalities have the potential to become the main sources of planting materials for urban greening and play a critical role in the advancement of urban forest research in the country. A tree traits and microclimate relationship study was done in selected barangays of these municipalities.

Tree Architecture and Microclimate

The present study focused on street trees growing on primary roads in 3 and 2 barangays of Los Baños and Bay, respectively (Figure 2). The Los Baños barangays included Mayondon, San Antonio, and Batong Malake, while the Bay barangays included Puypuy and San Agustin.

The Philippine government requires the planting of trees not less than 3 m from the edge of the pavement (DPWH 2000). However, since different trees respond to existing site quality and environment differently, all trees within 5 m from the edge of the road were considered to determine the most appropriate distance with the minimum conflict between tree root systems and pavements per species (Hallé et al. 1978; Zobel and Talbert 2003; Morgenroth 2008).

Figure 3 shows the layout of the primary data collection using systematic sampling. Street trees on both sides of the road within a 5-m × 100-m plot, per 1,000-m intervals, were measured. Infrastructure (e.g., houses, buildings, etc.) and water bodies (e.g., river, creek, etc.), including their cardinal directions situated approximately within 20-m distance from each street tree, were recorded. Associated trees and undergrowth vegetation within a 2-m radius from the tree trunk were also documented. Important botanical information (e.g., common name, scientific name, family name), including their ecological distribution (native, introduced, or exotics), was listed for each tree using the Plants of the World Online (Royal Botanic Gardens Kew 2024) and Co's Digital Flora of the Philippines (CDFP)(Co 2011). Similar references were also used for the associated vegetations.

All trees identified as naturalized, exotic, and cultivated; but not native were considered NN in this study. GPS readings (Garmin eTrex 10 Worldwide Handheld GPS Navigator; Garmin, Olathe, KS, USA) for each plot were also recorded. Morphometric parameters were measured. These include the circumference at breast height (C), total height (TH), volume (V), number of major branches (NMB), and crown spread (North-South crown [NS] and East-West crown [EW]). TH was measured from the ground surface to the topmost portion of a tree using a laser range finder (Nikon Forestry Pro; Nikon, Shinagawa, Japan). The diameter at breast height (D) was calculated using the C that was measured using a meter tape (Tufmic 12C-GK12-10ME; Muratec-KDS Corp., Johor, Malaysia) at 1.3 m from the ground surface and later calculated by dividing each circumference by the value of π (3.14). The computed D and TH were then used and multiplied by a constant value (0.7854) to calculate the V. Also, the NMB or branches arising

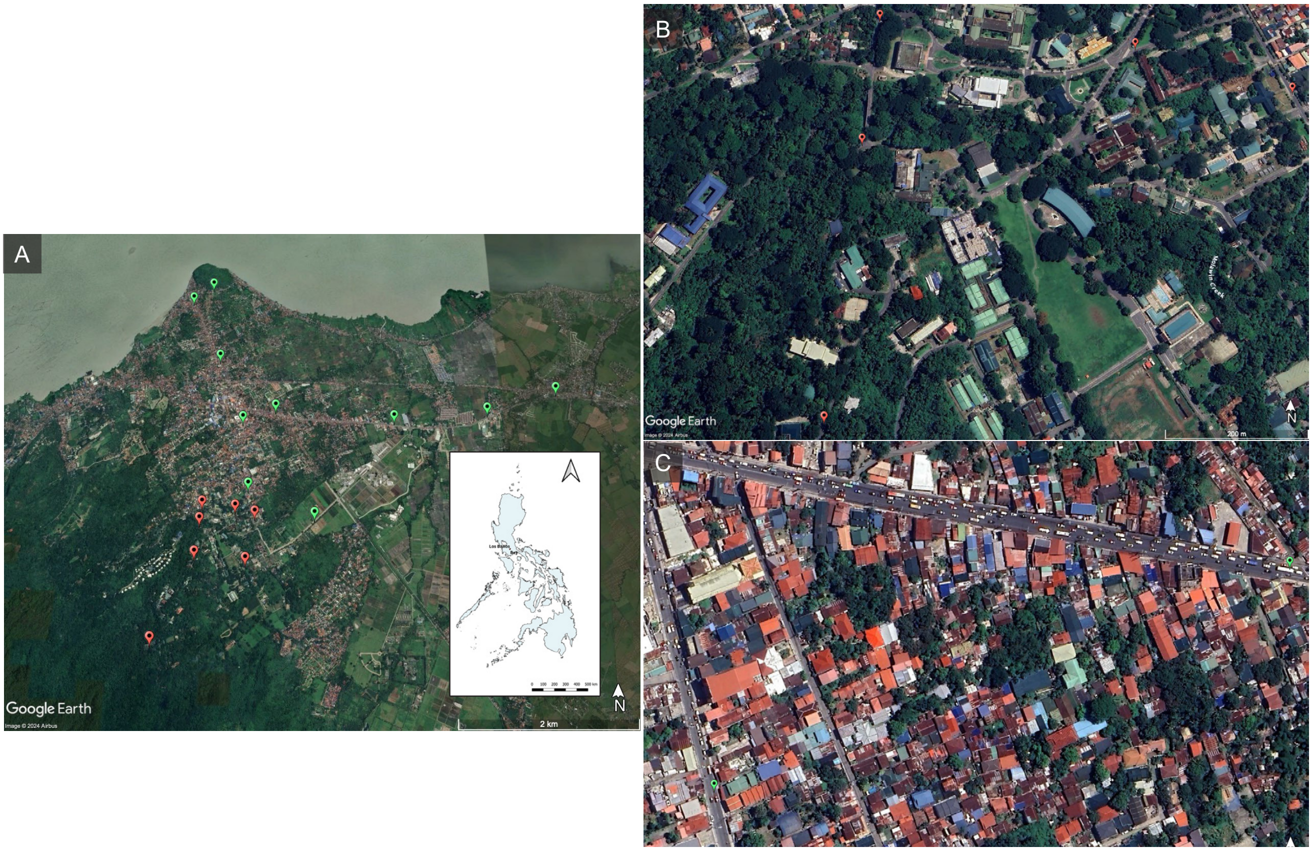


Figure 2. (A) Relative locations of the sampling plots showing the investigated street trees inside (red placemark) and outside (green placemark) of the University of the Philippines, Los Baños (UPLB) campus in Los Baños and Bay municipalities. Note the presence of neighboring trees and other associated plants in street trees within the UPLB campus (B) compared to those growing outside (C) the campus.

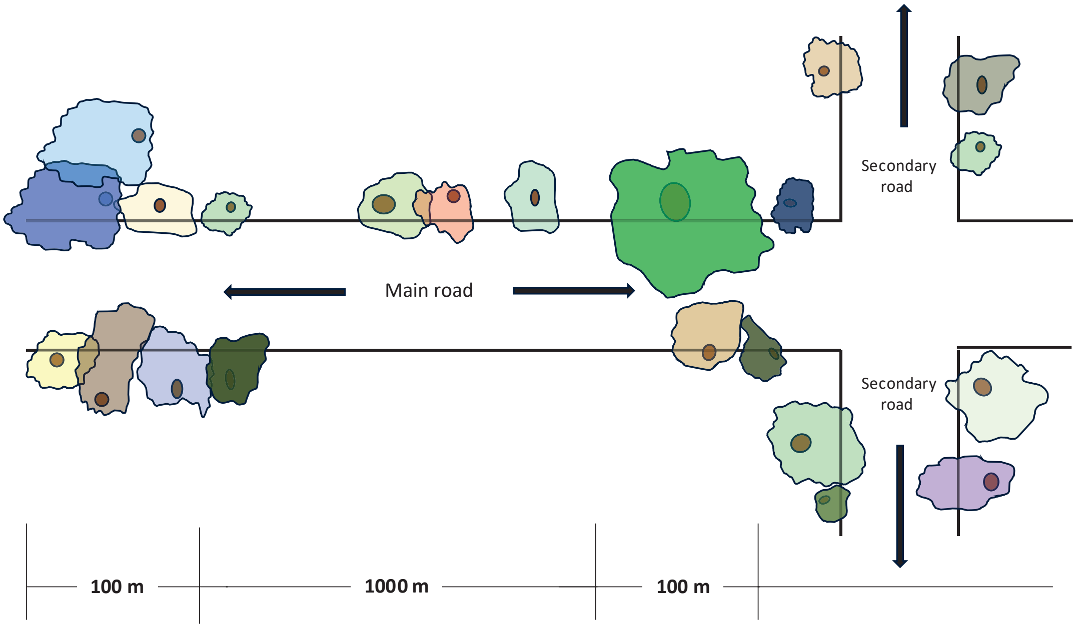


Figure 3. Schematic diagram showing how sampling and data collection were conducted.

from the main trunk per tree were counted. Crown traits such as crown spread (NS and EW), crown cover (CC), and average crown diameter (ACD) were gathered using a meter tape (Stanley 30-m Tape Measure; Dewalt, Towson, MD, USA). The distance of each tree from the road edge (DTR) was also measured using the same meter tape. Finally, any presence of issues (e.g., heaving and cracking of the roads) between each tree and the pavement was also recorded.

Air temperature (AT)(measured around 1.1 m from ground level), heat index (HI), relative humidity (RH), and light intensity (LI) were the microclimate parameters used in the study. These parameters were also considered in various related studies (Helletsgruber et al. 2020; Sharmin et al. 2023). The 1.1-m height is based on the most common position applied in outdoor thermal comfort studies (Mayer et al. 2008; Armson et al. 2012; Helletsgruber et al. 2020). Aside from LI, which was measured using a digital light meter (Extech Model 401025 Digital Light Meter; Extech, Pittsburgh, PA, USA), these microclimate parameters were gathered using a multifunctional environmental meter (Extech EN510 Environmental Meter; Extech, Pittsburgh, PA, USA). Other researchers collected their measurements on heat days between 1:30 pm and 3:30 pm under cloudless conditions (Helletsgruber et al. 2020). In the present study, measurements were undertaken between 10:00 am and 3:00 pm where most of the hottest periods within the day were normally felt and recorded in the country (Pineda 2025). These temperature peaks, however, may not necessarily be similar with the HI peaks observed in other countries; hence, caution should be observed if others want to adapt the same strategy. The difference in microclimate between crown-shaded and full sun-exposed reference areas was calculated and considered in this study as a change or mitigation effect per tree (Gillner et al. 2015). Each microclimate parameter was gathered under a tree crown-shaded area per tree at the central point, while the open area near the subject tree was used as the reference area (Helletsgruber et al. 2020). Measurements were then averaged to determine the mean values per parameter. Crown-shaded microclimate parameters were denoted as air temperature (ATt), heat index (HIt), relative humidity (RHt), and light intensity (LIt), while those in the nearest reference open area were denoted as air temperature (ATo), heat index (HIo), relative humidity (RHo), and light intensity (LIo). Finally, mitigation effects were denoted as air temperature (ΔAT), heat index (ΔHI), relative humidity (ΔRH), and light intensity (ΔLI).

Experimental Design and Data Analysis

One sampling plot for each site (inside and outside the University of the Philippines, Los Baños [UPLB]) was randomly selected to prepare a drawn-to-scale top-view map of street trees in the subject areas. These maps were prepared using Google Earth Pro and Microsoft Office 365 PowerPoint (Microsoft, Redmond, WA, USA)(Figure 3). Meanwhile, collected data both for tree traits and microclimate measurements were encoded and organized in a Microsoft Office 365 Excel spreadsheet. T-test analyses were used to determine the differences between N and NN street trees and between such trees growing inside and outside the campus. The same statistical tool was used to compare the tree canopy temperature and below-canopy temperature in another study (Cheung et al. 2021). Although this study used a large number of samples, future similar studies should consider using correction technique (e.g., Bonferroni) to ensure statistical robustness. Correlation analysis was then conducted to identify the relationships between and among tree parameters and microclimate measurements using the “metan”, “ggplot2”, and “lares” packages in R (R Foundation, Vienna Austria). Finally, multiple linear regression was used to predict the degree of relationship between tree parameters and microclimate using the “tidyr” and “ggplot2” packages in R. All statistical analyses including visualizations were undertaken using R-statistics version 4.3.2.

RESULTS

Native vs. Non-Native Street Trees

A total of 172 individual street trees were evaluated. From this figure, 116 and 56 trees belonging to 21 families were identified inside and outside the UPLB, respectively (Table 1). Of 42 species, 23 and 19 species were classified as N and NN, respectively. Both origins were significantly different ($P < 0.001$) in over 89% of traits and very significant ($P < 0.017$) between their traits and the microclimate parameters, except on iight intensity (Table 2). Also, highly significant variations ($P < 0.0001$) were detected in DBH, TH, and NMB. Finally, very significant differences were calculated in V ($P < 0.003$), NS crown ($P < 0.006$), EW crown ($P < 0.008$), and ACD ($P < 0.016$).

Table 1. Species of street trees identified in the study. N (native); NN (non-native); NT (number of individual trees).

Common name	Scientific name	Family name	Origin	NT
Alim	*Melanolepis multiglandulosa*	Euphorbiaceae	N	2
Almaciga	*Agathis philippinensis*	Araucariaceae	N	1
Anabiong	*Trema orientalis*	Ulmaceae	N	6
Antipolo	*Artocarpus blancoi*	Moraceae	N	2
Anubing	*Artocarpus ovatus*	Moraceae	N	2
Balete	*Ficus* spp.	Moraceae	N	1
Balitbitan	*Cynometra ramiflora*	Fabaceae	N	4
Batitinan	*Lagerstroemia* spp.	Lythraceae	N	37
Bignai-kalabaw	*Antidesma bunius*	Euphorbiaceae	N	1
Binunga	*Macaranga tanarius*	Euphorbiaceae	N	1
Botong	*Barringtonia asiatica*	Lecythidaceae	N	1
Dao	*Dracontomelon dao*	Anacardiaceae	N	2
Hagakhak	*Dipterocarpus validus*	Dipterocarpaceae	N	1
Igyo	*Dysoxylum gaudichaudianum*	Anacardiaceae	N	1
Ipil	*Intsia bijuga*	Fabaceae	N	1
Kalios	*Streblus asper*	Moraceae	N	1
Mangga	*Mangifera indica*	Anacardiaceae	N	3
Narra	*Pterocarpus indicus*	Fabaceae	N	16
Pili	*Canarium ovatum*	Burseraceae	N	34
Santol	*Sandoricum koetjape*	Meliaceae	N	3
Talisay	*Terminalia catappa*	Combretaceae	N	1
Tangisang-bayawak	*Ficus variegata*	Moraceae	N	1
Tindalo	*Afzelia rhomboidea*	Fabaceae	N	1
African tulip	*Spathodea campanulata*	Bignoniaceae	NN	2
Araucaria	*Araucaria* spp.	Araucariaceae	NN	1
Bayabas	*Psidium guajava*	Myrtaceae	NN	1
Big-leaf Mahogany	*Swietenia macrophylla*	Meliaceae	NN	7
Chico	*Manilkara zapota*	Sapotaceae	NN	1
Datiles	*Muntingia calabura*	Muntingiaceae	NN	1
Duhat	*Syzygium cuminii*	Myrtaceae	NN	1
Fire tree	*Parkia roxburgii*	Fabaceae	NN	1
Gmelina	*Gmelina arborea*	Lamiaceae	NN	10
Ilang-ilang	*Cananga odorata*	Annonaceae	NN	1
Indian lanutan	*Polyalthia longifolia*	Annonaceae	NN	1
Ipil-ipil	*Leucaena leucocephala*	Fabaceae	NN	1
Kalachuchi	*Plumeria rubra*	Apocynaceae	NN	1
Kapok	*Ceiba pentandra*	Malvaceae	NN	2
Maki	*Prodocarpus macrophyllus* var. maki	Podocarpaceae	NN	1
Makopa	*Syzygium samarangense*	Myrtaceae	NN	2

Table 1. Continued.

Common name	Scientific name	Family name	Origin	NT
Paper mulberry	*Broussonetia papyrifera*	Moraceae	NN	7
Rain tree	*Samanea saman*	Fabaceae	NN	7
Rubber tree	*Ficus elastica*	Moraceae	NN	1
Total			**42**	**172**

Table 2. Differences in traits and microclimate between N and NN street trees. N (native); NN (non-native); *P* (significance value); pc (pieces); ns (not significant).

Parameters	Mean		*P*
	N	NN	
Traits			
Diameter (m)	0.37	0.67	0.000***
Total height (m)	8.53	13.64	0.000***
Volume (m^3)	2.32	11.30	0.003**
Distance from the road edge (m)	1.77	2.34	0.046*
Number of major branches (pc)	6.98	4.61	0.000***
North-South crown spread (m)	9.57	14.31	0.006**
East-West crown spread (m)	9.85	14.76	0.008**
Average crown diameter (m)	9.71	14.53	0.006**
Canopy cover (m)	96.41	265.00	0.016*
Presence of cracking & heaving	0.02	0.04	0.427^{ns}
Micro-climate (Crown-shaded)			
Air temperature (˚C)	35.30	35.21	0.713^{ns}
Heat index (˚C)	44.12	44.06	0.912^{ns}
Relative humidity (%)	55.71	56.53	0.447^{ns}
Light intensity (Lux)	3,966.29	2,039.96	0.017**
Nearest open area			
Air temperature (˚C)	37.74	37.33	0.119^{ns}
Heat index (˚C)	56.72	55.99	0.458^{ns}
Relative humidity (%)	64.95	63.73	0.223^{ns}
Light intensity (Lux)	87,034.15	84,740.82	0.222^{ns}
Mitigation effect (Change)[1]			
Air temperature (˚C)	2.43	2.12	0.207^{ns}
Heat index (˚C)	13.16	11.94	0.180^{ns}
Relative humidity (%)	9.72	8.56	0.334^{ns}
Light intensity (Lux)	83,067.85	82,700.86	0.833^{ns}

[1] Difference of the microclimate between the crown-shaded and nearest open area

*(significant)

**(very significant)

***(highly significant)

Around 55% of street trees were comprised of the N species. A little less (about 52%) were reported in studies conducted in Metro Manila (Valle 2018). In contrast, only 16% of urban trees in Cebu City were N trees (Jumonong et al. 2021). In some other cities, like Bacolod City and Iloilo City, a single NN species belonging to the genus *Swietenia* was commonly used as urban trees (Tutor et al. 2017; Pansit 2019). These suggest the need for more studies, policies, and programs that will prioritize the use of N species to ensure their proliferation in the country's urban landscapes.

Inside vs. Outside UPLB Street Trees

Nonsignificant variations were achieved in most of the tree traits (87.5%), but significant variations were observed in the majority (58.33%) of the microclimate parameters between inside and outside the subject campus (Table 3). A significant increase in the NMB was detected in trees growing outside (7.59

Table 3. Differences in traits and microclimate of street trees growing inside and outside UPLB. UPLB (University of the Philippines, Los Baños); *P* (significance value); ns (not significant); pc (pieces).

Parameters	Mean		*P*
	Inside UPLB	Outside UPLB	
Traits			
Diameter (m)	0.50	0.38	0.062^{ns}
Total height (m)	9.81	10.34	0.680^{ns}
Volume (m^3)	5.52	3.56	0.291^{ns}
Distance from the road edge (m)	2.10	1.60	0.043^{*}
Number of major branches (pc)	5.68	7.59	0.01^{**}
North-South crown spread (m)	10.84	11.09	0.839^{ns}
East-West crown spread (m)	11.55	10.62	0.473^{ns}
Average crown diameter (m)	11.19	10.85	0.779^{ns}
Canopy cover (m)	150.97	130.91	0.661^{ns}
Presence of cracking & heaving	0.03	0.00	0.045^{*}
Micro-climate (Crown-shaded)			
Air temperature (˚C)	35.13	35.59	0.065^{ns}
Heat index (˚C)	43.74	44.87	0.254^{ns}
Relative humidity (%)	56.68	54.43	0.01^{**}
Light intensity (Lux)	3,539.59	3,164.64	0.669^{ns}
Nearest open area			
Air temperature (˚C)	37.34	38.19	0.000^{***}
Heat index (˚C)	55.64	58.32	0.000^{***}
Relative humidity (%)	64.76	64.26	0.619^{ns}
Light intensity (Lux)	88,326.72	82,350.00	0.000^{***}
Mitigation effect (Change)[1]			
Air temperature (˚C)	2.22	2.60	0.101^{ns}
Heat index (˚C)	11.91	14.69	0.001^{***}
Relative humidity (%)	8.57	11.09	0.027^{*}
Light intensity (Lux)	84,787.14	79,185.36	0.000^{***}

[1] Difference of the microclimate between the crown-shaded and nearest open area

*(significant)

**(very significant)

***(highly significant)

pieces, $P < 0.01$) than inside (5.68 pieces, $P < 0.01$) the UPLB. Significant variations were also generated in other parameters (distance from the road edge, $P < 0.043$; presence of cracking and heaving of pavement, $P < 0.045$). Meanwhile, a significant increase in RHt was observed inside the campus (56.68%, $P < 0.01$). A similar observation was recorded in the nearest open area, such as ATo (38.19 °C, $P < 0.000$) and HIo (58.32 °C, $P < 0.000$) outside the subject university, but those trees growing inside the campus achieved greater values in LIo (88,326.72 lux, $P < 0.000$). Finally, significant reductions in ΔHI (14.69 °C, $P < 0.001$) and ΔRH (11.09%, $P < 0.027$) were detected in street trees outside the UPLB, while similar observation inside the campus was noted only for ΔLI (84,787.14 lux, $P < 0.000$)(Table 3).

Correlations Among and Between Tree Traits and Microclimate Parameters

Positive with moderate to very strong correlations were calculated among tree traits for N trees ($r^2 = 0.58$ to 0.97), while very strong associations were observed only between and among crown traits for NN species ($r^2 = 0.14$ to 0.97, $P > 0.05$)(Figure 4). All of these associations were highly significant ($P < 0.001$). On the other hand, although highly significant, negative and low associations were established between tree traits and microclimate parameters, particularly the values derived from ΔLI for N trees ($r^2 = -0.19$ to -0.30, $P < 0.05$ to $P < 0.001$). Almost similar strength was also observed between tree traits and the crown-shaded microclimate, particularly the ATt and HIt for NN species ($r^2 = -0.30$ to -0.37, $P < 0.05$ to $P < 0.01$). Although statistically significant, these correlations were not strong enough and, therefore, caution in their use should be observed. Interestingly, compared to NN species with correlations between crown-shaded microclimate and mitigation effect ($r^2 = -0.22$, $P > 0.05$ [ATt vs. ΔAT]; $r^2 = -0.51$, $P < 0.001$ [RHt vs. ΔRH]), N trees obtained highly significant and negative values with strong associations in similar parameters ($r^2 = -0.72$, $P < 0.001$ [ATt vs. ΔAT]; $r^2 = -0.64$, $P < 0.001$ [RHt vs. ΔRH]). The strongest negative relationship among microclimate parameters was computed between ATt and RHt. Such observation is reflected in their corresponding mitigation effect ($r^2 = -0.72$, $P < 0.001$ [ATt vs. ΔAT]; $r^2 = -0.64$, $P < 0.001$ [RHt vs. ΔRH]).

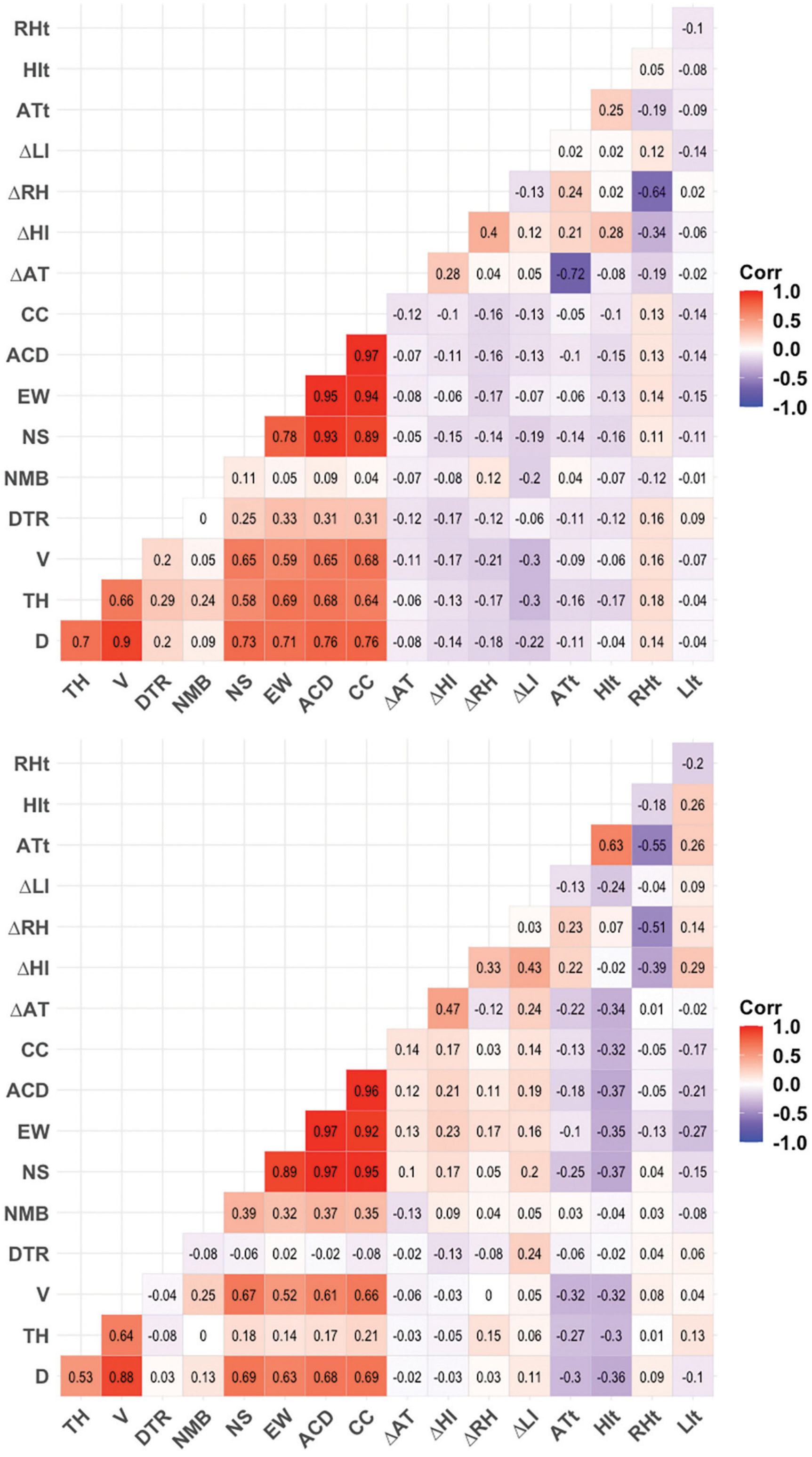
Relationship Between Tree Traits and Microclimate Parameters

Multiple linear regression analysis was undertaken between tree traits and microclimate parameters, both in terms of species origin and their location, to predict which among these traits were effective in improving the microclimate condition in the subject municipalities. Statistically significant results were determined only between tree traits and all crown-shaded microclimates, except the HIt in trees growing outside the campus (Figure 5). Hence, discussions were considered only in these parameters. Decreasing ATt and LIt were calculated with increasing growth rates of tree traits, except in the NMB. Among tree traits, TH significantly influenced ($P < 0.001$) the AT, followed by V ($P < 0.003$). On the other hand, LI was significantly affected by the NMB ($P < 0.002$), followed by TH ($P < 0.003$) and V ($P < 0.002$). Meanwhile, the increase in RHt with increasing growth rates of tree traits, except the NMB, was observed in crown-shaded areas outside the UPLB. The RHt in such an area was significantly affected by V ($P < 0.009$) and the NMB ($P < 0.002$), followed by TH ($P < 0.016$) and NS crown ($P < 0.011$).

DISCUSSION

Native vs. Non-Native Street Trees

All the tree traits of street trees evaluated in the subject municipalities differed significantly, but not the microclimate, except in the case of LIt. NN street trees achieved higher mean values in all tree traits examined except for the NMB (6.98, $P < 0.000$). This suggests that NN trees, compared to their N counterparts, can adapt more in areas with unfavorable environmental conditions that are very common to many urban landscapes (Gilman and Sadowski 2007; Jack-Scott 2012; Arcos-LeBert et al. 2021). Meanwhile, unlike tree traits, nonsignificant variations in all microclimate parameters were obtained, except for LIt. Interestingly, light generated from N trees was more intense (3,966.29 lux, $P < 0.017$) than the NN species (2,039.96 lux, $P < 0.017$). Such a result is consistent with the study of Takacs et al. (2016). Trees' cooling capacity depends on the amount of leaf surface area (LSA) per tree and crown size, which can be assessed by determining the LAI (Duursma and Mäkelä 2007; Sinoquet et al. 2007; Sharmin et al. 2023). Apparently, species with greater LSA per unit ground area generally enhance the cooling capacity



	TH	V	DTR	NMB	NS	EW	ACD	CC	ΔAT	ΔHI	ΔRH	ΔLI	ATt	HIt	RHt	LIt
RHt																-0.1
HIt															0.05	-0.08
ATt														0.25	-0.19	-0.09
ΔLI													0.02	0.02	0.12	-0.14
ΔRH												-0.13	0.24	0.02	-0.64	0.02
ΔHI											0.4	0.12	0.21	0.28	-0.34	-0.06
ΔAT										0.28	0.04	0.05	-0.72	-0.08	-0.19	-0.02
CC									-0.12	-0.1	-0.16	-0.13	-0.05	-0.1	0.13	-0.14
ACD								0.97	-0.07	-0.11	-0.16	-0.13	-0.1	-0.15	0.13	-0.14
EW							0.95	0.94	-0.08	-0.06	-0.17	-0.07	-0.06	-0.13	0.14	-0.15
NS						0.78	0.93	0.89	-0.05	-0.15	-0.14	-0.19	-0.14	-0.16	0.11	-0.11
NMB					0.11	0.05	0.09	0.04	-0.07	-0.08	0.12	-0.2	0.04	-0.07	-0.12	-0.01
DTR				0	0.25	0.33	0.31	0.31	-0.12	-0.17	-0.12	-0.06	-0.11	-0.12	0.16	0.09
V			0.2	0.05	0.65	0.59	0.65	0.68	-0.11	-0.17	-0.21	-0.3	-0.09	-0.06	0.16	-0.07
TH		0.66	0.29	0.24	0.58	0.69	0.68	0.64	-0.06	-0.13	-0.17	-0.3	-0.16	-0.17	0.18	-0.04
D	0.7	0.9	0.2	0.09	0.73	0.71	0.76	0.76	-0.08	-0.14	-0.18	-0.22	-0.11	-0.04	0.14	-0.04

	TH	V	DTR	NMB	NS	EW	ACD	CC	ΔAT	ΔHI	ΔRH	ΔLI	ATt	HIt	RHt	LIt
RHt																-0.2
HIt															-0.18	0.26
ATt														0.63	-0.55	0.26
ΔLI													-0.13	-0.24	-0.04	0.09
ΔRH												0.03	0.23	0.07	-0.51	0.14
ΔHI											0.33	0.43	0.22	-0.02	-0.39	0.29
ΔAT										0.47	-0.12	0.24	-0.22	-0.34	0.01	-0.02
CC									0.14	0.17	0.03	0.14	-0.13	-0.32	-0.05	-0.17
ACD								0.96	0.12	0.21	0.11	0.19	-0.18	-0.37	-0.05	-0.21
EW							0.97	0.92	0.13	0.23	0.17	0.16	-0.1	-0.35	-0.13	-0.27
NS						0.89	0.97	0.95	0.1	0.17	0.05	0.2	-0.25	-0.37	0.04	-0.15
NMB					0.39	0.32	0.37	0.35	-0.13	0.09	0.04	0.05	0.03	-0.04	0.03	-0.08
DTR				-0.08	-0.06	0.02	-0.02	-0.08	-0.02	-0.13	-0.08	0.24	-0.06	-0.02	0.04	0.06
V			-0.04	0.25	0.67	0.52	0.61	0.66	-0.06	-0.03	0	0.05	-0.32	-0.32	0.08	0.04
TH		0.64	-0.08	0	0.18	0.14	0.17	0.21	-0.03	-0.05	0.15	0.06	-0.27	-0.3	0.01	0.13
D	0.53	0.88	0.03	0.13	0.69	0.63	0.68	0.69	-0.02	-0.03	0.03	0.11	-0.3	-0.36	0.09	-0.1

Figure 4. Correlations among and between tree traits and microclimate (crown-shaded and change) of N (above) and NN (below) street trees growing along the primary road.

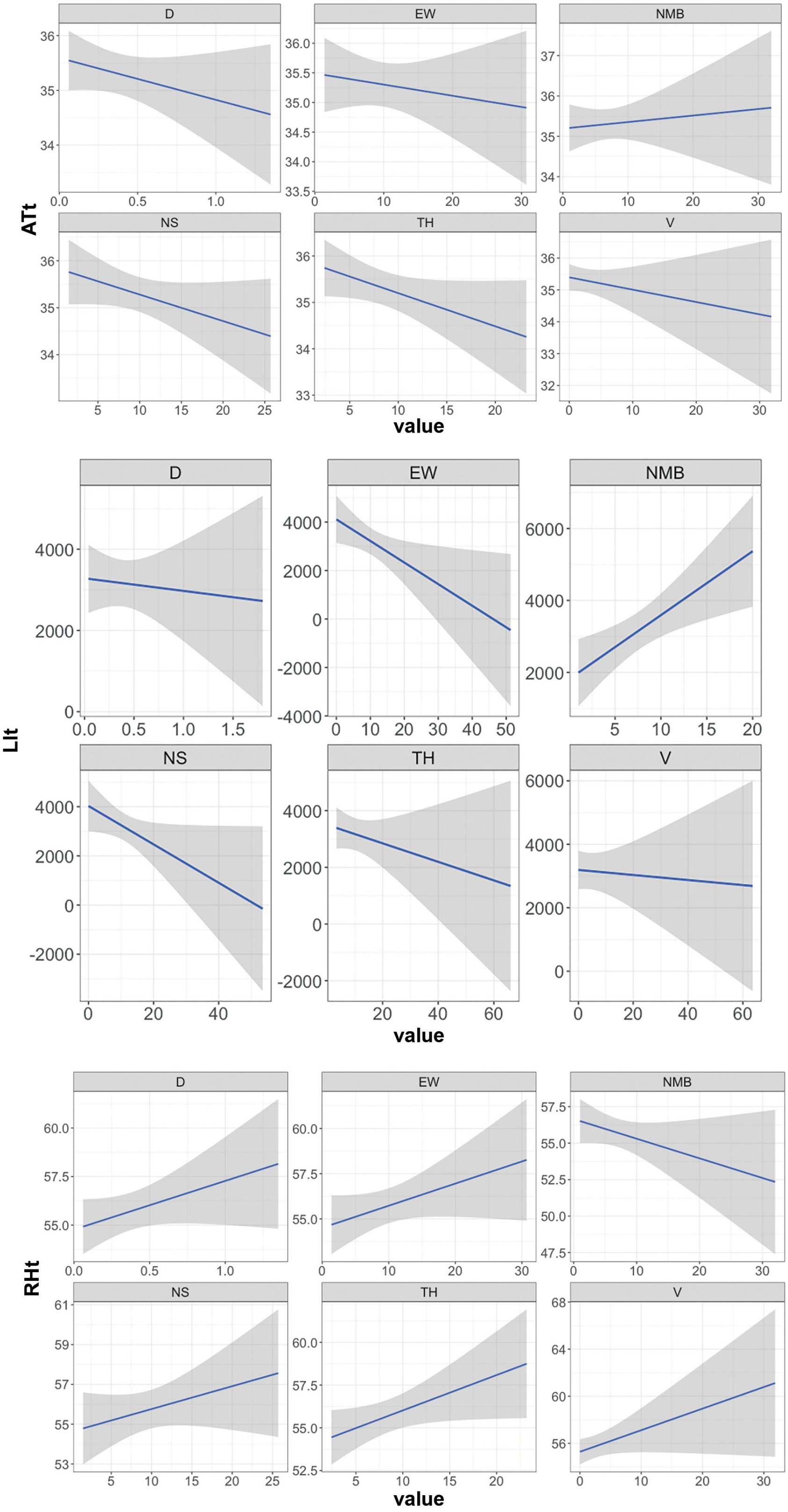


Figure 5. Relationship between tree traits (diameter at breast height [D], East-West crown spread [EW], number of major branches [NMB], North-South crown spread [NS], total height [TH], and volume [V]) and air temperature (ATt), relative humidity (RHt), and light intensity (LIt) in crown-shaded areas of street trees growing outside the UPLB campus.

of trees through shading and evapotranspiration (Alonzo et al. 2025). However, while LIt was significantly greater in N trees, LAI, as a direct measurement of trees' cooling ability, was not considered in this study. Hence, it should be included in future investigations to clearly infer the heat reduction capacity between N and NN street trees.

Meanwhile, the absence of significant variation in the microclimate's mitigation effect between the N and NN trees is similar to the results of Mitra (2020). Nonetheless, the ability of N trees to generate higher mean reduction values in all microclimate parameters used indicates the relative advantage of these trees to be used as street trees. Further investigation, however, should be done to consider those street trees growing not only on primary roads but also on other road networks (e.g., secondary and tertiary roads) to comprehend how street trees of different origins contribute to improving the thermal comfort in built environments.

Inside vs. Outside UPLB Street Trees

Unlike the species' origin, street trees' locational differences did not differ significantly in tree traits aside from the NMB. Significant variations were obtained in the majority of the microclimate parameters. For crown-shaded areas, 25% of the microclimate parameters were significantly different. Meanwhile, 75% of the microclimate parameters in both the nearest open areas and their corresponding mitigation effects were found to be significantly different. Overall, street trees in the study sites noted a significant reduction in ΔAT (2.41 °C), ΔHI (13.3 °C), ΔRH (9.83%), and ΔLI (81,986.25 lux). Interestingly, compared to those growing inside the campus, street trees outside have registered higher significant mean values in the NMB and microclimate mitigation effect for AT, HI, and RH, but lower in LI.

Additionally, a larger number of trees inside the campus (8.57 trees, $P < 0.04$) were significantly

Table 4. Frequency and cardinal direction of infrastructures and water bodies near each street tree found in municipalities of Los Baños and Bay. UPLB (University of the Philippines, Los Baños); N (North); S (South); E (East); W (West).

Plot	Infrastructure (frequency)				River (frequency)			
	N	S	E	W	N	S	E	W
Inside UPLB								
1	2	1	12	-	-	-	-	-
2	11	1	-	16	-	-	-	-
3	-	2	1	-	-	-	-	-
4	1	3	9	3	2	2	-	2
5	3	2	5	-	-	-	-	-
6	21	4	16	13	-	-	-	-
7	3	-	17	-	-	-	-	-
Total	**41**	**13**	**60**	**32**	**2**	**2**	**0**	**2**
Outside UPLB								
8	-	4	2	-	-	-	-	-
9	1	2	2	-	-	-	-	-
10	*2*	2	-	4	-	-	-	-
11	*5*	5	6	5	-	-	-	-
12	3	-	2	3	-	-	-	-
13	4	3	2	5	-	-	-	-
14	6	-	1	-	3	-	-	-
15	3	-	3	3	-	-	-	-
16	-	-	-	-	-	-	-	-
17	1	-	-	1	-	-	-	-
Total	**25**	**16**	**18**	**21**	**3**	**0**	**0**	**0**

shadowed by buildings in the East direction than those growing outside (1.80 trees, $P < 0.04$)(Table 4). Furthermore, the presence of relatively fewer street trees and wider road networks outside the university further supports these findings (Figures 2 and 6). In a study that compared the crown architecture and within-crown leaf area distribution of *Pinus taeda,* researchers discovered a 14% greater number of branches before than after crown closure, indicating that photosynthesis is seemingly more efficient when a tree receives more sunlight from various directions (Albaugh et al. 2020). This may imply that in the absence or with a limited number of neighboring trees and associated species, street trees growing in open and highly stressful areas tend to enhance the production of more branches and leaves to protect themselves from the effects of extreme microclimate conditions, resulting in a significant reduction in the LI (Tables 3 and 5). This is because trees can produce leaves in both well-lit and shaded positions of the crown, which allows them to exploit the light more completely, especially when they receive sunlight in all directions (Kitajima et al. 2005; Terashima et al. 2005).

Correlations Among and Between Tree Traits and Microclimate Parameters

Functional tree traits are morphological, biochemical, physiological, structural, phenological, or behavioral characteristics of trees that influence performance or fitness (Nock et al. 2016). Trees' growth and survival depend on these traits, as their associations may dictate their interaction and response to their environment (Maynard et al. 2022). The study revealed that highly significant, positive, and strong to very strong associations were observed among phenotypic traits of N trees, but similar relationships were only true for the canopy traits of the NN species. These findings may imply that since genetic, morphological, and biophysical constraints subsequently limit the range of traits that a species can exhibit, N and NN street trees may respond to such limitations differently to maximize their ecological "trade-offs" (Maynard et al. 2022; Climent et al. 2024). While the former seemingly give more attention to distributing their energy (photosynthates) equally to the different parts of the tree, the latter appears to focus more on increasing their production of such energy in the canopy as a response to environmental stressors in the urban areas (Lüttge et al. 2003). The variable amount and rate of translocation and distribution of photosynthates among different trees were documented in tea plants and cherry bark oak (Hakamata 1983; Lockhart et al. 2003). However, these observation remains an assumption as in-depth analysis to understand their physiological dynamics (e.g., rate of photosynthesis, carbohydrate assimilation, etc.) was not undertaken in this study. Nonetheless, such strong positive correlations among phenotypic traits would indicate that, to some degree, N trees are capable of improving the microclimate conditions at the subject municipalities, especially since they established a highly significant, strong, and negative association between the crown-shaded microclimate and its mitigation effect, particularly the AT and RH. This suggests that controlling their crown-shaded microclimate through arboricultural treatments (e.g., pruning) can improve their mitigating ability. Appropriate and timely pruning may enhance the production of leaves, twigs, and branches of urban trees, which consequently improves their heat reduction ability (Fini et al. 2015; Perrette et al. 2020).

Relationship Between Tree Traits and Microclimate

Multiple linear regression had predicted that among the growth traits of street trees outside the subject campus, TH, NMB, and V significantly influence the ATt, LIt, and RHt, respectively. Regardless of species origin, these observations may suggest that the best species for street trees to be planted outside the UPLB (and/or areas with a similar environment and site quality) should possess these traits. Tall trees to reduce the ATt, more branches for lower LIt, and big trunk trees to enhance the RHt. Arboricultural interventions (e.g., fertilizer application, watering, pruning, etc.) can be applied to produce trees with these growth traits (Gilman and Sadowski 2007). However, while these strategies are useful, it appears that silvicultural practices (e.g., species selection) coupled with appropriate arboricultural treatments could be the best strategy to maximize their environmental benefits and minimize the economic costs (Zobel and Talbert 2003; Pataki et al. 2021). This is important as improvement of one trait may not necessarily result in improvement of the other traits. For instance, the NMB could increase, as top pruning encourages the production of more epicormic branches by inhibiting the apical dominance in trees (Fini et al. 2015; Perrette et al. 2020). This technique can increase the production of trees'

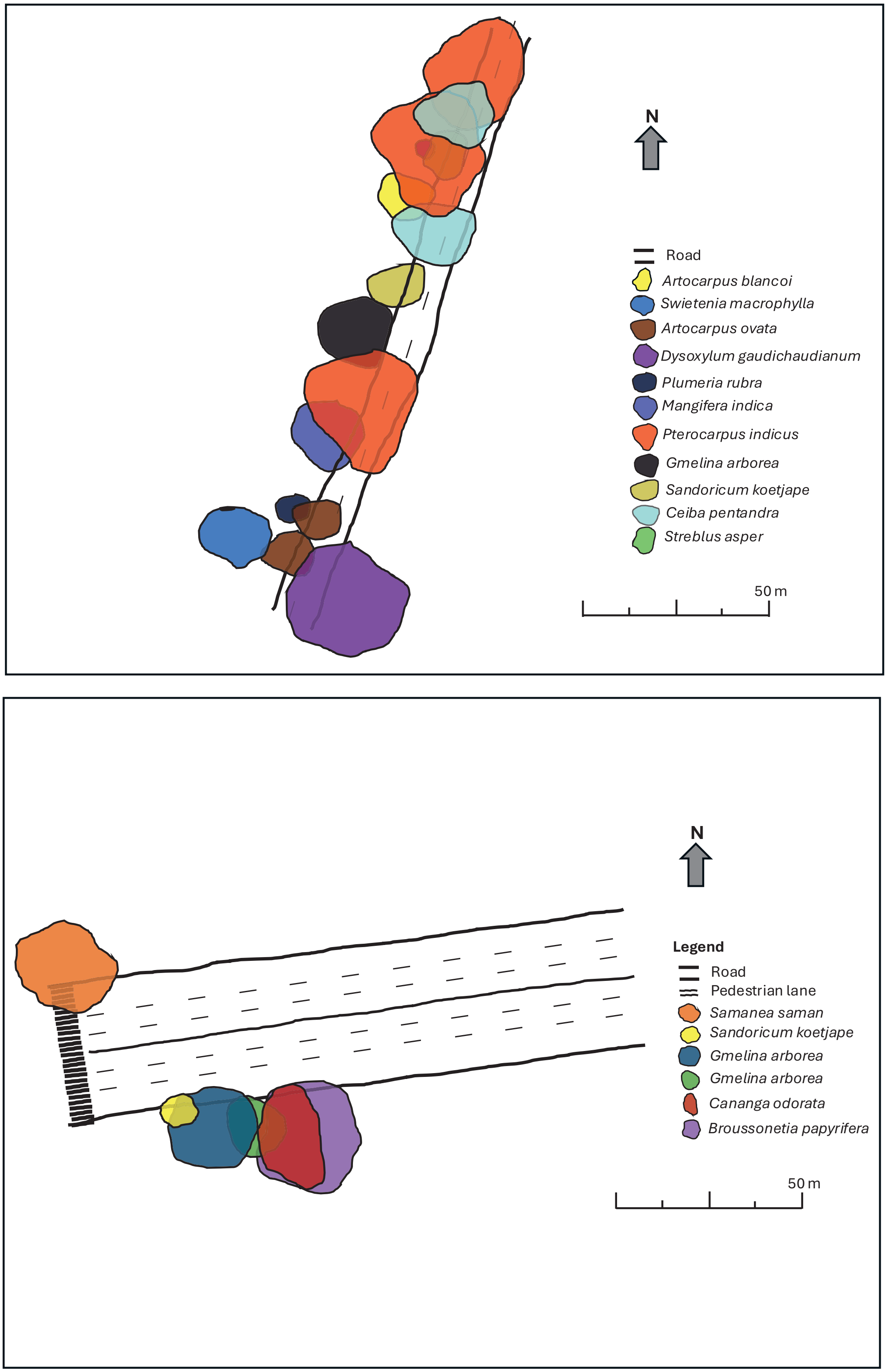


Figure 6. Drawn to scale map of randomly selected sampling plot showing the relative locations of street trees inside (above) and outside (below) the UPLB.

Table 5. Frequency of associated vegetation of street trees found in municipalities of Los Baños and Bay. UPLB (University of the Philippines, Los Baños); FGT (fully-grown trees); SUV (seedlings and understory vegetation).

Plot	Frequency	
	FGT	SUV
Inside UPLB		
1	25	72
2	27	64
3	3	18
4	9	92
5	4	28
6	3	119
7	0	184
Total	**71**	**577**
Outside UPLB		
8	1	183
9	1	20
10	1	17
11	4	18
12	4	18
13	8	20
14	3	12
15	3	11
16	26	109
17	14	32
Total	**65**	**440**

protective traits (e.g., leaves), and therefore could lead to a reduction of the LIt. However, such a strategy may not simultaneously improve the TH and V to address the ATt and RHt. Additionally, although statistically significant, these predictions on the heat reduction ability of street trees by enhancing the growth and development of their physical traits need further investigation, as the strengths of relationships in the present study were not strong enough ($r^2 = 0.29$ to 0.35, $P < 0.001$). Further study using other tree parameters (e.g., LAI, leaf density, etc.), which were proven effective in detecting the cooling ability of trees used in previous studies, may be considered in future investigations (Helletsgruber et al. 2020; Sharmin et al. 2023).

CONCLUSIONS

Regardless of species origin, all tree traits varied significantly in the subject municipalities. Higher mean values in all tree traits indicate that NN trees are relatively more adaptable to existing urban environments. This observation appears to be due to their apparently maximized ecological “trade-offs” in response to their genetic, morphological, and biophysical constraints by seemingly focusing their energy to increase the production of photosynthates, as implied by the strong and positive correlations among their canopy traits. Interestingly, apart from the ability of N trees to generate higher mean reduction values in all microclimate parameters used, the multiple linear regression had predicted that street trees’ TH, NMB, and V could significantly reduce the ATt, LIt, and RHt, particularly those planted outside the UPLB, which seemingly pointed to N trees as they established positive, strong, and significant associations in all of the tree traits assessed.

These findings suggest 3 recommendations. First, a mixture of N and NN species should be used as street trees in the subject municipalities to capture their respective positive qualities—higher heat reduction capacity for N trees, while greater adaptability for NN species. For instance, these could be used as technical basis to revise the over two decades old DPWH guidelines on tree planting along national roads, particularly in matters related to species selection. Second, the study revealed the importance of considering the inclusion of the associated species (e.g., neighboring trees, shrubs, grasses, etc.) of street trees planted in urban areas with relatively higher concentrations of infrastructure and pavements. This finding is also helpful for the implementation of the country’s Executive Order 193 or the “Expanded National Greening Program” and updating the “Philippine Master Plan for Climate Resilient Forestry Development”, especially in the use of appropriate spacing and planting design of street trees in the urban landscapes as part of the government’s greening initiatives (FMB 2015, 2016). Finally, further investigation and more in-depth analysis, such as the measurement of LAI and the determination of production, translocation, and distribution of photosynthates, are needed to clearly understand not just the street trees’ external but also their internal dynamics to infer their ability to modify the microclimate.

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