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COMPATIBILITY BETWEEN FOREST SPECIES, SOIL AREA, AND ACCESSIBILITY ON SIDEWALKS

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Resumo

Compatibilidade entre espécies florestais, área de solo e acessibilidade nas calçadas. A compatibilidade entre o ambiente construído e as árvores também é um desafio do planejamento urbano. Entretanto, são escassas as diretrizes relacionadas ao espaço de crescimento das árvores nas calçadas. Objetivou-se analisar o espaço ocupado pelas árvores em calçadas da cidade de Frederico Westphalen, RS. Foram utilizados dados de 400 árvores de 10 espécies (variáveis dendrométricas e qualitativas) e dados da estrutura urbana (largura dos passeios e canteiros) para analisar a relação das espécies com a capacidade do solo e a acessibilidade de pedestres. Constatou-se que 90,25% das árvores estão em locais onde as calçadas apresentam acessibilidade e que 60,25% delas apresentam canteiros com capacidade adequada, podendo-se aumentá-los para melhorar o desenvolvimento das árvores em 39,75% dos casos. Quanto à quantidade de solo necessário para cada árvore, constatou-se que a maioria das espécies (72,25%) não estaria com a quantidade de solo adequada (Situação 1 – largura da calçada x 4). Já para a Situação 2 (largura do canteiro x 1), 100% dos indivíduos não estariam com a quantidade de solo adequada. Pode-se concluir que o método de avaliação da compatibilidade área de solo e acessibilidade das calçadas é de fácil replicação e útil para ocasiões de estudos das árvores urbanas e planejamento urbano.
Palavras-chave: Capacidade do canteiro. Estrutura urbana. Floresta urbana.

Abstract

The compatibility between the built environment and trees is also a challenge for urban planning. However, there are few guidelines related to the space for tree growth on sidewalks. This research aimed to analyze the space occupied by trees on sidewalks in the city of Frederico Westphalen, RS, Brazil. We used data from 400 trees of 10 species (dendrometric and qualitative variables) and from the urban structure (width of sidewalks and tree bed area) to analyze the relationship between the species according to the soil capacity and pedestrian's accessibility. It was found that 90.25% of the trees are in places where the sidewalks promote accessibility to pedestrians and that 60.25% of them tree bed areas with adequate capacity, being possible to increase their size to improve the development of the trees in 39.75% of the cases. Regarding the amount of soil required for each tree, it was found that most species (72.25%) would not have an adequate amount of soil, (Situation 1 – sidewalk width x 4). For Situation 2 (tree bed width x 1), 100% of the individuals would not have an adequate amount of soil. We concluded that the method to evaluate the compatibility between soil area and sidewalk accessibility is easy to replicate and helpful for studies on urban trees and urban planning.
Keywords: Tree bed capacity. Urban structure. Urban forest.

INTRODUCTION

The lack of adequate planning of cities is a problem that has caused high costs with maintenance, repair of urban equipment, and even loss of tree coverage (LIMA NETO *et al*., 2016). Meanwhile, trees may cause a disservice due to the species, location relative to urban structures, growth patterns, stress caused by external conditions, and/or the intensity of maintenance activities (LYYTIMÄKI, 2017). To circumvent and avoid these disservices, it is necessary to prepare an urban forest management program considering the different urban forest typologies, the characteristics of the species, the dimension of available growth sites, the location and dimension of urban structures, and their compatibility with the pedestrian accessibility conditions (LIMA NETO *et al*., 2016; PINHEIRO *et al*., 2018).

The importance of the urban forest to the well-being of the population is highlighted in different research modalities since it plays a fundamental role in society and can improve environmental conditions and the quality of life of people in cities, providing several ecosystem services (MEINEKE; FRANK, 2018), in addition to positively contributing to the conservation of flora and fauna of municipalities (BETHMANN *et al*., 2018).

Among the urban forest typologies, the tree-lined sidewalks are the one that stands out for representing a higher level of human interference and, at the same time, the delivering of ecosystem services to humans (BIONDI; ALTHAUS, 2005; LIMA NETO *et al*., 2010; LIMA NETO *et al*., 2016). For being one of the most restrictive environments to add trees, the tree-lined sidewalks must undergo a rigorous planning process, independent of the size of the city or population size, to reduce possible future problems (MANFRIN *et al*., 2018). This idea highlights the importance of technical-scientific knowledge that urban managers must have, represented by qualified professionals with deep expertise on the growth of trees in the urban environment, who can prepare strategies that allow the urban forest to reach maximum performance in the offer of ecosystem services (ANGULURI; NARAYANAN, 2017).

However, due to the wrong choice of species, trees can cause expenses associated with damage to sidewalks, the water network, powerlines, and walls, among other conflicts with public infrastructure. For these reasons, it is valuable to promote proper planning of the tree-lined sidewalks, seeking to reconcile pedestrian accessibility with adequate space for the growth and development of trees, reducing future problems (VOGT *et al*., 2015). The planning process is an important step in the urban management procedures because most of the tree growth problems are related to the lack of space for the development of trees, influenced by the location of the powerlines, underground structures, type of pavement, number of lighting posts, the layout of urban equipment (trash bins, traffic signs, benches, among others) and the existence of frontal retreat at each lot's building (LIMA NETO *et al*., 2010).

Furthermore, the damage caused to sidewalks and attributed to trees is higher when the width of the tree bed is small relative to the size of the trees' anchorage (HILBERT *et al*., 2020). Therefore, smaller tree beds or those not proportional to the size of the trees (tree beds with smaller dimensions than the tree needs to anchor) generate more damage to the health of the trees, such as, for example, the reduction of the crown and damage to the roots, which consequently accelerate senescence (SANDERS *et al*., 2013).

In part, the problems generally related to the roots of trees on sidewalks derive from superficial anchoring or trunk flare, which is formed by the lateral roots of trees, from the extension of the trunk, on the surface of the soil. As tree ages, the trunk flare diameter increases, and thus a more pronounced tree anchorage occurs, potentially exceeding the tree bed dimension and thus causing damage to the sidewalk paving (NORTH *et al*., 2015; HILBERT *et al*., 2020). North *et al*. (2015) stated that the trunk flare diameter for trees on sidewalks with small spaces can be a valuable measure for the planning and management of the urban forest, helping to find solutions to the problem or, at least, reduce the damage to the infrastructure over time, through suitable projects capable of providing the ideal space for mature trees.

To create information and guidelines for the best planning process of planting and managing trees on sidewalks, the present study focused on analyzing the relationship between the trunk flare diameter of trees and the size of sidewalks, tree beds, and pedestrian accessibility, regarding ten forest species planted on sidewalks of Frederico Westphalen, Rio Grande do Sul State (RS), Brazil.

MATERIAL AND METHODS

The work was carried out based on data from trees composing the tree-lined sidewalks in the municipality of Frederico Westphalen, which is located in the Northwest region of the State of Rio Grande do Sul, 429 km far from the capital - Porto Alegre - at coordinates 27º 21' 33" South latitude and 53º 23' 40" West longitude.

Data collection procedure

From the tree-lined sidewalks, 40 trees of each species were randomly selected. Tree species included in the research were *Cenostigma pluviosum* (DC) E. Gagnon & G.P. Lewis (sibipiruna), *Cinnamomum zeylanicum* Blume (canela-da-índia), *Eugenia uniflora* L. (pitangueira), *Ficus auriculata* Lour. (figueira-de-jardim), *Ficus benjamina* L. (ficus), *Inga marginata* Willd. (ingá-feijão), *Lagerstroemia indica* L. (extremosa), *Ligustrum lucidum* W.T. Aiton (alfeneiro), *Mangifera indica* L. (mangueira), and *Syzygium jambolanum* (Lam.) DC (jambolão), with examples of the tree-lined sidewalks in the city of Frederico Westphalen in Figure 1. These species were chosen because they represented the highest number of trees on the city's sidewalks (SANTOS *et al*., 2019) and because we needed a minimum number of trees to achieve repeatability and an equitable number of trees by species.

Figure 1. Tree-lined sidewalks in Frederico Westphalen, Rio Grande do Sul, Brazil, highlighting some of the species studied and the sidewalk condition, and the trunk flare diameter of trees (TFD). (A) *Cenostigma pluviosum*; (B) *Eugenia uniflora*; (C) *Mangifera indica*; (D) TFD of the species *Cenostigma pluviosum*; (E) TFD of the species *Eugenia uniflora*; (F) TFD of the species *Mangifera indica*.

Figura 1. Arborização de calçadas em Frederico Westphalen, Rio Grande do Sul, Brasil, com destaque de algumas das espécies estudadas e a condição da calçada e do diâmetro de ancoramento das árvores (DAC). (A) *Cenostigma pluviosum*; (B) *Eugenia uniflora*; (C) *Mangifera indica*; (D) DAC da espécie *Cenostigma pluviosum*; (E) DAC da espécie *Eugenia uniflora*; (F) DAC da espécie *Mangifera indica*.

For each evaluated species, quantitative and qualitative data were collected from the trees and the associated urban structure, between January and February 2020. The variables obtained were: Diameter at breast height (DBH): measured with a tape measure, in centimeters, at 1.30 m above the surface of the ground; Total height (h): measured with a Haglöff electronic clinometer, in meters; average crown diameter (CD): determined from the average of four equidistant crown radii (CR), measured with a measuring tape, in meters; Trunk flare diameter (TFD): measured with a caliper, in four different positions, in centimeters (Figure 2); distance from the curb (DC): distance from the base of the tree trunk to the curb, measured with a tape measure, in centimeters; sidewalk width (SW): distance between the wall and the curb, with a metric tape, in centimeters; pedestrian pathway width (PW): distance from the tree bed to the wall; tree bed width (TBW): dimension of available space for the tree anchorage, with a tape measure, in centimeters; number of epicormic shoots (ES): number of existing shoots from the base of the tree up to 1.30 m in height; tree topping (TT): visual analysis of the presence (1) or absence (0) of this type of inadequate pruning performed on the trees.

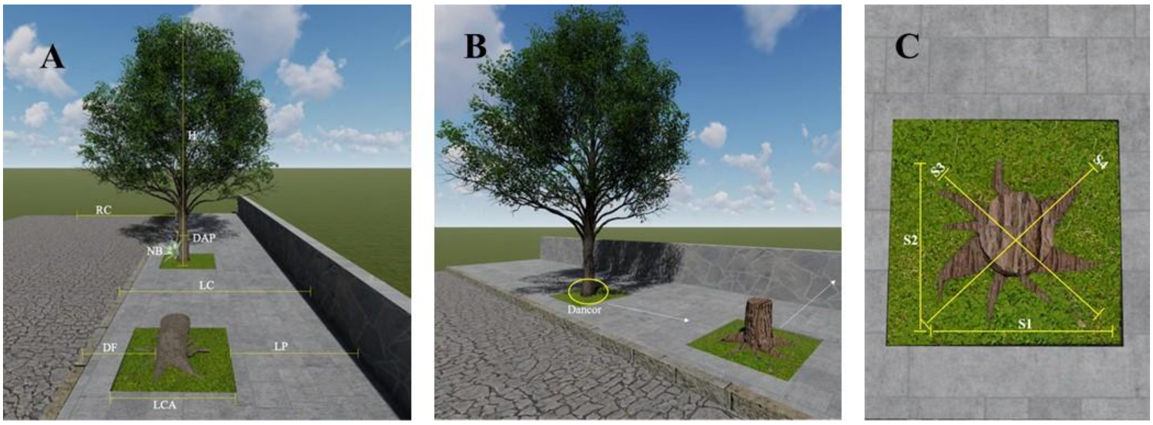

Figure 2. Variables measured on trees and sidewalks (A) and procedures to measure the trunk flare diameter (TFD), considering the longitudinal and transversal axes to the curb position (B, C). Measures were taken in the longitudinal axis of the sidewalk following the curb direction (S1), in the transversal axis of the sidewalks, in the street – front yard direction (S2) and in angles of 45º (S3, S4) according to the longitudinal and transversal positions (B, C).

Figura 2. Variáveis mensuradas nas árvores e nas calçadas (A) e procedimento para medir a variável diâmetro de ancoramento superficial (TFD), considerando os eixos longitudinal e transversal ao meio fio (B, C). As medidas foram realizadas no sentido longitudinal da calçada, ao longo do meio-fio (S1), transversal à calçada, na direção rua-muro (S2) e em ângulos de 45º (S3, S4) em relação aos sentidos longitudinal e transversal (B, C).

Data analysis procedures

We promoted different analyses regarding the relationship between the trunk flare diameter and the size of the sidewalks. This procedure was carried out by analyzing the suitability of the soil surface occupied by the trees relative to pedestrian accessibility and to the available soil volume for tree growth.

Adequacy regarding the accessibility of sidewalks

To characterize the suitability for pedestrian accessibility on the examined sidewalks, we used information on the distance from the tree to the curb, width of the tree bed and width of the sidewalks. This information served as a baseline for comparing the minimum dimensions of sidewalks to promote pedestrian accessibility and allow for planting and growing trees (LAMOUNIER, 2015).

The rules that make up a sidewalk and the adequate size of free circulation (pavement) for pedestrians (walkaway) were set by the Brazilian Federal Law 10.098/00, which addresses the basic criteria for promoting accessibility for people with disabilities or reduced mobility, and by ABNT NBR 9050, which addresses urban accessibility, space and equipment. In order to reconcile the planning of tree-lined sidewalks and the promotion of pedestrian accessibility, it is assumed that the sidewalks must be at least 2.00 m wide, bearing in mind that the walkaway must be at least 1.20 m width and the service lane must be at least 0.8 m (LAMOUNIER, 2015).

The data collected were grouped into classes regarding sidewalk accessibility, based on information regarding the sidewalk width and the tree bed width. The difference in value between these two variables allowed separating the trees into two sidewalk accessibility classes:

Class A1: Accessibility not met (pedestrian walkaway < 1.20 m wide)

Class A2: Accessibility met (pedestrian walkaway ≥ 1.20 m wide)

Each examined tree was framed in one of the two accessibility classes to allow the data analysis by a multiple canonical correspondence procedure, from a matrix containing the list of the species names, the accessibility classes, the tree bed capacity classes, and the ratio classes (described in the next topic). This statistical procedure was carried out via the *factoextra* package of the *R® software* and aimed to demonstrate, spatially, the distribution of species in the conditions of sidewalks with and without accessibility.

Suitability of soil available for tree growth

To characterize the adequacy of the available soil to the growth of the trees, we used information on the distance from the tree to the curb, the width of the tree bed, the width of the sidewalks, the DBH, the trunk flare diameter and the total height of trees. With this, we aimed to verify whether the trees and species were in adequate spaces and, when possible, whether it would be possible to enlarge the tree bed size, to indicate whether the trees could have more suitable conditions for growth. This analysis procedure was used to confront the common idea that trees on sidewalks tend to have inadequate growth spaces, in relation to root system growth, in Brazilian cities (BIONDI; ALTHAUS, 2005; SILVA *et al*., 2018).

Based on the method proposed by Koeser and Northrop (2017), for each examined tree, we analyzed the suitability of the species size according to the sidewalk width (Table 1). To perform this, we considered the tree bed area, the distance from the tree to the curb, the distance from the tree to the wall (sidewalk width minus the distance from the tree to the curb and half of the average value of the trunk flare diameter) the size of the species planted, and the recommended species size. The variables presented in Table 1 were evaluated in each tree. Through the "IF" function in the Excel software, trees were classified according to the recommended size for the site, whether it should be small, medium, or large tree. We compared tree by tree the classified data for the size of the sampled species and the recommended species size.

Based on the relationship between the sidewalk width (SW) and the minimum accessibility dimension (1.20 m), the tree bed capacity was evaluated to determine the possible increase of the permeable area around the trees (SW - 1.20m). We compared the data from the tree bed width with the data from the tree bed capacity to determine the proportion of loss of space available to trees, mainly to support surface anchoring for trees. Data from tree bed capacity were grouped into three different classes, and together with the accessibility classes, another multiple canonical correspondence analyses (MCA) were performed to map the condition of the species planted on the sidewalks. The tree bed capacity classes proposed were:

Class C1: tree bed capacity < 0.5 m

Class C2: tree bed capacity between 0.5 m and ≤ 1.0 m

Class C3: tree bed capacity > 1.0 m

Table 1. Guidance on planting spaces (tree bed total area, distance between the walkaway and the curb and minimum distance from the tree to the street pavement or wall) in relation to the size of the tree at maturity (h = total height).

Tabela 1. Orientações quanto aos espaços de plantio (área total do canteiro, distância entre o passeio e o meio-fio e distância mínima da árvore ao pavimento da rua ou muro) em relação ao tamanho da árvore na maturidade (h = altura total).

Tree bed total area	Distance between the walkaway and the curb	Minimum distance from tree to the pavement or wall	Size of the tree at maturity (h)
< 14.0 m²	< 1.20 m	< 0.60 m	Small size (< 9.0 m)
14.0 – 28.0 m²	1.20 – 2.10 m	0.60 – 1.80 m	Medium size (< 15.0 m)
> 28.0 m²	> 2.10 m	> 1.80 m	Large size (> 15.0 m)

Source: adapted from Koeser e Northrop (2017)

Aiming to determine if trees were planted in places with the suitable tree bed size to the trunk flare dimension, we evaluated the ratio between the trunk flare diameter (m) and the tree bed width (m). To perform a new MCA for mapping the situation of the species the data were distributed, tree by tree, in one of three classes:

Class R1: ratio with value < 0.5
Class R2: ratio between 0.5 and ≤ 0.8
Class R3: ratio with values > 0.8

To calculate the amount of suitable soil available for each tree and aiming to know if it would be possible to generate better growth conditions for trees, three situations of area and/or soil volume were evaluated, considering that the maximum depth of the root system is 1.0 m since most of the root volume is in this portion of the soil (HIRONS; THOMAS, 2018):

Situation S1: soil area available to the tree, obtained from the sidewalk width (SW) multiplied by four, which is the minimum spacing between trees on the sidewalks, as a function of the minimum tree crown diameter, on average, for a small-size mature tree (BOBROWSKI *et al*., 2020).

Situation S2: soil area available to the tree, obtained from the tree bed width (TBW) multiplied by one, which is the recommended minimum width for the tree bed, in meters, from a tree bed with a recommended minimum area of 1.0 m² (BIONDI; ALTHAUS, 2005; PINHEIRO *et al*., 2018).

Situation S3: soil area available to the tree, obtained from the method proposed by the Cornell University (GRABOSKY; BASSUK, 2017), through which a minimum of 0.61 m³ of soil is recommended for every 1.0 m² of tree crown area.

Taking into account the amount of soil calculated in Situation S3 as ideal, the values obtained by each tree in situations S1 and S2 were compared with the values from Situation S3. With this analysis, we aimed to find out if the minimum amount of soil was met when considering only the tree bed size (Situation S2) or the space available on the sidewalk where the roots can explore the environment beyond the tree bed (Situation S1).

RESULTS

Characterization of trees and sidewalks sampled in Frederico Westphalen

Among the variables evaluated in the tree-lined sidewalks (Table 2), the greatest variations were found for the number of epicormic shoots (ES) and tree topping (TT) (CV > 95%). Of the 400 trees evaluated, 50% showed signs of damages caused by improper pruning (topping), resulting in a profuse emission of epicormic shoots, in a ratio of 2:1. The species in which the highest proportion of trees presented epicormic shoots at the base of the trunk were *Lagerstroemia indica* (62.5%), *Eugenia uniflora* (65.0%), *Ficus benjamina* (62.5%), *Cinnamomum zeylanicum* (52.5%) and *Ficus auriculata*.

There was a remarkable variability in all data from the dendrometric variables because in the sampling process carried out, there were many trees of different species located in a diversified environmental condition (different neighborhoods) and with different undetermined ages. For the CD variable, the smallest variation was observed (CV= 33.51%), which indicates a certain uniformity of the tree crown spreading over the sidewalks.

Similarly, to the dendrometric and qualitative variables, the accessibility variables also showed accentuated variability (Table 3). For the three variables measuring zero, some places did not have a clearly defined sidewalk, as there was only a construction site, without the presence of a curb and pedestrian walkway. Likewise, there were sidewalks without tree beds (completely impervious tree base) and, consequently, without distancing from the curb. It was identified that 90.25% of the tree were planted in places with accessibility (Figure 3A), for most of the evaluated species, except for the species *Inga marginata* and *Syzygium jambolanum*, which were predominantly present in places without adequate accessibility (9.75%).

Table 2. Descriptive statistics of dendrometric and qualitative variables of sampled trees in the city of Frederico Westphalen – RS. DBH – diameter at breast height (cm); h – tree total height (m); TFD – trunk flare diameter (cm); CD – crown diameter (m); TT – tree topping presence of absence; ES – number of epicormic shoots from tree bottom up to 1.30 m.

Tabela 2. Estatística descritiva das variáveis dendrométricas e qualitativas das árvores amostradas na cidade de Frederico Westphalen – RS. DBH – diâmetro à altura do peito (cm); h – altura total da árvore (m); TFD – diâmetro de ancoramento superficial (cm); CD – diâmetro de copa (cm); TT – presença ou ausência de poda drástica; ES – número de brotações presentes na base da árvore até 1,30 m.

Variables measured	Mean value	Standard deviation	Minimum value	Maximum values	CV%
DBH (cm)	24.19	11.73	4.30	57.30	48.49
h (m)	7.01	2.82	2.20	16.60	40.22
TFD (cm)	49.98	27.72	8.80	160.30	55.46
CD (m)	5.51	1.85	0.51	13.25	33.51
TT	0.51	0.50	0.00	1.00	98.03
ES	2.88	6.16	0.00	37.00	213.88

Table 3. Characterization of sidewalks, tree bed and tree position. SW = sidewalk width (m); TBW = tree bed width (m); DC = distance from the tree to the curb (m).

Tabela 3. Caracterização das calçadas, do canteiro e da posição da árvore. SW = largura da calçada (m); TBW = largura do canteiro (m); DC = distância da árvore até o meio fio (m).

Variables measured	Mean values	Standard deviation	Minimum values	Maximum values	CV%
SW(m)	2.49	0.88	0.00	5.70	35.10
TBW (m)	3.39	0.45	0.00	2.00	134.16
DC (m)	2.59	0.38	0.00	3.80	147.31

Most of the evaluated trees (60.25%) were planted in site conditions with adequate minimum tree bed capacity, class C3 (Figure 3B). We noted that the tree bed capacity for the *Ficus auriculata* species was in class C1, which indicates an urgent need to expand the tree bed dimensions, especially for being smaller than 0.5 m in width. There is also a need to expand the tree bed capacity for trees presented in class C2 (34% of the tree evaluated), to promote the best tree development conditions and reduce stress factors due to reduced oxygen concentration and soil humidity.

As for the TFD/TBW ratio (Figure 3C), we observed that 63.75% of the trees fitted in class R3, that is, 255 trees, of which 200 did not have permeable tree beds around the trunk. We found that 20.5% of the trees showed low values for the relationship between the TFD and the TBW (the most interesting condition for the development of trees) and were in class R1, which means that they were in sites with tree beds with minimum sizes. The other 15.75% were in class R2, which represents a non-limiting condition for the development of adequate TFD and tree anchorage, without damaging the pedestrian walkways and curbs, but what can become a problem over the years, depending on the growth rate and characteristics of the tree species.

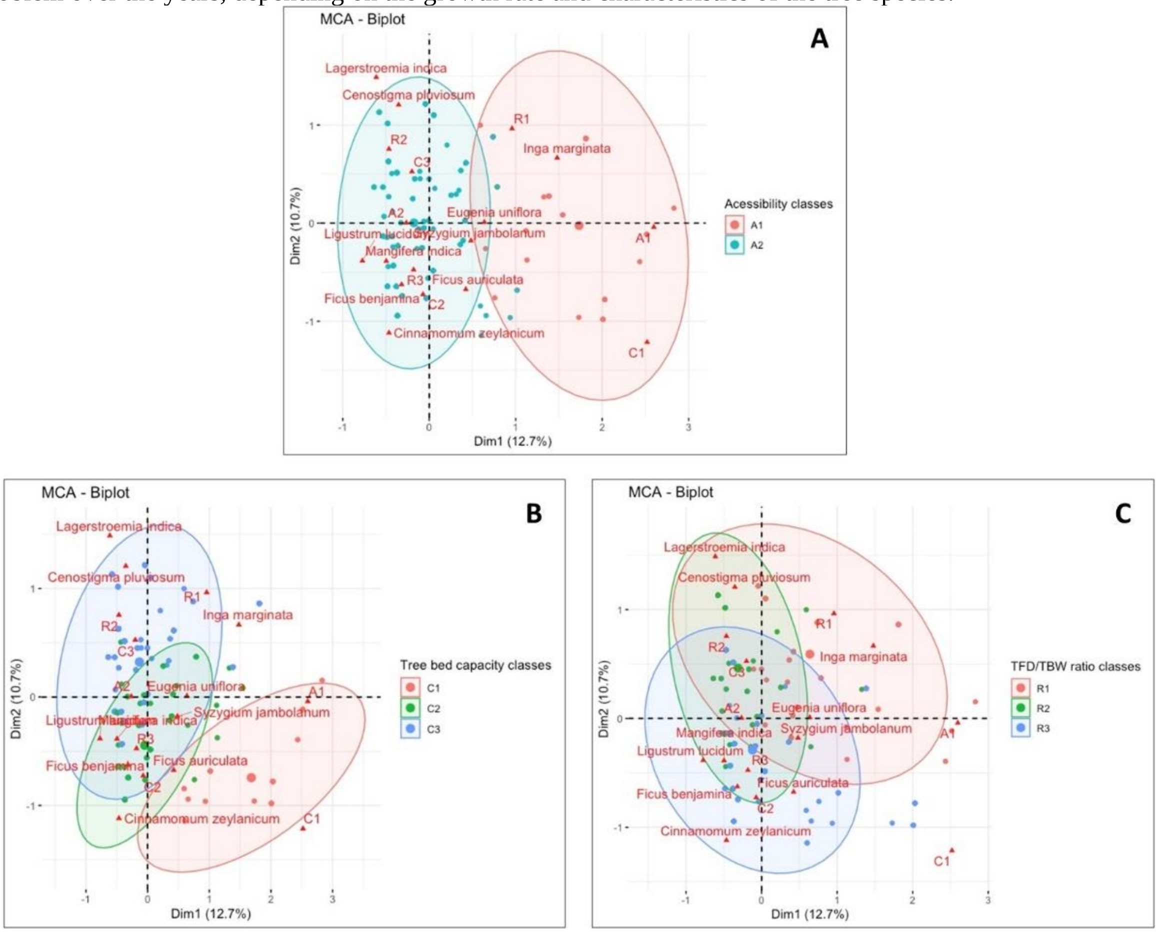

Figure 3. Graphic representation of multiple canonical correspondence analysis (MCA) between different attributes of tree-lined sidewalks in Frederico Westphalen, RS. The evaluated species are indicated, (A) the accessibility classes: accessibility no met (A1) and accessibility met (A2); (B) the tree bed capacity classes (C1, C2 and C3); (C) the classes for the ratio between the tree bed width (TBW) and the trunk flare diameter (TFD) (R1, R2 and R3).

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Figura 3. Representação gráfica da análise de correspondência canônica múltipla (MCA) entre diferentes atributos da arborização de calçadas em Frederico Westphalen, RS. Estão indicadas as espécies avaliadas, (A) as classes de acessibilidade: acessibilidade não atendida (A1) e acessibilidade atendida (A2); (B) as classes de capacidade dos canteiros (C1, C2 e C3); (C) as classes de razão entre a largura do canteiro (TBW) e o diâmetro de ancoramento superficial (TFD) (R1, R2 e R3).

Characterization of the tree growth space

By using the amount of soil needed for each tree, determined as Situation S3 (0.61 m² of soil/m² of tree crown area), we observed that most trees (72.25%) would not have the amount of soil necessary for their growth if considered the most realistic situation regarding the spread of tree roots on the sidewalks soil, outside the tree bed limits, and the minimum distance between trees, corresponding to Situation 1 (SW x 4). When considering the most popular and least ideal situation for root growth, Situation 2 (TBW x 1), we found that 100% of the trees would not have an adequate amount of soil.

In "Situation 1", the greatest ranges of variation in relation to the amount of soil were observed for the species *Mangifera indica*, *Ligustrum lucidum*, and *Cenostigma pluviosum*. The species that showed the smallest range of variation were *Cinnamomum zeylanicum*, *Ficus auriculata* and *Ficus benjamina* (Figure 4A). As for "Situation 2", the greatest ranges of variation in relation to the amount of soil were observed for the species *Inga marginata* and *Cenostigma pluviosum* (Figure 4B).

Most trees (62%) did not present the size corresponding to those described by Biondi and Althaus (2005) for trees planted on sidewalks. Regarding the measured size of trees, most of them were small to medium size, and none of them was largely sized, i.e., trees presented small size (Table 1) as recommended by Koeser and Northrop (2017), considering the tree bed area, the distance between the walkway and the curb, and the minimum distance from the tree to the street pavement or the wall (in the opposite side).

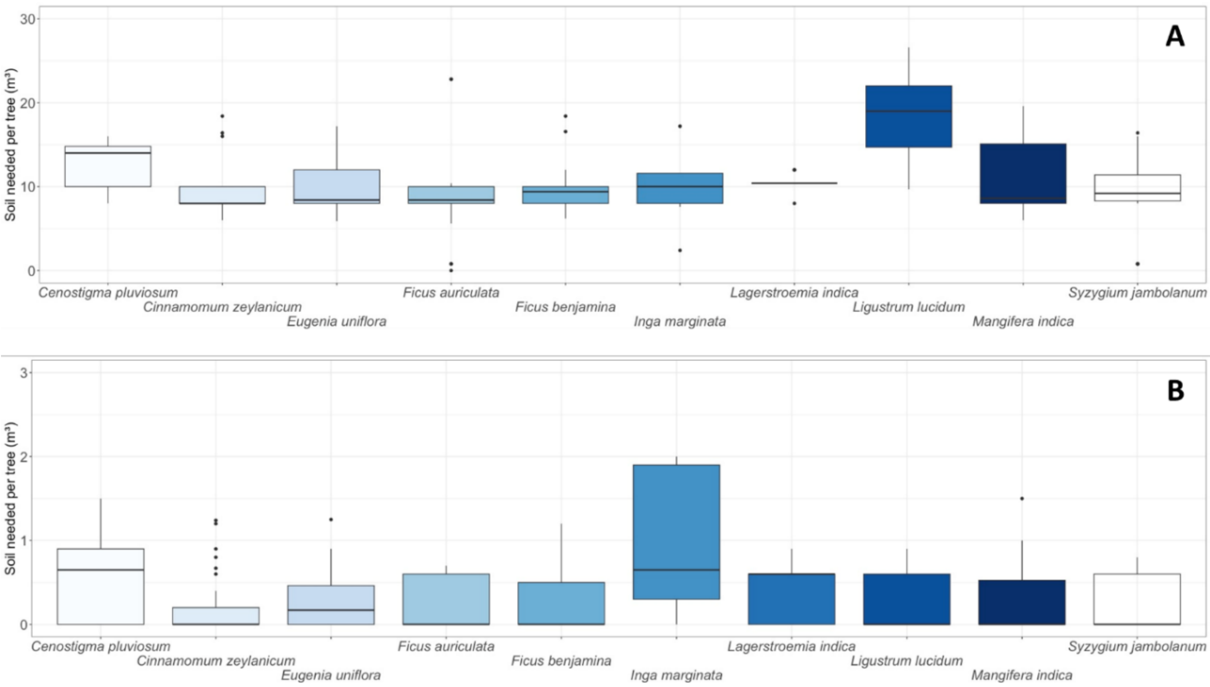

Figure 4. Variation in the amount of soil needed by trees (m³) for the Situation 1 (A), corresponding to the sidewalk width multiplied by four (SW x 4), and Situation 2 (B), corresponding to the tree bed width multiplied be one (TBW x 1).

Figura 4. Variação da quantidade de solo necessário às árvores (m³) para a Situação1 (A), correspondendo à largura da calçada multiplicada por quatro (SW x 4), e Situação 2 (B), correspondendo à largura do canteiro multiplicado por um (TBW x 1).

DISCUSSION

The results presented in this research show two different features concerning the environment on sidewalks and the necessary compatibility between trees and infrastructure for pedestrians. First, there are limitations on the ground level for trees to grow due to a high percentage of impervious surface. Second, trees can grow and develop under more adequate conditions of surface permeability because there is space available on sidewalks to improve the environment quality. It would provide trees with a more interesting volume of soil for gas exchanges and water infiltration without compromising the suitability of the environment in terms of pedestrian accessibility standards. Therefore, the approach to analyzing the sidewalks' environment is a key factor in verifying and planning the suitable space for trees on the ground level aiming to reconcile the tree growth with pedestrian accessibility.

Unfortunately, the impervious surface on sidewalks can provide pedestrians with a good path for mobility, but it can restrict the trees' growth quality. This limitation for trees to grow can be a common problem in Brazilian cities, as research has demonstrated the inadequacy of space for some tree species (SANTOS *et al*., 2015; MARIA *et al*., 2017; SILVA *et al*., 2018). On the other hand, not only the presence of trees on sidewalks can affect the accessibility patterns, but their general structural and health condition regarding the trunk leaning and defects. The epicormic shoots resulting from tree topping damages have been reported as an undesirable structural defect in trees planted on sidewalks because they compromise the space available for pedestrians' movement and accessibility (LIMA NETO *et al*., 2010).

It is worth noting that minimum values for sidewalk width and tree bed width are strategic for the survival of trees planted on sidewalks, since the greater their size, the greater the survival rate of trees (GRABOSKY; BASSUK, 2017; HAUER *et al*., 2020). The provision of good space for trees, compatible with the ideal size of the accessibility variables, prevents their mortality, as it maintains their good health and leads to a greater provision of ecosystem services, adding to sidewalks a more interesting value (LIMA NETO *et al*., 2010; GRABOSKY; BASSUK, 2017; PINHEIRO *et al*., 2018; HILBERT *et al*., 2020).

The results related to the tree bed capacity corroborate the statement that one of the biggest challenges for trees on sidewalks is the volume of soil available for the roots to penetrate and grow, which is influenced by the availability of fertile soil suitable for healthy growth of trees (GRABOSKY; BASSUK, 2017). The lack of adequate soil volume for root growth is probably one of the main factors that affect the long-term availability of water and nutrients for trees (HIRONS; THOMAS, 2018; JUST *et al*., 2018).

The amplitude of soil area and volume required by trees analyzed in this research may be due to variations in the tree crown diameter and area, caused by topping practices (as previously highlighted for *Cenostigma pluviosum*, *Ligustrum lucidum*, *Inga marginata*, and *Mangifera indica*), or due to differences in their ages, which implies smaller crown areas and, therefore, less need for calculated soil. However, smaller amplitudes of soil requirements can also be derived from changes in the natural spread of the tree crown, in a larger number of trees, making them uniform in size, such as for the *Cinnamomum zeylanicum* species.

So, the potential effect of trees to damage sidewalks and curbs varies according to species, soil condition, climate, and the distance to urban structures (curb, pedestrians' pathway), among other factors as pruning practices (GRABOSKY; GUCUNSKI, 2019). Nevertheless, when the tree bed width is made larger, damage to curbs and pathways is reduced, which leads to a better sidewalk environment quality (SCHOLZ *et al*., 2016).

In this sense, the partial remotion of the sidewalk pavement for the enlargement of the tree bed to manage the planting of trees associated with herbaceous vegetation should be planned in such a way as to allow the adequate thickening of the trunk at the base (growing trunk flare diameter over the years), as a natural load compensation mechanism to ensure the robust growth of the trees in isolated conditions, which tends to ensure better tree stability reducing damage to the sidewalk and accidents (BIONDI; ALTHAUS, 2005; GRABOSKY; BASSUK, 2017; HILBERT *et al*., 2020).

The ability of a tree to grow and remain healthy depends on the rooting space available (NORTH *et al*., 2015; HILBERT *et al*., 2020). This is particularly evident in highly urbanized areas, where there are many trees in small planting spaces and sometimes associated with a small volume of soil in porous surface conditions. Trees in this situation tend to have short longevity (JUST *et al*., 2018).

In this study, the high frequency of trees inserted in environments with an inadequate amount of soil for their growth was an expected condition, since the vast majority of trees were planted in places with very limited tree bed size or, even without a remarked tree bed (impervious surface completely surrounding tree trunk). It is worth noting that these characteristics of the tree bed are undesirable for qualified tree development on sidewalks, as the impervious surface negatively influences the survival of trees (VOGT *et al*., 2015; JUST *et al*., 2018). This condition for the development of trees derives from the lack of criterion planning by the local municipality, which has not yet prepared a master plan for the urban forest in the city, in line with adequate urban growth and development.

CONCLUSION

- This research allowed us to conclude that regarding the dimensional characteristics of the sidewalks and the size of trees on the sidewalks of Frederico Westphalen, RS, most trees were planted in places that provide good accessibility for pedestrians, but improvements can be planned regarding the compatibility of the space to promote a better environmental quality to trees and pedestrians.

- Most of the tree beds presented an adequate capacity to support tree growth, with species that were in places that can be managed to improve the tree bed capacity without affecting pedestrian accessibility. Therefore, it is important to use the information on the maximum size of the tree at maturity, mainly the possible trunk flare diameter, to avoid damage to both the tree and the urban infrastructure.
- Most trees were planted in inadequate soil area or volume, which indicates the need for better planning actions to circumvent conflict that may merge from the interaction between trees and sidewalk infrastructures.
- The method used for assessing soil area compatibility and sidewalk accessibility is easy to replicate and useful for studies of urban trees and urban planning in other cities.

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