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Aesthetic growth of a native tree species with desirable characteristics for urban green areas in arid and semiarid environments

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ABSTRACT

Having an aesthetic form is one of the desirable aspects of trees used to create or reforest urban green areas, which is often achieved by procedures that require a great effort. The understanding of factors affecting the architecture of plants in natural conditions may be useful to promote a desirable shape during the growth process. Under the hypothesis that trees in high luminosity conditions have a more aesthetical growth, in this study we explore the relationship between plant shape and photosynthetically active radiation (PAR) in *Bursera fagaroides,* a characteristic species of the tropical dry forest and xerophytic shrub-lands useful for urban green areas in semiarid environments. To evaluate trees shape we calculate a symmetry index (I_S) by using two diameters of the crown, perpendicular to each other, and the total height. Measurements were made over three periods (before, during and after the growth period); and PAR was also measured for each tree. Linear regressions were used to analyze the relationship between the symmetry of trees and PAR received during the growth period. The post-growth symmetry of trees showed a positive relationship with the PAR received by trees during the growth period, suggesting that PAR effects can be harnessed to develop post-germination strategies for the production of trees with a more aesthetical growth in the studied species. Effect of PAR on the shape of plants may represent a practical option to promote aesthetical growth of trees and shrubs with importance for creation and restoration of urban green areas.

1. Introduction

Bursera fagaroides (Humb., Bompl. & Kunth) Engl. (Buseraceae) is a characteristic tree species of the Tropical Deciduous Forest (TDF), and secondary vegetation in TDF and xerophytic shrub-lands as well, which is distributed throughout the southwest of the United States to the southeast of México (Rzedowski et al., 2004). In natural conditions the species grow mainly during the summer rainy season (Johnson, 1992; Ortiz-Pulido and Rico-Gray, 2006), being an ideal native plant for the creation and reforestation of urban green areas in semiarid environments (including public parks, urban and peri-urban forest, particular gardens, urban agriculture systems and trees in streets; Krishnamurthy and Rente-Nascimento, 1998; Panduro and Veie, 2013; WHO, 2016) due to its ability to grow in shallow soils, dry environments and conditions of moderate disturbance (Terrones et al., 2004; Ortiz-Pulido and Rico-Gray, 2006; Malda-Barrera et al., 2009; Suzán-Azpiri et al., 2017), in addition to its relative ease of propagation by stem cuttings and the availability of seed propagation protocols (Terrones et al., 2004; Bonfil-Sanders et al., 2008; Sánchez-Martínez et al., 2011).

An important aspect of trees and shrubs used in urban green areas is the aesthetic growth (Sadeghian and Vardanyan, 2013); which generally is achieved and maintained by different pruning techniques and practices like pollarding or topiary (Bedker et al., 1995; Ruemler, 2004). However, such practices may require constant efforts to maintain a desirable shape when it is different to the natural growth of trees (Bedker et al., 1995). Thus, understanding of factors affecting the architecture of plants in natural conditions may be useful to complement the propagation protocols with strategies that influence the trees growth shape, so that a natural shape is similar to what is desirable.

The architecture (and thus, symmetry) of trees is determined by intrinsic factors and environmental influences as well. Light, particularly the photosynthetically active radiation (PAR), is an important signal to control plant growth and development (Lambers et al., 2008). Shading by trees canopy reduces the quantity of light perceived in the understory (Canham, 1988), where the far-red ratio diminished, affecting stem and petiole elongation, controlled by phytohormones

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production and signaling (such as auxins and gibberellins; Lambers et al., 2008). Thus, when shaded, plants tend to bend and elongate toward the light, having sometimes an asymmetrical shape (Fankhauser and Chory, 1997). But exposed to direct sunlight, plants will grow mostly straight and will develop lateral buds (Fankhauser and Chory, 1997), having a more proportional shape.

In this study we analyze the influence of the photosynthetically active radiation (PAR) on the growth shape of *B. fagaroides*. Based on field observations, we hypothesized that trees under high luminosity conditions have a more symmetrical growth (and hence, a more aesthetical growth) that trees growing in shaded conditions.

2. Materials and methods

The study site is located in the facilities of the Faculty of Natural Sciences (Autonomous University of Querétaro, Querétaro, México; central coordinates: 20° 41′ 58.8″ N, 100° 26′ 36.24″ W).To implement the study, we tagged all individuals of *B. fagaroides* smaller than 2 m tall (n = 109 individuals) in the spring of 2017, within a plot of 2347 m^2 located in a remnant of TDC maintained as an area with wild vegetation. For each individual we measured the total height and two diameters of the crown (canopy), which were perpendicular to each other. Individuals were measured for the first time during the spring (before the growth period), and subsequently in the summer (growth period) and autumn (post-growth period).

In the summer, we also measured the photosynthetically active radiation in μmol s^{-1} m^{-2} (PAR) received by each of the individuals with a light meter LI-250 (LI-COR). Each PAR measurement was based on three PAR average measures (average of 15 s) registered in the upper, medium and lower edges around the tree crown. Immediately after each individual PAR measurement, an additional PAR measure for the direct sun exposition outside the canopy was registered in order to estimate the PAR extinction (PAR_{ext}), i.e. the reduction of PAR outside the canopy that an individual experiences under the canopy expressed as percentage. PAR_{ext} was calculated as:

PAR_{ext} = [1-(PAR received by an individual/PAR outside the canopy)]*100

To evaluate individual aesthetics, we calculate a dimensionless index of symmetry (I_S) with the measurements of the total tree height and two diameters of the canopy. This index was developed considering that other indices potentially useful to estimate the aesthetic of plants do not adequately reflect variations in the general shape of trees and/or their values depend on size of trees (e. g., Niu and Rodriguez, 2010; Schiappacasse et al., 2017); moreover, some variables associated with the aesthetic of plants (e. g., De Reffye et al., 1995; Crespel et al., 2013) may result impractical and inaccessible for a generalized and extensive use. The index I_S was defined as:

$$I_S = d/2D(l_{hd}/L_{hd} + l_{hD}/L_{hD})$$

Where d and D, are the minor and the major of the two diameters of the crown of a tree or shrub, and h its total height (Fig. 1A). l_{hd} and L_{hd} are the shortest and the longest lengths, respectively, selected between the height and the minor of the diameters. So, whether $d < h$ then $d = l_{dh}$ and $h = L_{dh}$ in the equation, and the opposed (i. e. $h = l_{dh}$ and $d = L_{dh}$) is true whether $h < d$. The same reasoning is followed for the relationship between lengths of D and h considering that l_{hD} and L_{hD} are the shortest and the longest lengths, respectively, selected between the height and the major of the diameters.

The index I_S has a value of 1 when there is equality between the height and the two diameters of the crown (i.e., it achieves the maximum symmetry), and it approaches to 0 as there is a greater difference between lengths of the two canopy diameters, or at least between one of the diameters and the height (Fig. 1B). The basic idea of this index is that the more symmetrical a tree is, the more aesthetical it will be.

Previous to test the relationships of symmetry with PAR and PAR_{ext}, we performed an autocorrelation analysis on symmetry data for the three periods ($I_{S\ spring}$, $I_{S\ summer}$ and $I_{S\ autumn}$), to evaluate the importance of non-considered factors influencing spatially on the symmetry (e. g., soil, microclimate, genetic, etc.), and an ANOVA for repeated measures to evaluate if the symmetry in the post-growth period ($I_{S\ autumn}$) was an artifact of the previous symmetry of trees. To evaluate the relationship of tree symmetry with the PAR and PAR_{ext} we performed multivariate regression analysis with $I_{S\ spring}$, $I_{S\ summer}$ and $I_{S\ autumn}$ as dependent variables. All analysis was done with the program PAST 3.16 (Hammer et al., 2001).

3. Results

Factors that may influence spatially did not seem to affect the independence of the measures of symmetry (Fig. 2A). Symmetry of *B. fagaroides* trees was different between the spring, summer and autumn, suggesting that symmetry in the post-growth period was not an artifact of the previous symmetry of trees ($F = 117.4$, $d.f. = 2/216$, $P < 0.0001$; Fig. 2B), and was related to PAR ($F = 26.7$, $d.f. = 3/105$, $P < 0.0001$) and PAR_{ext} ($F = 19.2$, $d.f. = 3/105$, $P < 0.0001$). Relationships were significant for the symmetry in autumn ($I_{S\ autumn}$ vs PAR: $r^2 = 0.41$, $P < 0.0001$ and $I_{S\ autumn}$ vs PAR_{ext}: $r^2 = 0.33$, $P < 0.0001$; Fig. 3), but not for the symmetry in spring ($I_{S\ spring}$ vs PAR: $r^2 = 0.016$, $P = 0.19$ and $I_{S\ spring}$ vs PAR_{ext}: $r^2 = 0.012$, $P = 0.26$) and summer ($I_{S\ summer}$ vs PAR: $r^2 = 0.028$, $P = 0.08$ and $I_{S\ summer}$ vs PAR_{ext}: $r^2 = 0.015$, $P = 0.20$).

4. Discussion

The effect of the photosynthetically active radiation received by trees of *B. fagaroides* in the growth period can be harnessed to develop strategies post-germination during the production of trees with a more aesthetical growth. Nevertheless, the development of more effective strategies to produce trees destined for the creation and restoration of urban green areas must consider other factors besides aesthetic criteria. For example, one study by Ortiz-Pulido and Rico-Gray (2006) suggest that germination rates and survival of seedlings of *B. fagaroides* is higher in moderately-shaded environments (receiving around 30–40 μmol s^{-1} m^{-2}) than in environments more exposed to the sunlight (receiving around 500–600 μmol s^{-1} m^{-2}). According to this study, production of individuals may then combine an initial phase of growth under moderately shadow to increase the survival probability, and a posterior phase for growth in conditions of sunlight exposition, in order to promote a symmetrical shape.

While photosynthetically active radiation is one of the most determining factors for growth and several other descriptors of the architecture of plant species under different environments (e. g., stem orientation, branching frequency, lateral shoots growth, thickness and width of leaves) (Nobel, 1981; Smith et al., 1998; Bartlett and Remphrey, 1998), its effect on geometry of plants may represent a practical option to promote an aesthetical growth of valuable trees and shrubs for the creation and restoration of urban green areas.

Although the relationship between symmetry and PAR could have been studied with an experimental approach, we based our approach in field observations principally because juvenile trees (lesser than two years old) frequently have an incipient ramification preventing an appropriate evaluation of their symmetry. In consequence, the possibility to work under an experimental approach would require a long-time study to have a significant sample of juvenile trees. On the other hand, the conduction of the study in the field was advantageous, allowing to capture the continuous variation in the PAR received by trees, which may be helpful to plan a proper experimental approach.

Finally, the index of symmetry proposed in this study may represent a practical method to evaluate the effect of different factors (such as the photosynthetically active radiation) on the architecture of a large

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