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INTERDIMENSIONAL RELATIONSHIPS OF TREES IN GREEN AREAS IN CENTRAL CURITIBA, PARANÁ, BRAZIL

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Resumo

Relações interdimensionais de árvores em áreas verdes do centro de Curitiba, Paraná, Brasil. Análises morfométricas de árvores podem auxiliar na seleção de espécies mais adequadas em áreas urbanas, ao permitir compreender a dinâmica das formas de crescimento das árvores. O objetivo foi desenvolver um índice morfométrico para árvores localizadas em áreas verdes de Curitiba, Paraná. Foram selecionadas 122 árvores das cinco espécies com o maior número de registros de queda e remoção em Curitiba: *Tipuana tipu*, *Jacaranda mimosifolia*, *Erythrina falcata*, *Melia azedarach* e *Ligustrum lucidum*, no Passeio Público Municipal de Curitiba e em nove praças localizadas no bairro Centro. A partir dos dados biométricos obtidos em campo, foi calculado o Índice Morfométrico Integrado (IMI), por meio da análise multivariada fatorial realizada no *software* estatístico IBM SPSS® *Statistics*. Houve baixa variabilidade entre os portes interdimensionais, indicando um padrão de crescimento entre as espécies, sobretudo para *T. tipu*. Por outro lado, *J. mimosifolia*, *E. falcata* e *M. azedarach* apresentam maior variabilidade dos dados morfométricos, com árvores de porte consideravelmente superior à média das demais, enquanto *L. lucidum* foi a espécie com menor porte interdimensional. As variáveis biométricas altura total, altura de copa, raio de copa norte, raio de copa leste e DAP foram as mais correlacionadas com o padrão de crescimento das árvores, explicando 57,9% da variação dos dados. O IMI gerado foi adequado para avaliar o comportamento das variáveis, ao explicar 72% da variação dos dados. As árvores de *T. tipu* apresentaram a menor variabilidade entre seus portes interdimensionais, indicando assim um padrão de crescimento mais evidente para essa espécie.
Palavras-chave: Arboricultura, Floresta urbana, Índice Morfométrico Integrado, Praças.

Abstract

Morphometric analysis of trees can help in the selection of the most suitable species in urban areas, by allowing us to understand the dynamics of tree growth forms. The objective was to develop a morphometric index for trees located in green areas of Curitiba, Paraná. 122 trees of the five species with the highest number of records of fall and removal in Curitiba were selected: *Tipuana tipu*, *Jacaranda mimosifolia*, *Erythrina falcata*, *Melia azedarach* and *Ligustrum lucidum*, in the Passeio Público Municipal of Curitiba and in nine squares located in the Centro district. From the biometric data obtained in the field, the Integrated Morphometric Index (IMI) was calculated through multivariate factorial analysis performed in the statistical software IBM SPSS® Statistics. There was low variability between interdimensional sizes, indicating a pattern of growth among species, especially for *T. tipu*. On the other hand, *J. mimosifolia*, *E. falcata* and *M. azedarach* present greater variability of the morphometric data, with trees of size considerably higher than the average of the others, while *L. lucidum* was the species with the smallest interdimensional size. The biometric variables total height, crown height, north crown radius, east crown radius and DBH were the most correlated with the tree growth pattern, explaining 57.9% of the data variation. The generated IMI was adequate to evaluate the behavior of the variables, as it explained 72% of the data variation. The *T. tipu* trees showed the lowest variability between their interdimensional sizes, thus indicating a more evident growth pattern for this species.
Keywords: Arboriculture, Integrated Morphometric Index, Squares, Urban forest.

INTRODUCTION

Trees present in urban areas are subject to different stresses and disturbances than those located in non-urban forest environments (MEUNPONG *et al.*, 2019). Thus, to maintain their health, these trees must be able to adapt to the inherent characteristics of the urban environment, such as extreme weather events, and air and soil pollution (DURYEA; KAMPF, 2007). For this, public managers need to be concerned about promoting better conditions for the development of urban trees.

In this sense, some tools have proved to be efficient, such as morphometric analysis of trees. This approach allows for determining the interdimensional structure of tree elements, whose information helps in choosing the most appropriate species and in silvicultural planning (BOBROWSKI; BIONDI, 2017).

Thus, the application of tools associated with morphometric analysis can favor a balance between the protection of urban trees and the safety of city residents (JUDICE *et al*., 2021). Likewise, by contributing to the efficient management of afforestation, these tools also allow for maximizing the provision of environmental benefits offered by trees (MARIA *et al*., 2020).

However, morphometric analyzes are often applied to non-urban trees. Several researchers related to the topic had as their object of study trees that are components of forests for commercial purposes, agroforestry systems, or natural environments (CONDÉ *et al*., 2013; SILVA *et al*., 2017).

Among the studies related to the morphometry of urban trees, those present in the streets are commonly evaluated (BOBROWSKI *et al*., 2013; BOBROWSKI; BIONDI, 2017; OLIVEIRA *et al*., 2018; MARIA *et al*., 2020). On the other hand, knowledge about the morphometric development of trees located in urban green areas is still limited, lacking information about their development in these locations.

In this sense, multivariate analysis allows the development of an index for the morphometric analysis of trees (PROTÁSIO *et al*., 2011), allowing the variables to be grouped and transformed into a single representative value of each tree, which contemplates the tree structure as a whole, or, in other words, the interdimensional size of trees, to understand the relationship between the biometric variables that describe the dynamics of their growth. Analyzes of this nature allow grouping of the information contained in the biometric variables, aiming to understand more clearly the relationship between these variables (PROTÁSIO *et al*., 2011). However, there are still no records of using this tool for urban trees.

In this context, this research sought to investigate the hypothesis that the biometric variables of trees measured in the field are effective to establish the interdimensional size, through the creation of a morphometric index, specific to urban trees. Therefore, the objective was to develop an Integrated Morphometric Index (IMI) for trees located in green areas of Curitiba, Paraná.

MATERIAL AND METHODS

Location and characterization of the study area

The research was performed in the city of Curitiba, the capital of the state of Paraná, located in southern Brazil. According to the Curitiba Urban Planning and Research Institute (IPPUC, 2021), the city's ground zero is located at Tiradentes Square (25°25'46.89" S and 49°16'16.56" W), at 934.6 m of altitude. The city has a total area of 435.27 km², with a north-south extension of 33 km and an east-west extension of 21 km, subdivided into 75 districts within 10 administrative units, called regionals (CURITIBA, 2021), as presented in Figure 1.

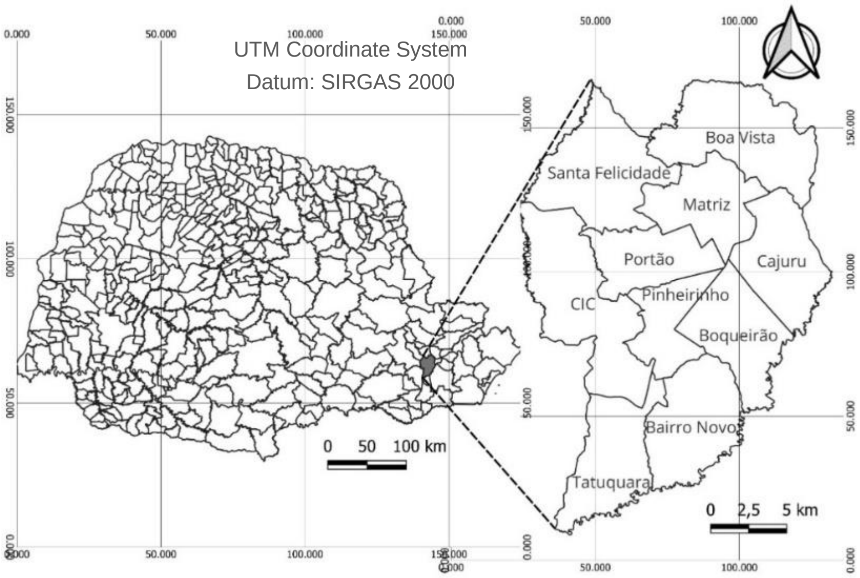


Figure 1. Location of the administrative regions of Curitiba, Paraná
Figura 1. Localização das regionais administrativas de Curitiba, Paraná

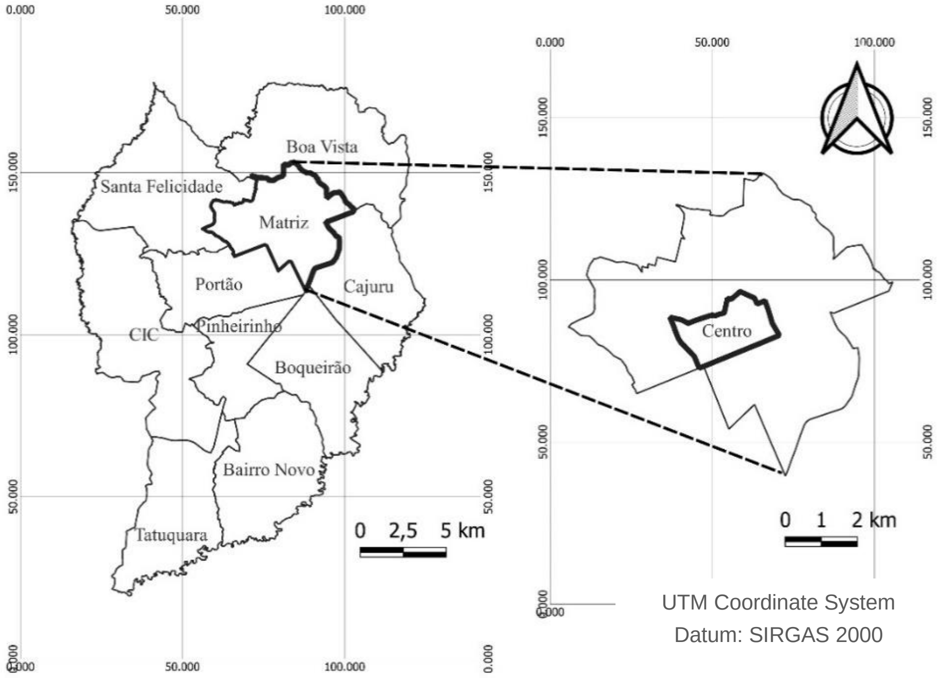
According to the Köppen-Geiger climate classification, the predominant climate in the region is Cfb – Mesothermal Humid Subtropical, characterized by mild summers and winters with frequent frosts, without a defined dry season. Curitiba has an annual temperature average of 17 °C; monthly average relative humidity of 85%; and annual average precipitation varying between 1,300 and 1,500 mm (IPPUC, 2021).

Currently, the area corresponding to the urban forest of Curitiba comprises 43.69% of the city's territory, of which 34.70% comprise its private urban forest and another 8.98% represent the public urban forest (GRISE *et al*., 2016). Within the area corresponding to the public urban forest, 4.99% are represented by the vegetation present on the streets, 3.23% in green areas and another 0.76% refer to water bodies (GRISE *et al*., 2016). In total, Curitiba has 1288 green areas in its territory, in different typologies (IPPUC, 2021).

Selection of sampled locations

The research was performed in the *Passeio Público Municipal de Curitiba* and in the 14 squares of Central Curitiba. Central Curitiba is the second largest neighborhood in territorial extension among the 18 neighborhoods that make up the Matriz region, with 328.30 ha, which represents 0.76% of the city's territory (IPPUC, 2021).

This neighborhood was chosen due to the intense flow of people in its green areas and for the fact that these green areas are the oldest in Curitiba, being mostly in an advanced stage of senescence. Figure 2 displays the location of Central Curitiba.



Note: On the left, the location of the regional offices in Curitiba, and on the right, the location of Central Curitiba, in the Regional Matriz.

Figure 2. Location of the Central district, Curitiba, Paraná.
Figura 2. Localização do bairro Centro, Curitiba, Paraná.

Species analyzed

A morphometric analysis of all trees belonging to the five species that presented the highest frequency of records of falls and cutting authorizations issued by the Municipal Secretary of the Environment of Curitiba (SMMA) in the last 20 years was performed, according to information found in the literature (CUQUEL *et al*., 2011; SILVA *et al*., 2019; SILVA *et al*., 2020). Therefore, the following species were selected: *Tipuana tipu* (Benth.) Kuntze, *Jacaranda mimosifolia* D. Don, *Erythrina falcata* Benth., *Melia azedarach* L. and *Ligustrum lucidum* W.T. Aiton. The on-site survey indicated the presence of individuals of the species of interest in the Passeio Público Park and in nine squares, which were selected for data collection (Figure 3).

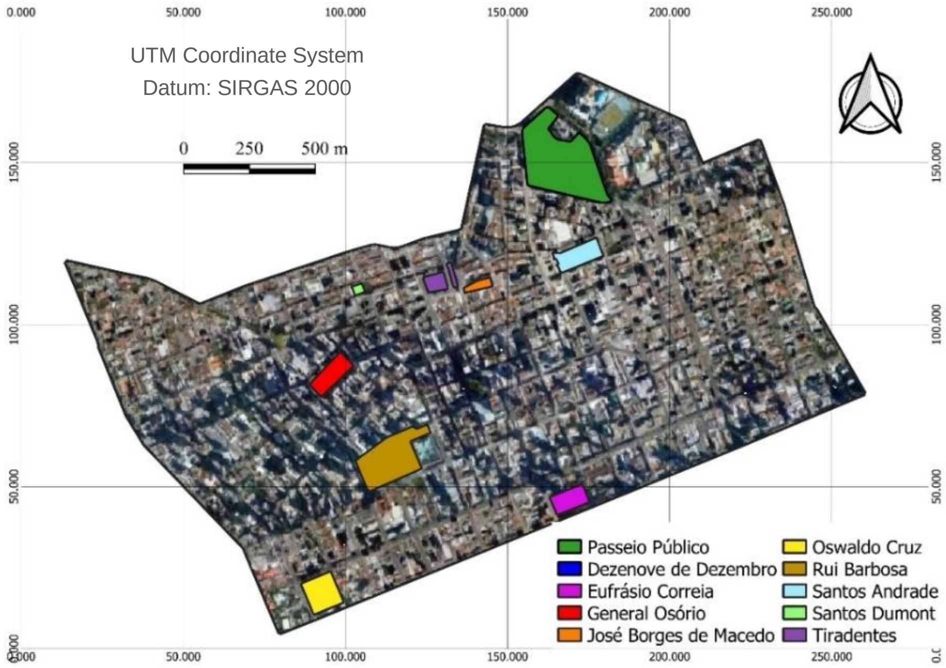


Figure 3. Location of the green areas sampled in the Centro district, Curitiba, Paraná.
Figura 3. Localização das áreas verdes amostradas no bairro Centro, Curitiba, Paraná.

Methodological procedures

To establish the IMI, seven biometric variables were collected in the field: total height (TH) and crown height (CH), obtained with the aid of a hypsometer; four radii of crown projection: north crown radius (NCR), south crown radius (SCR), east crown radius (ECR) and west crown radius (WCR), which served as a basis for determining the crown diameter (CD), comprised of the average of the diameters corresponding to the north-south and east-west axes of the crown projection; and diameter at breast height (DBH), obtained with the aid of a metric tape. Data collection was performed between May and September 2021.

Data from the seven variables collected were subjected to Bartlett's sphericity test, at the level of 95% probability ($p<0.05$), which indicates whether there is a sufficient relationship between the variables to create the integrated morphometric index (HONGYU, 2018), and to the Kaiser-Meyer-Olkin (KMO) test, which suggests the proportion of variance in the data that may be explained by a latent variable (HONGYU, 2018), to verify the adequacy of the sample.

Factor analysis was performed using the IBM SPSS® *Statistics* statistical *software*, version 20.0. It used the principal components method from the correlation matrix as a basis and rotated the factors using the Varimax method, which generated the weights for each factor.

To calculate the factors of each tree, the original biometric variables that presented correlations or weights equal to or greater than 0.4 with the factors were selected, that is, factors that presented correlation with the variables measured in the field. For the calculation of each of the factors, standardized variables were used, in a *Microsoft Excel 2013* spreadsheet. The calculation was performed according to Equation 1:

$$F_{ij} = V_{nij}.P_{nij} \text{ (Equation 1)}$$

where: *Fij* is the m-th factor, of the i-th component, for the j-th tree; *Vnij* is the default value of the nth variable, the i-th component, for the j-th tree; and *Pnij* is the weight of the m-th factor, for the n-th variable, of the i-th component.

The IMI was calculated according to Equation 2:

$$IMI_{ij} = \frac{F_{1ij}.Var_{F1i} + F_{2ij}.Var_{F2i}}{(Var_{F1i} + Var_{F2i})} \text{ (Equation 2)}$$

where: *IMIij* is the integrated morphometric index of the i-th component, for the j-th tree; *F1ij* is the F1 factor, of the i-th component, for the j-th tree; *F2ij* is the F2 factor, from the i-th component to the j-th tree; *VarF1i* is the variance explained by factor 1 of the i-th component and *VarF2i* is the variance explained by factor 2 of the i-th component.

The analysis of the principal components established the weights that correlated with each biometric variable. These weights were used for the calculation of factors and the preparation of the IMI.

RESULTS

The sampled subjects were 53 trees of *T. tipu*, 32 of *J. mimosifolia*, 25 of *E. falcata*, 6 of *M. azedarach*, and 6 of *L. lucidum*, totaling 122 trees.

According to Table 1, which presents the behavior of biometric variables for each of the five analyzed species, it can be observed that the trees with the largest dimensions were of the species *T. tipu*, which presented the highest values for the four biometric variables. On the other hand, *L. lucidum* presented the lowest values for height and crown diameter, DBH, and total height.

Table 1. Biometric variables for estimating morphometric indices by species.
Tabela 1. Variáveis biométricas para a estimativa dos índices morfométricos por espécie.

Species	**N**	**Variáveis (m)**							
		DBH				**Total Height (TH)**			
		Min	**Med**	**Max**	**CV (%)**	**Min**	**Med**	**Max**	**CV (%)**
T. tipu	53	0.43	0.71	1.24	24.12	14.61	26.88	46.05	24.65
J. mimosifolia	32	0.15	0.51	0.95	37.00	9.52	18.54	32.45	26.44
E. falcata	25	0.29	0.63	1.05	36.84	12.05	20.6	45.35	33.71
M. azedarach	6	0.27	0.44	0.59	25.80	9.20	13.33	20.85	34.58
L. lucidum	6	0.11	0.3	0.57	58.11	5.16	9.67	17.39	43.63
		Crown Height (CH)				**Crown Diameter (CD)**			
		Min	**Med**	**Max**	**CV (%)**	**Min**	**Med**	**Max**	**CV (%)**
T. tipu	53	8.06	19.02	33.73	29.65	6.95	16.92	24.90	24.02
J. mimosifolia	32	6.44	11.60	22.59	34.07	5.25	11.28	25.20	42.35
E. falcata	25	4.76	12.33	22.55	38.92	6.90	12.71	22.75	35.43
M. azedarach	6	3.88	7.37	13.09	44.09	6.60	11.20	19.45	40.76
L. lucidum	6	1.50	5.96	8.25	38.78	1.95	7.55	10.70	42.46

Also according to Table 1, the values obtained in the field for the biometric variables of *T. tipu* trees presented the lowest coefficients of variation (CV %). On the other hand, for *L. lucidum* trees, the smallest dimensions and the highest coefficients of variation were observed.

Bartlett's test of sphericity presented that there is a correlation between the variables since it was not significant at the 95% probability level. In the same way, the KMO adequacy test indicated that the factor analysis performed for the morphometric variables was appropriate, presenting a value of 0.778.

Factor analysis applied to morphometric data generated two factors, F1 and F2, which were able to explain 72% of the total variance of the data (Table 2). In this way, the factor analysis was efficient in obtaining the factors capable of explaining the behavior of the morphometric variables of the trees.

The first principal component obtained (F1) presented the highest eigenvalue and, consequently, a high estimated variance. The main component variables of the F1 factor were total height (TH), crown height (CH), north crown radius (NCR), east crown radius (ECR), and DBH, responsible for explaining 57.9% of the total data variance. Meanwhile, the south crown radius (SCR), the west crown radius (WCR), and the DBH composed the F2 factor, explaining 14.4% of the total variance of the data.

The variables total height and crown height have a high positive correlation with the F1 factor, above 0.80, while the south and west crown radii presented correlations above 0.75 with the F2 factor.

In addition, it appears in Table 2 that, of the four radii of projection of the crown, two of them were correlated with the F1 factor and two with the F2 factor. The F1 factor combines characteristics related to the total height and crown height and one of the sides of the crown, corresponding to the north and east crown radii (NCR and ECR), while the F2 factor correlates with the other side of the crown, corresponding to the south and west crown radii (SCR and WCR) (Figure 4).

On the other hand, the DBH variable presented a correlation with the two factors created by the factor analysis, whose correlation appears in Figure 4.

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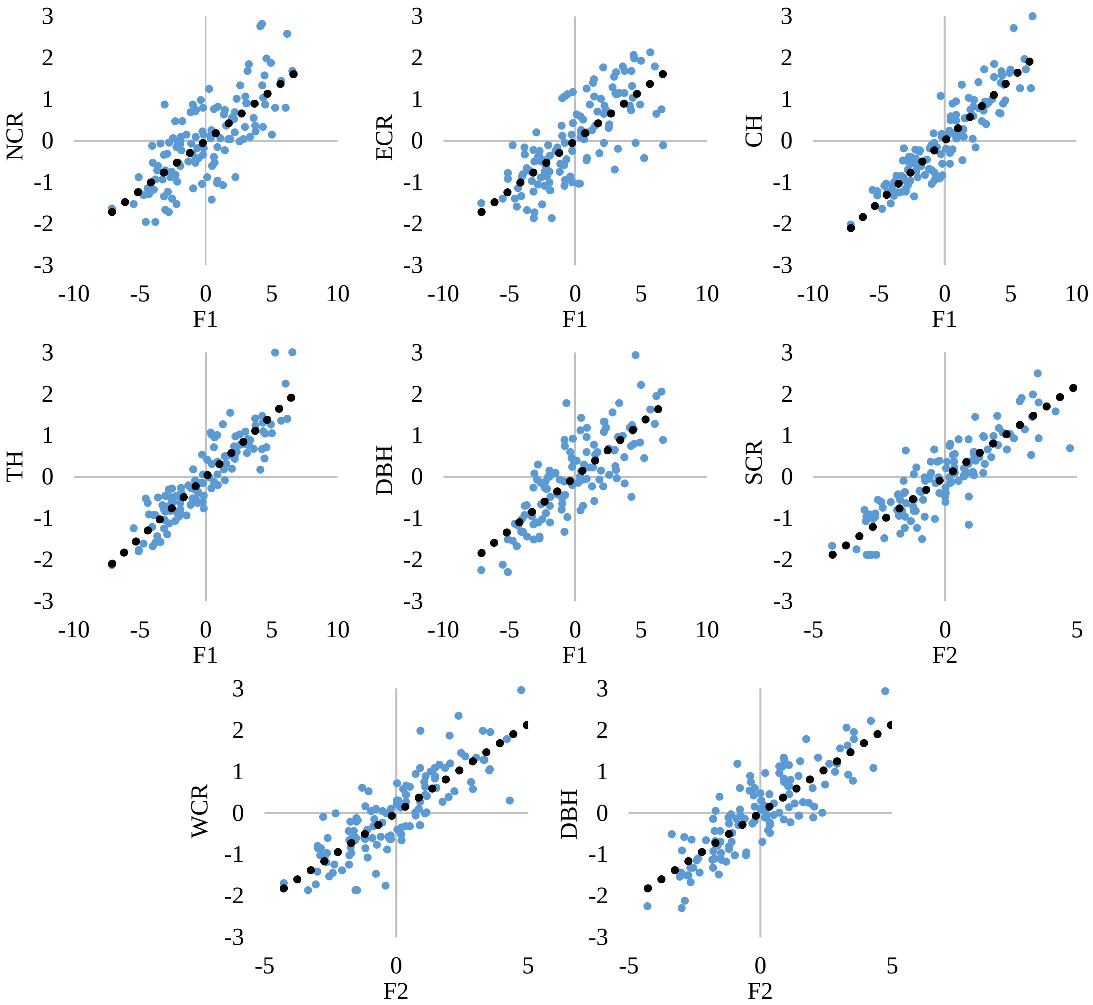
Table 2. Summary of the factor analysis of the biometric variables of the trees studied.
Tabela 2. Resumo da análise fatorial das variáveis biométricas das árvores estudadas.

Variables	**Rotated weights**		**Commonalities**	**Specific Variances**
	F1	**F2**		
NCR	0.799		0.641	0.359
SCR		0.909	0.833	0.167
ECR	0.706		0.542	0.458
WCR		0.759	0.663	0.337
CH	0.812		0.819	0.181
TH	0.829		0.809	0.191
DBH	0.584	0.645	0.758	0.242
Eigenvalues	4.056	1.009		
Variance (%)	57.944	14.415		
Ac. variance (%)	57.944	72.360		

Note: F1 and F2 are the F1 and F2 factors; Ac. variance (%) is the accumulated variance; NCR is the north crown radius; SCR is the south crown radius; ECR is the east crown radius; WCR is the west crown radius; CH is the crown height; TH is the total height and DBH is the diameter at breast height.

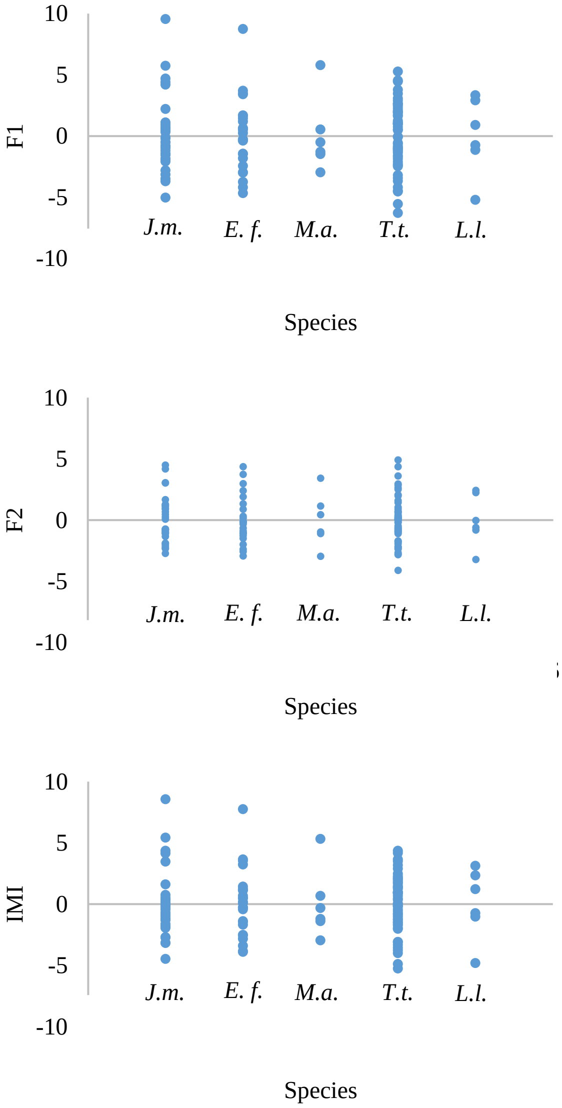


Note: The blue dots indicate the relationship between the factor and the standardized value of the morphometric variable and the black dots indicate the trend line. F1 and F2 are the F1 and F2 factors; Ac. variance (%) is the accumulated variance; NCR is the north crown radius; SCR is the south crown radius; ECR is the east crown radius; WCR is the west crown radius; CH is the crown height; TH is the total height and DBH is the diameter at breast height.

Figure 4. Relationship between standardized biometric factors and variables in urban afforestation.
Figura 4. Relação entre os fatores e as variáveis biométricas padronizadas na arborização urbana.

Figure five presents the interdimensional sizes of species, considering the behavior of the relationship between all variables for each species since the seven biometric variables measured in the field presented correlations with each other.

There was low variability between the interdimensional sizes, indicating that there is a pattern of growth between the species (Figure 5). This result is expected since these interdimensional sizes are determined based on the standardized integrated morphometric index.



Note: F1 and F2 are F1 and F2 factors; IMI is the integrated morphometric index; *J.m.*, *Jacaranda mimosifolia*; *E.f.*, *Erythrina falcata*; *M.a.*, *Melia azedarach*; *T.t.*, *Tipuana tipu*; and *L.l.*, *Ligustrum lucidum*.

Figure 5. Behavior of factors and IMI by urban afforestation species.
Figura 5. Comportamento dos fatores e do IMI por espécies da arborização urbana.

This low variability in the interdimensional sizes of the species was evident for *T. tipu*, indicating that individuals of this species have a better-defined growth pattern. On the other hand, *J. mimosifolia*, *E. falcata*, and *M. azedarach* present greater variability in the morphometric data, being verified the presence of trees of these species with a size considerably higher than the average of the others, while *L. lucidum* was the species with the smallest interdimensional size.

In addition, the F1 factor presented greater variability between the interdimensional sizes of the species compared to the F2 factor. Furthermore, the F1 factor presented greater variability between the interdimensional sizes of the species compared to the F2 factor. This was because the DBH and south (SCR) and west (WCR) crown radii data, which were loaded by the F2 factor, have higher correlations than the correlations of DBH and north (NCR) and east (ECR) crown radii, which were explained by the F1 factor (Table 2).

As the integrated morphometric index weights the weights of the F1 and F2 factors by the percentage of variance that each one can explain, and the F1 factor accounts for approximately 58% of the total variance of the data, this means that the F1 factor is responsible for the similar behavior of this factor with the integrated morphometric index (IMI).

The F1, F2, and IMI factors can be represented according to equations 3, 4 and 5, respectively:

$$F1 = 0{,}799 * NCR_{pad} + 0{,}706 * ECR_{pad} + 0{,}812 * CH_{pad} + 0{,}829 * TH_{pad} + 0{,}584 * DBH_{pad}$$ (Equation 3)

$$F2 = 0{,}909 * SCR_{pad} + 0{,}759 * WCR_{pad} + 0{,}645 * DBH_{pad}$$ (Equation 4)

$$IMI = {}^{57{,}944 * F1 + 14{,}41 * F2}/_{72{,}354}$$ (Equation 5)

where: *F1* and *F2* are F1 and F2 factors; *IMI* is the integrated morphometric index; *NCRpad* is the standardized north crown radius; *SCRpad* is the standardized south crown radius; *ECRpad* is the standardized east crown radius; *WCRpad* is the standardized west crown radius; *CHpad* is the standardized crown height; *THpad* is the defaulted total height and *DBHpad* is the standardized diameter at breast height.

DISCUSSION

The data in Table 1 present that *T. tipu* was the largest species in comparison with the others. In this way, this species can provide more environmental benefits than others (OLIVEIRA *et al*., 2013) can. On the other hand, because of its smaller size, *L. lucidum* presented less capacity to provide environmental benefits among the five species studied. The drastic pruning and topiary pruning with geometric shapes performed in specimens of this species can explain this.

In the same way, the fact that the species *T. tipu* presents the lowest coefficients of variation indicates a certain pattern of development of the species in comparison with the others. *L. lucidum*, presented the highest coefficients of variation, confirming that the individuals of the species are morphologically different, with small trees and more developed ones.

In general, the variation coefficients were greater than 10%, which, according to Bobrowski and Biondi (2017), would be expected under ideal experimental conditions. The authors explain that this variability can occur due to the morphology of the species, the environmental conditions of growth, such as soil compaction and nutrition, and the variation in the morphological dimensions of the trees, due to management and vandalism.

Knowing the dynamics of tree crown growth is important, considering that this is the structure capable of regulating several environmental factors, such as temperature, humidity, wind, and lighting, either through the processes of photosynthesis or through the conformation density of its foliage (BOBROWSKI; BIONDI, 2017).

According to Klepacki (2017), it is common to find a significant correlation between the total height of trees and the height and width of their crowns and it is important to know this relationship to predict the behavior of crown development as the trees grow in height. In the case of trees in green areas, where the limitation for space tends to be smaller compared to trees in streets, larger trees are acceptable, which favors the offer of benefits, mainly of an environmental nature (YOTAPAKDEE *et al*., 2019).

While the competition for space is generally lower in green areas (PRETZSCH *et al*., 2021), it exists, mainly among the larger species, such as *T. tipu* and *J. mimosifolia*, by presenting the correlation between the lengths of the north and east crown radii and between the south and west crown radii. For Dahlhausen *et al*. (2016), this occurs due to the lack of prior planning regarding the planting distance between the trees, which often does not consider the large size that certain species can reach when adults. Thus, the fact that crown radii are correlated with different factors may be related to competition for space between trees or even to the interaction of trees with urban structures, such as poles, bus stops, and others, which can favor the development of treetops in certain directions where competition for space is less (SCHALLENBERGER *et al*., 2010).

Likewise, Pretzsch *et al*. (2015) state that the tree crown size and DBH have a high correlation since the development of DBH is directly proportional to the growth of the crown axes, and the growth of these two biometric variables is highly influenced by the level of competition existing among the trees in their surroundings.

As all variables measured presented a positive correlation with the two factors (Figure 4), the results indicate that as the value of the variables total height, crown height, DBH, and the four crown projection radii increase, there is also an increase in the F1 and F2 factors, so that higher values of the factors indicate morphologically more vigorous trees with larger interdimensional sizes.

As trees with larger interdimensional dimensions can provide more benefits (YOTAPAKDEE *et al*., 2019), all trees should have the highest possible integrated morphometric index, if they are present in places where there is no competition for space with other trees or those trees with urban structures present in green areas. Then, this should be avoided in the case of trees that are part of street afforestation, where space limitations and competition between trees and urban structures are more significant (CZAJA *et al*., 2020).

The results obtained demonstrated that the variables with the highest weights in the F1 factor are the most important when analyzing the morphometric data of the five species present in the sampled green areas: the total height and crown height, the DBH, and the north (NCR) and east (ECR) crown radii, followed by the south (SCR) and west crown radii (WCR), loaded by the F2 factor.

Thus, the analysis of integrated morphometric indices proved to be an efficient alternative to traditional morphometric analysis, through which it was possible to know the interdimensional size of the evaluated species. Thus, this tool can assist in planning the space occupied by the afforestation component not only in green areas but mainly with street afforestation, where the space limitation for the development of trees is considerably greater, due to the possible and eventual problems associated with the interaction of the trees with the electrical wiring and the damage of sidewalks or other urban structures.

Finally, it is important to point out that these results reflect the condition of the trees of the species analyzed in Curitiba, and, therefore, the factors and the generated IMI can be used to analyze the morphometry of trees in this same condition. To assess the morphometric patterns of other species and in other places, it will be necessary to reprocess these new data, since there will be changes in the means and variances of the data, as well as in the correlations between the factors and the morphometric variables.

CONCLUSIONS

The analyses performed allow the conclusion that:

- The hypothesis that morphometric variables would be efficient to establish the interdimensional size of trees was accepted, and it was possible to verify that the variables total height, crown height, north crown radius, east crown radius, and DBH managed to explain 57.9% of the data variation, indicating that the relationship between these variables explains the growth dynamics of the species evaluated.
- The Integrated Morphometric Index generated was also adequate to assess the behavior of the variables since it explains 72% of the data variation. Among the species studied, the trees of *T. tipu* presented the lowest variability between their interdimensional sizes, thus indicating a more evident growth pattern for this species, compared to the others.

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