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UDK 630*232.4+236+114.5+522 (*Quercus robur* L.)

THE NUMBER OF PLANTS AND SITES AS IMPORTANT FACTORS IN THE GROWTH OF YOUNG STANDS OF PEDUNCULATE OAK (*QUERCUS ROBUR* L.)

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The paper presents the results of research of 11 years in two forest cultures of pedunculate oak established in two different sites (forest soil, non-forest pastureland) with six different planting spaces and different number of plants (3,000, 5,000, 7,000, 10,000, 15,000, and 20,000 plants per ha) with three repetitions. An increased tree quality and a higher number of plants per ha have been achieved in both sites. A trend of increased quality is particularly evident with 10,000 to 20,000 plants/ha. The smallest number of low-quality trees and the highest number of medium-quality trees were obtained on forest soils, while the largest number of bad-quality trees and the lowest number of quality trees occurred on non-forest pastureland. Significant differences in tree quality were obtained in the two sites with all planting distances. Aggressive expansion of common hornbeam and the occurrence of natural young sprouts of pedunculate oak were noted in the cultures established on forest soils. A higher number of plants per surface unit are accompanied with increased tree heights. On average, absolute height values are 25 cm higher in the cultures on forest soils. In the last 6 years heights have been reduced in the cultures with 20,000 plants/ha due to competition among pedunculate oaks and the formation of lower storeys. In such cases cleaning is necessary. It is recommended that the cultures of pedunculate oak with at least 10,000 plants per ha, as well as natural stands, be raised only on forest soils.

Key words: pedunculate oak, forest cultures, planting spacing, forest soil, non-forest soil, tree quality, tree height.

INTRODUCTION

Natural regeneration of a mature forest stand is a natural manifestation of a good quality stand in terms of its structure and site, as well as of professional silvi-

cultural treatments during a stand's life (Matić 1993, 1994). This type of regeneration reduces stresses occurring in the site and in the young stand during the "death" of the old and the birth of the young stand.

The problems that may aggravate or even undermine natural regeneration of pedunculate oak stands can be divided into three groups. These are:

- absence or impossibility of a good quality seed crop
- regeneration made difficult due to weeds, waterlogging, drying and degradation of forest soil,
- disturbed structural relations in a site caused by tree dieback or improper management procedures during exploitation, tending or regeneration of a stand.

Forest soils that have not been degraded (by waterlogging, weeds, etc.) should be subjected to artificial regeneration by planting seedlings or planting or sowing seeds of pedunculate oak and shelterwood cutting.

Degraded soils or areas to be afforested such as meadows, plough land or pastureland are not afforested with pedunculate oaks but with adequate pioneering tree species (narrow-leaved ash, black alder, willows, poplars and others) (Matić 1999). During one rotation, these species will create forest soil of good quality and conditions conducive to pedunculate oak.

THE PROBLEM, AREA AND RESEARCH METHOD

For successful growth of young pedunculate oak stands, an adequate, optimal number of plants per surface unit is needed. This will ensure good stand conditions, microclimate, competition among trees, good growth and increment, good quality trees and other factors.

Research dealing with an optimal number of plants and impacts of site on the growth of young stands of pedunculate oak was done in two areas within the natural areal of pedunculate oak with 6 different planting spaces or plant numbers (3,000, 5,000, 7,000, 10,000, 15,000 and 20,000 per ha).

The experiment was set up in the autumn of 1987 in the Forest Office Vrbovec in the central part of Croatia on good quality forest soil, and in the Forest Office Stošinci in eastern Croatia on former pastureland. Each experiment was done in six randomly distributed variants (planting spaces) with three repetitions.

During the 11-year period the success of planting was monitored, as well as height and diameter growth and increment, growth of weed vegetation and the succession of autochthonous vegetation. The quality of trees was assessed as good (0), medium (1) and poor (2), and the soil was pedologically analysed.

The experiment in the Vrbovec area was established in the site of a stand of pedunculate oak and common hornbeam, where a coppice of common hornbeam growing on good quality forest soil was converted. The experiment is located within the natural areal of pedunculate oak forests in the Forest Administration Bjelo-

var, the Forest Office Vrbovec and Management Unit Novakuša, Compartment 1, forest region Seljansko, in the seed district of forests of lowland Posavina and seed zone of Upper Posavina and Pokuplje.

The soil is podzoluvisol, dystric, deep (Haplic planosol). Up to 100 cm in depth the soil is loam to clayey loam in structure, with very acid to acid reaction, very rich in humus and total nitrogen in the surface horizon.

The experiment in the area of Strošinci was established on non-forest soil of former pastures. It is located in the area managed by the Forest Administration Vinkovci, Forest Office Strošinci, Management Unit Debrinja, Compartment 88, over 40,000 ha of an unbroken complex of pedunculate oak forests "Spačva" in the seed district of lowland forests of Posavina, seed zone Lower Posavina.

The soil is mollic gleysol, carbonate vertic, clayey (Calci-mollic Gleysol), clayey in structure (light clay), neutral (in the surface part) to medium alkali reaction, moderately rich in humus and rich in total nitrogen in the surface horizon. It should be pointed out that this soil has very large reserves of humus and total nitrogen in the humus-accumulative horizon: 324,000kg/ha humus and 19,500kg/ha nitrogen. G-horizon occurs at a depth of 45 cm.

RESEARCH RESULTS AND DISCUSSION

Research on structural properties of young stands of pedunculate oak aged 3 to 10 years has shown that at this age, an average of about 40,000 plants of woody tree species per hectare are found in these stands (Matić 1993, 1994, 1996, 1999). The association of pedunculate oak and common hornbeam is a climatogenous association containing other tree species apart from pedunculate oak. These are primarily common hornbeam and other pioneering tree species (lime, maple, narrow-leaved ash, fruit trees and others).

During stand regeneration, the number of accompanying species depends mostly on the number of pedunculate oaks, that is, on the success of its natural or artificial regeneration. Of the total of 40,000 plants/ha, the standing space per plant is 0.25 m². In regeneration, this space is at the disposal of both pedunculate oak and other tree species. If the space is taken predominantly by the pedunculate oak, then, with proper tending, it has realistic conditions for a permanent stay in the stand. In a natural stand of pedunculate oak, an optimal mixture ratio is 80% of pedunculate oak (about 30,000 plants/ha) and 20% of other tree species (about 10,000 plants/ha). A pedunculate oak stand of such a structure is stable, productive, biologically diverse and sustainable.

This paper will present some measurement results of 11-year-old experimental plots in the area of Seljansko (forest soil) and Strošinac (non-forest soil), as well as the results of previous measurements and some published papers on this problem matter.

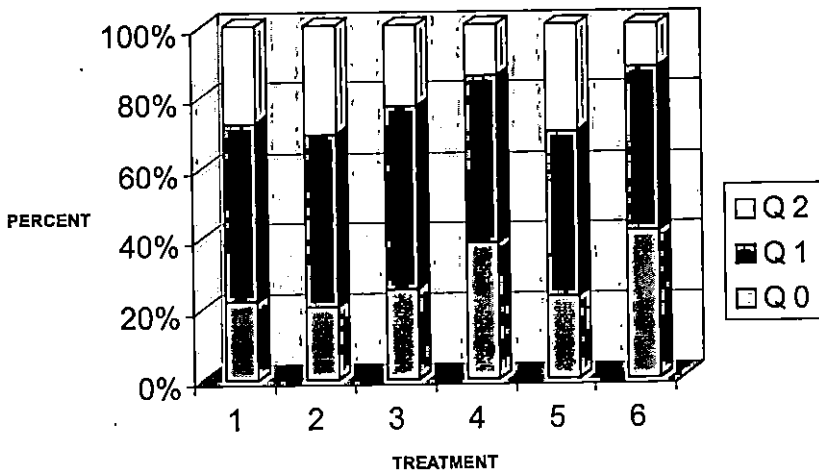
Special attention will be paid to the influence of site and planting spacing (plant number) on the quality and height growth and increment of pedunculate oaks in a stand.

IMPACTS ON THE QUALITY OF TREES

Table 1 presents the results of measurements in experimental plots established on quality forest soil during the conversion of a hornbeam coppice into a pedunculate oak stand in the area of Seljansko. The number of plants in the area of each repetition (400 m²), the condition in the spring of 1999, planting spacing, and height and quality per number of plants and per percentage are shown. Graph 1 gives a graphic representation of the impact of planting distance on the quality percentage of pedunculate oak plants for the same area. Data from the Table and the Graph show that the percentage of best-quality trees (0) rises with smaller planting distances, that is, with increased number of plants per surface unit. A growth in the trend of good quality trees is noted at 10,000, 15,000 and 20,000 plants per ha. According to the data, trees of medium quality (1) are the most numerous, while those of the poorest quality (2) are the least numerous.

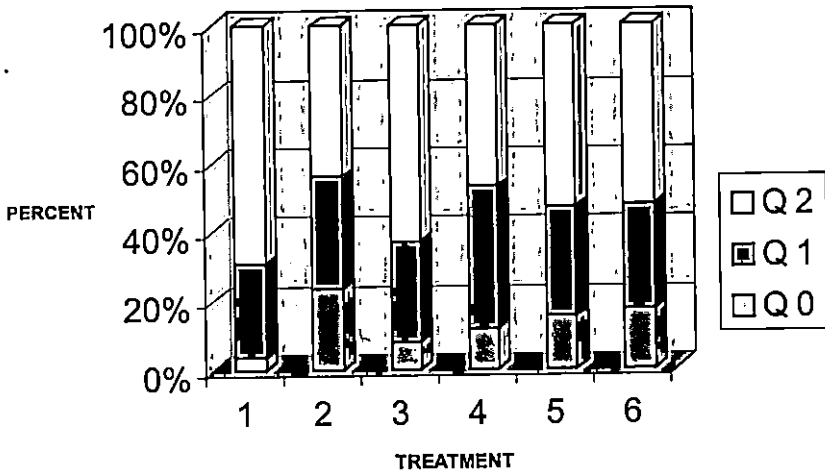
Table 1. Number, heights and quality of pedunculate oak plants at different planting spacing on forest soil of the Seljansko area

Treatment	Distance	piece	Height cm	Quality			Quality		
	m			0	1	2	0	1	2
				piece			%		
I/1	1.8x1.8	91	273	14	54	23	15.38	59.34	25.27
II/1		96	178	25	48	23	26.04	50.00	23.96
III/1		85	229	20	37	28	23.53	43.53	32.94
Mean		91	227	20	46	25	21.65	50.96	27.39
I/2	1.4x1.4	125	316	22	67	36	17.60	53.60	28.80
II/2		99	244	25	43	31	25.25	43.43	31.31
III/2		133	203	23	68	42	17.29	51.13	31.58
Mean		119	254	23	59	36	20.05	49.39	30.56
I/3	1.2x1.2	147	267	42	78	27	28.57	53.06	18.37
II/3		89	240	19	43	27	21.35	48.31	30.34
III/3		142	199	36	78	28	25.35	54.93	19.72
Mean		126	235	32	66	27	25.09	52.10	22.81
I/4	1.0x1.0	187	265	57	101	29	30.48	54.01	15.51
II/4		138	339	72	44	22	52.17	31.88	15.94
III/4		185	232	60	104	21	32.43	56.22	11.35
Mean		170	279	63	83	24	38.36	47.37	14.27
I/5	0.8x0.8	215	276	43	102	70	20.00	47.44	32.56
II/5		308	278	72	137	99	23.38	44.48	32.14
III/5		227	305	57	112	58	25.11	49.34	25.55
Mean		250	286	57	117	76	22.83	47.09	30.08
I/6	0.7x0.7	311	233	80	158	73	25.72	50.80	23.47
II/6		259	267	96	142	21	37.07	54.83	8.11
III/6		269	256	168	92	9	62.45	34.20	5.36
Mean		280	252	115	131	34	41.75	46.61	12.31



Graph 1. The impact of planting spacing on the quality percentage of pedunculate oak plants on forest soils of the Seljansko area

Similar data relating to oak cultures established on pastureland in the area of Strošinci are shown in Table 2 and Graph 2. Like in Table 1 and Graph 1, it is evident that the percentage of the best quality trees rises with more plants per surface unit. A trend of an increased quality of trees is notable with planting 10,000, 15,000 and 20,000 plants per hectare. Under these site conditions the same trend is noted with medium-quality trees (1), where the percentage of these trees is higher than that of best quality trees (0), but lower than that of poorest quality trees (2), whose number is the highest.



Graph 2. The impact of planting spacing on the quality percentage of pedunculate oak plants on non-forest soils of the Strošinci area

Table 2. Number, height and quality of pedunculate oak plants at different planting spacing on non-forest soil in the Strošinci area

Tretment	distance m	piece	Height cm	Quality			Quality		
				0	1	2	0	1	2
				piece			%		
I/1	1.8x1.8	109	243	2	45	62	1.83	41.28	56.88
II/1		107	159	9	21	77	8.41	19.63	71.96
III/1		105	198	1	22	82	0.95	20.95	78.10
Mean		107	200	4	29	74	3.73	27.29	68.98
I/2	1.4x1.4	182	271	80	55	47	43.96	30.22	25.82
II/2		193	214	44	74	75	22.80	38.34	38.86
III/2		183	176	7	52	124	3.83	28.42	67.76
Mean		186	220	44	60	82	23.53	32.33	44.15
I/3	1.2x1.2	246	228	2	79	165	0.81	32.11	67.07
II/3		257	203	44	69	144	17.12	26.85	56.03
III/3		680	177	45	184	451	6.62	27.06	66.32
Mean		394	203	30	111	253	8.18	28.67	63.14
I/4	1.0x1.0	382	228	43	166	173	11.26	43.46	45.29
II/4		349	282	44	131	174	12.61	37.54	49.86
III/4		375	202	44	156	174	11.73	41.60	46.40
Mean		369	237	44	151	174	11.87	40.87	47.18
I/5	0.8x0.8	601	240	77	209	315	12.81	34.78	52.41
II/5		601	235	44	177	380	7.32	29.45	63.23
III/5		559	263	142	174	243	25.40	31.13	43.47
Mean		587	246	88	187	313	15.18	31.79	53.04
I/6	0.7x0.7	627	197	100	168	359	15.95	26.79	57.26
II/6		629	230	148	165	316	23.53	26.23	50.24
III/6		737	221	102	271	364	13.84	36.77	49.39
Mean		664	216	117	201	346	17.77	29.93	52.30

The data above suggest that the quality of pedunculate oak increases with a larger number of plants per surface unit. Likewise, forest cultures established on forest soils of good quality have a higher participation of good and medium quality trees in relation to the cultures established on former pastureland. This can be particularly seen from the data in Table 3, where cultures on the forest soil in the area of Seljansko contain 28.3% of good quality (0), 40% of medium quality (1) and 22.8% of poor-quality trees in relation to the forest cultures established on pastureland of Strošinci, where only 13.4% of good quality (0) trees, 31.8% of medium-quality (1) trees and 54.8% of poor-quality (2) trees occur.

Table 3. Participation percentage per quality (0, 1, and 2) of pedunculate oak seedlings on forest (Seljansko) and non-forest soil (Strošinci)

LOCATION	QUOLITY 0	QUOLITY 1	QUOLITY 2
	%		
Seljansko	28.28	48.91	22.79
Strošinci	13.37	31.81	54.80

If we compare the quality of trees at all planting distances in Seljansko (forest soil) and Strošinci (pastureland), then we can conclude from Table 4 that there is a significant difference in the quality of trees at all planting spacing in these two areas. The smallest variability in the thickness occurs with poor-quality trees (2) and the highest with best-quality trees (0).

Table 4. Significant difference in the quality of seedlings between the locations of Seljansko and Strošinci

	Sum of squares	df	mean square	F	
Effect	0.312444	1	0.312444	3,948.104	p-level
Error	0.079138	10	0.007914		9.10E-05

Table 5. Significant difference between the planting density for all qualities (0, 1 and 2) in the locations of Seljansko and Strošinci

Quality 2				
	df	Mean square	F	p-level
Blocks	2	216.0556		
Treatment	5	1150.322	3.984183	0.030024
Error	10	288.7222		
Quality 1				
	df	Mean square	F	p-level
Blocks	2	459.0555		
Treatment	5	3364.089	5.845958	0.009073
Error	10	575.4556		
Quality 0				
	df	Mean square	F	p-level
Blocks	2	468.3889		
Treatment	5	3798.056	8.722028	0.002057
Error	10	435.4556		

Measurements done in the experimental plots of Seljansko in the spring of 1999 clearly show that cultures of pedunculate oak with different planting spacing

are intensively and aggressively invaded by common hornbeam. A certain degree of spontaneous natural expansion of pedunculate oak with seeds (birds, rodents and others) was also noted. All this indicates gradual increase in biological diversity in the stands established on forest soils of good quality.

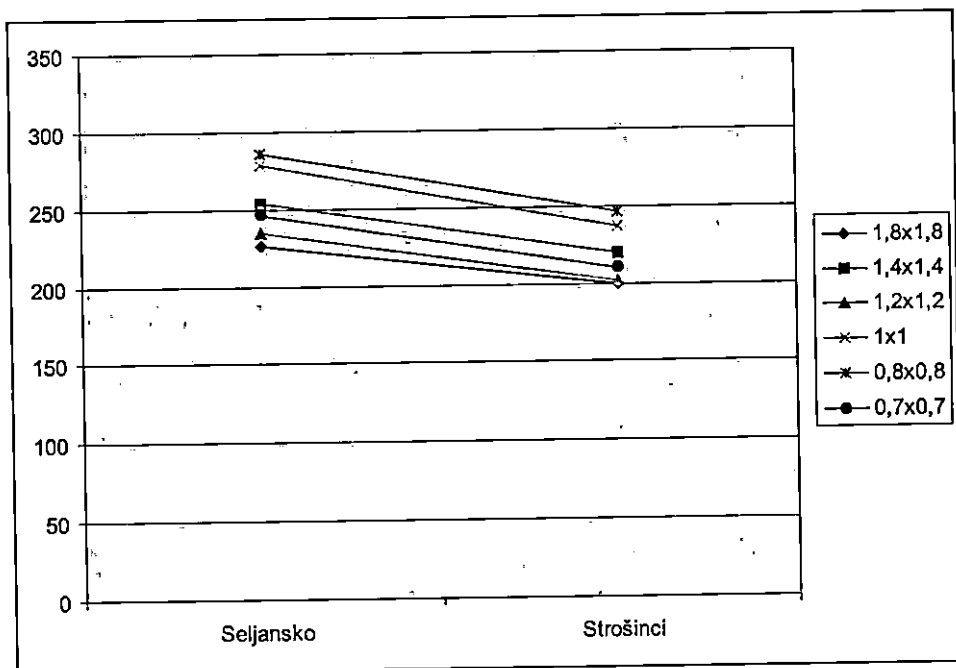
An expansion of common hornbeam and pedunculate oak was not detected in the area of Strošinci.

IMPACTS ON THE HEIGHT OF TREES

Table 6 shows mean heights of pedunculate oak trees for six planting distances in the forest culture of pedunculate oak raised on forest soils in the Seljansko area and the same data for the forest cultures raised on pastureland in the Strošinci area. The same data are also shown graphically in Graph 3. According to the data, the heights of trees at all six planting distances in the Seljansko area exceed the heights measured in the same experiment in the Strošinci area. It is important to mention that the best heights (287.7cm) were measured in the cultures with 15,000 plants/ha in Seljansko. This is followed by cultures with 10,000 plants/ha (287.7cm), then by those with 5,000 plants/ha (254.3cm), 20,000 plants/ha (252.0cm), 7,000 plants/ha (235.3cm) and 3,000 plants/ha (226.7cm). The same phenomena, but with different and lower absolute height values was noted in the Strošinci area.

Table 6. Mean heights of pedunculate oak for six planting spacing on forest (Seljansko) and non-forest site (Strošinci)

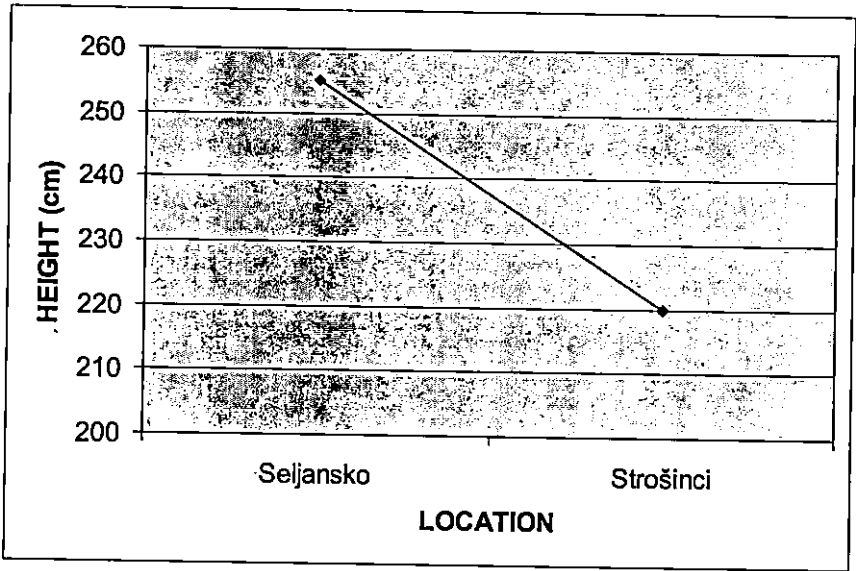
LOCATION	TREATMENT	HEIGHT (cm)
Seljansko	1	226
Seljansko	2	254
Seljansko	3	235
Seljansko	4	278
Seljansko	5	286
Seljansko	6	252
Strošinci	1	200
Strošinci	2	220
Strošinci	3	202
Strošinci	4	237
Strošinci	5	246
Strošinci	6	216



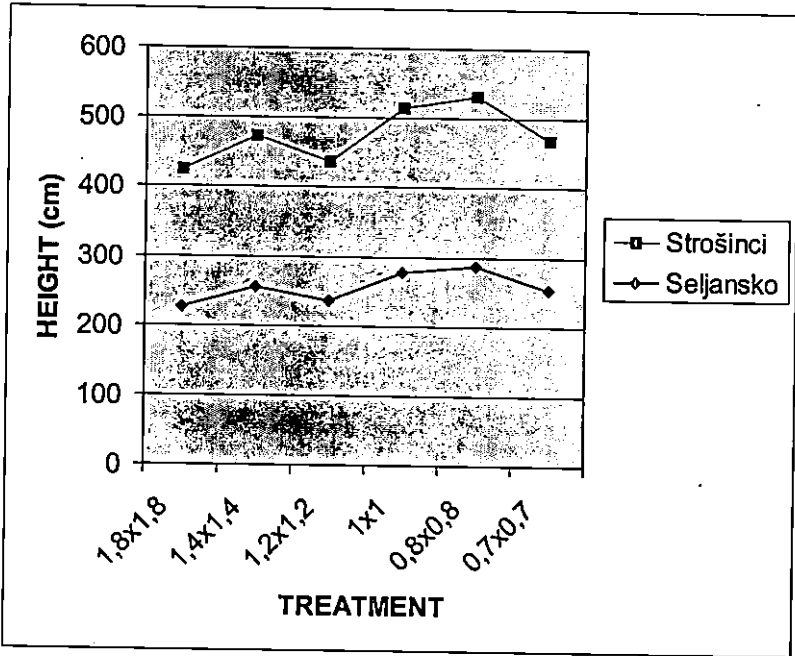
Graph 3. Graphic representation of mean heights for different planting spacing in Seljansko (forest soil) and Strošinci (non-forest soil)

The mean tree height in the Seljansko area (255.1cm) and that in the Strošinci area (221.1cm) are given in Graph 4. These data clearly indicate that the site has an important role in the development of tree heights in establishing forest cultures of pedunculate oak. In the 11 years of stand development, the difference in the mean height is 25 cm in favour of the trees growing on forest soils.

Graph 5 shows frequency distribution of mean heights for various planting spacing for pedunculate oak in the area of Seljansko and Strošinci. A trend can be seen of height development in individual areas, already shown in Table 6 and Graph 3. In this case, a drop in the height for the plots with 20,000 plants/ha is interesting in relation to the results obtained in earlier years (Matić 1993). After five years of the stand's development in the Seljansko area, the best heights were achieved in the plots with 20,000 plants/ha (175.3cm), followed by those with 15,000 plants/ha (161.2cm), 10,000 plants/ha (156.8cm), 5,000 plants/ha (159.1cm), 3,000 plants/ha (155.3cm) and 7,000 plants/ha (148.2cm). Although the results did not differ significantly, a trend in increased plant heights was noted with 10,000 plants to 20,000 plants/ha. The most densely planted area, that with 20,000 plants/ha, dropped from the first to the fourth place in the six years of growth, which can be explained by mutual competition among trees and the formation of lower storeys. The trees in lower storeys visibly lag behind in their growth, espe-



Graph 4. Mean heights of pedunculate oak in the area of Seljansko (forest soil) and Strošinci (non-forest soil)



Graph 5. Frequency distribution of mean heights for various planting spacing for pedunculate oak in the area of Seljansko (forest soil) and Strošinci (non-forest soil)

cially in comparison to the trees in the dominant storey that have secured the space above the soil and in the soil. This is the reason why average height values in the thickest stand are falling although dominant future trees are higher than the trees in the stands with a smaller number of plants. Similarly, it is also a proof of very intense processes and changes occurring in young stands of pedunculate oak. Cleaning is necessary in the thickest stands in order to remove trees of poor quality.

On the basis of these data it can be concluded that the quality of a site and number of plants per surface unit (planting spacing) have a significant impact on the height of pedunculate oak trees. Stands erected on good quality forest soil have better heights than those established on agricultural, pasture, non-forest or degraded forest soil.

When forest cultures are formed or artificial regeneration following the principles of natural regeneration is conducted, stands of pedunculate oak should be established on forest soils of good quality. Plants should be planted or seeds sown in such a way as to ensure at least 10,000 plants/ha to the future stand.

CONCLUSIONS

In order to study the influence of planting spacing and site quality on the growth of young stands of pedunculate oak, experimental plots were established on good quality forest soils in the forest area of Seljansko in Forest Office Vrbovec and on the pastureland in the area of Strošinci.

Each plot consists of 18 smaller plots (400m² area), where oak was planted with six different planting spacing and plant numbers per hectare (3,000, 5,000, 7,000, 10,000, 15,000 and 20,000 plants/ha). Each variant has three repetitions.

After 11 years of research on the experimental plots, the following conclusions can be drawn:

1. In the stands of pedunculate oak established on good quality forest soils (Seljansko) the percentage of best-quality trees (0) increases with smaller planting spacing, that is, a larger number of plants per surface unit. A rising trend is noted in good quality trees at plant numbers of 10,000, 15,000 and 20,000 per ha. Trees of medium quality (1) are the most numerous, while those of the poorest quality (2) the least numerous.
2. In the stands established on non forest pastureland (Strošinci) the percentage of best quality trees increases with a larger number of plants per surface unit. A rising trend in the quality of trees at 10,000, 15,000 and 20,000 plants per hectare is evident. The percentage of best trees (0) is the lowest, those of medium quality (1) is higher, while those of the poorest quality (2) is the highest.
3. There are significant differences in the quality of trees at all planting spacing and numbers of pedunculate oaks between the locations in Seljansko (forest soil) and Strošinci (non forest pastureland).

4. The cultures on the forest soil have 28.3% good quality (0), 49% of medium-quality (1) and 22.8% of poor-quality trees, while the cultures established on pastureland have 13.4% of good-quality (0), 31.8% of medium-quality (1) and 54.8% of poor-quality (2) trees.
5. Cultures of pedunculate oak on forest soils at all planting spacing are intensively and aggressively invaded by common hornbeam. Natural expansion of pedunculate oak with seeds (birds, rodents and others) was also noted. This phenomenon was not detected in forest cultures of pedunculate oak raised on non-forest soils. All this indicates a gradual increase in biological diversity of stands established on forest soils of good quality.
6. Mean tree heights at all six planting spacing in the area of Seljansko (forest soil) are higher than those measured in the same experiment in Strošinci (non-forest soil). In the period of 11 years, the difference in the mean height is 25 cm in favour of the trees growing on forest soils.
7. With a larger number of trees/ha, heights display a rising trend in growth and increment both on forest soils and non-forest soils. The difference is that absolute values of tree heights are bigger in the cultures established on forest soils at all planting spacing.
8. Plots with the largest number of plants/ha (20,000) suffered mutual competition and selection into lower storeys. The trees in lower storeys display notably weaker growth, particularly if compared with those trees in the dominant storey that have secured their place above the soil and in the soil. For this reason, average height values in the thickest stand have dropped in the last 6 years, so that they fell from the first place in the 5th year to the 4th place in the eleventh year of development. Cleaning aimed at removing poor quality trees from the stand and thus lessen the competition for future trees is the necessary silvicultural treatment to be undertaken in the most densely populated stands.
9. Forest cultures should be established or artificial regeneration conducted according to the principles of natural regeneration on forest soils of good quality, and plants should be planted or seeds sown in such a way that at least 10,000 plants/ha are ensured to the future stand.

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BROJ BILJAKA I STANIŠTE KAO ZNAČAJNI ČIMBENICI USPIJEVANJA MLADIH SASTOJINA HRASTA LUŽNJAKA (*Quercus robur* L.)

Prikazani su rezultati 11-godišnjih istraživanja u dvjema šumskima kulturama hrasta lužnjaka podignutim na dvama različitim staništima (šumsko tlo, nešumsko pašnjačko tlo) u šest različitih razmaka sadnje i broja biljaka (3000, 5000, 7000, 10 000, 15 000, 20 000 kom./ha) u tri ponavljanja. Trend povećanja kvalitete osobito je uočljiv od 10000 do 20000 biljaka/ha. Na šumskim tlima najmanje je nekvalitetnih, a najviše srednje kvalitetnih, dok je na nešumskim pašnjačkim tlima najviše nekvalitetnih, a najmanje kvalitetnih stabala. Dobiveni su signifikantni rezultati razlike kvalitete stabala na dvama različitim staništima kod svih razmaka sadnje. U kulturama podignutim na šumskim tlima uočeno je agresivno širenje običnoga graba te pojava prirodnoga pomlatka hrasta lužnjaka.

Povećanjem broja biljaka po jedinici površine povećavaju se i visine stabala s tim da su apsolutne vrijednosti visina veće u kulturama na šumskim tlima u prosjeku za 25 cm. U kulturama s 20 000 biljaka/ha u posljednjih se 6 godina smanjuju visine zbog međusobne konkurencije lužnjakovih stabala i izlučivanja u donjec etaže. U takvim slučajevima nužna je njega čišćenjem. Preporuka je da se kulture hrasta lužnjaka kao i prirodne sastojine mogu podizati samo na šumskim tlima i s brojem biljaka od najmanje 10 000 kom./ha.

Ključne riječi: hrast lužnjak, šumske kulture, razmak sadnje, šumsko tlo, nešumsko tlo, kvaliteta stabala, visine stabala