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EFFECT OF TREE SHELTERS ON THE SURVIVAL AND GROWTH OF DECIDUOUS TREE SPECIES IN NORTH-WESTERN BULGARIA

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Abstract

The effects of tree shelters on the survival, height, and diameter growth of three deciduous tree species – common beech (*Fagus sylvatica* L.), sycamore (*Acer pseudoplatanus* L.) and sessile oak (*Quercus petraea* Matt. (Liebl.) were studied. The study was conducted in two experimental plantations, established in the spring of 2018 in the Training and Experimental Forest Range Petrohan (North-Western Bulgaria). Four experimental variants with tree shelters – Tubex Ventex Classic, Tubex Ventex Clear, Layflat Shelterguard, Layflat Treeguard and a control one (without tree shelters) were used. Twenty to twenty-seven seedlings in three replications of each variant and tree species were planted. The experimental plantation-1 was established on an east-facing flat terrain at an altitude of 600 m. The soil is Grey Luvisol mixture of sandy and clay, slightly stony, and very deep. The site class is medium rich to rich. The experimental plantation-2 is located in a high-density game area. The area is a meadow, aspect north, slope with gradient 8° and an altitude of 850 m. The soil is Dystric-Eutric Cambisol, mixture of sandy and clay, slightly stony and deep. The site class is medium rich to rich. In the autumn of the second and third year after the planting height, height increment and root collar diameter were measured. The survival in both experimental plantations was high but without any statistical significance of the tree shelter. The height growth of all tree species was better in tree shelter variants, with the highest average in that with Tubex Ventex Clear. The root collar diameter growth was not yet significantly affected by the use of tree shelters. As a result of research, ventilated tree shelters (Tubex Ventex Classic and Tubex Ventex Clear) may be recommended as suitable.

Key words: *Acer pseudoplatanus*, root collar diameter, *Fagus sylvatica*, height, *Quercus petraea*, plantation success.

Introduction

The issue of successful survival and growth of forest plantations is particularly important in the context of climate change (high temperatures and prolonged drought in summer and early autumn). The use of tree shelters for protection of seedlings from competing vegetation and browse damage is of particular interest. In addition, a specific microclimate is created around each plant, similar to that in a greenhouse, which helps to accelerate growth and prolong the growing period due to the higher temperature of the growing environment of protected plants (Ponder 1994). In some cases, tree shelters help to better nutrients absorption (Ponder 1995).

The use of tree shelters was first evaluated in United Kingdom in 1978 (Tuley 1985). Later, they became popular in the Mediterranean, especially in dry and degraded site classes. The effect of their use has been the subject of a number of publications. Marques et al. (2001), Sharew and Hairston-Starng (2005), Mechergui et al. (2012), Defaa et al. (2015) proved a positive effect of different types of tree shelters on the survival and height growth of carob tree (*Ceratonia siliqua* L.), cork oak (*Quercus suber* L.), green ash (*Fraxinus pennylvanica*), northern red oak (*Quercus rubra* L.), pin oak (*Quercus palustris*), american sycamore (*Platanus occidentalis*), black walnut (*Juglans nigra* L.), flowering dogwood (*Cornus florida* L.), eastern white pine (*Pinus strobus* L.), *Quercus canariensis* Willd. and *Argania spinosa* (L.) Skeels. Better growth in height using tree shelters has been found also in *Quercus douglasii* Hook & Arn. (McCreary 2011), as well as sycamore, common beech, white oak (*Quercus alba* L.), shingle oak (*Quercus imbricaria* Michx.), bur oak (*Quercus macrocarpa* Michx.) (Bardon 1992, Lantagne 1997, Willoughby et al. 2009).

Different results have been obtained for the effect of tree shelters on diameter growth. According to Mechergui et al. (2012), Stuhlinger (2013), Defaa et al. (2015), it was weaker in the variants with protection and established insufficient stability of the stem.

In most studies, the effect was observed in all types of tree shelters. Bellot et al. (2002) studied the effect of five types of tree shelters (polypropylene – ventilated, unventilated, and made of biodegradable material) on the microclimate, survival, stem, and root growth of kermes oak (*Quercus coccifera* L.) and note that polypropylene tree shelters have significant advantages over those made of biodegradable material.

The territory of Training and Experimental Forest Range in Petrohan (North-Western Bulgaria) is characterised by its highly productive beech forests. The climate is temperate continental, but the annual rainfall is high and stimulates the vigorous development of weeds. In addition, there is a base for intensive management of fallow deer in the region. These are the main prerequisites that hinder successful afforestations. In order to overcome the difficulties, two experimental plantations with four types of tree shelters of the company Tubex (www.tubex-deutschland.de) were established in this territory.

The aim of the research was to study the effects of tree shelters on the survival and height, and root collar diameter growth of common beech, sycamore and sessile oak in the second and third year after the establishment of the plantations.

Material and Methods

The object of the research are two experimental plantations (EP1 and EP2), established in spring 2018 in the Training and Experimental Forest Range in Petrohan (North-Western Bulgaria). EP1 was established on an east-facing flat terrain at an altitude of 600 m (43.187247° N, 23.141207° E). The soil is Grey Luvisol mixture of sandy and clay, slightly stony and very deep. The site class is medium rich to rich (Table 1). The plantation

Table 1. Site classes of the experimental plantations.

Object number	Altitude, m	Aspect	Slope, °	Relief	Type of soil	Site index*
EP1	600	E	3	flat terrain	Gray Luvisol	CD_2
EP2	850	N	8	meadow	Cambisols	CD_2

Note: * In Bulgaria, the system used to evaluate the site classes is based on 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). CD_2 means medium rich to rich and slightly moist soil.

was established after windthrow in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) plantation. The stumps were pushed with a bulldozer and the area was cleaned and levelled. EP2 was located in high-density game area. It is a meadow, aspect north, slope with gradient 8° and an altitude of 850 m (43.177994° N, 23.133380° E). The soil is Dystric-Eutric Cambisol, mixture of sandy and clay, slightly stony and deep. The site class is medium rich to rich. The climate in the region is temperate with an average annual temperature of 10.2 ℃ and annual precipitation of 1004 mm. The duration of the growing season is about 6 to 6.5 months (Kyuchukova et al. 1983, Koleva and Peneva 1990).

During the three-year study period, the average annual temperature was in the range from 11.3 to 12.0 °C, and the annual amount of precipitation from 706 to 979 mm (Table 2). Most of the precipitation fell during the growing seasons. For all three years no minus temperatures in spring and in autumn were reported, i.e. no frost damage was found.

The soil in EP1 is Gray Luvisol, poor in humus, well stocked with nitrogen, poorly stocked with phosphorus and potassium and slightly acidic pH (Table 3). EP2 is located on brown forest soil (Dystric-Eutric Cambisol), poor in humus, moderately stored in nitrogen, poor in phosphorus, moderately stored in potassium and acidic pH.

Table 2. Air temperature and precipitation in the study period in the region of Berkovitsa town.

Year\Month	IV	V	VI	VII	VIII	IX	IV-IX	Annual
				Temperature, °C				
2018	14.9	17.4	19.3	20.8	20.8	16.5	18.3	11.3
2019	10.8	14.1	19.3	20.3	21.9	17.1	17.2	12.0
2020	9.1	15.0	17.9	20.6	21.3	18.7	17.1	11.8
				Precipitation, mm				
2018	27	120	163	154	84	20	568	979
2019	78	49	175	151	24	14	491	706
2020	59	108	91	91	148	25	522	972

Table 3. Soil properties of the study sites.

Object number	Humus, %	pH in H_2O	N, %	P_2O_5, mg/100 g	K_2O, mg/100 g
EP1	2.43	5	0.243	1.5	2.9
EP2	0.87	4.7	0.153	1.5	11

Method

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

Tubex Ventex Classic (Fig. 1A) has a light green colour, is made of polypropylene and has a patented ventilation system. In the lower third of it 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 the plant is protected 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.

Tubex Ventex Clear (Fig. 1B) is similar to Tubex Ventex Classic, but is white and has greater transparency. It is intended for shade-tolerant species, such as common beech.

Layflat Shelterguard (Fig. 1C) 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. 1D) is a stable safety net, especially suitable for protection of seedlings, which grow very quickly in closed tree shelter and the crown becomes heavy and unstable. By using it, the tree can grow in natural conditions,

A B C D

Fig. 1. Tree shelters used in experimental plantations: A – Tubex Ventex Classic; B – Tubex Ventex Clear; C – Layflat Shelterguard; D – Layflat Treeguard.

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 afforestation in EP1 was carried out on 17.04.2018 under the scheme 2.0×1 m, and the tree shelters were installed on 27 and 30.04.2018. In EP2 the afforestation was performed on 19.04.2018 and the installation of the tree shelters – on 03.05.2018. The planting of the seedlings in both experimental plantations was done with a motor drill. Common beech seedlings were 1-year-old, and those of sycamore and sessile oak – 2-year-old. In the autumn of the second and third year after the establishment (2019 and 2020), the height and root collar diameter of the seedlings were measured.

Statistical analysis

The influence of 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 within the tree species and experimental plantation, and for each year of measurement was studied according to GAM model (Wood 2017). The comparison of the effect of the type of tree shelter on the height growth of the individual tree species in EP1 and EP2 was performed using the nonparametric analogue of ANOVA – Kruskal – Wallis test (Mangiafico 2016). In this test, Games-Howell multiple comparisons method was applied.

Results and Discussion

Survival

Our results show that both in the second (2019) and the third (2020) year in both experimental plantations the average survival rate is relatively high – for sessile oak and sycamore – about and over 90 %, and for common beech – 85–80 % (Table 4).

The verification of the significance in the variants shows the following:

- In EP1 of common beech in both the second and the third year there are no significant differences among the variants of the experiment. The control variant (E) differs significantly from variants A and B by sycamore ($p < 0.05$) of the second year and only from variant A in the third year, and from variants A, B and C ($p < 0.05$) by sessile oak for both the second and the third year.

Table 4. Survival by site, species and treatment.

Object number	Treatment	Common beech		Sycamore		Sessile oak	
		2019	2020	2019	2020	2019	2020
EP1	A Tubex Ventex Classic	92	85	99 b	96 b	99 b	99 b
	B Tubex Ventex Clear	89	89	98 b	93 ab	99 b	99 b
	C Shelterguard	83	83	94 ab	88 ab	96 b	96 b
	D Tree guard	88	88	97 ab	96 ab	93 ab	93 ab
	E Control	86	85	82 a	77 a	80 a	80 a
EP2	A Tubex Ventex Classic	77 a	75 a	70	100 b	93	93
	B Tubex Ventex Clear	94 b	94 b	94	93 ab	92	90
	C Shelterguard	91 ab	91 ab	81	93 ab	98	92
	D Tree guard	78 ab	76 ab	73	98 b	95	93
	E Control	86 ab	81 ab	79	82 a	97	92

- In EP2 of the second year by sessile oak and sycamore no significant differences were found among the experimental variants on the survival, and by common beech differences were found only between variants A and B ($p < 0.01$). In the third year, there are no significant differences between the variants in sessile oak, in the case of common beech with sufficient significance only A differs from the B variant ($p < 0.01$), and in the sycamore – the control variant E differs from A and D at $p < 0.05$ (Table 4).

The influence of the tree shelter type on survival is reported in a number of studies, but the results are different. Defaa et al. (2015), Mechergui et al (2012), McCreary et al. (2011), Marques et al. (2001), West et al. (1999) established a positive effect of tree shelters on survival, but according to Stuhlinger (2013) and Sharew and Hairston-Strang (2005) the tree shelter type did not affect survival. Bellot et al. (2002) found that survival was affected by rainfall, not by tree shelter type.

In the present study, no significant differences in survival between protected and unprotected seedlings were observed in common beech in EP1 and sessile oak in EP2. In sycamore in EP1, the survival rate in the control variant was lower, but the differences were significant only with variant A and B of the second and with variant A of the third year.

In EP2, which is located in a high-density game area mass sycamore seedlings without shelters were heavily browsed, mainly by fallow deer. Common beech and sessile oak seedlings seem to be less preferred. In the same experimental plantation, damage to the top shoot was also observed in seedlings that had a height greater than the tree shelter (over 120 cm). With such a height in the third year are 30 seedlings of sycamore from all protected variants and three from sessile oak – two from B and one from C variant. Fallow deer browse probably contributed to stunted seedling growth but not to mortality. For browsing damage by deer to unprotected seedlings of green ash, and less of *Quercus pagoda* Raf. reported by Stuhlinger (2013).

In EP1, the browsing damage of unprotected seedlings were episodic, the problem was the lush grass vegetation, which competes significantly with the seedlings and this leads to the death of a large part of them. In contrast to EP2 in this plantation, the growth of sessile oak is significantly better than that of sycamore and common beech, as site class conditions are more suitable for sessile oak – lower altitude and richer sandy-clay soil (Table 3). The total number of seedlings with a height of more than 120 cm in the protected variants is 37. The mean part of them (21) were of variant B.

Height growth

In the second year after establishment of EP1 in sessile oak the highest seedlings were observed in variant B (Fig. 2), but statistically significance had the difference between B variant of D and E ($p < 0.0001$) and A variant of E ($p < 0.05$). No significant differences were found of the sycamore, and of the common beech with the highest statistical significance B variant differed from E (without tree shelter) at $p < 0.0001$. There was a significant influence of the variant in height increment of sessile oak and the common beech in the third year at $p < 0.0001$. In the sycamore, the differences in height increment were not statistically significant.

In the second year after the establishment of EP2 (Fig. 3), the highest seedlings of the sessile oak were observed in vari-

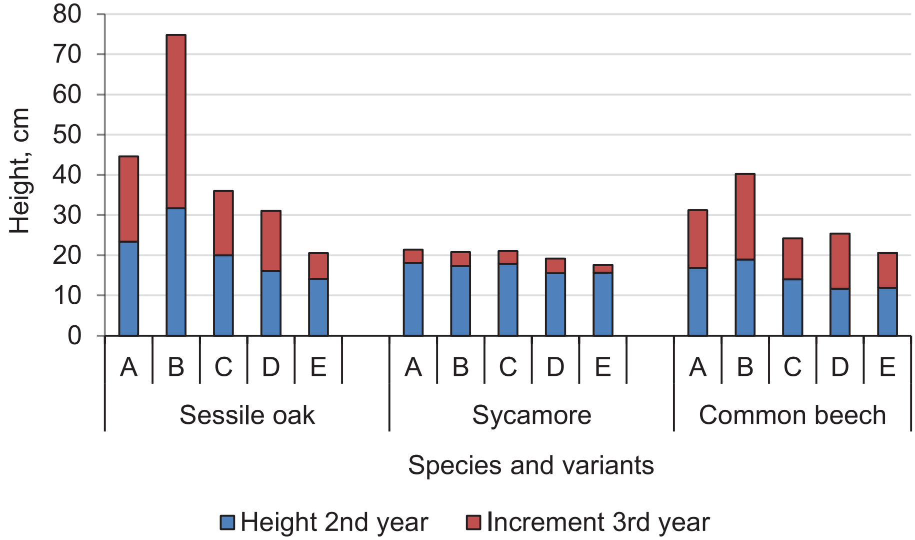


Fig. 2. Height growth at EP1.

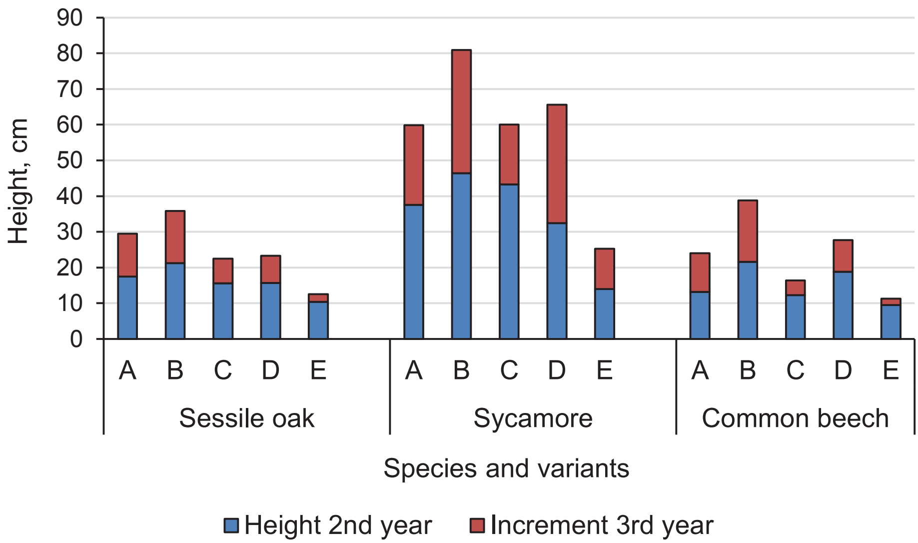


Fig. 3. Height growth at EP2.

ant B. The difference was significant only to variant D and control E at $p < 0.0001$. Of the sycamore, the variant was not statistically significant. Of common beech, variants B and D differed significantly from control E (B at $p < 0.0001$ and D at $p < 0.05$).

The differences in height growth in the third year for sessile oak and common beech were statistically significant, while for sycamore were not significant.

Similar results confirming the positive effect of tree shelters on height growth were obtained for northern red oak (Bardon 1992), for northern red oak, sycamore and common beech (Lantagne 1997), for *Fraxinus excelsior* L. and *Acer pseudoplatanus* (Willoughby et al. 2009), for *Quercus douglasii* (McCreary et al. 2011).

Root collar diameter growth (RCD)

In EP1, the best RCD growth and increment was found of the sessile oak and common beech (Fig. 4), but the differences were not statistically significant. No differences were found between the variants of sycamore, as RCD increment in all variants was negligible.

In EP2 better RCD growth and increment was observed of the sycamore. Of the sessile oak and common beech its growth and especially increment in this indicator was negligible (Fig. 5). Of all three species, no statistically significant differences in RCD were found between the experimental variants.

The results of our studies on RCD growth of protected and unprotected seedlings were in agreement with the work of other researchers, who also found no significant differences by using tree shelters (Defaa et al. (2015). Some of them reported even weaker RCD growth of protected than unprotected plants (Mechergui et al. 2012, Sharew and Hairston-Starng 2005).

Comparison of height growth

In the second year (2019) statistically significant differences in common beech height growth were found in variants D (at $p < 0.0001$) and in the E variant (at $p < 0.05$). In variant D (Tree guard), the height growth was better in EP2, and in the control in EP1 (Fig. 6A).

In the third year (Fig. 6B), the average height of the common beech was higher and statistically significant in variants A (at $p < 0.05$), C (at $p < 0.001$) and control E

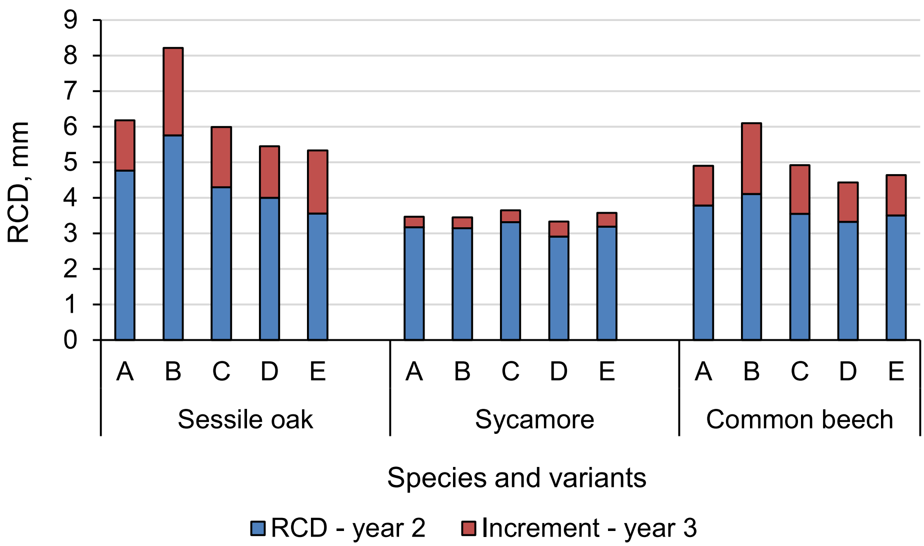


Fig. 4. RCD growth at EP1.

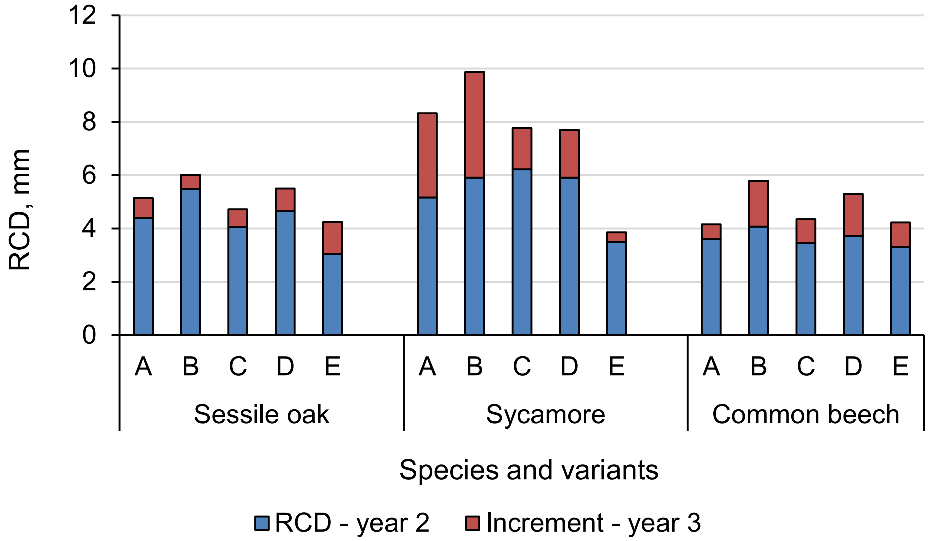


Fig. 5. RCD growth at EP2.

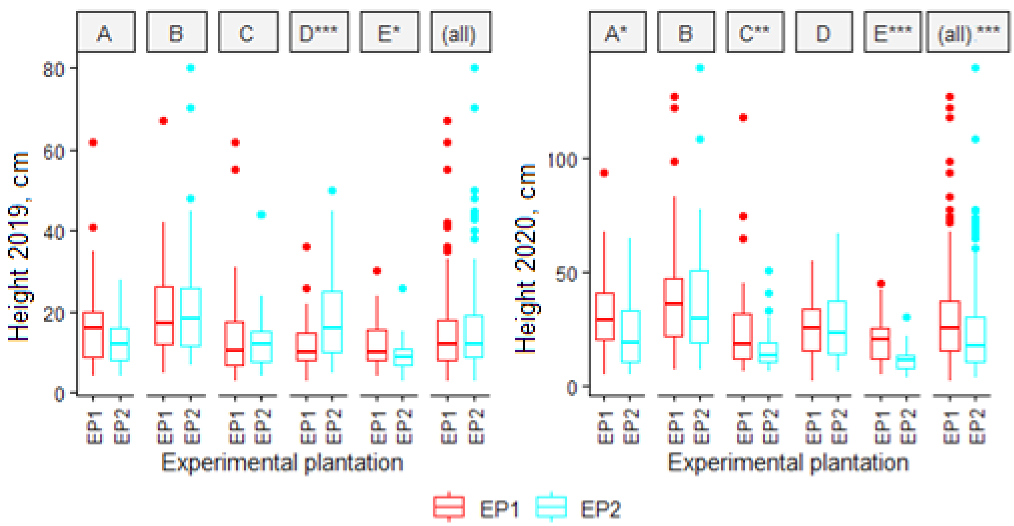


Fig. 6. Comparison of the height growth of the common beech: A – in the second year (2019) and B – in the third year (2020).

Note: Significance codes: *** – 0.0001; ** – 0.001; * – 0.05.

(at $p < 0.0001$).

The weaker height growth in the variant E (without tree shelter) of EP2, both in the second (Fig. 6A) and in the third year (Fig. 6B) was due to the mass browsing damage, which led to a smaller growth.

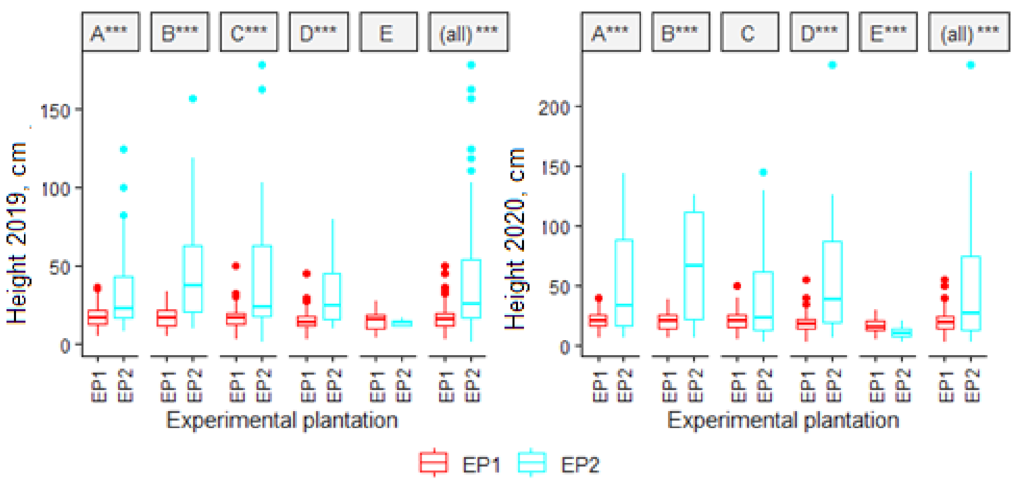
Of the sycamore, in the second year, the average height was higher in all protected variants (A, B, C and D) in EP2, and the differences were of high statistical significance (at $p < 0.0001$) – Fig. 7A. In the third year the average height was higher in all protected variants (Fig. 7B), but the differences were statistically significant in variants A, B and D at $p < 0.0001$. In the control the difference is in favour of EP1. The better height growth of the sycamore in EP2 was due to the fact that the site class and climatic conditions in the middle mountain belt are more suitable for this tree species. The worse results in the control variant can be explained by the browsing damage in EP2, where the game concentration is especially high and without protection no seedling can grow and develop normally.

Of the sessile oak, the total height growth in both the second (Fig. 8A) and the third year (Fig. 8B) was better in EP1, but with different statistical significance. Statistically significant were the differences in variants B Tubex Ventex clear and control variant of the second year, and in the third – in variants B Tubex Ventex Clear, C Layflat Shelterguard and control E.

The better height growth of the sessile oak in EP1 could be explained by the ecological optimum of this tree species, which is mainly in the lower belt at lower altitudes.

Conclusions

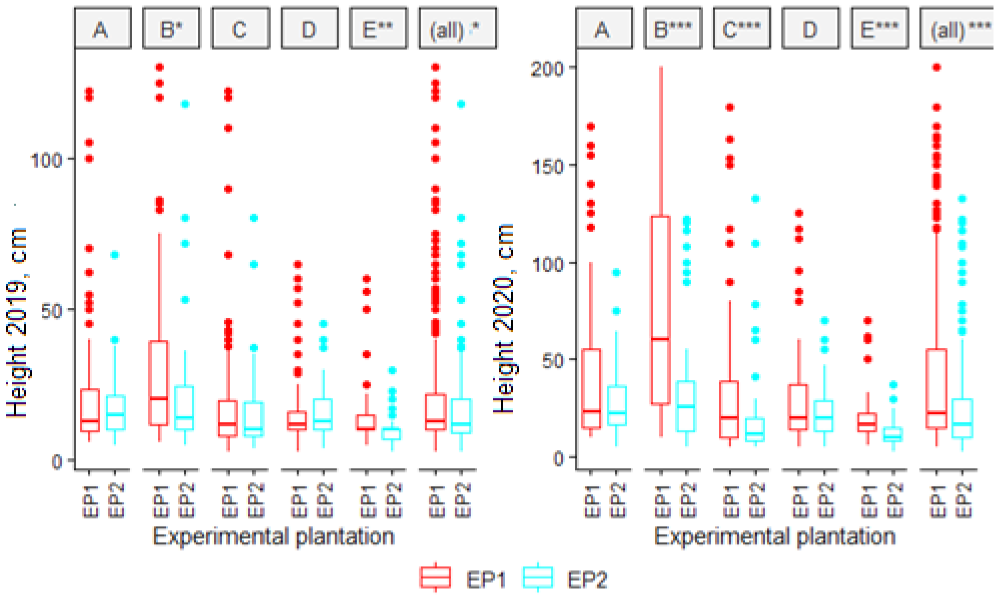
In both the second (2019) and the third (2020) year after afforestation in both experimental plantations, the average survival rate is relatively high – for the sessile oak and sycamore – about 90 % and for the common beech – 85–80 %, but there are no significant differences between protected and unprotected variants. In addition, the root collar diameter growth is not yet significantly affected by the use of tree shelters.



A B

Fig. 7. Comparison of the height growth of the sycamore: A – in the second year, 2019 and B – in the third year, 2020.

Note: Significance codes: *** – 0.0001; ** – 0.001; * – 0.05.



A B

Fig. 8. Comparison of the height growth of the sessile oak: A – in the second year, 2019 and B – in the third year, 2020.

Note: Significance codes: *** – 0.0001; ** – 0.001; * – 0.05.

The tree shelters stimulate the height growth of all three tree species. The highest average height was found in variant B Tubex Ventex Clear in EP2 for all species, and in EP1 – for sessile oak and common beech.

The height growth of the sycamore in all variants in EP2 is significantly better than in EP1, which can be explained by the more suitable growth conditions for this species at higher altitudes. A similar explanation could be made for better height growth of the sessile oak in EP1 at lower altitudes but richer site class.

Ventilated protectors could be recommended as suitable at this stage. In the third year, of the sessile oak from EP1 12.5 % of the surviving seedlings in variant A and 26 % – from variant B and from 10 to 15 % of the sycamore seedlings from EP2 were higher of the tree shelters.

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