Research Article
doi: 10.1590/01047760202127012709
vol(27), 2021

CERNE

Dendrometric characterization of *Cupressus lusitanica* mill. planted under *Pinus taeda* L. shelter in southern Brazil

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FOREST MANAGEMENT

ABSTRACT

Background: We analyzed if *C. lusitanica* can be planted in a shelterwood system with *P. taeda* as the shelter stratum. The study was conducted in a 13-yr-old *C. lusitanica* stand under *P. taeda* canopy in Southern Brazil. Samples of these trees were measured in terms of diameter at breast height (DBH), total height, individual volume, and crown projection area. The species´ growing space efficiency (GSE) was also analyzed. A 10-meters distance criterion from *P. taeda* trees was applied to check their influence on *C. lusitanica* growth behavior through correlation.

Results: The 36-yr-old *P. taeda* trees showed expressive means in the dendrometric variables, compatible with its age (mean DBH of 58 cm, total height 30 m, individual volume of 3.7 m^3, and crown projection area of 128 m^2). There was a statistically significant effect ($p>0.05$) of *P. taeda* cover on *C. lusitanica* diameter (mean of ~13 cm). Although not significant, an effect of *P. taeda* canopy was also observed on *C. lusitanica* height. The two species summed a basal area of 36.5 m^2 ha^{-1} and a crown projection area of 34,209.2 m^2 ha^{-1}. A tendency of increasing GSE with increasing diameter was observed for both species.

Conclusion: These results show that a shelterwood with *C. lusitanica* under *P. taeda* is possible, but further investigations with longer production cycles and with silvicultural treatments (i.e. thinnings and shelter removal) should be conducted for a better understanding of shelterwood systems with these species in southern Brazil in terms of growth performance and soil use sustainability.

Keywords: Forest management; growing space efficiency; forest mensuration; shelterwood; underplanting

HIGHLIGHTS

There was an effect ($p>0.05$) of *Pinus taeda* trees on *Cupressus lusitanica* diameter (DBH).
An effect of *P. taeda* cover on *C. lusitanica* height was also observed.
The growing space efficiency increased with increasing diameter for both species.
P. taeda trees showed a tendency of decreasing GSE with increasing crown projection area.

TOPANOTTI, L. R.; VAZ, D. R.; DOBNER JR, M.; NICOLETTI, M. F. Dendrometric characterization of *Cupressus lusitanica* mill. planted under *Pinus taeda* L. shelter in southern Brazil. CERNE, v. 27, e-102709, doi: 10.1590/01047760202127012709

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Received: 24/08/2020 Accepted: 18/03/2021

CERNE
ISSN 0104-7760
UNIVERSIDADE FEDERAL DE LAVRAS

INTRODUCTION

Even though most of the world's forests are composed of uneven-sized mixed-species stands, forest management practices around the globe have focused on the development of monocultures to produce timber on a large scale, quickly and cheaply. However, social and environmental expectations have changed over the years (Pukkala and Gadow, 2012; O´hara, 2014), and, combined with concerns about biodiversity loss and climate change, they have intensified the need to manage forests for multiple ecosystem services and functions, including timber production and biodiversity maintenance (Biber et al., 2015; Raymond and Bédard, 2017).

One silvicultural system that has been applied mostly in European and North American forests (temperate) but also in other regions (tropical/subtropical, i.e. New Zealand) to promote the regeneration of key-species is the shelterwood silvicultural system. It is characterized by the maintenance of a canopy that is gradually removed (the residual trees are called "shelter trees") to promote the regeneration under it, particularly to establish shade-tolerant late-successional species (Balandier et al., 2007; Pukkala and Gadow, 2012; Stokes et al., 2020).

The regeneration in a shelterwood system can be natural or artificial. The artificial is characterized by planting trees under an existing canopy, which is a process called underplanting. Besides improving regeneration, this practice is carried out to introduce new species, to increase the proportion of the desired species, or to enrich and diversify the forest structure (Scolforo, 1998; Kerr and Haufe, 2016).

The shelterwood system presents several silvicultural advantages, such as seedlings protection against adverse weather conditions, maintenance of soil moisture, erosion reduction, and better utilization of soil nutrients than on clear-cut (Kelty, 2006; Dey et al., 2012; Pukkala and Gadow, 2012; Kerr and Haufe, 2016). Another benefit of this system is the establishment of a next crop at an earlier stage since the shelter trees are completely harvested only when the overstory is well-established. Thirdly, the remaining mature trees on the cover layer increase their increment and produce larger and high-quality logs, so the system also provides harvest products from different species on different periods (Kelty 2006; Dobner Jr. et al., 2009; Stokes et al., 2020).

On the other hand, this system also presents some disadvantages. Some of them are related to management practices since they become more complex due to species diversity, especially to avoid damages in the understory due to shelter tree harvesting. Others are related to ecological and silvicultural aspects, such as the intensification of inter and intraspecific competition, the difficulty of estimating the species´ growth, and a possible effect from the canopy trees on the growth of understory trees due to reduction in light level and, consequently, decrease in photosynthetic rates (Strand et al., 2006; Dobner Jr. et al., 2009; Kerr and Haufe, 2016; Stokes et al., 2020).

Although this technique has been applied in several countries around the world (Strand et al., 2006; Dey et al., 2012; Forbes et al., 2014; Kerr and Haufe, 2016; Stokes et al., 2020), in Brazil, underplanting to enrich the understory diversity has been applied only to natural forests, as studied by Venturoli et al. (2011). In 1981, the first experiment with exotic species in a shelterwood scheme was carried out in Brazil, where native valuable timber species were planted under *Pinus taeda* L. cover (Carvalho, 1984). After that, Dobner et al. (2009) also studied a shelterwood with *P. taeda* in the canopy and *Eucalyptus dunnii* Maiden in the understory, in southern Brazil. Their results showed that the shelter intensity decreased the damages caused by frosts, but there was also a decrease in height and collar diameter growth of *E. dunnii* due to the shelter.

The present study is probably the third research in Brazil about a shelterwood system using *P. taeda* as the canopy. As *P. taeda* is the most planted pine species in Southern Brazil, in monocultures, (Embrapa, 2014), there is potential to transform some of these stands into shelterwood systems if the practical outcomes from this system prove themselves advantageous. For small to medium-size private owners, the multilayer arrangement could represent several incomes from different times, especially from the large *P. taeda* trees that occupy the canopy for a longer time, and, consequently, increase their size and commercial value (Topanotti, 2021, unpublished data)

Thus, studies focused on the dendrometric characterization of shelterwood are crucial to verify its potential and to create a database about this system in Brazil. This research aimed to (i) describe dendrometric variables of *Pinus taeda* and *Cupressus lusitanica* in a 13-year shelterwood in Santa Catarina, Brazil, (ii) evaluate the species' growing space efficiency (GSE), and (iii) evaluate the existence of correlation among *C. lusitanica* variables and distance from *P. taeda* trees in this system. We analyzed the following overall hypothesis: *C. lusitanica* can be planted in a shelterwood system with *P. taeda* in the canopy without constraints to its growth.

MATERIALS AND METHODS

Site description

The study was conducted in an experimental site established in the municipality of Capão Alto, south of Santa Catarina, Brazil (28° 03′ 35″ S and 50° 46′ 22″ W), in an area of approximately 2 ha (Fig. 1). The climate is classified as Temperate Oceanic Climate (Cfb type), with an annual mean temperature of 13 °C, an altitude of 1,000 m.a.s.l. and an annual rainfall mean of 1,750 mm (Alvares et al., 2013). The system component *P. taeda* was planted in 1982 (initial density of 2,500 trees.ha^{-1}, spacing of 1.6 x 2.5 m) and thinned during several periods as a commercial stand until 2005 (23 years of age), when the surrounding stands were harvested. One stand was selected for this experiment, which was partially harvested to a stocking density of 60 trees per hectare. The second component, *C. lusitanica*, was planted in 2005 under the *P. taeda* trees, in a spacing of 2.5 m x 2.5 m (1,600 stems.ha^{-1}) (Fig. 2).

Data collection

Ten circular plots of 500 m^2 were installed using the random start systematic sampling (Fig. 1). We measured

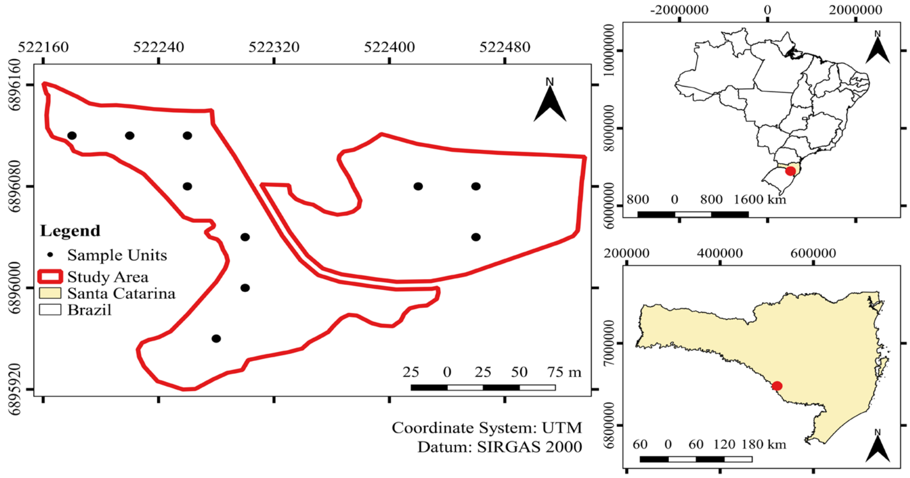

Fig. 1 Location of the study area and sample units. A) Study area and sample units; B) Brazil; C) Santa Catarina State.

Fig. 2 *Cupressus lusitanica* (lower layer) and Pinus taeda (upper layer) in a 13-yr-old shelterwood system in Southern Brazil.

diameter at breast height (DBH), total height (h), and crown radii (cr). The DBH was taken from all *C. lusitanica* and *P. taeda* in the plots at 1.3 m above ground. The total height was measured for the *C. lusitanica* trees in the planting line located in the center of each plot, plus five dominant *C. lusitanica* trees (Fig. 3), which corresponded to a total sampling of 132 trees. Also, we obtained the total height of all the *P. taeda* trees found in the plots. The DBH and h were measured with a measuring tape and a digital hypsometer Vertex IV®, respectively.

Regarding the crown measurements, four radii, from the stem until the end of the longestbranch, were measured following the cardinal directions. The crown survey included 94 *C. lusitanica* individuals (all the trees in the central line) and all *P. taeda* trees, using a laser rangefinder TruPulse 200.

Based on the empiric diameter distribution of both species (class interval of 5 cm), 33 *C. lusitanica* and 16 *P. taeda* trees were harvested and scaled in the following stem positions: 0.1 m, 0.3 m, 0.5 m, 0.7 m, 0.9 m, 1.3 m, 2 m, and after that, every 1 meter up to the top of the tree, using a caliper. The volume per section was calculated through Smalian's and added to the top volume (cone) to get the individual total volume per tree. Five volume models were fitted to these data (Husch (1963), Spurr (1952), linearized Schumacher-Hall (1933), and Stoate (1945)), and due to their better performance, Schumacher-Hall (for *P. taeda*) and Spurr (for *C. lusitanica*) models were used to estimate the volume of the other trees, and, after that, the volume per hectare. The fitted volumetric equations obtained were the following: (1) (Schumacher-Hall – *P. taeda*) and (2) (Spurr – *C. lusitanica*).

$$Lnv_i = -8.96 + 1.539\, ln\, dbh_i + 1.802 lnh_i + e_i \quad [1]$$

$$v_i = 0.008828 + 0.0000318 dbh_i^2 + e_i \quad [2]$$

Besides these measurements, a sketch was made locating the *P. taeda* trees in the study area, taking their distance to the center of the plot. The *C. lusitanica* trees position in the plots was determined based on the plantation spacing (Fig. 3).

Statistical Analyses

All statistical analyses were conducted on Statistical Software R® version 3.6.0. The crown projection area was obtained through the following formula (Eq. 3), Where CA is the crown projection area, in m²; R_1... R_4 are the crown radii, in m.

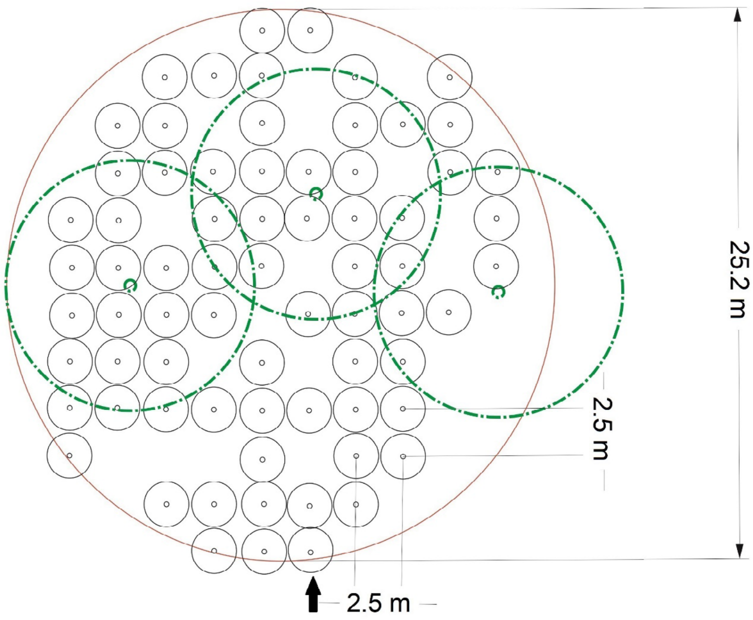

Fig. 3 Sketch of one of the plots sampled during the inventory. Note: the red circle illustrates the plot boundary; the green dashed circles and the black circles represent the crown projection area of the *Pinus taeda* and *Cupressus lusitanica* trees, respectively; the black arrow indicates the planting line where *Cupressus lusitanica* trees were measured in terms of total height and crown radii.

The basal area and the total volume per hectare were calculated for both species. The d_{100} and h_{100} of *C. lusitanica* were obtained as the mean diameter and height of the 100 largest-diameter stems ha^{-1}. For *P. taeda*, d_{100} and h_{100} were calculated as the mean diameter and height since the number of trees sampled in each sample unit was not enough to obtain the d_{100} and h_{100} (average of 3 trees per sample unit).

$$CA = \left[\left(\frac{R_1 \cdot R_2 \cdot \pi}{4}\right) + \left(\frac{R_2 \cdot R_3 \cdot \pi}{4}\right) + \left(\frac{R_3 \cdot R_4 \cdot \pi}{4}\right) + \left(\frac{R_4 \cdot R_1 \cdot \pi}{4}\right)\right] \quad [3]$$

The crown projection area was summed for both species, based on the mean value, to verify the area occupied by the trees' crowns and then extrapolated to a hectare, based on the number of trees per hectare. Besides, the correlation among *C. lusitanica* variables and the distance from *P. taeda* trees was verified through the Pearson method, at 5% of significance, adopting a radius of 10 m (as adopted in other studies with shelterwood systems, i.e. Strand et al 2006). Also, the growing space efficiency (GSE), which represents the stem volume growth per unit of projected leaf area (Berrill and O´hara, 2007), was calculated for both species as the ratio of total volume per crown projection area (adapted from O´hara (1988).

RESULTS

A total of 722 trees of *C. lusitanica* and 30 trees of *P. taeda* were measured on the forest inventory. The diameter, height, individual volume, and crown area variation are shown in Fig. 4. The species *C. lusitanica* and *P. taeda* presented mean dbh values of 12.6 cm and 58.0 cm, total height of 12.0 m and 29.8 m, individual volume of 0.1190 m^3 and 3.6612 m^3 and crown projection area of 2.4 m^2 and 128.0 m^2, respectively.

The species *P. taeda* presented higher values in all analyzed variables, especially in terms of individual tree volume and crown projection area (Fig. 4). In both basal area and crown projection area, *C. lusitanica* had higher values than *P. taeda*, as a result of a higher number of trees per hectare (Tab. 1). However, even with a density stocking of 60 stems ha^{-1}, the *P. taeda*' s crown projection area is around 76% of a hectare, which illustrates the big size of these crowns and their occupation in the horizontal area.

The correlation indexes among the *C. lusitanica* variables and distance from *P. taeda* are displayed in Tab. 2. There is not an evident overall relationship between the variables and the distance. A positive significant but weak correlation was detected only for the correlation between DBH and distance. Although the correlation was not significant for the other *C. lusitanica* variables, a negative effect of *P. taeda* cover on *C. lusitanica* height was detected, especially when compared to pure stands (see "Discussion" section).

The growing space efficiency for both species shows a difference between them. Overall, *P. taeda* was more

Tab. 1 Stocking, basal area, total volume, mean top height, and mean top diameter for *C. lusitanica* and *P. taeda*.

Variables	*C. lusitanica*	*P. taeda*	Total
Stocking density (stems·ha^{-1})	1,444	60	1,504
Basal area ($m^2 \cdot ha^{-1}$)	20.6	15.9	36.5
Crown projection area ($m^2 \cdot ha^{-1}$)	~26,526	~7,680	~34.206
Total volume ($m^3 \cdot ha^{-1}$)	171.9	219.7	391.4
h100 (m) Ranges	13.6 (10.9 – 17.3) ±1.5	29.7 (26.0 – 33.7) ±2.1	
d100 (cm) Ranges	20.9 (16.0 – 30.6) ±2.9	59.4 (53.8 – 70.7) ±4.7	

Note: h_{100} = mean top diameter (cm); d100 = mean top diameter (cm); Range = mean (minimum – maximum) values; s = standard deviation.

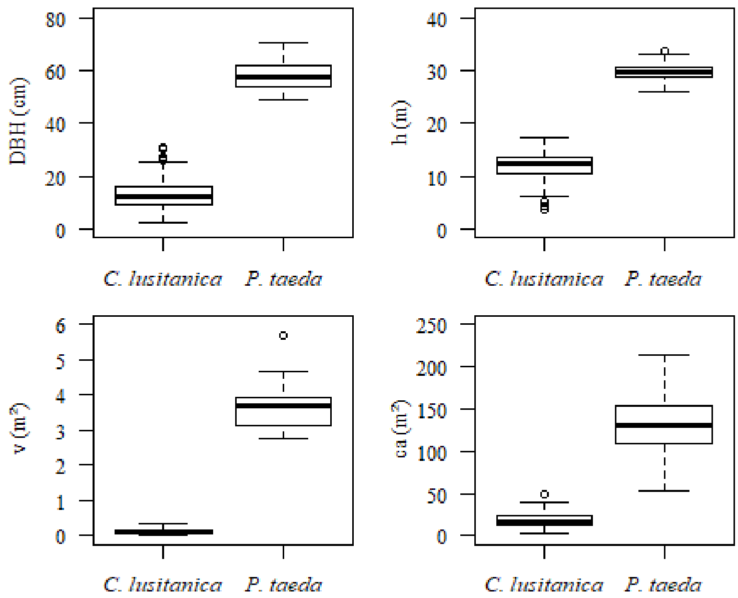

Fig. 4 Data distribution of *Cupressus lusitanica* and *Pinus taeda* dendrometric variables in an underplanting system. Note: dbh = diameter at breast height (cm); h = total height (m); v = individual total volume (m^3) and ca = crown projection area (m^2). The whiskers represent the minimum and maximum values of each variable, the bold line represents the median, and the region between the first and third quartiles represents the distribution of 50% of the data, illustrated by the boxes.

Tab. 2 Correlation values for d (cm), height (m), individual volume (m^3), and crown projection area (m^2) of *Cupressus lusitanica* in terms of distance (10 m) from *Pinus taeda*.

Variables	*r*	*d.f.*	t	t_{tab}	p-value
d x distance	0.10	886	2.99	1.96	0.0028*
h x distance	-0.06	160	-0.85	1.97	0.3933
v x distance	-0.01	160	-0.13	1.97	0.8904
ca x distance	-0.10	126	-1.16	1.97	0.2458

Note: d = diameter at breast height (cm); h = total height (m); v = tree individual volume (m^3.$stem^{-1}$); ca = crown projection area (m^2); r = correlation coefficient; d.f. = degrees of freedom; t = t calculated value; ttab = t value from Student table; ; p-value = significance correlation value.; * = significant at 5% level.

efficient in using the growing space than *C. lusitanica*. There was a tendency of increasing efficiency with increasing diameter for both species. The *C. lusitanica* trees with up to 25 m^2 of crown projection area were the most efficient, while there was a tendency of decreasing efficiency with increasing crown projection area for *P. taeda* (Fig 5).

The growing space efficiency for both species generally increases with height (Fig. 5). Trees between 11 to 14 meters of height were the most efficient in using the growing space for *C. lusitanica*. For *P. taeda*, height does not seem to have a linear relation with GSE, with some of the tallest trees presenting both high and low values in this variable

DISCUSSION

A preliminary analysis of the diameter results suggests that this variable was somehow affected by the *P. taeda* cover. This tendency becomes clear when compared to pure plantations of the species, especially to the results of Venturini et al. (2018) and Souza et al. (2018), which were developed in *C. lusitanica* stands in the same geographic region (Tab. 3). According to the Farm Forestry New Zealand (2005), in New Zealand, *C. lusitanica* plantations are desired to present a mean diameter around 15 to 25 cm at age 10 under favorable soil and climate conditions. Studies with younger trees had already shown a mean diameter equal to or even higher than the one obtained in this study (Tab. 3).

Studies about the diameter growth of *C. lusitanica* and spacing noted that the trees of *C. lusitanica* with more space tend to show higher diameter, as reported by Kimberley and Nicholas (2006). Indeed, the studies conducted in the same geographic region by Venturini et al. (2018) and Souza et al. (2018) found higher means of diameter under lower stocking density compared to this research. However, even under (Asaye and Zewdie, 2013) or similar (Chinchilla et al., 2011) stocking densities, the mean *C. lusitanica* diameter in this study was equal to or lower compared to these two papers with 3-yr younger stands, despite the regional differences among the location of these studies and ours.

The smaller diameter values compared to pure plantations are probably a direct consequence of the *P. taeda* cover effect. The positive correlation of *C. lusitanica* diameter and distance from *P. taeda* supports this idea. Alem et al. (2015), in Ethiopia, verified that *C. lusitanica* presented a higher mean diameter in pure plantation than in a mixed plantation with *Eucalyptus camaldulensis*, with a difference of almost 10 cm for the same age. Milne (2006) noted that *Cupressus* sp., grown with shelter and/or companion species in a mixed stand, are protected against exposure (especially to wind load, because this species is susceptible to toppling), developed better form and decreased branch development, but, as a negative consequence, there could be an effect on diameter growth.

Likewise, the mean height and mean top height of *C. lusitanica* are lower compared to results on pure plantations of *C. lusitanica* of similar ages even though a significant correlation between *C. lusitanica* height and the vicinity to *P. taeda* trees was not identified. In New Zealand, Farm Forestry New Zealand (2005) states that *C. lusitanica* can reach 12 m of height at age 10 under favorable soil and climate conditions. Also, in Alem et al. (2015) study, *C. lusitanica* exhibited a lower mean height in a mixed stand with *E. camaldulensis* than in its pure plantation, indicating a possible negative effect of an upper layer for this species on height as well.

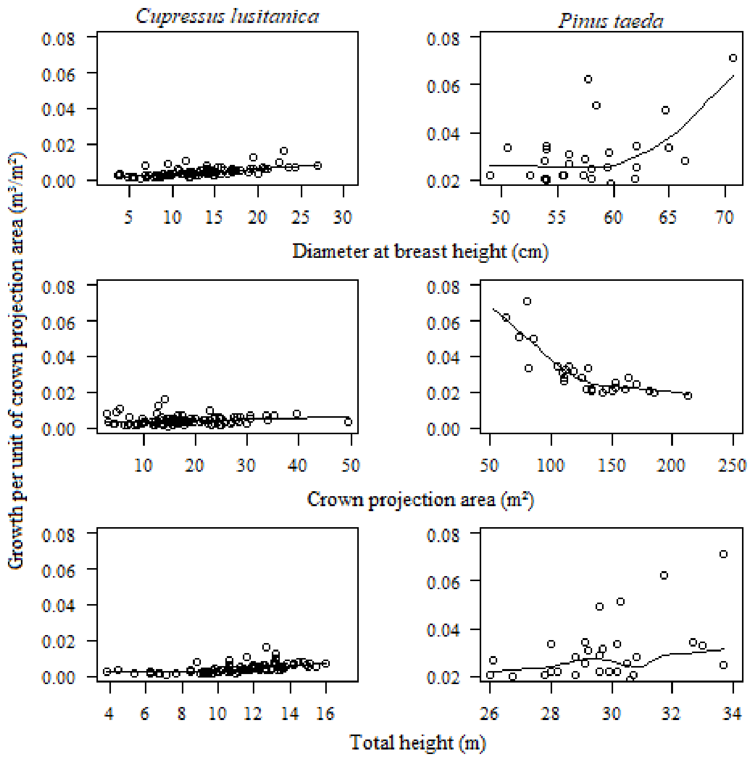

Fig. 5 Growing space efficiency (volume per unit of crown projection area) in relation to diameter (A and B), crown projection area (C and D), and total height (E and F) for *Cupressus lusitanica* and *Pinus taeda*, respectively.

Tab. 3 Dendrometric variables of *C. lusitanica* found in other studies with pure plantations.

Country	*Age*	*S*	DBH	h	V	G	h_{100}	Authors
Ethiopia	10	1,503	12.6	18.2	-	4.7	-	Asaye and Zewdie (2013)
Costa Rica	10	1,293	15.5	-	-	24.1	14.0	Chinchilla et al. (2011)
Costa Rica	10	1,427	16.8	-	-	14.9	14.9	Chinchilla et al. (2011)
Ethiopia	12	-	-	-	-	-	18.8	Mamo and Sterba (2006)
Brazil	13	1,444	12.6	12.0	171.9	20.6	13.6	This study
Ethiopia	13	-	-	-	-	-	19.2	Teshome and Petty (2000)
Brazil	14	833	20.0	11.6	-	-	-	Souza et al. (2018)
Ethiopia	14	-	-	-	-	-	20.4	Mamo and Sterba (2006)
Brazil	15	833	20.0	20.0	-	28.2	-	Venturini et al. (2018)
Ethiopia	15	803	-	-	220.0	-	-	Lemenih et al. (2004)
Costa Rica	18	408	28.0	19.2	-	-	-	Roque et al. (2010)
Ethiopia	27	444	31.5	18.6	-	-	-	Alem et al. (2015)

Note: Age (years); S = Stocking density (stems ha-1); d = dbh (cm); h = total height (m); V = total volume (m³ ha-1); G = basal area (m² ha-1); h100 = mean top height (m).

There are just a few studies about *C. lusitanica* growth in pure plantations in Brazil so far (Souza et al., 2018; Venturini et al., 2018). However, a study with this species in Southern Brazil indicates that a higher mean top height was expected for 13-yr-old *C. lusitanica* based on its guide curve of dominant height growth (Dobner Jr., 2020, unpublished data). On the other hand, the mean top height visualized in this shelterwood system agrees with the site curve index of 14 m for *C. lusitanica* at 13 years obtained by the same author.

Some studies have assessed the negative effect of shelter trees on the height growth of understory trees in shelterwood systems. Dobner Jr. et al. (2009) verified that the *P. taeda* cover affected negatively the growth of *E. dunnii* in terms of collar diameter and total height, with the most pronounced negative effects in a 4 m ratio from the *P. taeda* trees. Strand et al. (2006), studying the height growth of seedlings in a Scots pine shelterwood in Sweden, observed that the three assessed species showed reduced height growth due to the vicinity to shelter trees. Also, Valkonen et al. (2002) noticed a reduction between 9 and 17% of seedling's height growth potential because of retained trees in the upper layer, within a circle of 10 m radius of each shelter tree, in Finland.

The species summed, together, 36.5 $m^2.ha^{-1}$ in basal area (Tab. 1), and *C. lusitanica* represents most of it, with 20.6 $m^2 \cdot ha^{-1}$. Compared to the pure plantations (Tab. 3), this value represents a good area occupancy by the trees, buffering the effect of the cover on diameter. This behavior was also observed for *C. lusitanica* volume, which showed good results even with the *P. taeda* canopy.

Referring to the crown area and growing space efficiency, the *P. taeda* trees occupied an area of 7,680 $m^2 \cdot ha^{-1}$, which represents around 76% of a hectare. When compared to the GSE values, the largest trees in the crown projection area showed the lowest growing space efficiencies than smaller-crowned trees, as observed by O´hara (1988) for Douglas-fir. This may be a consequence of shading of lower branches among dominant trees (BERRILL and O´HARA, 2007), or a result from variation in net photosynthesis among trees and variation in carbohydrate allocation to stem volume growth (O´HARA, 1988). For *C. lusitanica*, tall trees with small-medium crowns proved themselves as the most efficient producers of volume per unit of crown projection area, which was also verified by Webster and Lorimer (2003) for different species in the USA.

Also, the tendency of improving GSE with an increase in diameter for *P. taeda* shows that growth in diameter, without leading to a significant increase in crown area, enhances the efficiency of volume production per unit of crown projection area (Webster and Lorimer, 2003). The tendency of increasing tree growth efficiency with increasing diameter was also observed by Tschieder et al. (2012), for *P taeda*, in Argentina.

The GSE measurement applied in our study is useful to describe the efficiency of growing space for both species in terms of stem wood volume, which is the main product desired from this shelterwood. Indeed, the trees with higher values of GSE were the ones with the highest values of total volume as well.

The *P. taeda* basal area data (15.9 $m^2.ha^{-1}$) and volume (220 $m^3.ha^{-1}$) are consistent if compared to higher stocking stands in Brazil. Nascimento et al. (2015) reported a basal area of 52.9 $m^2.ha^{-1}$, a volume of 776 $m^3.ha^{-1}$ for a density of 586 stem ha^{-1} for 33 to 34-yr-old *P. taeda*. Dobner Jr. (2014) obtained a basal area of 47.7 $m^2.ha^{-1}$ at 30 years for *P. taeda* under an extreme thinning regime, which remained with 150 $stem.ha^{-1}$ after the last thinning.

In a shelterwood, the canopy's basal area is an important criterion to reduce the shade effect on the overstory trees. Kerr and Haufe (2016) suggest maximum values of canopy trees basal area according to the species´ shade tolerance to ensure the success of the trees planted in a shelterwood system, for Britain. Following their criteria, in our case, the maximum basal area of the canopy should be up to 20 m^2 ha^{-1} since both *P. taeda* and *C. lusitanica* are classified as shade intolerant (Schultz, 1997; Shimizu et al., 2006). Indeed, shade-tolerant species tend to outperform light-demanding species planted under an existing canopy (Forbes et al., 2014). However, as the *P. taeda* basal area was 15.9 m^2 ha^{-1}, its cover should not be an issue to the *C. lusitanica* growth, and, yet, *C. lusitanica* is growing less than in pure plantations

Besides the basal area, another aspect that must be considered when installing a shelterwood system is the canopy stocking density. Agestam et al. (2003) observed that the height growth of *Fagus sylvatica* was higher in the sparser shelterwood in the first years, but, after that, the highest growth rates were obtained on the clear-cut areas. The authors suggested that this shift was a result of canopy closure, followed by a reduction in light intensity, but it could be also related to the need for protection that *F. sylvatica* may require in the first years, as they observed higher seedling emergence and less frost damage in the shelterwood.

In this study, a density of 60 $stem.ha^{-1}$ for the cover layer represents a sparse canopy. Örlander and Karlsson (2010) verified that the seedlings of *Picea abies* (L.) Karsten, planted under a *P. abies* and *Pinus sylvestris* L. cover, showed the highest annual mean height on the shelterwood with canopy density of 80 and 160 stems ha^{-1}, which are stocking densities even higher than the present study. We cannot deny that the possible canopy closure by *P. taeda* trees in the last years reduced the light entrance to the understory due to its large crown area values (Fig. 4 and Tab. 5) and, somehow, affected the growth behavior of *C. lusitanica*.

Considered the most important limiting aspect to the development of plants in the understory (Coomes and Grubb, 2000), light is, undoubtedly, a key factor for the height growth of trees under a canopy (Strand et al., 2006; Dey et al., 2012; Forbes et al., 2014; Stokes et al., 2020). However, it is been recently found that radiation could be a less decisive stressor for tree height growth (Tishler et al., 2020) than the distance to shelter trees, which is more correlated to the understory trees growth (Strand et al., 2006). In this sense, one explanation to the non-significative correlation between distance from *P. taeda* and *C. lusitanica* height could be a possible edge effect in some plots closer to the stand boundaries, where some trees would have less influence of P. taeda trees to grow in height" to "where some trees would have less influence of P. taeda on height growth.

Nutrient availability and water supply also affect tree's growth in height. On infertile and drier soils, the belowground competition plays an important rol, while the light is a decisive factor for seedlings' height growth on moist and nutrient-rich soils (Coomes and Grubb, 2000). Thus, in future researches, we suggest including light and soil analysis as well to better understand the growth behavior of species in a system with shelter trees.

Despite the effects of *P. taeda* canopy on *C. lusitanica* diameter and height, the *C. lusitanica* understory showed good results in volume and basal area. Besides, it has established well under the canopy and in a sufficient density to fully stock a future stand, which demonstrates the potential of such a silvicultural system in diversifying an existing forest, as stated by Stokes et al. (2020). In further investigations, we suggest, if possible, analyzing shelterwood stands and monocultures of the species under the same or similar climate and soil conditions, which would promote a better understanding of the growth behavior of the selected species in a shelterwood arrangement in contrast with their pure plantations.

CONCLUSION

This initial characterization of the shelterwood system showed that the presence of *P. taeda* trees in the canopy somehow affected the growth of *C. lusitanica* in diameter and height. Both species showed a tendency of increasing growing space efficiency with increasing diameter, and *P. taeda* decreased its efficiency with increasing crown projection area. Although the canopy basal area and density in this study were within some established boundaries to ensure the understory establishment and growth success in terms of the light entrance, other variables also play an important role in the understory species growth, such as soil fertility and belowground competition, and they should be further investigated in other studies with this silvicultural system.

ACKNOWLEDGMENTS

The authors wish to thank the private forest enterprise Florestal Gateados for field assistance and support on this project, the Fundação de Amparo à Pesquisa e Inovação do Estado de Santa Catarina (FAPESC) and the research group Forestry Resources Management of the Santa Catarina State University (UDESC) Campus Lages.

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