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VARIABILITY AND BALANCE OF CROWN PROJECTION OF TREES PLANTED ON SIDEWALKS OF THREE BRAZILIAN CITIES

Keywords:
Urban forestry
urban tree management
Hazardous trees

ABSTRACT: Tree crown form can be used as a variable to the comprehension of factors that influence tree growth, mainly maintenance practices and interactions with urban structures, but also the potential risks that can exist. In this research, we aimed to evaluate crown projection unbalance of trees planted on sidewalks of three Brazilian cities, in order to determine the existence and the sort of asymmetry and crown angle formed in relation to the central axis of the trunk. We measured the length of four crown projection radii and compared them by means of Kruskal-Wallis Test. Each one of the crowns was framed in one of the four asymmetry classes to verify the uniformity of projection in relation to the central axis of the trunk. We also determined the distance between central axis of the trunk and crown centroid, with respective angle formed, in order to characterize the unbalance of crown projection. There was a significant difference among crown projection radii, with greater values to radius faced to street and the smallest ones faced to buildings. In the three cities evaluated there were a predominance of trees framed on class 3 of asymmetry, which represents the model with the greatest deformations on crown of trees. We observed the lowest mean angle of crown centroid projection with distinctions among species sampled in Bonito.

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VARIABILIDADE E EQUILÍBRIO DA PROJEÇÃO DE COPA DE ÁRVORES PLANTADAS NAS CALÇADAS DE TRÊS CIDADES BRAZILEIRAS

Palavras chave:
Silvicultura urbana
Gestão de árvores urbanas,
Árvores perigosas

RESUMO: A forma da copa das árvores pode ser utilizada como variável para compreender fatores de influência sobre o crescimento, principalmente as ações de manejo e as inter-relações com estruturas urbanas, mas também os riscos potenciais que podem existir. Nesta pesquisa objetivou-se avaliar o desequilíbrio da projeção das copas de árvores plantadas nas calçadas de três cidades brasileiras, a fim de determinar a existência e o tipo de assimetria e o ângulo de copa em relação ao eixo central do tronco. Mensurou-se o comprimento de quatros raios de projeção de copa, em cada árvore, comparando-os por meio do teste de Kruskal-Wallis. Cada copa foi enquadrada em uma de quatro classes de assimetria, a fim de caracterizar a uniformidade de projeção em relação ao eixo central do tronco. Dimensionou-se a distância entre o eixo central do tronco e o centroide da copa, com respectivo ângulo formado, a fim de caracterizar o desequilíbrio de projeção da copa. Constatou-se diferença significativa entre os raios de projeção de copa, com maiores valores para o raio de copa voltado para a rua e menores valores para o raio de copa voltado para a calçada. Nas três cidades avaliadas houve a predominância de indivíduos enquadrados na classe 3 de assimetria, a qual representa o modelo com as maiores deformações nas copas das árvores. Para a cidade de Bonito constatou-se o menor ângulo médio de projeção do centroide, com distinções entre as espécies amostradas.

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INTRODUCTION

Changes caused to natural ecosystems by the urban process and land use has been modifying natural landscapes and creating a big greyish and impervious matrix intersected by patches and plant corridors formed by trees along sidewalks, squares and urban parks. In this scenario, Baur et al. (2016) stated that all over the world the fast population growth generated challenges to urban management in order to provide human well-being and environmental quality.

On the other hand, there is a growing recognition of plants as central part of a green infrastructure system in urban areas, what is important for the effectiveness of urban planning and the provision of the environmental, social, aesthetic and economic benefits (ZHU; ZHANG, 2008; ZÖLCH et al., 2016; CALDERÓN-CONTRERAS; QUIROZ-ROSAS, 2017).

However, environmental benefits are the most desired ones through trees development in urban areas, because trees affect the microclimate regulation, by means of evapotranspiration, the thermal and acoustic regulation provided by trees crowns closure, the increase of soil permeability, among others (FANG; LING, 2003; MARTINI et al., 2013). Tallis et al. (2011) also emphasize the mitigating effect of trees and urban green areas against atmospheric pollution and particulate matter caused by car traffic.

According to Bobrowski and Biondi (2012) tree crown is the most striking part of the tree that causes positive effects in urban afforestation, because by this kind of structure derives the main benefits wanted with urban forest. Canopy cover and size of trees are characteristics directly associated with freshness effect promoted by trees in urban areas (MULLANEY et al., 2015), but pruning activities can change tree crown projection and the effects related to this part of trees.

In this way, tree pruning is one of the main activities of urban forestry practices and represent the most important one applied to trees, what affects both the healthy, and structure of trees (CLARK; MATHENY, 2010). Nonetheless, damages caused by topping on trees range from crown deformation to induction of an intensive process of regrowth that run out the energetic stock of trees, and causes the atrophy of root system, what can result in tree falling due to the physiological imbalance caused (ROSSETTI et al., 2010). New shoots formed after topping come from epicormic buds beneath the bark and represent one kind of structural defect that generate risk conditions together with crown deformation that is another kind of structural defect (HARRIS et al., 1999; ALBERS et al., 2003; MARUTHAVEERAN; YAMAN, 2010).

Studies that had reported the source and the effects of crown tree asymmetry are scarce and related to forest stands or natural areas (YOUNG; PERKOCHA, 1994; UMEKI, 1995; RAUTIAINEN et al., 2008; LONGUETAUD et al., 2013), while researches to the comprehension of characteristics and the effects of morphological changes on roadside trees planting are still lacking.

By the context presented, the goals of this research were to dimension the radius crown projection of trees comparing them statistically, to describe and analyze crown asymmetry classes and the angle of crown centroid in relation to trunk central axis of forest species planted on sidewalks of three Brazilian cities.

MATERIAL AND METHODS

For this research, data came from three databases of street tree inventories carried out between 2010 and 2016 in the cities of Bonito (MS), Curitiba (PR) and Itanhaém (SP). These cities have different foundation process and distinct planning systems and street tree management.

The spreadsheet used had information about a number of qualitative and quantitative variables, but we decided to use only information about species, tree total height, sidewalks width and four crown projection radii (radius to building, radius to street, radius to right and radius to left of the observer placed at the sidewalk). These variables were chosen because they can help in the comprehension process of crown asymmetry variability of trees planted on sidewalks. We excluded from the analysis trees without crown projection due to topping.

The first analysis consisted of putting general data of each city through Kruska-Wallis Test, via R software, just to verify if there were significant differences among lengths of crown projection radii. We applied a post-hoc test right after Kruskal-Wallis test to know which of the four crown projection radii was the most different. Moreover, we carried out a descriptive analysis of data by distributing them into minimum, mean and maximum values plus coefficient of variation in order to describe the canopy cover in each city.

In the second analysis, we classified crowns in classes of asymmetry by using models of crown asymmetry suggested by Kontogianni et al. (2011) in order to describe the uniformity of crown projection in relation to the central axis of the trunk (Figure1). These models of asymmetry do not depend on the direction of crown projection radius, if it is oriented to building or street or if it is oriented to right or left, because they are models to establish comparisons among crown projection radii. By using four radii crown measured in the inventories, we classified each tree as having symmetric or asymmetric crown.

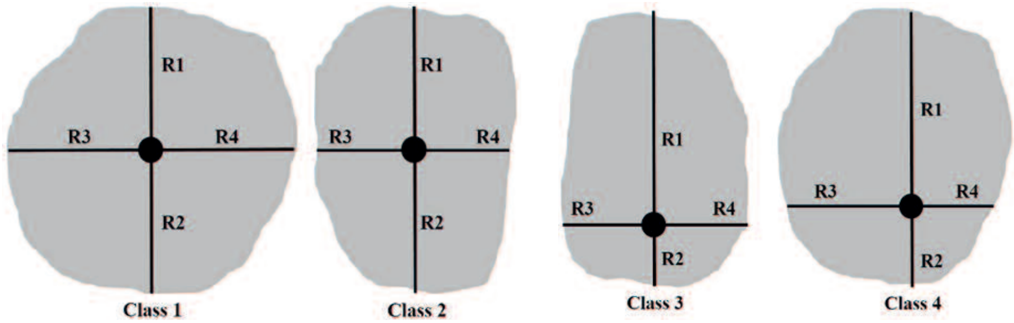

FIGURE 1 Graphic representation of crown asymmetry classes determined from the trunk position in relation to crown projection radii (R1, R2, R3 and R4). Adapted from Kontogianni et al. (2011).

Each asymmetry class were determined accordingly to models of Figure 1 by establishing comparisons among crown projection radii as: Class 1: R1 = R2 = R3 = R4; Class 2: R1 = R2 e R3 = R4; Class 3: R1 ≠ R2 e R3 = R4; Class 4: R1 ≠ R2 ≠ R3 ≠ R4.

In order to verify differences among crown projection radii according to Kontogianni et al. (2011) models, we used the following equation and assumed that the value obtained would be greater than 25% (DR > 25) [1] in order to capture drastic changes on tree crown format, since this structure usually does not have a perfect circle form. In wich, DR: difference between crown radii, in %; Cr1: length of crown radius 1, in meters; Cr2: length of crown radius 2, in meters.

$$DR = \frac{(Cr1 - Cr2)}{\left(\frac{Cr1 + Cr2}{2}\right)} * 100 \quad [1]$$

We established this criterion because the adoption of an absolute value as reference would affect the analysis by the fact that there is dimensional difference between the crown of small trees and large trees. From the definition of differences or similarities among four crown projection radii of each tree we proceeded to the framing of data into the models of asymmetry by means of logical test (IF function) on Microsoft Excel.

The third analysis was the dimensioning of distance between the central axis of trunk and crown centroid (YOUNG; PERKOCHA, 1994; UMEKI, 1995), with determination of the leaning angle formed (Figure 2). We obtained this information in order to characterize the crown projection unbalance that can enhance failure risk in face of harsh weather conditions and the presence of structural defects on trees, mainly on trunk bottom and on the branch insertion zone.

We determined the distance between the central axis of the trunk and the crown centroid by a trigonometric relation among hypotenuse (a) and cathetus (b, c), as [2]:

$$a = \sqrt{b^2 + c^2} \quad [2]$$

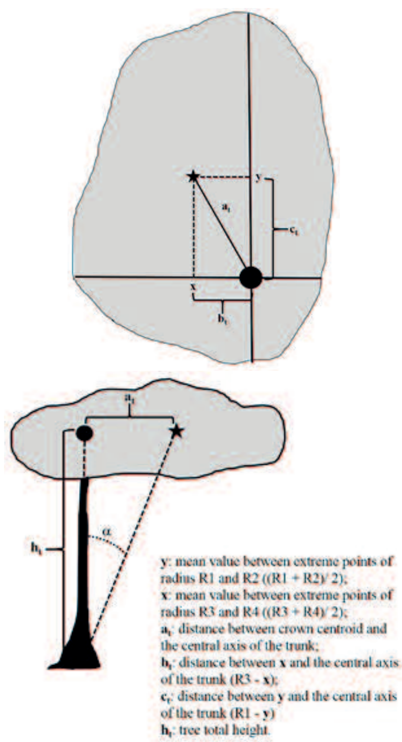

FIGURE 2 Determination of crown centroid (*), distance between crown centroid and central axis of the trunk (a) and leaning angle of crown projection (α) in relation to the central axis of tree trunk (•).

The leaning angle (a) between the central axis of the trunk and crown centroid was determined by the inverse tangent of the ratio between cathetus a and h_t. Special attention was given to data from trees with a leaning angle greater than 10° because this kind of defect can increase the risk of failure and accidents on streets.

We analyzed crown asymmetry and leaning angle for total data, however a summary was done for ten main species of each city in order to describe the variability of information found.

RESULTS AND DISCUSSION

The variability of data obtained for crown radii (Table 1) allow us to determine that for all three cities evaluated crown projection showed as with the same tendency, with greater values for crown radius faced to street (s) and lower values for crown radius faced to building (b). By means of Kruskal-Wallis Test we observed a significant difference among crown projection radii for trees in Bonito (c^2_{KW}=41.91; GL=3; *p*-valor=4.19x10^{-9}), Curitiba (c^2_{KW}=21.69; GL=3; *p*-valor=7.56x10^{-5}) and Itanhaém (c^2_{KW}=67.72; GL=3; *p*-valor=1.31x10^{-14}). To the cities of Curitiba and Itanhaém crown radius faced to building showed significantly different from others (*p*-valor < 0.01). In contrast, to Bonito crown radius faced to street showed significantly different from others (*p*-valor < 0.01).

Between crown radii faced to building (B) and to street (S) differences were more prominent for data from Curitiba (59.29%) in relation to data from Bonito (14.81%) and Itanhaém (14%). The greatest difference observed to Curitiba can be explained by the greatest mean dimension of trees planted on sidewalks, which showed a mean total height 21.43% and 69.29% greater than those observed in Bonito and Itanhaém respectively.

The greatest values of crown radius faced to street are due to the greatest free area for crown projection without competition in this direction, different from what happens in relation to crown radii to the right (R) and to the left (L), mainly when the planting distance is tiny and affects the complete growth and spread of trees earlier. Melo et al. (2007) the evaluation of crown on the longitudinal direction of sidewalk allows checking the adequacy of planting distance used for trees. Meanwhile, this kind of information is rarely considered during floristic surveys of street trees, what ends by limiting the availability of basic information for planning and decision-making, notably during master plan development for street trees.

TABLE 1 Distribution of minimum (Min), mean (Med) and maximum values (Max) of total height (ht) and crown projection radii to the right (R), to the left (L), to street (S) and to building (B), with respective values of coefficient of variation (CV%) by each city evaluated.

Values	Crown projection radii (m)				Total Height (m)
	R	L	S	B	ht
Bonito - MS					
Min	0,0	0,0	0,0	0,0	1,5
Med	2,8	2,8	3,1	2,7	6,3
Max	9,6	10,0	9,4	10,0	18,5
CV%	47,05	45,22	46,13	45,98	40,00
Curitiba - PR					
Min	0	0	0	0	1,10
Med	3,05	3,01	3,12	2,80	7,65
Max	14,40	16,40	18,00	11,30	27,00
CV%	75,62	74,94	79,16	76,26	60,58
Itanhaém - SP					
Min	0	0	0	0	0,60
Med	2,27	2,27	2,40	1,90	4,51
Max	10,30	12,90	11,40	10,00	19,00
CV%	72,05	97,83	73,49	73,69	54,09

Recently, few papers report information about tree crown dimension on sidewalks when trees are adult (MELO et al., 2007; BOBROWSKI; BIONDI, 2012; LIMA NETO et al., 2012). Also, there is a deficiency of paper reporting the mean planting distance of trees, together with information about crown projection due to allow more suitable analysis of species adequacy in relation to planting site.

On the other hand, lower values for crown radius faced to building can be related to improper pruning done to reduce conflicts with power lines, or building placed on a plot without front yard or the deposition of leaves over the rain gutter.

Schwab et al. (2014) stated that pruning is the main factor that change the architecture of forest species planted on sidewalks, but that this problem can arise from many factors. In a study realized in Santa Maria, RS, they observed that 74.88% of trees showed deformations caused by improper pruning. In the same way, Paiva (2009) notice that in Cosmópolis, SP, 21.60% of trees showed this kind of problem.

Considering the main species presented, we observed that to Bonito the mean angle of crown centroidprojection (TABLE 2) and asymmetry classes (TABLE 3), we noticed particular characteristics for each city, which are related to the way of planting trees on sidewalks.

Considering the main species presented, we observed that Bonito the mean angle of crown centroid projection was equal to 5°, to Curitiba was equal to 6° and to Itanhaém equal to 8°. The variation among cities can be related to maintenance practices as topping or power line pruning, but also to the natural way of growth in an environment with no competition for space or due to environmental factors such as artificial light, wind and heat. According to Harris et al. (1999) induced long days by artificial lighting can cause a continuous shoot elongation because it depresses the formation and maintenance of chlorophyll on leaves, but it varies among species that are sensitive to day length.

In Bonito, species that showed the greatest mean value for the angle of crown centroid projection were *Poincianella pluviosa* (sibipiruna), *Bauhinia* sp. (pata-de-vaca) and *Schinus molle* (aroeira-salsa). With the exception of the last one, to others species we observed that more than 20% of trees presented an angle greater than 10° and that *P. pluviosa* was the one with the greatest angle measured.

The data from Curitiba we observed the greatest mean values for centroid projection angle for *Tipuana tipu* (tipuana), *Acer negundo* (acer), *Anadenanthera colubrina* (monjoleiro) and *Cassia leptophylla* (falso-barbatimão). All of them together with *Ligustrum lucidum* represented more than 20% of trees with an angle greater than 10°.

TABLE 2 Distribution of mean values of total height (Ht), crown radius (Rc), length of sidewalk (Lc), mean centroid angle (Méd), range of variation for crown centroid angle (Amp) and proportion of trees with crown centroid angle > 10° (P10).

Species	Mean Values (m)			Centroid Angle		
	Ht	Rc	Lc	Méd	Amp	P10
Bonito City						
Bauhinia sp.	4,2	2,3	4,4	7	1 - 20	26,09
Handroanthus sp.	8,8	4,1	4,9	4	0 - 10	3,70
Licania tomentosa (Benth.) Fritsch	6,4	2,7	4,9	5	0 - 22	8,58
Mangifera indica L.	6,1	2,5	5,5	4	0 - 14	6,67
Murraya exotica L.	2,8	1,3	4,3	6	1 - 19	11,11
Pachira aquatica Aubl.	6,9	2,4	4,8	5	0 - 22	13,04
Poncianella pluviosa DC.	7,9	3,5	4,9	7	0 - 37	20,00
Tabebuia avellanedae Lorentz ex Griseb.	8,7	3,1	5,4	5	2 - 14	14,29
Tabebuia roseoalba (Ridl.) Sand.	4,8	1,5	5,4	4	1 - 8	0
Schinus molle L.	5,2	2,7	4,3	7	0 - 18	12,5
Curitiba City						
Acer negundo L.	7,2	3,1	4,9	8	0 - 26	31,91
Anadenanthera colubrina (Vell.) Brenan	16,9	6,9	5,4	8	0 - 24	27,19
Cassia leptophylla Vogel	8,5	4,3	4,6	8	0 - 23	24,14
Handroanthus chrysotrichus (Mart. ex A.DC.) Mattos	6,6	2,2	4,6	5	0 - 28	11,08
Handroanthus albus (Cham.) Mattos	7,3	2,9	5,5	6	0 - 40	17,42
Lafoensia pacari A.St.-Hil.	4,9	1,7	5,2	4	0 - 19	5,61
Lagerstroemia indica L.	5,0	1,8	4,6	4	0 - 21	6,64
Ligustrum lucidum W. T. Aiton	8,2	3,1	5,1	6	0 - 27	20,38
Parapiptadenia rigida (Benth.) Brenan	15,9	6,0	5,1	6	0 - 21	15,59
Tipuana tipu (Benth.) Kuntze	14,9	6,7	5,2	8	0 - 29	33,94
Itanhaém City						
Cassia fistula L.	3,8	2,3	2,1	10	2 - 26	40,00
Cocos nucifera L.	5,1	2,1	2,4	5	0 - 19	8,79
Cocos nucifera var. nana L.	4,3	2,3	2,2	4	0 - 40	2,86
Delonix regia (Bojer ex Hook.) Raf.	6,3	4,6	2,3	12	3 - 23	59,09
Dypsis lutescens H. Wendl.	4,4	1,7	2,4	5	0 - 21	7,86
Ficus benjamina L.	3,9	1,9	2,8	7	0 - 57	21,53
Handroanthus chrysotrichus (Mart. ex DC.) Mattos	2,9	1,2	2,2	7	1 - 15	38,89
Nerium oleander L.	3,2	1,5	2,1	7	1 - 17	25,93
Schinus terebinthifolius Raddi	3,6	2,1	2,3	10	1 - 30	33,33
Terminalia catappa L.	6,6	4,1	3,0	9	0 - 58	34,72

The greatest mean values were observed to *Delonix regia* (flamboyant), *Cassia fistula* (cassia-imperial) and *Schinus terebinthifolius* (aroeira-pimenteira), in Itanhaém. All of them with more than 20% of trees with centroid projection angle greater than 10°. Other species also showed this kind of problem, however in a more expressive way than observed to the other cities evaluated (TABLE 2).

Among evaluated cities, differences of species composition with centroid projection angle greater than 10° are interesting because it demonstrate that this problem is not related to a small number of species, but to a group of species that present crown deformation by management practices or inadequate or unnecessary pruning. However, species like *Tipuana tipu* and *Delonix regia* can present these centroid deviations more easily due to crown structure of plagiotropic type (SEITZ, 1996), which tends to expand branches sideways. Nevertheless, by data observed to Itanhaém, the process of tree maintenance by pruning must take care of trees in order to manage crown centroid deformations because species like *Schinus terebinthifolius*, *Cassia fistula* and *Terminalia catappa* presented a great mean to this characteristic in relation to other species, even to other cities evaluated.

According to Benatti et al. (2012) leaning trees on sidewalks can put people, cars and properties at risk by branches or whole tree falling, in addition to the aesthetic disqualification of public spaces. These authors observed in Pirapora (SP) about 14.3% of sampled trees presented an excessive leaning. This data seems to be too small but the challenge of urban forest managers focuses on the maximum reduction of tree falling events or the accidents and damages caused. Kontogianni et al. (2011) explained that the planning failure of pruning activities can lead trees to an asymmetric form and consequential unbalance. Likewise, Wu and Shao (2016) stated that the existence of cavities on the trunk when associated with an intense asymmetric crown create torsional strain and longitudinal cracks that promote trunk failure.

With the exception of species *C. nucifera* var. *nana* (coqueiro-anão), in Itanhaém city, and species *P. aquatica* (embiratanha), *Handroanthus* sp. (ipê) and *M. exotica* (murta), in Bonito city, to all the others species there were a higher proportion of trees framed in class 3 of asymmetry. The observation of a great number of data framed on class 3 raise some questions about management practices, even knowing that crown growth is not exact all over its projection.

Would public agencies be performing improper pruning practices in order to maintain crown unbalance? Would trees be planted in suitable distances to match the full growth similarly among crown projection radii? Would people be intervening in trees with or without public agency approval and promoting changes on crown balance by means of pruning done in an improper way? What is the effect of pruning practices done by electric power companies upon crowns unbalance when it is aimed the reduction of problems on power lines? How many risks are created by unintended pruning practices upon crown of trees when it causes unbalance? How many environmental, economic and aesthetic benefits are lost with earlier removal of trees with unbalanced crowns associated with risks due to improper management?

TABLE 3 Proportional distribution of asymmetry classes for data evaluated in each city.

Species	Asymmetry Class (%) 1	2	3	4
Bonito City				
Bauhinia sp.	26,09	17,39	56,52	0
Handroanthus sp.	33,33	29,63	3,04	0
Licania tomentosa (Benth.) Fritsch	28,02	16,99	54,47	0,53
Mangifera indica L.	26,67	6,67	66,66	0
Murraya exotica L.	33,33	22,22	38,89	5,56
Pachira aquatica Aubl.	43,47	13,04	43,47	0
Poncianella pluviosa DC.	14,29	11,43	65,71	8,57
Tabebuia avellanedae Lorentz ex Griseb.	42,85	7,14	50,00	0
Tabebuia roseoalba (Ridl.) Sand.	20,00	10,00	70,00	0
Schinus molle L.	0	25,00	75,00	0
Curitiba City				
Acer negundo L.	14,89	11,70	70,74	2,66
Anadenanthera colubrina (Vell.) Brenan	6,78	5,08	83,05	5,08
Cassia leptophylla Vogel	19,83	9,48	70,69	0
Handroanthus chrysotrichus (Mart. ex A.DC.) Mattos	21,20	10,12	66,99	1,69
Handroanthus albus (Cham.) Mattos	24,62	7,20	65,53	2,65
Lafoensia pacari A.St.-Hil.	37,85	11,68	48,60	1,87
Lagerstroemia indica L.	28,79	14,86	54,95	1,39
Ligustrum lucidum W. T. Aiton	19,75	9,13	69,00	2,12
Parapiptadenia rigida (Benth.) Brenan	12,90	12,37	73,12	1,61
Tipuana tipu (Benth.) Kuntze	9,23	12,55	75,80	2,95
Itanhaém City				
Cassia fistula L.	10,00	10,00	75,00	5,00
Cocos nucifera L.	31,87	9,89	58,24	0
Cocos nucifera var. nana L.	48,57	8,57	42,85	0
Delonix regia (Bojer ex Hook.) Raf.	9,09	18,18	72,72	0
Dypsis lutescens H. Wendl.	21,43	12,14	66,43	0
Ficus benjamina L.	24,88	5,74	67,46	1,91
Handroanthus chrysotrichus (Mart. ex DC.) Mattos	16,67	5,55	77,78	0
Nerium oleander L.	22,22	0	77,78	0
Schinus terebinthifolius Raddi	20,00	26,67	53,33	0
Terminalia catappa L.	17,43	14,68	66,06	1,83

To answer these questions a lot of research must be done due to establish a frame of problems observed and solutions to be achieved. This is an important task to help urban forest managers with the development of programs and laws that can make cities more livable and safe.

Data from asymmetry classes of trees with respective centroid projection angle (P10) could provide basic information to decision-making, mainly about prioritizing actions to evaluate failure risk of trees and problems that can happen to the traffic in cities with a great number of trees on sidewalks and a small group of professionals to do it.

CONCLUSIONS

The crown projection showed the same tendency of spread for all cities evaluated, the greater values of crown radius are faced to the streets and lower values for building side. There was significant difference among crown projection radii for trees in Bonito, Curitiba and Itanhaém.

There was a predominance of trees framed on class 3 of asymmetry ($R1 \neq R2$ and $R3 = R4$), which represents the model with the greatest crown deformation, mainly in the transverse direction along sidewalks, due to the interaction with buildings and the spread over streets.

We observed the lowest mean angle of crown centroid projection in Bonito city. However, species with the greatest centroid deviation were *Poincianella pluviosa* (sibipiruna), *Bauhinia variegata* (pata-de-vaca) and *Schinus molle* (aroeira-salsa) in Bonito city; *Tipuana tipu* (tipuana), *Acer negundo* (acer), *Anadenanthera colubrina* (monjoleiro) and *Cassia leptophylla* (falso-barbatimão) in Curitiba city; *Delonix regia* (flamboyant), *Cassia fistula* (cassia-imperial) and *Schinus terebinthifolius* (aroeira-pimenteira) in Itanhaém city.

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