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Growth of Pedunculate Oak Seedlings under Soil Contamination by Mineral and Biodegradable Oils

Milan Oršanić, Dubravko Horvat, Nikola Pernar, Marijan Šušnjar, Darko Bakšić, Damir Drvodelić

Abstract – Nacrtak

The purpose of this study is to research the effects of different concentrations of mineral and biodegradable oils for chainsaws on seedling growth of pedunculate oak (Quercus robur L.) during two-year vegetation period. The paper also examines the influence of the above mentioned oils and their concentrations on the development of the seedling root system at the end of the second vegetation.

Tests were carried out in forest nurseries on seven 1 m^2 plots. Three plots were treated, after the planting of the pedunculate oak acorns, with biodegradable oil in the concentrations of 0.1 L/m^2, 0.2 L/m^2, and 0.5 L/m^2. The other three plots were treated with mineral oil of the same concentrations. The control plot received only seed sowing.

The analysis of the root system of the two-year-old seedlings of pedunculate oak was carried out with WinRHIZO ProLA 2400 software. The SAS and Statistica 7 program packages were used for the statistic data processing and for determination of statistically significant differences among variables.

Results showed that the lower oil concentration the larger root lengths. The lowest heights of the two-year-old pedunculate oak seedlings were measured from the test plots treated with mineral oil and the highest on those from the plots treated with bio-oil, although the heights of seedlings from the control plots were very close to heights of those treated with bio-oil.

Keywords: pedunculate oak seedlings, mineral oil, biodegradable oil, root system, growth

1. Introduction – *Uvod*

Oils for lubricating power chainsaw chains are called »Total Loss Oils«, because they end completely and irreversibly in sawdust on timber surface and the soil, or arrive on the surface of leaves of the surrounding plants. Skoupý (2004) established that 75–77% of the oil was absorbed by sawdust, 7–13% adhered to the surface of the cut timber, while 12–16% ended up in the surface.

Biodegradable chainsaw oils appeared in 1986. They can be made either of base-fluids of artificial origin (saturated and unsaturated esters), or of natural vegetable oils and animal fats. The most common base-fluid is rape oil, though other base-fluids can also be used. At present, pine oil, also named tall oil, is being investigated in Finland (Takalo and Lauhanen 1994).

It has been assessed that the total quantity of chainsaw lubricants discharged into the environment in Finland amounts to 2 million litres whereas in Croatia this quantity is about 420,000 litres per year (Anon 1996). According to the data obtained from the company »Hrvatske šume«, which manages 80% of the total forest areas, the unit consumption of chainsaw oil amounts to 0.168 L/m^3, which is far more than in Finland where due to highly mechanised felling and processing the unit consumption ranges from 0.015 L/m^3 to 0.027 L/m^3. Horvat and Šušnjar (2003) established a considerably lower unit consumption of biodegradable and mineral oil for

lubricating chainsaw chains. Thus, in the final cut of pedunculate oak they used 0.07 L/m^3, in thinning of beech stands the respective amount was 0.04 L/m^3, while 0.035 L/m^3 was required for the selective cut of fir stands.

Takalo and Lauhanen (1994) established a considerably lower wear of the lower parts of chain teeth when the chain was lubricated with biodegradable oil, than when it was lubricated with mineral oil. However, their low oxidation stability requires low operating temperatures. Oil viscosity is inversely proportionate to the temperature, which can lead to problems with the lubricant flow quality during winter. In the summer, the incidence of too abundant lubrication is possible due to decreased operating viscosity of oil. The use of additives with biodegradable oils can improve their viscosity index (change of viscosity with the change of temperature) which in that case can be compared to the one of mineral oils if not even better (Auguštin et al. 2000).

Lauhanen et al. (2000) treated plants with biodegradable oils in the laboratory and found no harmful effects. However, the interviewed operators, who used mineral and biodegradable oils, reported a much higher rate of skin and allergic diseases when biodegradable oils were used.

While investigating the impacts of spilling two concentrations (0.002 L/m^2 and 4.0 L/m^2) upon the germination of Scots pine (*Pinus sylvestris* L.) seeds in glasshouse over three weeks, Lauhanen and Kolppanen (2003) established that lower concentrations of both oil types decreased the germination and that mineral oil was less suitable. A higher concentration (4 L/m^2), which corresponds to an incidental oil spilling, was lethal for all seeds.

Oršanić et al. (2008) investigated the influence of 3 concentrations (0.1 L/m^2, 0.2 L/m^2, 0.5 L/m^2) of chainsaw oils (biodegradable and mineral) on germination of oak acorns in two nurseries. Results showed that biodegradable oil, regardless of the concentration, does not significantly reduce nursery germination of oak acorns, and in one nursery it lead to an increase of germination.

Considering the harmful impacts of oil upon the soil and plants, it should be pointed out that a film is formed upon the surface composed of firm particles. The film prevents the contact of the particles with water and air. Impeded breathing of oots, metabolic disorders, and even root dieback were the established consequences (Bašić et al. 1999).

Accordingly, the purpose of this study is the research on the impacts of different concentrations of both mineral and biodegradable oils on the growth of pedunculate oak seedlings (*Quercus robur* L.) during the two years vegetation in the nursery. The impact of different oil concentration of mineral and biodegradable oils on certain morphological characteristics of the root system of two-year-old seedlings would also be examined.

2. Materials and methods – *Materijal i metode*

The experiment was set in forest nursery. The soil in the nursery is classified as lowland pseudogley (stagnosol). In the upper 30 cm, the soil is a clayey loam by its texture. Deeper down, it acquires a slightly heavier texture, and turns into light clay. The soil reaction is between neutral and slightly acid. The upper 10 cm of the soil is moderately supplied

Fig. 1 Test plots
Slika 1. *Pokusne plohe*

Table 1 Mean values of root characteristics
Tablica 1. *Srednje vrijednosti značajki korijena*

Root characteristic *Značajka korijena*	Oil type – *Vrsta ulja*			Oil concentracion – *Koncentracija ulja*			
	Biodegradable *Biorazgradivo*	Mineral *Mineralno*	Control *Kontrola*	0 L/m^2	0.1 L/m^2	0.2 L/m^2	0.5 L/m^2
No. of seedlings *Broj sadnica*	30	30	10	10	20	20	20
Root lenght, mm *Duljina korijena,* mm	626.67	501.53	632.33	632.33	572.60	560.81	558.87
Root diameter, mm *Promjer korijena,* mm	1.22	1.24	1.17	1.17	1.30	1.17	1.22
Root volume, mm *Obujam korijena,* mm	7.37	5.99	7.14	7.14	7.39	6.05	6.60

with humus. The contents of the organic matter decrease in relation to the soil depth.

The forest nursery contained seven 1 m^2 test plots (Fig. 1). First, the planting of pedunculate oak acorns was carried out. The acorns were covered with the soil from the nursery, with the layer thickness of two acorn diameters. Upon covering the seeds, the plots were treated with different concentrations of biodegradable and mineral oils. Using a compressor and a sprinkler, the oil was evenly sprayed over the test plots. Three plots were treated with biodegradable oil in the concentrations of 0.1 L/m^2, 0.2 L/m^2, and 0.5 L/m^2. The other three plots were treated with mineral oil of the same concentrations. The control plot received only seed sowing.

The height and the root collar diameter of two-year-old seedlings were measured. The root collar diameter was measured with a digital movable measurer of an accuracy of 0.01 mm, while the heights were measured with a measuring rod, the accuracy of which was 1 mm. During vegetation, the usual nursery tending routine was carried out with the exception of root cutting. After two vegetations of growth 10 seedlings were taken out from each test pot (the total of 70 seedlings). After washing the particles the root system was scanned by Epson Expression 10000XL and then analyzed using WinRHIZO ProLA2400 software for analyzing washed roots. The SAS and Statistica 7 program packages were used for the statistic data processing.

3. Research results – *Rezultati istraživanja*

The analysis of the root system obtained using WinRHIZO ProLA2400 software revealed that the two-year-old seedlings of pedunculate oak from the control plot (not treated with oil) had the best average root length of 632.33 cm (Table 1). The root length of seedlings from the bio treated plots was on average by 125.14 cm longer compared to the seedlings from the mineral oil treated plots (501.53 cm). The total root length increased with lower oil concentration. With the oil concentration of 0.5 L/m^2 it was 558.87 cm, with the oil concentration of 0.2 L/m^2 it was 560.81 cm and with 0.1 L/m^2 the root length was 572.60 cm (Fig. 2).

The univariant analysis revealed a significant difference (p = 0.0324) in the total root lengths with respect to the treatment (bio and mineral oils) while

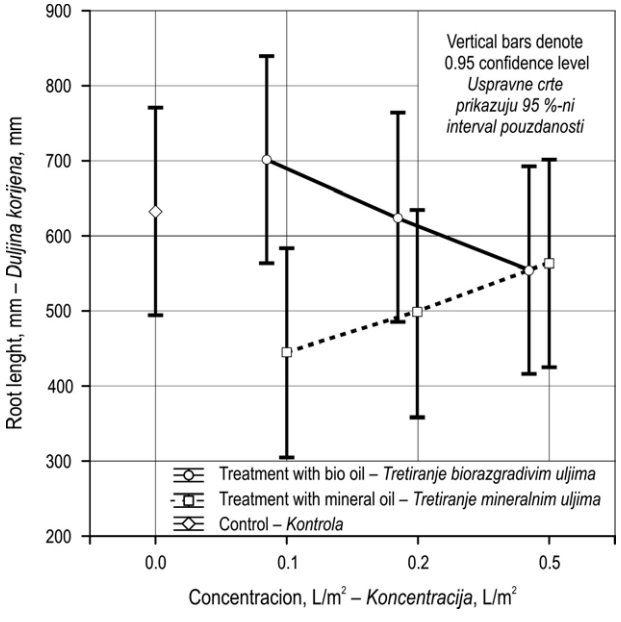

Fig 2 Impact of different oil types and concentrations on root lengt
Slika 2. *Utjecaj različitih vrsta i koncentracija ulja na duljinu korijena*

Table 2 Univariant analysis of root characteristics
Tablica 2. *Univarijantna analiza značajki korijena*

Root characteristic *Značajka korijena*	Effect *Djelovanje*	Sum of squares *Suma kvadrata*	Degree of freedom *Stupanj slobode*	Variance *Varijanca*	F value *F vrijednost*	p-value *p vrijednost*
Root length *Duljina korijena*	Treatment – *Tretiranje*	234898	1	234898	4.7758	0.0324
	Concentration – *Koncentracija*	2208	2	1104	0.0224	0.9778
	Error – *Greška*	3197000	65	49184.6		
Root diameter *Promjer korijena*	Treatment – *Tretiranje*	0.001002	1	0.001002	0.3229	0.5718
	Concentration – *Koncentracija*	0.180857	2	0.090428	2.9146	0.0613
	Error – *Greška*	2.016676	65	0.031026		
Root volume *Obujam korijena*	Treatment – *Tretiranje*	28.4516	1	28.4516	2.9607	0.0901
	Concentration – *Koncentracija*	17.9345	2	8.9672	0.9332	0.3985
	Error – *Greška*	624.6202	65	9.6095		

the oil concentration itself did not significantly affect this property (Table 2).

The seedlings grown on mineral oil treated plots had the largest average root diameter of 1.24 mm. An average root diameter of seedlings from bio oil treated plots was on average by 0.05 mm larger than that of seedlings from control plots (1.17 mm). Seedlings from the plots treated with 0.1 L/m^2 had the largest average root diameter, while those from the plots treated with 0.5 L/m^2 had the average root diameter of 1.22 mm, followed by root diameter of 1.17 mm on plots treated with 0.2 L/m^2 (Fig. 3). The univariant analysis did not show any significant differences in the average seedling root diameter with respect to the treatment (p = 0.5718) and oil concentration (p = 0.0613)

The largest average root volume (7.37 cm^3) was measured on seedlings from the plots treated with bio oil and the smallest (5.99 cm^3) on those from mineral oil treated plots. The root volume of seedlings from the control plot was 7.14 cm^3. Certain regularities between an average root volume and average root diameter have been proved related to oil concentration. The largest root volume of 7.39 cm^3 was measured with seedlings from the plots with oil concentration of 0.1 L/m^2, followed by the average root volume of 6.60 cm^3 from the plots treated with 0.5 L/m^2 and 6.05 cm^3 for the plots treated with 0.2 L/m^2 (Fig. 4). The univariant analysis did not show any significant differences in the average root volume of seedlings with respect to the treatment (p = 0.0901) and oil concentration (p = 0.3985).

The results of the descriptive statistics show that seedlings from mineral oil treated plots had the poorest average heights (Table 3). Considering the concentration of spilling oil on test plots, the best heights (698.11 mm) were obtained with the 0.2 L/m^2

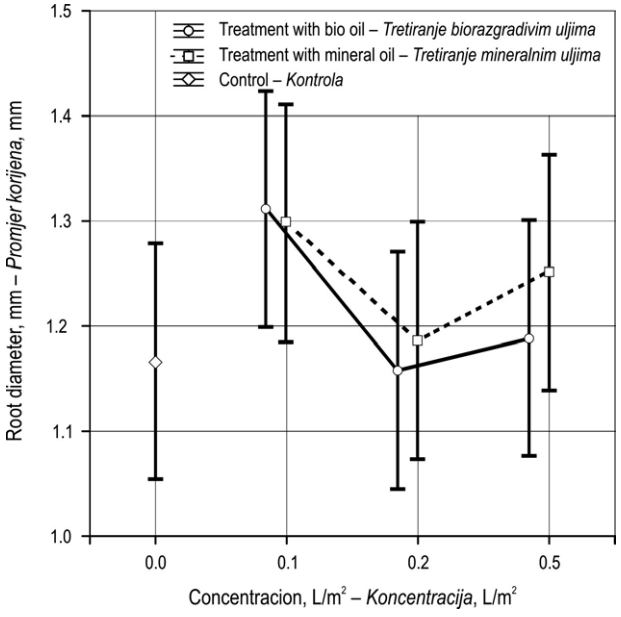

Fig 3 Impact of different oil types and concentrations on root diameter
Slika 3. *Utjecaj različitih vrsta i koncentracija ulja na promjer korijena*

of biodegradable oil, followed by seedlings from the control plot (653.03 mm) and the plot treated with 0.5 L/m^2 of biodegradable oil (630.69 mm). The poorest heights (476.83 mm) were measured on seedlings from the test plot treated with mineral oil in concentration of 0.5 L/m^2 (Fig. 5).

At the end of the second growth vegetation, the largest average root collar diameter was measured on the control plot seedlings (7.90 mm), followed by those from the bio-oil treated plots (7.75 mm at the 0.1 L/m^2 concentration, 7.17 mm at the 0.2 L/m^2 concentration, 7.19 mm at the 0.5 L/m^2 concentra-

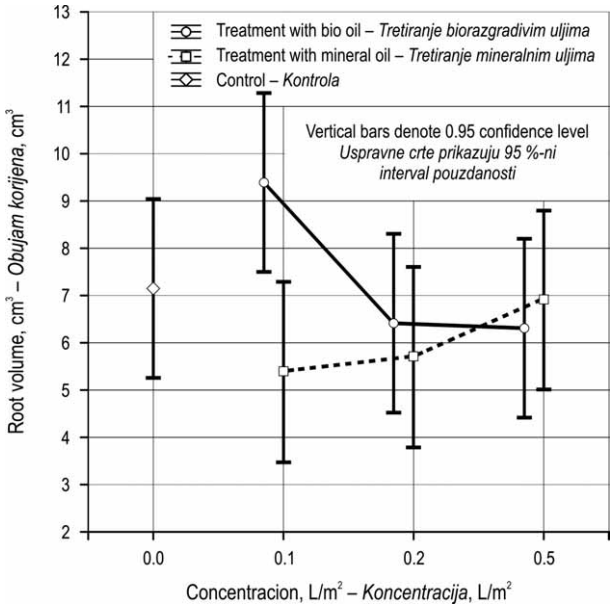

Fig 4 Impact of different oil types and concentrations on root volume
Slika 4. *Utjecaj različitih vrsta i koncentracija ulja na obujam korijena*

tion). The lowest values were measured on seedlings from plots treated with mineral oil (Fig. 6).

The univariant analysis (Table 4) established significant differences in seedling heights with respect to oil type and oil concentration (p = 0.00008). The Tukey HSD test (Table 5) revealed significant differences in seedling heights with respect to oil concentration in all cases except between the oil concentration of 0.2 L/m² and 0.5 L/m² (p = 0.7916).

Table 3 Mean values of seedling dimensions
Tablica 3. *Srednje vrijednosti veličina sadnica*

Oil type *Vrsta ulja*	Oil concentracion *Koncentracija ulja*	No. of seedlings *Broj sadnica*	Seedling dimension *Veličina sadnice*	
			Height *Visina*	Root collar diameter *Promjer vrata korijena*
	L/m²		mm	
Biodegradable *Biorazgradivo*	0.1	100	622.74	7.75
	0.2	100	698.11	7.17
	0.5	100	630.69	7.19
Mineral *Mineralno*	0.1	80	484.79	6.33
	0.2	80	479.28	6.70
	0.5	80	476.83	6.66
Control *Kontrola*	0	90	653.03	7.90

The univariant analysis of the data revealed significant differences in the root collar diameter with respect to the type of oil while oil concentration did not have a major impact on this morphological feature. The Tukey HSD test (Table 6) showed significant differences in the seedling root collar diameter

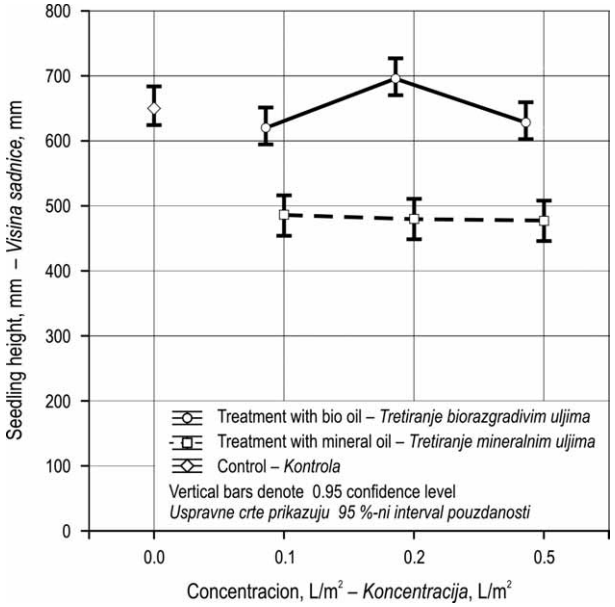

Fig 5 Influence of different oil types and concentrations on height growth of seedlings
Slika 5. *Utjecaj različitih vrsta i koncentracija ulja na visinski rast sadnica*

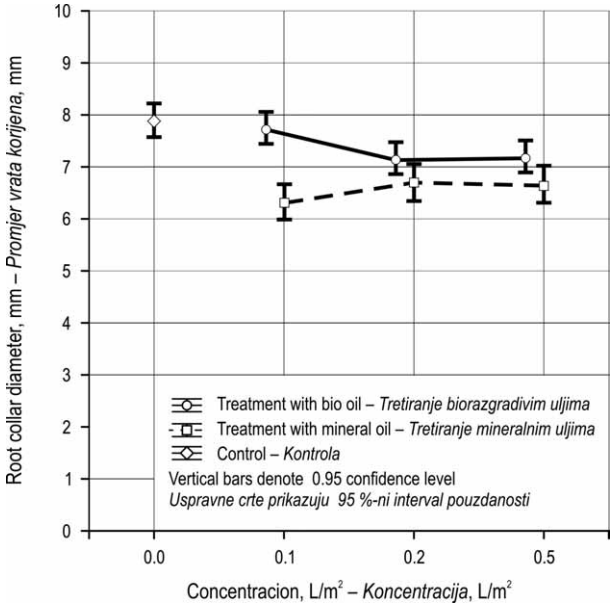

Fig 6 Influence of different oil types and concentrations on root collar diameter of seedlings
Slika 6. *Utjecaj različitih vrsta i koncentracija ulja na debljinski rast sadnica*

Table 4 Univariant analysis of seedling dimensions
Tablica 4. *Univarijantna analiza veličina sadnica*

Seedling dimension *Veličina sadnice*	*Effect* *Djelovanje*	Sum of squares *Suma kvadrata*	Degree of freedom *Stupanj slobode*	Variance *Varijanca*	F value *F vrijednost*	p-value *p vrijednost*
Height *Visina*	Treatment – *Tretiranje*	1443741	1	1443741	291.321	0
	Concentration – *Koncentracija*	94925	2	47462	9.577	0.00008
	Error – *Greška*	3246080	655	4956		
Root collar diameter *Promjer vrata korijena*	Treatment – *Tretiranje*	102.088	1	102.088	12.872	0.00036
	Concentration – *Koncentracija*	19.849	2	9.9246	1.251	0.28679
	Error – *Greška*	5194.78	655	7.931		

Table 5 Influence of oil concentration on heights of seedlings – Tukey HSD test
Tablica 5. *Utjecaj koncentracija ulja na visinski rast sadnica – Tukey HSD test*

Concentration *Koncentracija*	0 L/m^2	0.1 L/m^2	0.2 L/m^2	0.5 L/m^2
0 L/m^2		0.0000	0.0296	0.0025
0.1 L/m^2	0.0000		0.0001	0.0036
0.2 L/m^2	0.0296	0.0001		0.7916
0.5 L/m^2	0.0025	0.0036	0.7916	

Table 6 Influence of oil type on root collar diameter of seedlings – Tukey HSD test
Tablica 6. *Utjecaj koncentracija ulja na debljinski rast sadnica – Tukey HSD test*

Treatment *Tretiranje*	Control *Kontrola*	Biodegradable oil *Biorazgradivo ulje*	Mineral oil *Mineralno ulje*
Control *Kontrola*		0.9984	0.0282
Biodegradable oil *Biorazgradivo ulje*	0.9984		0.0009
Mineral oil *Mineralno ulje*	0.0282	0.0009	

between the control test plot and plots treated with mineral oils (p = 0.0282) as well as between plots treated with bio-oil and mineral oil (p = 0.0009). No significant differences in this morphological feature were established only between the control plot and plots treated with bio-oil (p = 0.9984).

4. Conclusions – *Zaključci*

The analysis of the root system of the two-year-old seedlings of pedunculate oak carried out with WinRHIZO ProLA 2400 showed that seedlings from the control plot (no oil spilling) had the best average total root length and that the lower the oil concentration the bigger the root lengths. The univariant analysis revealed significant differences in the total length of the seedling root system with respect to the type of oil while no significant differences were found for the other morphological features of the root (average diameter, volume). The same test showed that oil concentration had no influence on the total root length.

The lowest heights of the two-year-old pedunculate oak seedlings were measured from the test plots treated with mineral oil and the highest on those from the plots treated with bio-oil, although the heights of seedlings from the control plot were very close to heights of those treated with bio-oil. The univariant analysis showed significant differences in seedling heights with respect to type of oil and oil concentration. Significant differences in the root collar diameter were established only between the types of oil while the oil concentrations had no major impact on this feature.

Additional research should try to explain physiological condition of seedlings treated with mineral and biodegradable oil.

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Sažetak

Rast sadnica hrasta lužnjaka pri onečišćenju tla mineralnim i biorazgradivim uljima

Ovim se radom istražuje utjecaj različitih koncentracija mineralnoga i biološki razgradivoga ulja za podmazivanje lanaca motornih pila na rast sadnica hrasta lužnjaka (Quercus robur L.) i razvoj korijenskoga sustava sadnica na kraju druge vegetacije.

Ulja za podmazivanje lanaca motornih pila nazivaju se »total loss oils«, jer sve ulje nepovratno odlazi na površinu prepiljenoga drva, u piljevinu, u tlo ili završava na lisnim površinama okolnoga bilja. Skoupý je (2004) ustanovio da se 75 – 77 % ulja apsorbira u piljevinu, 7 – 13 % ostaje na površini prepiljenoga drva i 12 – 16 % odlazi u tlo. Ukupna količina ulja za podmazivanje lanaca motornih pila koja je ispuštena u okoliš u Finskoj je procijenjena na 2 mil. litara, dok se ta količina u Hrvatskoj kreće oko 420 000 litara godišnje (Anon. 1996). No, prema podacima poduzeća »Hrvatske šume«, koje gospodari s 80 % ukupne površine šuma, jedinična potrošnja ulja za podmazivanje lanca iznosi 0,168 L/m^3, što je mnogo više od finskoga primjera, gdje se zbog visoko mehanizirane sječe i izrade jedinična potrošnja kreće od 0,015 L/m^3 do 0,027 L/m^3. Horvat i Šušnjar (2003) zamijetili su mnogo manju jediničnu potrošnju biorazgradivoga i mineralnoga ulja za podmazivanje lanaca motornih pila koja se kretala od 0,07 L/m^3 kod dovršnoga sijeka hrasta lužnjaka, preko 0,04 L/m^3 u proredi bukove sastojine, do 0,035 L/m^3 kod preborne sječe u jelovoj sastojini.

U šumskom je rasadniku osnovano 7 pokusnih ploha površine 1 m^2. Na pokusnim je plohama posijano sjeme. Žir je prekrivan matičnom zemljom iz rasadnika u debljini od dva promjera sjemena. Nakon prekrivanja sjemena pokusne su plohe tretirane različitim koncentracijama biorazgradivoga i mineralnoga ulja. Pomoću kompresora i brizgaljke ulje se pod tlakom ravnomjerno raspršivalo po pokusnim plohama. Tri su pokusne plohe tretirane biorazgradivim uljem u koncentracijama od 0,1 L/m^2, 0,2 L/m^2 i 0,5 L/m^2 (slika 1). Sljedeće su tri pokusne plohe tretirane mineralnim uljem u istim koncentracijama. Na kontrolnoj je plohi samo posijano sjeme.

U rasadniku tlo taksonomski pripada pseudogleju ravničnomu. U gornjih 30 cm tlo je prema teksturi glinasta ilovača, a dublje poprima neznatno težu teksturu i prelazi u laku glinu. Tlo je neutralne do slabo kisele reakcije te osrednje opskrbljeno humusom u površinskih 10 cm. Sadržaj organske tvari opada s obzirom na dubinu tla.

Nakon dva vegetacijska razdoblja na pokusnim su plohama mjereni visina i promjer vrata korijena sadnica. Promjer vrata korijena sadnica mjeren je pomoću digitalne pomične mjerke s točnošću 0,01 mm, dok su visine mjerene mjernom letvom s točnošću od 1 mm. Tijekom vegetacije obavljena je standardna njega sadnica koja se inače provodi u rasadnicima. Od tih radova nije obavljeno jedino podrezivanje korijena sadnica. Nakon dviju vegetacija uzgoja, sa svake pokusne plohe, izvađeno je po 10 komada sadnica, a nakon ispiranja od čestica tla korijenski je sustav digitaliziran uz pomoć skenera Epson Expression 10000XL, dok je njegova analiza obavljena pomoću softvera za analizu opranoga korijenja WinRHIZO ProLA2400. Za statističku obradu podataka korišteni su programski paketi SAS i Statistica 7.

Analiza korijenskoga sustava sadnica dobivena uz pomoć softvera WinRHIZO ProLA2400 pokazala je kako su dvogodišnje sadnice hrasta lužnjaka s kontrolne plohe (bez tretiranja uljima) imale prosječno najveću ukupnu

duljinu korijena od 632,33 cm (tablica 1). Duljina korijena sadnica s ploha tretiranih biouljima bila je prosječno za 125,14 cm veća od sadnica s ploha tretiranih mineralnim uljima (501,53 cm). Ukupna duljina korijena povećavala se sa smanjenjem koncentracije ulja (slika 2). Univarijantnom analizom dobivena je signifikantno značajna razlika u ukupnoj duljini korijena s obzirom na tretiranje (biološka i mineralna ulja), dok koncentracija ulja nije značajno utjecala na to svojstvo (tablica 2).

Najveći prosječni promjer korijena od 1,24 mm imale su sadnice uzgojene na pokusnim plohama tretiranim mineralnim uljima. Prosječni je promjer korijena sadnica s ploha tretiranih biouljima za 0,05 mm veći od sadnica s kontrolne plohe (1,17 mm). Najveći prosječni promjer korijena od 1,30 mm imale su sadnice s ploha doziranih s 0,1 L/m^2 (slika 3). Univarijantna analiza nije pokazala postojanje signifikantno značajnih razlika u prosječnom promjeru korijena sadnica s obzirom na tretiranja (p = 0,5718) i različite koncentracije ulja (p = 0,0613).

Prosječno najveći obujam korijena (7,37 cm^3) imale su sadnice s ploha tretiranih biouljem, a najmanji (5,99 cm^3) s ploha tretiranim mineralnim uljem. Obujam korijena sadnica s kontrolne plohe iznosio je 7,14 cm^3 (slika 4). Univarijantna analiza nije pokazala postojanje signifikantno značajnih razlika u prosječnom obujmu korijena sadnica s obzirom na tretiranje (p = 0,0901) i koncentraciju ulja (p = 0,3985).

Rezultati deskriptivne statistike pokazuju kako su najmanju visinu imale sadnice s ploha tretiranih mineralnim uljima (tablica 3). Najveće visine sadnica (698,11 mm) dobivene su pri koncentraciji ulja od 0,2 L/m^2, slijede sadnice s kontrolnih pokusnih ploha (653,03 mm) i ploha tretiranih koncentracijom ulja od 0,5 L/m^2 (630,69 mm). Najmanje su visine sadnica (476,83 mm) izmjerene na pokusnoj plohi tretiranoj mineralnim uljem u koncentraciji 0,5 L/m^2 (slika 5).

Prosječne najveće vrijednosti promjera vrata korijena sadnica hrasta lužnjaka na kraju druge vegetacije uzgoja imale su sadnice s kontrolne pokusne plohe (7,90 mm), slijede promjeri sadnica s ploha tretiranih biouljem. Najmanje su vrijednosti imale sadnice uzgajane na plohama tretiranim mineralnim uljem (slika 6).

Univarijantnom analizom (tablica 4) dobivena je signifikantno značajna razlika u visinama sadnica s obzirom na vrstu ulja (p = 0,000000) i koncentraciju (p = 0,000125). Parametrijski Tukey HSD test (tablica 5) pokazao je signifikantno značajnu razliku u visini sadnica s obzirom na koncentraciju u svim slučajevima osim između doze 0,2 L/m^2 i 0,5 L/m^2 (p = 0,791636).

Univarijantnom analizom dobivena je signifikantno značajna razlika u promjeru vrata korijena sadnica s obzirom na vrstu ulja, dok različite koncentracije nisu značajno utjecale na ovo morfološko obilježje. Tukey HSD test (tablica 6) pokazao je signifikantno značajnu razliku u promjeru vrata korijena sadnica između kontrolne pokusne plohe i ploha tretiranih mineralnim uljima (p = 0,0282) te između ploha tretiranih biouljem i mineralnim uljem (p = 0,0009). Nisu dobivene značajne razlike u ovom morfološkom svojstvu jedino između kontrolne plohe i ploha tretiranih biouljem (p = 0,9984).

Ključne riječi: sadnice hrasta lužnjaka, mineralno ulje, biorazgradivo ulje, korijenski sustav, rast

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