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RESEARCH ARTICLE

Effect of tree shelters on the survival and growth of coniferous tree species in Central South Bulgaria

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Abstract

The effects of tree shelters on the survival, height and diameter growth of three coniferous tree species – Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) H. Karst.) and Silver fir (*Abies alba* Mill.) were observed. The study was conducted in two experimental plantations, established in the spring of 2016 in the Training and Experimental Forest Range Jundola (Central South Bulgaria). Three experimental variants with tree shelters – Tubex Ventex Classic, Layflat Shelterguard, Layflat Treeguard and a control one (without tree shelters) were used. Twenty to twenty-five seedlings in three replications of each variant and tree species were planted. The experimental plantation 1 included Scots pine and Norway spruce and was established on a south east-facing terrain at an altitude of 1400 m. The soil is Cambisols (FAO) mixture of clay and sandy, medium stony, medium deep to deep. The habitat is medium rich, slightly moist. The experimental plantation 2 is of Silver fir and was located on an east-facing terrain at an altitude of 1400 m. The soil is Cambisols (FAO) mixture of clay and sandy, medium stony, medium deep to deep. The habitat is medium rich, slightly moist to moist.

In the autumn of the fifth year after the establishment, inventories and measurements of heights, height increment and groundline diameter of the seedlings were made. The survival in both experimental plantations was higher in the variants with tree shelter. The height growth of all tree species was better in tree shelter variants, with the highest average height in the variant with Tubex Ventex Classic. The biggest height increment was established in the variant with Layflat Shelterguard for Norway spruce and Silver fir and in variant without tree shelters for Scots pine. The ground line diameter was highest in control variant for Scots pine and Norway spruce and in the variant with Layflat Treegard for the Silver fir.

Keywords

Pinus sylvestris, Picea abies, *Abies alba*, height, height increment, ground line diameter

Introduction

Tree shelters were originally introduced in order to protect plants from damage by animals. They have also been used to create a favourable microclimate for growth and to protect seedlings from herbicide application (Kays, 1995). Compared to the open air, light access is lower in tree shelters, but CO_2, temperature, and relative humidity increase (Jacobs and Steinbeck, 2001).

The influence of tree shelters on the survival and growth of seedlings has been the subject of a number of publications, mostly related to deciduous tree species. There are fewer studies documenting the use of tree shelters in coniferous tree species.

Jimenez et al. (2005) reported a 100% survival of *Juniperus thurifera* L. seedlings, both inside and outside the protectors, citing the very good soil preparation before afforestation as the reason behind it. Leroy and Caraglio (2003) found that protectors have a positive effect on height and diameter growth of *Pinus brutia* Ten., while studies by Dupraz (1997) show a positive effect on height growth but negative on *Pinus pinea* L. diameter increment. Better growth in height, but weaker growth in diameter of container seedlings of *Cedrus deodara* (Roxb.) G.Don with tree shelters was also found by Burger et al. (1992).

An interesting experiment was conducted with three types of tree shelters and controls (without tree shelters) with seedlings of *Picea engelmannii* Parry ex Engelm. in the Rocky Mountains (USA) at an altitude of over 3000 m (Jacobs, 2004). In the fourth year 50% of the shelters were removed and all seedlings were remeasured in the sixth year. Shelter removal did not result in mortality, indicating that seedlings are able to grow in full sun after 4 years in tree shelters. Survival in the sixth year of all shelter treatments (with or without shelter removal) was 88%, while survival of the control was 45%. Shelter removal resulted in less mean height growth but greater mean diameter growth.

Burger et al. (1996) reported about 2-years tree shelters experiment with ten tree species common to California. Periodic (~ every 2 months) height and diameter measurements were taken and, at the end of the second year, all trees were harvested for fresh and dry weight biomass determinations. Height was greater for sheltered versus unsheltered trees during the first 30 to 250 days for all species. After 2 years, only *Ginkgo biloba* L. and *Pinus canariensis* C.Sm. ex D.C. trees grown in shelters were taller than their unsheltered counterparts. The basal diameter was often reduced for sheltered trees. The authors recommend the use of tree shelters until the plants outgrow them, after which they should be removed.

Ward and Stephens (1995a) present the results of an experiment with *Pinus strobus* L., which used two types of Tubex tree shelters with a height of 120 resp. 180 cm and control (without protection). After the fifth growing season, the tallest were the plants in the 180 cm high tree shelters, but the difference with the other variants was insignificant. A significant effect was observed with regard to the damage from game, as in the variant without protection the top buds of 67% of the seedlings and 82% of the side buds of the seedlings were damaged. Plastic tree shelters reduced deer browsing damage to ponderosa pine seedlings during a 5-year study in central Oregon (Anthony, 1982). Seventy-seven percent of unprotected seedlings were damaged, but none of the seedlings in the tubes were damaged. Protection also improved seedling survival and height growth.

A study in Germany on the use of Douglas fir tree shelters (Petersen, 2016) found that they have a positive effect on survival in temperature extremes – frost or drought, but in terms of growth and stability of seedlings the tree shelters weren't recommended because seedlings develop long and slender stems that are unstable and prone to wind and snow damage, and overgrown plants are damaged by game.

In the spring of 2016, two experimental plantations with three different types of tree shelters of the company Tubex (www.tubex-deutschland.de) were established in the Training and Experimental Forest Range in Jundola (Central South Bulgaria).

The aim of the work was to study the effects of tree shelters on the survival and height and ground line diameter growth of Silver fir, Scots pine and Norway spruce in the fifth year after the establishment of the plantations.

Materials and Methods

The object of the study were two experimental plantations (EP1 and EP2), established in the spring of 2016 in the Training Experimental Forest Range in Jundola (Central South Bulgaria).

The experimental plantation 1 included Scots pine and Norway spruce and was established on an south east-facing terrain at an altitude of 1400 m (42°03'22.085"N, 23°48'31.25"E). The soil is Cambisols (FAO) mixture of clay and sandy, medium stony, medium deep to deep. The habitat is medium rich, slightly moist. The plantation was established after windthrow in Scots pine plantation. The experimental plantation 2 is of Silver fir and was located on an east-facing terrain at an altitude of 1400 m (42°03'34.45"N, 23°51'36.9"E). The soil is Cambisols (FAO) mixture of clay and sandy, medium stony, medium deep to deep. The site class is medium rich, slightly moist to moist (Table 1).

Table 1. Site classes of the experimental plantations

Object number	Altitude, [m]	Exposition	Slope [o]	Type of soil	Site index
EP1	1400	SE	14	Cambisols	C_2
EP2	1400	E	8	Cambisols	$C_{2,3}$

Note: * In Bulgaria, a system is used to evaluate the site index, consisting of soil richness (A – very poor, B – poor, C – medium rich, D – rich) and a digital index for soil moisture (0 – very dry, 1 – dry, 2 – slightly moist, 3 – moist, 4 – very moist) (Raykov et al. 2011). C_2 means medium rich and slightly moist soil.

The climate in the region is mountainous with an average annual temperature of 5.3 °C and average temperature of the growing period 11.2 °C. The average annual precipitation is 697.1 mm, of which more than half (383.5 mm) falls during the growing period. The average relative humidity varies over the year from 69% to 85% and there are no prolonged droughts. The duration of the growing period is approximately four months. Strong winds, more often with erratic direction, are specific for higher and uncovered parts of the region. During the three-year study period, the average annual temperature was in the range from 5.5 to 6.0°C, and the annual amount of precipitation from 508 to 939 mm (Table 2). More than half of the falls happened during the growing period.

Table 2. Air temperature and precipitation in the study period in the Jundola region

Year/Month	V	VI	VII	VIII	IX	V-IX	Annual
Air temperature							
2018	10.0	11.9	13.6	14.0	10.3	11.9	5.5
2019	7.7	13.1	13.6	15.4	11.3	12.2	6.0
2020	8.9	10.8	13.9	14.7	12.0	12.0	5.8
Precipitation							
2018	131.5	179.3	198.1	0.0	0.0	508.9	938.9
2019	83.9	83.4	0.0	0.0	10.6	177.9	507.6
2020	254.8	107.6	99.7	57.0	17.1	536.2	713.4

Three experimental variants with tree shelters – Tubex Ventex Classic (A), Layflat Shelterguard (B), Layflat Treeguard (C) and a control one (without tree shelters) were used (Fig. 1). Twenty to twenty-five seedlings in three replications of each variant and tree species were planted. All tree shelters were 120 cm tall.

Tubex Ventex Classic (Fig. 1A) has a light green color, it is made of polypropylene and has a patented ventilation system. In the lower third of the tree shelter there are 16 round holes with a diameter of 15 mm, which provide optimal supply of carbon dioxide and optimal growth conditions through a mini greenhouse effect, which accelerates growth, and protects the plant from extreme weather conditions – solar heat, humidity, danger of fungal pathogens. This tree shelter type protects against competing vegetation and animal damage. Its duration of use is about 10 years.

Layflat Shelterguard (Fig. 1B) protects plants from animal damage and at the same time offers better conditions for initial growth. It is made of recycled plastic mesh with holes of 12 mm and is additionally reinforced with a transparent polyethylene layer. The plant is protected from winds and herbicides as long as the access of light is not limited. The decomposition of this tree shelter type takes place in two phases – first the polyethylene layer decomposes (after about 3 years), the net remains to protect the plant from animals, and the plant successfully adapts to external conditions.

Layflat Treeguard (Fig. 1C) is a stable safety net, which is especially suitable for the protection of seedlings, which grow very quickly in closed tree shelters and the crown

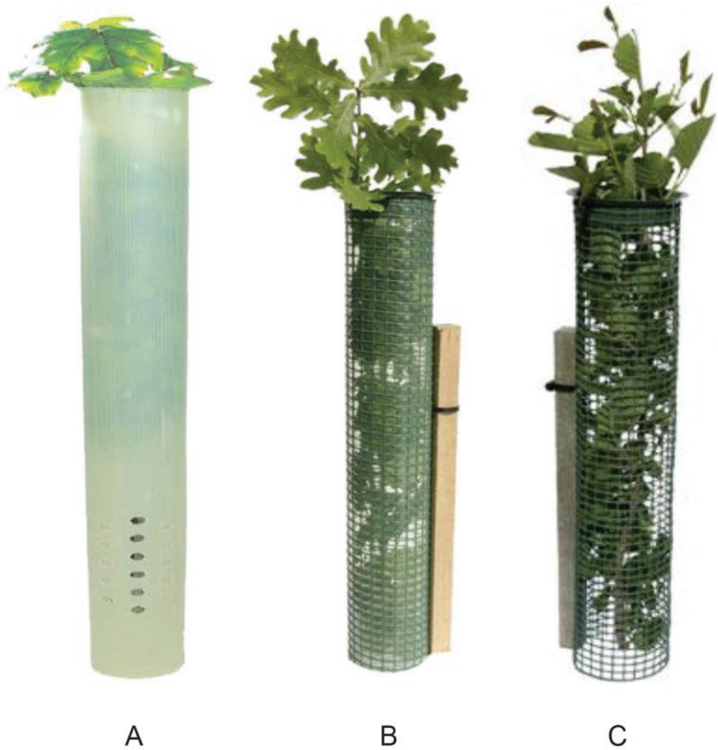

Figure 1. Tree shelters used in experimental plantations: A – Tubex Ventex Classic https://www.die-forstpflanze.de/tubex-ventex-120-cm-art.nr.-130726; B – Layflat Shelterguard https://www.grube.eu/p/tubex-standard-shelterguard-tree-protection/P73-044/; C – Layflat Treeguard – https://www.terragala.de/tubex-treeguard-layflats-baumschutz-flach-gitter-zum-verbissschutz-hohe-120cm-ab-20cm-grun.html

becomes heavy and unstable. By using it, the tree can grow in natural conditions, being exposed to sunlight and rain. The durability of the tree shelter is about 10 years. At its upper end, the net is rounded to avoid injury to the shoots and stem.

The soil preparation in EP1 was manual terraces with a width of 30 to 50 cm and a tillage depth of 25 cm. The distance between the terraces was 2 m, and between the seats from 1.2 to 1.5 m. Two-year old (2/0) Scots pine seedlings were planted with an earth auger. Three-years old (3/0) Norway spruce seedlings were planted with hollow spade. The afforestation and the installation of the tree shelters were performed on 20.04.2016.

The soil preparation in EP 2 was in the form of square sites 30 x 30 cm, treated to a depth of 15 cm. The distance between the rows of platforms was 1.5 m, and between the seats – 1.1 m. Four-years old (4/0) Silver fir seedlings were planted with hollow spade. The afforestation and the installation of the tree shelters was performed on 03. and 04.05.2016.

In the autumn of the fifth year after the establishment, inventories and measurements of heights, height increment and groundline diameter of the seedlings were made. The influence of the tree shelter type on the survival rate was modelled by beta regression (Mangiafico, 2016). The statistical significance of the experimental variant on the growth in height on the fourth year and height increment and groundline diameter growth on the fifth year after the afforestation for each tree species and variant was studied according to the GAM model (Wood, 2017).

Results and discussion

Survival

It was found that the survival of the fifth year after afforestation was different for different species (Table 3). The highest survival rate was in the experimental plantation of Silver fir – 92%, and in all three types of protection it was high – about 95%. The highest survival rate was in variant A Tubex Ventex Classic – 98.7%, and slightly lower in variants B (Shelterguard) and C (Treeguard) – 94.7%. There were more losses in control, but the survival rate was relatively high – 80%. There was a significant difference only in the control variant from the others at a significance level by p <0.001. In experimental plantation 1, better survival results were found in Scots pine – 81.8%. Survival rate was the best in variant A (Tubex Ventex) – 89.3%, followed by variant C (Treeguard) – 88% and the lowest survival rate was registered in variant B (Shelterguard) – 84%. The most losses were in the control variant at a survival rate of 66% and differs significantly from the other variants- by p <0.001. The lowest average survival rate was reported for Norway spruce – 53.2 with best survival rate in variant B (Shelterguard) – 66.7, followed by variant C (Treeguard) – 60.9 and the lowest one in variant A (Tubex Ventex) – 56%. Statistically significance (p <0.01) was found only for the control variant with survival of just 29.3%. In short – in all three tree species only the control variant differs significantly from the variants with tree shelters.

Table 3. Survival by species and variants

Variant	Scots pine	Norway spruce	Silver fir
A Tubex Ventex Classic	89.3b	56.0b	98.7b
B Shelterguard	84.0b	66.7b	94.7b
C Tree guard	88.0b	60.9b	94.7b
D Control	66.0a	29.3a	80.0a

A number of publications have also reported better survival in tree shelters protection. Ward, Stephens (1995b) studied the effect of different types of tree shelters on the survival of 5 tree species incl. Norway spruce, and found that the mortality was lower for seedlings protected by Tubex tree shelters than for other types of tree shelters. As a result of a 2-year study of the effect of tree shelters whose walls had 4 different degrees of light transmission and control (without protection) on the survival of *Pinus halepensis* Mill. Oliet et al. (2021) found the highest survival rate in tree shelters with the highest light transmittance. Anthony (1982) reported a positive effect of tree shelters on the survival of *Pinus ponderosa* (Douglas ex. C. Lawson).

Height growth

The biggest average height of Scots pine in the fourth year after the establishment of the plantation was found in variant A (Fig. 2) – 59.0 cm, as the difference compared to variants B and C was with high ($p < 0.001$), and with D variant with little lower ($p < 0.05$) significance level. Regarding the height increment in the fifth year, its greatest value in the control D variant (20.9 cm) was impressive, as there was a significant difference only with variants B (15.0 cm) and C (15.3 cm) at $p < 0.05$. It can be assumed that in the variant without tree shelters the seedlings are stronger and this affects their height growth.

The biggest average height of Norway spruce was found also in variant A (38.5 cm), but the difference with the other variants was insignificant. Only the variant D (without protection) stands out significant (at $p < 0.05$) – Fig. 2. Regarding the height increment the differences between the variants were minimal. The variant B was different from the other variants, but the statistical significance was too small (at $p < 0.1$).

In the Silver fir plantation, the biggest average height in the fourth year after afforestation was found in variant B (Shelterguard) – 49.2 cm, the difference was significant (at $p < 0.001$) compared to variant A and control D (Fig. 3). The control variant has the lowest value of the average height of 23.6 cm and differs significantly (at $p < 0.001$) from all other variants. The largest height increment in the fifth year after

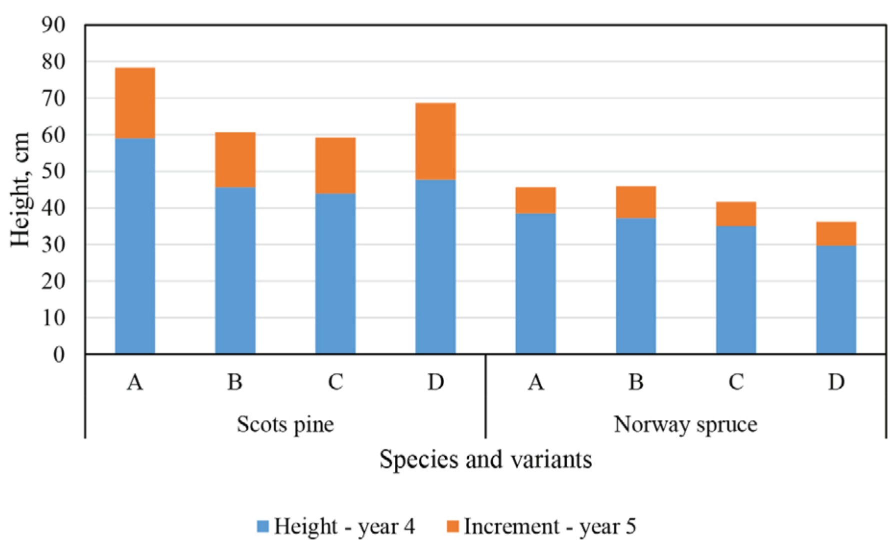

Figure 2. Height growth at experimental plantation of Scots pine and Norway spruce (EP1)

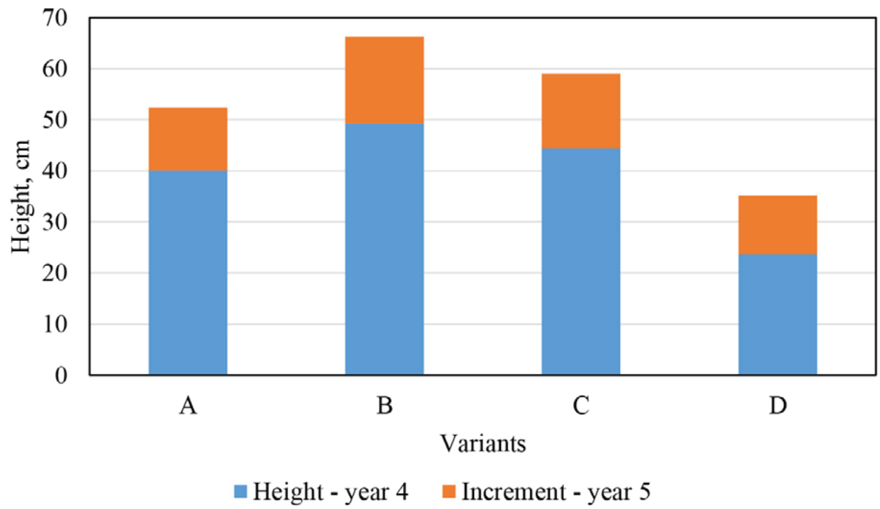

Figure 3. Height growth at experimental plantation of Silver fir (EP2)

afforestation was also observed in variant B (17.0 cm), as the difference compared to other variants was with different significance level (with A and D variant at $p < 0.001$, and with C variant at $p < 0.05$).

Bigger height in the tree shelter variant than the control one was found by Anthony (1982) for *Pinus ponderosa*, by Burger et al. (1996) for *Pinus canariensis*, by Ward, Stephens (1995b) for Norway spruce, by Oliet et al. (2021) for *Pinus halepensis*. Leroy, Caraglio (2003) reported that tree shelters had a significant effect on the height of *Pinus brutia*. The individuals with tree shelters were 1.5 times higher than those without. The authors argue that these results could be related to the micro-environmental conditions inside tube shelters, because the young trees grow more quickly and thus avoid the strong competition they face from dense natural vegetation. Jiménez et al. (2005) explain the height increase of *Juniperus thurifera* seedlings with tree shelters also with the conditions inside tree shelters – higher temperature and lower radiation. Conner et al. (2000) emphasize that, the use of tree shelters significantly increased early height growth. This is probably the result of reduced browsing and increased growth response from microclimate differences inside the shelters as compared to outside (increased carbon dioxide levels, increased relative humidity, decreased transpiration loss, etc. all contributing to a greenhouse effect).

Ground line diameter growth

The best growth in ground line diameter in Scots pine was observed in the control (14.3 mm) – Fig. 4 and the difference was of high statistical significance (at $p < 0.001$). The mean diameter in protected variants ranged from 8.9 mm in variant B to 10.7 in variant A, with the difference between these two variants being significant (at $p < 0.05$). In the case of the Norway spruce, the differences between the individual

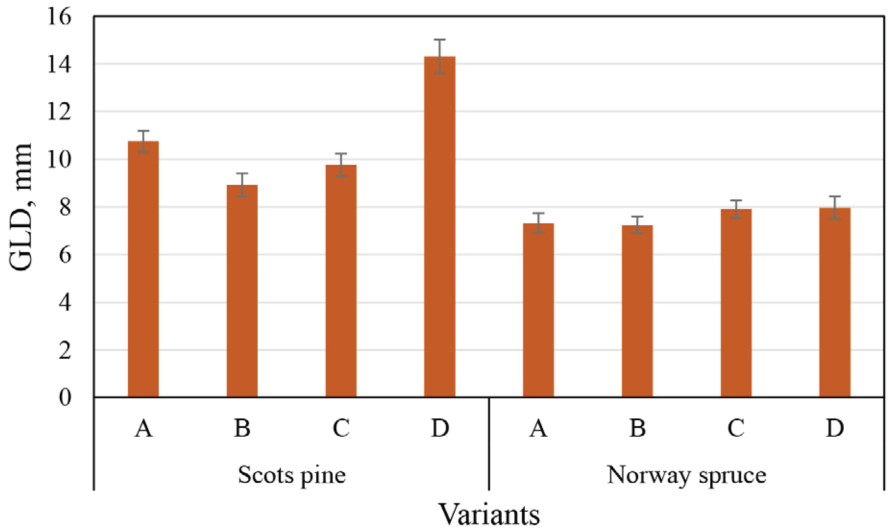

Figure 4. Ground line diameter (GLD) growth at experimental plantation 1 (EP1)

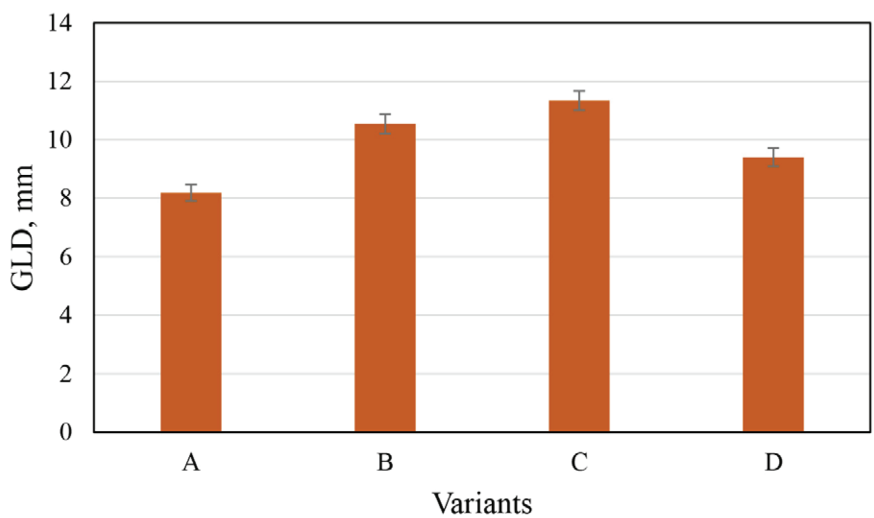

Figure 5. Ground line diameter (GLD) growth of the Silver-fir at experimental plantation 2 (EP2)

variants were minimal and didn't have statistical significance. The average values of the diameter was from 7.2 in variant B to 7.95 in the control. Despite the minimal difference, the average ground line diameter was the largest in the control variant.

In the case of Silver fir in EP 2, the largest average ground line diameter was reported in variant C (11.3 mm), and the smallest in variant A (8.1 mm). Variant A differs significantly from all others (with variants B and C at $p < 0.001$ and with control D – at $p < 0.01$).

Better diameter growth in the control variant compared to the protected variants was found by Burger et al. (1996) for *Pinus canariensis*, by Dupraz (1997) for *Pinus pinea*, by Jiménez et al. (2005) for *Juniperus thurifera*, by Oilet et al. (2021) for *Pinus halepensis*. Burger et al. (1996) explain the weaker diameter growth in seedling in tree shelters with the lower light intensity in them.

Conclusions

The survival rate in the fifth year after the establishment of the experimental plantations was different for different tree species. The highest average survival rate was found for silver fir – 92%, and the lowest for Norway spruce – 53.2%. In all tree species, lower survival was found in the control variant compared to tree shelters variants.

The tree shelters stimulated the height growth for all three tree species. The biggest average height of Scots pine and Norway spruce in the fourth year after the afforestation was found in variant A (Tubex Ventex Classic), and of Silver fir – in variant B (Shelterguard).

The tree shelters affected positively the height increment in the fifth year after afforestation for Norway spruce and Silver fir with the largest effect in variant B (Shelterguard). In the case of Scots pine, the largest height increment was found in the control (D) variant.

The average ground line diameter in the fifth year after afforestation was largest in the control (without tree shelter) for Scots pine and Norway spruce, and for Silver fir – in variant C (Treeguard).

Based on the results for height growth, the use of Tubex Ventex Classic tree shelters can be recommended for Scots pine and Norway spruce, and for Silver fir – Layflat Shelterguard, but the recommendations cannot be definite yet.

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