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Study of the Effects of Polypropylene Tree Shelters and Hydrophilic Polymers on Growth, Survival, Health and Physiological Condition of Pedunculate Oak Seedlings (*Quercus robur* L.)

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ABSTRACT

This paper presents the results of eight years of scientific research on the effect of polypropylene shelters (Tully tubes) and hydrophilic polymers on growth, survival, health and physiological condition of pedunculate oak seedlings (*Quercus robur* L.). The experiment was established in 2014 on relative forest soil, on partially forested land in subcompartment 35a, forest management unit Kragujna, which is managed by the Forest Administration Vinkovci, Forest Office Županja. In the autumn of 2014, one-year-old bare-rooted pedunculate oak seedlings were planted as a randomized block design experiment - four blocks with four repetitions. Four types of planting were tested: seedlings without a polypropylene shelter, without the addition of Zeba hydrophilic polymer granules (S variant), seedlings without a polypropylene shelter, with the addition of Zeba hydrophilic polymer granules (SP variant), seedlings with a polypropylene shelter, without the addition of Zeba hydrophilic polymer granules (SS variant), and seedlings with a polypropylene shelter, with the addition of Zeba hydrophilic polymer granules (SSP variant). The experiment was established as a result of considering the long-term problem of difficulties in natural regeneration. Disturbances in natural regeneration are certainly caused by increasing climate changes (floods, long-term droughts, storms, hailstorms, etc.) and other unfavourable biotic and abiotic factors that cause a significant reduction in quantities and/or an almost complete absence of pedunculate oak acorn yield. Due to the aforementioned circumstances, in the very near future we will be forced to resort more often to different forms of artificial forest regeneration, such as regeneration by planting sheltered seedlings that are less exposed to risks and challenges during survival, and which have greater competitiveness in relation to other vegetation on the regeneration surface (higher growth). Nowadays, this method of regeneration is used mostly for filling in places where, for various reasons, natural regeneration has been unsuccessful on several occasions and over a long period of time, and/or where there are great difficulties in carrying out natural regeneration (floods, areas damaged by fires, game damages and competition of weeds). This paper presents the results of scientific research after five periodic measurements, i.e. after the first, second, fifth, sixth and eighth growing season. The results show that even after the eighth growing season, seedlings protected with a polypropylene shelter have greater survival rate and greater height growth than unprotected seedlings. The highest survival rate was found in seedlings protected with a polypropylene shelter, with the addition of Zeba hydrophilic polymer of 82.14% (SSP variant), while unprotected seedlings with the addition of Zeba hydrophilic polymer (SP variant) had the lowest survival rate of 62.63%. The highest growth was recorded on seedlings protected with a polypropylene shelter, with the addition of Zeba hydrophilic polymer (SSP variant) amounting to 202.75 cm, while on average the smallest seedlings were those without polypropylene shelter protection and without the addition of Zeba hydrophilic polymer (S variant), amounting to 129.02 cm.

Keywords: forest regeneration; polypropylene shelter; Zeba hydrophilic polymer granules; seedlings; height growth; survival; pedunculate oak

INTRODUCTION

Degradation of pedunculate oak lowland forests, i.e. the dieback of pedunculate oak (*Quercus robur* L.) and narrow-leaved ash (*Fraxinus excelsior* Vahl.) as a result of climate change and the influence of various biotic and abiotic factors that cause variability in yield, the yield reduction or almost complete absence of pedunculate oak acorn yield (Gradečki-Poštenjak et al. 2011) would as a result certainly require a more or less intense artificial forest regeneration by planting seedlings, in exchange of natural regeneration, which is still prevailing today. Furthermore, increasing climate changes with their various extreme weather events (floods, long-term droughts, storms, hailstorms, etc.) and calamities of autochthonous and especially invasive species will force us to rationalize the management of collected seeds (acorns) to a much greater extent (Garcia-Barreda et al. 2023). This implies a reduction in the required amount of seeds per regeneration area, and thus a lower need for work force to perform these works (Liović et al 2013). Planting seedlings without a polypropylene shelter (hereinafter: shelter) is financially more expensive than planting seedlings with a shelter (Liović et al. 2013) since it requires a larger number of seedlings per area, as well as more frequent and extensive cultivation work to care for seedlings after planting. In 1979, English forester Graham Tuley introduced the first shelters for seedling protection (Tuley 1983, Tuley 1985). The advantages of shelters are rapid growth and height growth and better seedling survival, which have been reported by numerous authors (Potter 1988, Bainbridge 1991, Kerr 1992, Lantagne 1995, Liović 1997, Conner et al 2000, Liović et al 2001, Liović et al 2013, Liović et al 2019, Benko 2020). The use of shelters positively affects growth and survival as well as transplant stress that usually occur after seedlings is moved from the nursery to the forest habitat, a condition also known as "transplant shock". Such a condition is associated with the loss of a significant part of the root system when taking out seedlings, as well as stress caused by insufficient moisture and nutrients, which can often lead to higher mortality in the first growing season (Rietveld 1989, Struve and Joly 1992, Jacobs et al. 2005). Also, dense weeds quickly overgrow the seedlings, overshade them, and thereby affect the process of photosynthesis, which affects their survival and height growth (Myers 1988). Oak seedlings are particularly sensitive to competition from weeds, shrubs and other competitive species that reduce available sunlight, moisture and nutrients in the soil (Matić 1996). Pedunculate oak seedlings protected with a shelter achieved a three times higher average height compared to seedlings without shelter protection, and such height growth would enable them to quickly leave the zone of competition with weeds and achieve better survival rate (Liović et al. 2019). In addition to protection from weeds, shelters provide shade for the seedlings, i.e. reduce solar radiation, slow down the evaporation of moisture, protect seedlings from sudden changes in temperature, and increase the humidity inside the shelter by condensing moisture on the walls (Kjelgren and Rupp 1997, Del Campo et al. 2006, Bergez and Dupraz 2009, Ghazian et al. 2020). Also, game has a detrimental effect on the growth of seedlings because animals bite off the end buds and thus reduce the seedlings competitiveness in relation to the weeds that surround them (Jeffrey 1995, Gill 2001, Watt et al. 2003). The influence of game on the natural regeneration in pedunculate oak stands during shelterwood cutting was research by Krejči et al. (1997), Krejči et al. (2001), Krejči and Dubravac (2004). The use of shelters also reduces the attack of powdery mildew on oak (*Microsphaerae alphitoides* Griff et Maubl) because of the specific climate inside the shelter (Liović 1997, Liović et al. 2019, Benko 2020).

Although shelters have been in use for more than 40 years, disadvantages such as necessity of removing the old shelters after usage and not using biodegradable materials for their construction are the reasons why public may not support these modern forestry technologies (Graf 2022). Since European environmental regulations on plastics are becoming stricter, it will be necessary to use environmentally friendly, biodegradable shelters (European Commission 2021).

The main goal of this study is to determine whether and how the application of polypropylene tree shelters and the addition of hydrophilic granules (polymers) affect the growth, survival rate and overall health of planted pedunculate oak seedlings for the purpose of restoring the oak stand.

Although, the importance and applicability of the results will become more pronounced in the upcoming inevitable and increasingly frequent extreme climate changes In addition to climate changes, numerous biotic and abiotic factors also contribute to the ever-increasing pressure on forest ecosystems, which, with their unfavourable effects, also affects the (ir)regularity of the acorn yield, thus impeding the natural regeneration of our most valuable stands of pedunculate oak as well as sessile oak (Harris RMB et al. 2018).

MATERIALS AND METHODS

The experiment is a continuation of a multi-annual scientific research, whose results of monitoring survival and height growth were published in scientific journal SEEFOR (Liović et al. 2019).

Experimental area is located in the lowland continental part of the Republic of Croatia and according to the Köppen climate classification it belongs to the Cfwbx climate. The average annual air temperature is 12.4°C, and the average annual air temperature during the growing season is 18.9°C. The average annual level of precipitation is 686 mm, while the average annual level of precipitation during the growing season is 382 mm.

The experiment was established on relative forest soil, partially forested only with scarce shrubby and grassy vegetation, in Forest Administration Vinkovci, Forest Office Županja, forest management unit Kragujna 35a. The area of the subcompartment is 2.77 ha and the altitude is 80–83 m (from the forest management plan for forest management unit Kragujna). The experimental area is a light zone along the forest road, and next to the road there is also a canal with an additionally widened belt for the purpose of its maintenance. The experimental plots were located on the edge of the micro-depression area along the edge of old forest which was naturally regenerated by shelterwood cutting and it belonged to the forest community of pedunculate oak and common hornbeam (*Carpino betuli - Quercetum roboris* Rauš 1969).

In the autumn of 2014, one-year-old bare-rooted pedunculate oak seedlings were planted: without shelter protection and without the addition of polymers (hereinafter: S variant), without shelter protection and with the addition of polymers (hereinafter: SP variant), with shelter protection and without the addition of polymers (hereinafter: SS variant) and with shelter protection and with the addition of polymers (hereinafter: SSP variant). The scheme of the experiment is shown in detail in Figure 2.

To protect the seedlings, 1.2-m-high double-layer polypropylene shelters resistant to UV rays were bolted by a wooden stake and attached with two plastic ties. When planting the SP variant and the SSP variant, polymer was added to the soil in the amount of 4 g per planting hole. A polymer that was used is based on corn starch that can absorb water up to 500 times its volume, creating a hydrogel around the roots of the plant, thus retaining and if necessary releasing the water for the plant. Due to their composition (glucose molecules), the granules are non-toxic, biodegradable, and pH-neutral, and they are food for microorganisms in the soil as well (Vizitiu et al. 2012).

Variants of protection and planting of seedlings, with plant spacing, and the total number of seedlings are shown in Table 1. Seedlings were planted in pits with a spacing of 1.5x1 m in the variants without a shelter, and 3x2 m in the variants with a shelter. The experiment was conducted as a randomized block design, including four blocks with four repetitions. A total of 2,160 seedlings were planted.

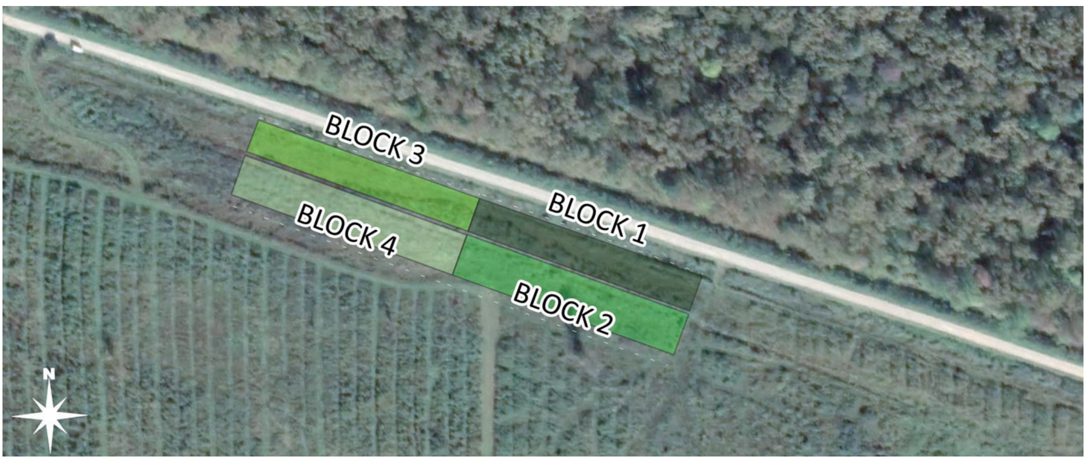

Figure 1. Location of the experiment Kragujna 35a, Forest Office Županja, Forestry Administration Vinkovci (682613 E, 4992867 N (HTRS96/TM)).

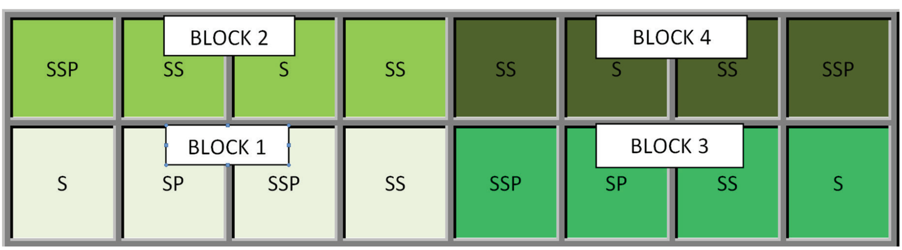

Figure 2. Experiment scheme - randomized block arrangement of experiment, four blocks with four repetitions.

Table 1. Variants of protection and planting of seedlings, plant spacing and the number of seedlings (N).

Variant	Protection	Polymer	Plant spacing (m)	N (total)	N (per ha)
S	Without shelter	Without polymers	1.5x1	800	6,667
SP	Without shelter	With polymers	1.5x1	800	6,667
SS	With shelter	Without polymers	3x2	280	1,667
SSP	With shelter	With polymers	3x2	280	1,667

During May 2015 and 2016, in a circle with a diameter of 1 meter around each shelter, shrubby and grassy vegetation was sprayed with herbicide based on the active substance glyphosate in order to reduce the negative impact of weeds (Liović et al. 2019). In the following years, there was no treatment with herbicides, nor with fungicides and insecticides.

During the growing season of 2020 and 2022, manual care of the seedling was carried out in order to free the end buds of plants and accelerate their height growth.

In the period from 2015 to 2022, at the end of the growing season, in five periodic measurements (2015, 2016, 2019, 2020, and 2022), survival rate and plant heights were measured. Seedling heights were measured with a measuring stick with an accuracy of 1 cm. Recorded data of survival and measured heights were analysed in MS Excel and include average value of survival rate and quantitative properties of height by standard indicators: mean, median, minimum and maximum, standard deviation (SD) and analysis of variance (ANOVA) for the quantitative property of height, as well as the Tukey-Kramer post-hoc test (α=0.05) to compare the differences between the varieties.

RESULTS AND DISCUSSION

Survival

The results in Table 2 and Figure 3 show that, after eight growing seasons and five measurements, i.e. after the first, second, fifth, sixth and eighth growing season, the planting of seedlings protected by shelters (SS and SSP variants) provides better conditions for survival, while seedlings planted without shelters (S and SP variants) have lower survival rates due to the fact that they are more exposed to harmful factors.

Seedlings of SSP variant have the best survival rate of 82.14%, while seedlings of SP variant have the lowest survival rate of 62.63%. Seedlings of SS variant have a survival rate of 80.00%, while seedlings of S variant have a survival rate of 66.75%. Potter (1998), Liović et al (2013, 2019) and Benko (2020) have also found that the survival rate of seedlings protected by shelters is higher than of those without shelters.

During the measurement all living seedlings were considered and measured. In 2019 some of seedlings seemed to be dry; however in 2020 they grow again from the roots of the plant also evident from number of survived seedlings and minimum height of seedlings in Table 6 and survival rate in Table 2.

The differences in survival between variants of seedlings with and without shelters are shown in Table 3. The variation in survival rates in favour of seedlings of SS variant compared to the seedlings of S variant increases with the number of growing seasons: 5.99% in 2015, 10.42% in 2016, 17.10% in 2019, 15.43% in 2020, and 16.56% in 2022. After eight growing seasons, the seedlings of SS variant had 16.56% better survival rate compared to the seedlings of S variant.

Also, the difference in survival rates increases in favour of the seedlings of SSP variant compared to the seedlings

Table 2. Total number (N) and survival of seedlings during measurements in S and SP variants (without shelters), and SS and SSP variants (with shelters) after the first, second, fifth, sixth and eighth growing season.

Variant	N	2015	2016	2019	2020	2022
				(%)		
S	800	86.46	79.50	69.88	70.38	66.75
SS	280	91.97	88.75	84.29	83.21	80.00
SP	800	85.54	84.75	69.75	69.75	62.63
SSP	280	95.57	87.00	86.07	86.43	82.14

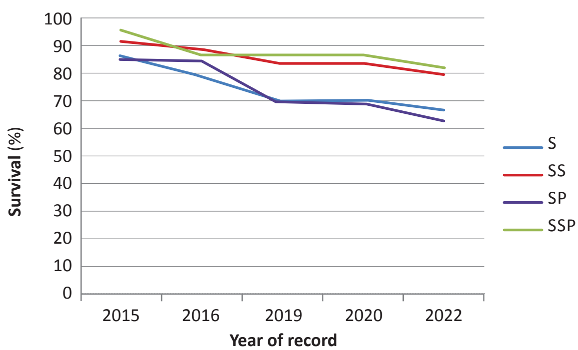

Figure 3. Survival of seedlings without shelters (S and SP variants) and seedlings with shelters (SS and SSP variants) after the first, second, fifth, sixth and eighth growing season.

of SP variant with the number of growing seasons: 10.49% in 2015, 2.59% in 2016, 18.96% in 2019, 19.30% in 2020, 23.76% in 2022. After eight growing seasons, the seedlings of SSP variant had 23.76% better survival rate than the seedlings of SP variant.

In the eight-year research period, the average annual level of precipitation (684 mm) corresponds to the average level of precipitation for the period 1991–2020 (Vučetić and Anić 2021). Table 4 shows the total monthly and annual precipitation according to data from the nearest meteorological station Gradište, of the Croatian Meteorological and Hydrological Service (DHMZ), which is located 15 km in aerial distance from the experiment location. The first year after planting had below average annual precipitation (2015, 644 mm), the second year was above average (2016, 746 mm), while the third year (2017) was the driest, with 581 mm. Most precipitation was recorded in 2018 (852 mm), while 2019 was above average (717 mm), and 2020 and 2021 were close to average (657 mm and 671 mm, respectively). The year 2022 was dry below average (605 mm).

However, Table 5 shows the average annual level of precipitation during the growing season (382 mm) of the research period (2015–2022) also corresponds to the average level of precipitation for the period 1991–2020 (Vučetić and Anić 2021).

Nevertheless, if the data of the average levels of precipitation during the growing season for the research period are analysed, a significant deviation from the average levels of precipitation can be observed, especially in 2015, 2017, 2021 and 2022. While 2016 and 2020 had values closest to the average, 2018 and 2019 were above average in terms of precipitation during the growing season.

Given the same conditions regarding moisture, the planting of seedlings protected by shelters (SS and SSP variants) provided better conditions for survival, while seedlings not protected by shelters (S and SP variants) had a lower survival rate. Other authors (Kjelgren and Rupp 1997, Del Campo et al. 2006, Bergez and Dupraz 2009, Ghazian et al. 2020) have found the advantages of the shelters by providing shade for the seedlings, slowing down the evaporation of moisture, protecting the seedling from sudden temperature changes and increasing the humidity inside the shelter by condensing moisture on the walls.

Height

The results of descriptive statistics of pedunculate oak seedlings heights with and without shelters, as well as with and without polymer addition, during the research period (2015–2022), i.e. after the first, second, fifth, sixth and eighth growing season are shown in Table 6. Seedlings protected by shelters had a higher average height than

Table 3. The difference in the survival of seedlings of different variants in planting after the first, second, fifth, sixth and eighth growing season.

Comparison of variants	2015	2016	2019	2020	2022
			(%)		
SS and S	5.99	10.42	17.10	15.43	16.56
SSP and SP	10.49	2.59	18.96	19.30	23.76

Table 4. Monthly and annual precipitation according to data from the nearest meteorological station Gradište (DHMZ) for the research period (2015–2022).

Year	Precipitation (mm)												
	Month												Annual
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
2015	69	70	46	24	99	26	10	49	103	90	57	2	644
2016	71	71	71	58	36	44	112	51	95	66	69	2	746
2017	27	46	45	68	43	42	72	17	74	59	43	47	581
2018	2	66	77	29	53	257	88	54	60	24	42	40	852
2019	43	24	20	97	113	94	87	37	60	26	65	51	717
2020	17	40	35	17	76	113	72	77	21	82	21	86	657
2021	59	41	33	51	47	22	83	50	11	90	105	82	671
2022	15	32	9	69	52	39	12	74	119	29	89	65	605
AVERAGE	38	49	42	52	65	80	67	51	68	58	61	47	684

Table 5. The average level of precipitation during the growing season (IV-IX month) for the research period (2015–2022) (DHMZ).

Year	Precipitation (mm)						
	Month						Total
	IV	V	VI	VII	VIII	IX	
2015	24	99	26	10	49	103	310
2016	58	36	44	112	51	95	395
2017	68	43	42	72	17	74	314
2018	29	53	257	88	54	60	542
2019	97	113	94	87	37	60	488
2020	17	76	113	72	77	21	377
2021	51	47	22	83	50	11	262
2022	69	52	39	12	74	119	365
AVERAGE	52	65	80	67	51	68	382

seedlings without shelters in all five measurements during the monitoring period of eight growing seasons.

After the eighth growing season, the average height of seedlings of S variant was 129.02 cm (range 28–390 cm), and the average height of seedlings of SS variant was 176.27 cm (range 50–353 cm). The average height of seedlings of SP variant was 137.26 cm (range 23–410 cm), and the average height of seedlings of SSP variant was 202.75 cm (range 38–412 cm). Seedlings of SSP variant had the biggest height growth of 202.75 cm, while on average the smallest seedlings were of S variant, achieving the height of 129.02 cm.

In the case of seedlings without shelters (S and SP variants), the transplant shock that lasts at least two years (the first and the second growing season) is visible on the chart in Figure 5, during which the seedlings did not increase in height, while seedlings with shelters increased in height significantly already after the first growing season. Transplant stress is a condition that occurs during transplanting and is associated with the loss of a significant part of the root system when removing seedlings, as well as lack of moisture and nutrients, which often leads to higher mortality in the first growing season (Rietveld 1989, Struve

Figure 4. Detail of the experimental planting with shelters, Forest Office Županja, FMU Kragujna, subcompartment 35a (photo: Dubravac, May 2020).

and Joly 1992, Jacobs et al. 2005). Based on Figure 5, it can be concluded that the use of shelters has a favourable effect on height growth, alleviates the transplant stress and thus has a positive effect on survival (Figure 4). The above has been confirmed by previous research (Liović et al. 2019, Benko 2020), which stated that the height of oak seedlings protected by shelters is greater than that of seedlings without shelter protection.

The average heights in the period from the planting of seedlings in 2014 until 2022 are shown in Figure 6. The seedling image presents the difference in height growth from planting to the end of the second growing season,

Table 6. Number of survived seedlings (N) and descriptive statistics of height, during measurements of pedunculate oak seedlings without shelters (S and SP) and with shelters (SS and SSP) after the first, second, fifth, sixth and eighth growing season.

Year	Variant	N	Height (cm)				
			Mean	Median	Min.	Max.	SD
2015	S	694	34.36	34	5	73	9.70
2016		687	39.04	37	9	79	12.62
2019		562	73.05	70	12	250	36.17
2020		566	94.64	88	18	298	46.63
2022		537	129.02	122	28	390	62.55
2015	SP	687	34.71	35	5	69	9.41
2016		681	37.97	38	4	82	12.01
2019		561	83.82	77	17	213	43.74
2020		561	102.27	95	20	290	52.65
2022		504	137.26	129	23	410	67.14
2015	SS	258	56.64	55	10	115	17.37
2016		249	117.27	132	22	199	41.27
2019		236	146.04	150	21	251	41.02
2020		233	160.54	158	36	290	38.76
2022		224	176.27	164	50	353	49.64
2015	SSP	270	54.94	52	5	115	17.26
2016		245	128.72	138	38	187	33.42
2019		244	167.63	165	50	293	35.45
2020		245	182.43	173	64	340	46.25
2022		233	202.75	187	38	412	61.50

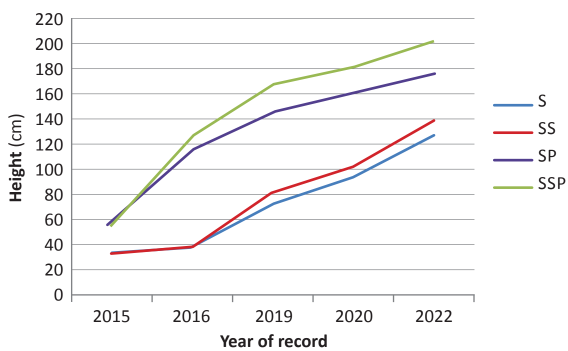

Figure 5. Height growth of seedlings, during measurements of seedlings without shelters (S and SP variants) and seedlings with shelters (SS and SSP variants) after the first, second, fifth, sixth and eighth growing season.

when seedlings with shelters (SSP and SS variants) had three times higher average height than seedlings without shelters (S and SP variants).

In the period from the end of the first to the end of second growing season seedlings of SSP variant had the highest annual height growth (73.78 cm). In the period from the third to the end of the fifth growing season (coloured green), the SSP and SS variants had slightly more than twice the average height of seedlings of the S and SP variants. Seedlings of SP variant had the highest height growth (45.85 cm). In the period from the end of the fifth to the end of the sixth growing season (coloured purple), the seedlings of SSP and SS variants also had about twice the average height of the seedlings of S and SP variants. Seedlings of S variant had the highest annual height growth (21.59 cm). In the period from the seventh to the eighth growing season (coloured blue), the seedlings of SSP and SS variants had about 1.5 times the average height of the seedlings of S and SP variants. Seedlings of SP variant had the highest height growth (34.99 cm).

By analysing the data from Table 7, we found a significant difference in the height of plants protected by shelters, which was supported by ANOVA statistical method, during which a significant difference in the average plant height (ANOVA F=48.09, p<0.001) was found within the variants.

The statistical results were processed with an additional Tukey-Kramer post-hoc test in order to determine whether there is a statistically significant difference between the variants of planting seedlings of SS variant with an average height of 176±49.64 cm and seedlings of SSP variant with an average height of 203±61.50 cm. Seedlings of SSP variant were on average 26.48 cm higher than the seedlings of SS variant, and they also had a statistically significant difference (p=0.000000574). Tukey-Kramer post-hoc test revealed statistically significant differences in the average height of the seedlings of SSP variant compared to the seedlings of SS variant, which is why it can be concluded that the addition of polymers influenced the increase of the average height of seedlings protected by shelters.

In the case of seedlings of S variant with an average height of 129±62.55 cm and seedlings of SP variant with an average height of 137±67.14 cm, the difference in average height was 8.25 cm, and the variants had no statistically significant difference (p=0.020449), so it can be concluded that in this case the effect of polymers on height growth was almost insignificant.

Table 7. ANOVA analysis of variance for height.

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1120852	6	186808.7	48.09493	3,8839E-54	2.104652
Within Groups	5791291	1,491	3884.165			
Total	6912143	1,497				

SS - sum of squares, df - degrees of freedom, MS - mean sum of squares, F - *F*-statistic, F crit - *F* critical value.

Figure 6. Average height growth and seedling heights by measurement periods.

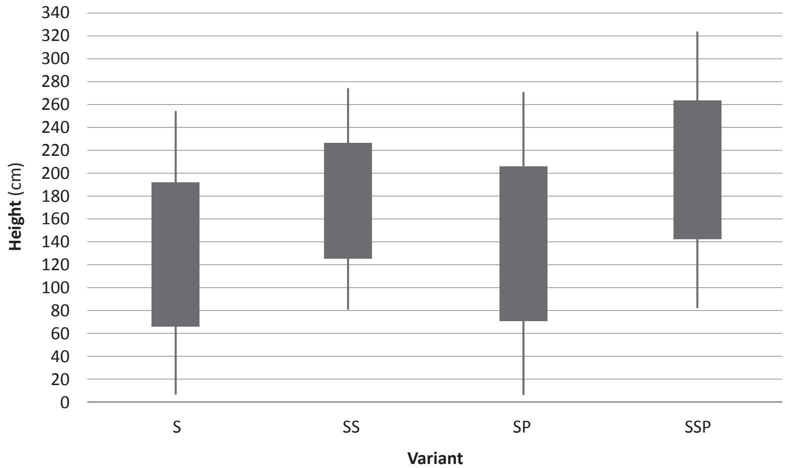

Figure 7. Average height of seedlings by measurement periods (Box-and-whisker chart). The upper and lower bounds of the rectangle represent the range within which there is a standard deviation of height. The line segment above and below the rectangle represents the circumference within which there is 1.96 standard deviations of seedling height, which includes 95% of all data).

CONCLUSIONS

During five measurements (2015, 2016, 2019, 2020 and 2022) in eight growing seasons (2015–2022), survival and seedling heights of S, SP, SS and SSP variants were recorded and measured.

Seedlings of SSP variant had the highest survival rate, amounting to 82.14%, along with the seedlings of SS variant with a rate of 80.00%. Seedlings of SP variant had the lowest survival rate of 62.63%, while the survival rate of the seedlings of S variant was slightly better, amounting to 66.75%. Seedlings of SSP variant had a 23.76% better survival rate compared to SP-variant seedlings, while SS-variant seedlings had a 16.56% better survival rate compared to S-variant seedlings.

Seedlings of SSP variant had the highest height growth, with an average height of 202.75 cm (range 38–412 cm), along with seedlings of SS variant with an average height of 176.27 cm (range 50–353 cm). The average height of SP variant seedlings was 137.26 cm (range 23–410 cm), and S-variant seedlings had the lowest average height of 129.02 cm (range 28–390 cm).

Statistically significant differences were found with regard to SS and SSP variants. The seedlings of SSP variant were on average 26.48 cm higher than the seedlings of SS variant, and it can be assumed that the addition of the polymers had a favourable effect on the increase in the average height of the seedlings protected by shelters due to the synergistic effect of the polymers and the shelters. For seedling of S variant and SP variant, the difference in average height was 8.25 cm, which indicates that these variants had no statistically significant difference (the effect of polymers on height growth is almost insignificant in this case).

Author Contributions

ŽT, BL and TD conceived and designed the research, RL, BL, TD and SŠ carried out the field measurements, RL processed the data and performed the statistical analysis, ŽT supervised the research RL, TD, BL and ŽT wrote the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

REFERENCES

Bainbridge DA, 1991. Successful tree establishment on difficult dry sites. In Proceedings of Third International Windbreaks and Agroforestry Symposium, Ridgetown, Canada, pp. 78-81.

Benko M, 2020. Sustavna praćenja konverzije sadnicama hrasta lužnjaka (*Quercus robur* L.) i kitnjaka (*Quercus petraea* L.) s obzirom na različit način sadnje. *Sumar list* 144(9-10): 485-495. https://doi.org/10.31298/sl.144.9-10.5. [in Croatian].

Bergez JE, Dupraz C, 2009. Radiation and thermal microclimate in tree shelter. *Agr Forest Meteorol* 149(1): 179-186. https://doi.org/10.1016/j.agrformet.2008.08.003.

Conner WH, Inabinette WL, Brantley EF, 2000. The use of tree shelters in restoring forest species to a floodplain delta: 5-year results. *Ecol Eng* 15(1): S47-S56. https://doi.org/10.1016/S0925-8574(99)00071-3.

Del Campo AD, Navarro RM, Aguilella A, González E, 2006. Effect of tree shelter design on water condensation and run-off and its potential benefit for reforestation establishment in semiarid climates. *Forest Ecol Manag* 235(1–3): 107-115. https://doi.org/10.1016/j.foreco.2006.08.003.

DHMZ, 2023. Climate, Total precipitation. Available online: URL https://meteo.hr/klima_e.php?section=klima_podaci&param=k2_1 (14/3/2023).

Garcia-Barreda S, Valeriano C, Camarero J, 2023. Drought constrains acorn production and tree growth in the Mediterranean holm oak and triggers weak legacy effects. *Agr Forest Meteorol* 334: 109435. https://doi.org/10.1016/j.agrformet.2023.109435.

Ghazian N, Zuliani M, Lortie, CJ, 2020. Micro-climatic amelioration in a California desert: Artificial shelter versus shrub canopy. *Journal of Ecological Engineering* 21(8): 216-228. https://doi.org/10.12911/22998993/126875.

Gill RMA, Beardall V, 2001. The impact of deer on woodlands: the effects of browsing and seed dispersal on vegetation structure and composition. *Forestry: An International Journal of Forest Research* 74(3): 209–218. https://doi.org/10.1093/forestry/74.3.209.

Gradečki-Poštenjak M, Novak Agbaba S, Licht R, Posarić D, 2011. Dinamika plodnošenja i kvaliteta uroda sjemena hrasta lužnjaka (*Quercus robur* L.) u narušenim ekološkim uvjetima. *Sumar list* 135(13): 169-181. [in Croatian].

Graf Y, Hein S, Schnabl AS. 2022. A review of challenges and future pathways for decision making with treeshelters – A German and European perspective. *J Forest Res*27(3): 191–199. https://doi.org/10.1080/13416979.2022.2029281.

Harris, RMB, Beaumont LJ, Vance TR et al. 2018. Biological responses to the press and pulse of climate trends and extreme events. *Nature Clim Change* 8(7): 579–587. https://doi.org/10.1038/s41558-018-0187-9.

European Commission, Directorate-General for Research and Innovation, 2021. Biodegradability of plastics in the open environment, Publications Office of the European Union. https://data.europa.eu/doi/10.2777/690248.

Jacobs DF, Salifu KF, Seifert JR, 2005. Growth and nutritionalresponse of hardwood seedlings to controlled-release fertilization at outplanting. *Forest Ecol Manag* 214(1–3): 28–39. https://doi.org/10.1016/j.foreco.2005.03.053.

Jeffrey SW, Stephens GR, 1995. Protection of Tree Seedlings from Deer Browsing. In: Gottschalk KW, Fosbroke SLC (eds) Proceedings of the 10th Central hardwood forest conference, Morgentown, WV, USA, 5-8 March 1995. Division of Forestry, West Virginia University; Northeastern Forest Experiment Station, USDA Forest Service, USA, pp. 507-514.

Kerr G, 1992. The use of treeshelters; 1992 survey. Forestry commission technical paper 11. Forestry commission, Edinburgh, pp. 1–11.

Kjelgren R, Rupp LA, 1997. Establishment in treeshelters I: Shelters reduce growth, water use, and hardiness, but not drought avoidance. *HortScience* 32(7): 1281-1283. https://doi.org/10.21273/HORTSCI.32.7.1281.

Krejči V, Dubravac T, 2004. Problemi obnove šuma hrasta lužnjaka (*Quercus robur* L.) vlažnoga tipa tijekom oplodnih sječa. *Sumar list* 3-4: 119-126. [in Croatian].

Krejči V, Dubravac T, Viličić V, 2001. Prirodna obnova hrasta lužnjaka (*Quercus robur* L.) u uvjetima prisutnosti srneće divljači. Znanost u potrajnom gospodarenju hrvatskim šumama, Denona, Zagreb, Hrvatska, pp. 77-85. [in Croatian].

Krejči, V, Viličić V, Dubravac T, 1997. Prilog obnovi lužnjakove sastojine koju oštećuje srneća divljač. *Radovi-Hrvatski šumarski institut* 32(2): 27-35. [in Croatian].

Lantagne DO, 1995. Effects of tree shelters on planted red oaks after six growing seasons. In Proceedings 10th Central Hardwood Forest Conference; USDA For. Serv. Northeast For. Exp. Stat., General Technical Report NE-197, pp. 515-521.

Liović B, Tomašić Ž, Dubravac T, Licht R, Turk M, 2019. The effect of polypropylene tree shelters on growth and survival of pedunculate oak seedlings (*Quercus robur* L.). *South-east Eur for* 10(1): 89-96. https://doi.org/10.15177/seefor.19-07.

Liović B, Tomašić Ž, Stankić I, 2013. Ecological and economic advantages of using polypropylene tree shelters in lowland oak forests. *South-east Eur for* 4(2): 115-125. https://doi.org/10.15177/seefor.13-12.

Liović B, 2001. Rezultati primjene polipropilenskih štitnika za zaštitu sadnica hrasta lužnjaka - 6 godišnji pokus. In Znanost u potrajnom gospodarenju hrvatskim šumama. Šumarski fakultet, Šumarski institut, Zagreb, pp. 309-316. [in Croatian].

Liović B, Ocvirek M, 1997. Plastični štitnici u sustavu integralne zaštite šumskih sadnica. *Radovi-Hrvatski šumarski institut* 32(1): 31-42. [in Croatian].

Matić S, 1996. Uzgojni radovi na obnovi i njezi sastojina hrasta lužnjaka. Hrast lužnjak (*Quercus robur* L.) u Hrvatskoj. HAZU, Hrvatske šume, p. o. Zagreb, Vinkovci-Zagreb, pp. 167-212. [in Croatian].

Myers BJ, 1988. Water stress integral - a link between short-term stress and long-term growth. *Tree Physiol* 4(4): 315-323. https://doi.org/10.1093/treephys/4.4.315.

Potter MJ, 1988. Treeshelters improve survival and increases early growth rates. *J Forest* 86(8): 39-41.

Rietveld WJ, 1989. Transplanting stress in bareroot conifer seedlings: Its development and progression to establishment. *North J Appl For* 6(3): 99–107. https://doi.org/10.1093/njaf/6.3.99.

Struve DK, Joly RJ, 1992. Transplanted red oak seedlings mediate transplant shock by reducing leaf surface area and altering carbon allocation. *Can J Forest Res* 22(10): 1441–1448. https://doi.org/10.1139/x92-194.

Tuley G, 1985. The growth of young oak trees in shelters. *Forestry: An International Journal of Forest Research* 58(2): 181–195. https://doi.org/10.1093/forestry/58.2.181.

Tuley G, 1983. Shelters improve the growth of young trees in forest. *Q J Forest* 77(2): 77–87.

Vizitiu O, Simota C, Calciu I, Loana P, 2012. Increasing the plant water availability as an effect of superabsorbents application. In Proceedings of Conference: Cea de a XX-a Conferinţă Naţională de Ştiinţa Solului, cu participare internaţională, Craiova, Romania, Volume: Agricultura, Montanologie, Cadastru vol. XLII-2012/1.

Vučetić V, Anić M, 2021. Agroklimatski atlas Hrvatske u razdobljima 1981.–2010. i 1991.–2020. Državni hidrometeorološki zavod (DHMZ), Zagreb, Croatia, pp. 80. [in Croatian].

Watt MS, Whitehead D, Mason EG, Richardson B, Kimberley MO, 2003. The influence of weed competition for light and water on growth and dry matter partitioning of young *Pinus radiata*, at a dryland site. *Forest Ecol Manag* 183(1-3): 363-376. https://doi.org/10.1016/S0378-1127(03)00139-7.