МАТИЦА СРПСКА
1826

МАТИЦА СРПСКА
ОДЕЉЕЊЕ ЗА ПРИРОДНЕ НАУКЕ
ЗБОРНИК
МАТИЦЕ СРПСКЕ ЗА ПРИРОДНЕ НАУКЕ

MATICA SRPSKA
DEPARTMENT OF NATURAL SCIENCES
MATICA SRPSKA J. NAT. SCI.

Покренут 1951 / First published in 1951.

Until volume 10, the journal was published under the title *Научни зборник Матице српске: Серија природних наука* (Scientific Proceedings of Matica Srpska: Natural Sciences Series) (1951–1955). Volume 11 was released under the title *Зборник Матице српске: Серија природних наука* (Matica Srpska Proceedings: Natural Sciences Series) (1956), volumes 12–65 under the title *Зборник за природне науке* (Proceedings for Natural Sciences) (1957–1983), and from volume 66 the journal was published under the title *Зборник Матице српске за природне науке* (Matica Srpska Proceedings for Natural Sciences) (1984–). From volume 84 (1993) the journal was published in English under the title *Matica Srpska Proceedings for Natural Sciences* (1993–2012), and since volume 125 under the title *Matica Srpska Journal for Natural Sciences* (2013–)

138

Articles are available in full-text at the web site of Matica Srpska and in the following data bases: Serbian Citation Index, EBSCO Academic Search Complet, abstract level at Agris (FAO), CAB Abstracts, CABI Full-Text and Thomson Reuters Master Journal List.

YU ISSN 0352-4906 UDK 5/6 (05)

MATICA SRPSKA JOURNAL FOR NATURAL SCIENCES

138

NOVI SAD
2020

Зборник Матице српске за природне науке / Matica Srpska J. Nat. Sci. Novi Sad, № 138, 83—95, 2020

UDC 630*4:631.81.031(497.11)
https://doi.org/10.2298/ZMSPN2038083K

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DOUGLAS FIR IMPACT ON THE DYNAMICS AND COMPOSITION OF HUMUS IN THE SOIL OF INDIGENOUS BEECH FOREST IN WESTERN SERBIA

ABSTRACT: This study investigates the impact of organic matter from Douglas fir (*Pseudotsuga menziesii* [Mirb.] Franco) on the amount and composition of humus in acid brown soil in a climatoregional beech forest (*Fagetum moesiacae montanum* B. Jov. 1967 s.l.) on Mt. Maljen. To accomplish this objective, we performed a one-year litterbag decomposition experiment with litterfall from *Fagus moesiaca* and *Pseudotsuga menziesii.* The quantitative and qualitative content of humus and the intensity of the decomposition process of organic matter from beech and Douglas fir were analysed. Less humus was found during the experiment under Douglas fir than under autochthonous beech at the control site, as well as a decreasing trend for humus levels and quality (unfavourable chemical composition). It was concluded that these changes, caused by the effects of the clearcutting of beech and, in the future, of Douglas fir, and the slower decomposition of organic matter from Douglas fir will contribute to further degradation of the beech habitat on Mt. Maljen in terms of productivity.

KEYWORDS: soil organic matter, *Fagus moesiaca*, *Pseudotsuga menziesii* plantation, silviculture, humus content, humic and fulvic acids, litter decomposition, litterbag experiment

INTRODUCTION

Organic matter is of primary importance to the sustainability of long-term site productivity in forest ecosystems (Prescott et al., 2000). However, it influences several critical soil functions and is affected by land management practices. Soil organic matter content is a function of organic matter inputs (residues and roots – plant litter) and litter decomposition (Bot and Benites, 2005). Even though these processes are related to moisture, temperature, aeration and the physical and chemical properties of the soils, as well as soil macrofauna activity,

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leaching by water and humus stabilisation (organomineral complexes and aggregates), the primary factor in these processes is the amount and quality of litter from woody species. For this reason, tree species substitution affects the quality and quantity of annual organic matter stock, as well as the decomposition rate, and can thus have a considerable impact on the modification of the physical and chemical characteristics of soil and on the processes in the soil (Pavlović et al., 1998; Albers et al., 2004; Moukoumi et al., 2006; Kostić et al., 2012, 2016). Hence, the amount of organic matter and its dynamics have become a focus of research (Augusto et al., 2002; Moukoumi et al., 2006; Bonifacio et al., 2008; Kostić et al., 2012, 2016).

The decomposition of organic matter is essential for the short-term availability of nutrients for tree growth and long-term site fertility due to humus formation (Prescott et al., 2000). Vegetation type is considered to be one of the main parameters affecting differences in the decomposition process. It has been established that litter from broadleaf forest species decomposes more quickly and leads to mull humus formation, while coniferous species decompose more slowly and form mor or moder humus (Binkley, 1995; Rovira and Vallejo, 2002; Pavlović et al., 1998a, b). This slower decomposition in coniferous forests results in the accumulation of forest litter, and thus of nutrients in insoluble forms (Vogt et al., 1986; Raulund-Rasmussen and Vejre, 1995). Over time, this can reduce the supply of available nutrients to plants, having a negative impact on habitat productivity thereby.

Humic acids are the most significant part of humus. They affect soil structure, participate in the transfer of micronutrients from soil to plants, improve water retention, increase seed germination and stimulate the development of microflora populations in soil, respiration and photosynthesis (Nardi et al., 2002; Chen et al., 2004; Velasco et al., 2004; Pena-Mendez et al., 2005). Humic acids also decelerate the evaporation of water from soil. This is of particular importance in soils containing only a low proportion of clay and sandy soils, which do not have the capacity to retain water. Fulvic acids, which behave like strong organic acids due to their acidity, act destructively on soil minerals. In addition, these acids can cause soil podzolisation as they form complex compounds with sesquioxides, which translocate from the surface layers of soil and accumulate in the B horizon (Riise et al., 2000). For example, planting spruce trees on acid brown soil intensifies the processes of podzolisation (Nielsen et al., 1999).

Due to the ever-increasing needs of society for wood, large areas of European broadleaf forests are being replaced by fast-growing coniferous cultures. This is also true for Serbia, where the high number of coppice and degraded forests meant the production potential of the habitat could not be exploited, resulting in the mass introduction of coniferous species, especially in low and degraded beech forests. Either translocated autochthonous species like Norway spruce were used or allochthonous species like Douglas fir (*Pseudotsuga menziesii* [Mirb.] Franco) (Kostić et al., 2012, 2016) and *Pinus strobus* L. (Pavlović et al., 1997; Pavlović, 1992). Research has shown the impact of anthropogenic activities in forest ecosystems on the quantitative and qualitative dynamics of humus (particularly humins, humic and fulvic acids) and the dynamics of organic matter (Wollum Schubert, 1975; Piene and VanClave, 1978; Vesterdal et al., 1995; Pavlović et al., 1997; Ussiri and Johnson, 2001; Kawahigashi and Sumida, 2006).

This study was part of wider ecological research aimed at investigating the impact of conifer cultures on pedogenesis and soil properties in a climatoregional zone of autochthonous montane beech forests. Alongside an experiment designed to determine the decomposition process model of organic matter from beech (*Fagus moesiaca* [Domin, Maly] Czeczott) and Douglas fir (*Pseudotsuga menziesii* [Mirb.] Franco), the spatial and temporal dynamics of humus were observed with the aim of establishing whether introducing allochthonous coniferous species disturbed the balance between the processes of organic matter humification and mineralisation. Furthermore, on the basis of humus composition and by monitoring the intensity of organic matter decomposition, the effect of the stated anthropogenic activities on habitat productivity in a zone of beech forest was analysed.

MATERIALS AND METHODS

Research was undertaken in the climatoregional belt of montane beech forests (*Fagetum moesiacae montanum* B. Jov. 1967 s.l.) on Mt. Maljen (lat. 44° 10’ N; long. 20° 5’ E), in the locality of Kaona (880 MASL). There were silviculture activities undertaken here, whereas, after the clearcutting of beech trees in 20 m-wide strips, plantations of Douglas fir (*Pseudotsuga menziesii* [Mirb.] Franco) were established, with these strips alternating with the strips of coppice forests of beech. The climatic conditions of this region are moderate continental, which is characteristic for the mountainous zone of Central European broadleaf forests (the mean annual temperature is 9.16 °C and mean annual precipitation is 890 mm). The study area lying within the forty-year-old silvicultural system of Douglas fir and the control area within the autochthonous beech forest are characterised by the same ecological conditions, i.e. western exposure, a 2–5 ° slope, and the same soil types, formed on the same geological substrate (diabase), (WRB, Cambisol, dystric 2006; Kostić et al., 2016; Pavlović et al., 2017).

To determine the decomposition intensity of leaf litter from beech and Douglas fir (6 and 12 months after the experiment started), a ‘litterbag approach’ was used. Fresh leaf litter (20 g), dried at 65 °C to a constant weight, was enclosed in bags (20x20 cm) made of 1mm nylon mesh. In October, ten bags were randomly placed on the surface of the forest floor for each species. Five of the bags (n=5) were collected from both areas in April and the remaining five in October. In order to determine the weight of the organic matter after decomposition, each bag was cleaned of soil and roots and dried to a constant weight (at 65 °C). Samples of soil (n=5) were taken from under each of the litterbags, up to a depth of 5 cm, so as to determine the quantity of humus using the Simakov modification of the Tyurin method (Beljčikova, 1975).

A qualitative analysis of humus, i.e. an analysis of the humic fractions of the leaf litter after extraction of bitumen (Ponomareva and Plotnikova, 1975a) and soil (Ponomareva and Plotnikova, 1975b), was conducted in soil profiles opened at both study sites. The content of Fe_2O_3 was determined using a complexometric method (Škorić and Sertić, 1963), while the content of R_2O_3 was established using gravimetry. The Al_2O_3 content, the R_2O_3:FK ratio and the Al_2O_3:Fe_2O3 ratio were calculated. Soil acidity in H_2O was determined using a potentiometer.

A prognosis for the decomposition of organic matter from beech and Douglas fir was given based on Olson's decomposition model and Olson's constant loss rate (Olson, 1963), using the formula:

$$M_t/M_0=e^{-kt}$$

where M_0 is the initial mass of organic matter, M_t is the mass of the organic matter after (t) years of decomposition, and k is Olson's constant loss rate after 12 months of decomposition. According to this decomposition model, half the decomposition time is $t_{1/2}$=0.639k, and the time constant k=0.368 of 1/e. To calculate the decomposition prognosis for 95% and 99% of the organic matter, the coefficients 3/k and 5/k were used.

The quantitative distribution of humus, i.e. its spatial (between the study sites) and temporal (during the experiment at each of the sites) distribution in the surface layer of soil and the coefficients of loss, as well as the prognosis for the decomposition of organic matter at the study sites were analysed using one-way analyses of variance (ANOVA), and significant differences were confirmed using a t-test.

RESULTS AND DISCUSSION

A comparison of the amount of humus in the layer of topsoil at the study sites at the beginning of the experiment revealed that the soil under the control beech stand was richer in humus (16.2%) than that under the Douglas fir stand (9.89%). This spatial trend was also true 6 (18.96% : 9.21%) and 12 months (17.40% : 9.89%) after the experiment started (Figure 1). The lower levels of humus in the topsoil from the Douglas fir stand are a result of the negative effects of clearcutting as a land management practice in this area. Specifically, the long period where the habitat was left open before the establishment of the Douglas fir stand led to the mineralisation process of humus intensifying and it being washed away (Pavlović et al., 1997; Ranger et al., 2008).

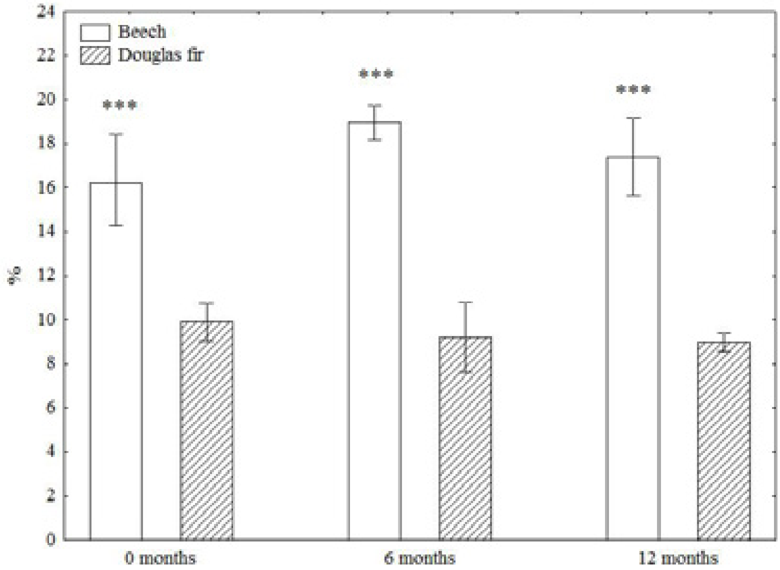

Figure 1. Spatial analysis of the amount of humus in topsoil (0–5 cm) (ANOVA, n=5; ***p<0.001)

In terms of time, the only significant increase in the amount of humus was determined in topsoil at the beech stand 6 months into the experiment (Figure 2).

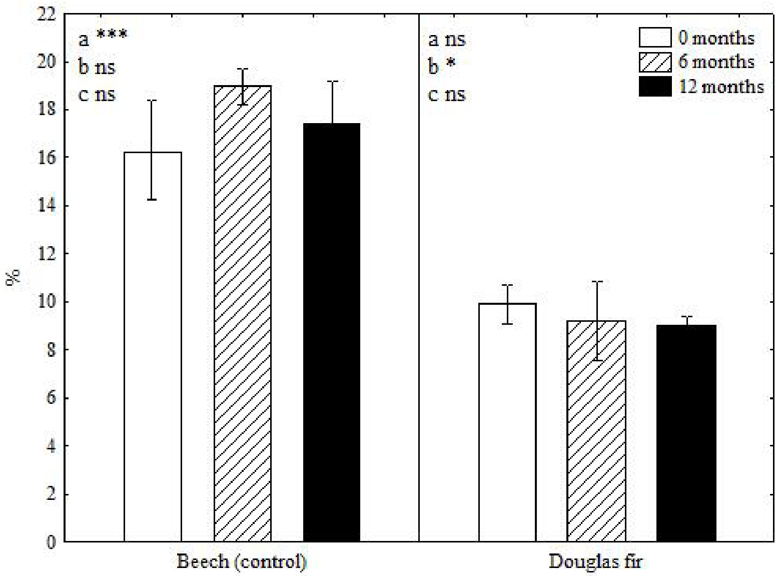

Figure 2. Temporal analysis of the amount of humus (%) in topsoil (0–5 cm) (ANOVA, n=5; ***p<0.001, *p<0.05, ns – not significant; a – 0 months/6 months; b – 0 months/12 months; c – 6 months/12 months)

During the decomposition of organic matter in soil, two processes occur simultaneously – the processes of humification and mineralisation of organic matter (Guggenberger, 2005; Ćirić, 1984). In the early stages of organic matter decomposition, humification is the dominant process, which explains the increase in the amount of humus 6 months into the experiment at the beech stand. In the later stages, the process of humification slowed down, i.e. the domination of organic matter mineralisation, which occurred during the second phase of the experiment from the 6^{th} to 12^{th} month, resulted in a decrease in the amount of humus in the topsoil (at a depth of 0–5 cm) at the beech stand. Even so, the lack of any difference in the amount of humus in the soil at the beech stand at the beginning and end of the experiment shows that the processes of organic matter humification and mineralisation are in dynamic equilibrium, which is characteristic of stable ecosystems (Ćirić,1984; Swift et al., 1979; Pavlović et al., 1998). The lower humus content in the topsoil under the Douglas fir stand after 12 months (Figure 2) indicates a continuing trend of depletion due to the clearcutting of already partially degraded habitats of beech subject to silviculture activities. Previous research showed that Douglas fir, as a fast-growing species, leads to the depletion of nutrients in soil, as indicated by the negative input-output budget of elements such as C, N, P, S, K, Ca and Mg (Marques et al., 1997; Ranger et al., 1997, 2002; Martinik, 2003; Kostić et al., 2016). These differences are more noticeable in young stands, particularly during periods of dormancy and are more pronounced as the time period between two rotations is shortened. Bearing in mind the fact that maintaining nutrient reserves at a level characteristic for each, individual ecosystem is a fundamental prerequisite for the stability of the ecosystem in question, disturbing the balance in their dynamics through reducing the amount of humus can have a negative impact on habitat productivity (Pavlović et al., 1997; Ranger et al., 1997; Kostić et al., 2016).

A morphological analysis of the soil profile and a qualitative analysis of the humus at the control site in the beech stand revealed the formation of mul-moder type humus, while the presence of an Oh horizon at the Douglas fir stand indicated that the planting of conifers at the beech habitat has resulted in the inhibition of the coupling of organic and mineral components in soil, i.e. the occurrence of moder-type humus (Table 1). Qualitative changes in humus were detected in terms of lower pH values in the soil under the Douglas fir stand (Table 2). The acidification of soil under conifer cultures, most marked in the surface layer, is the result of the impact of litter quality and the transformation of organic matter from conifers, which evolves in the direction of acidic humic substances (Kostić et al., 2012; Podrázský et al., 2009; Kostić et al., 2016). Although humus composition in both areas revealed a trend characteristic of acid brown soils, i.e. a ratio of humic (Ch) to fulvic (Cf) acids of less than one, which narrows with depth in the soil profile (Avdalović, 1971), the values of this ratio were higher at the control site under beech than within the Douglas fir stand. In terms of humic acids, fraction 1 was most present, with its highest content in the humus-accumulative horizon (18.32–20.14%) at both study communities, and the dominant proportion at the beech stand (Table 1). As for fulvic acids (Cf), fraction 1, which is bound with mobile R_2O_3 and humic acids of fraction 1, was

Table 1. Group and fractional composition of humus in soil and litter under beech and Douglas fir

Plot	Hor.	Depth cm	Total C	Humic acid			Fulvic acid				Total acids sum	Humin	Ch : Cf
				1	2	sum	1a	1	2	sum			
Beech (control)	O_{LF}	0–4 cm	37.54	4.44	0.15	4.59	0.48	4.90	0.35	5.73	10.32	27.22	0.80
			100.00	11.83	0.40	12.23	1.28	13.05	0.93	15.27	27.49	72.51	
	A	4–9 cm	10.40	2.02	0.00	2.02	0.44	2.05	0.17	2.66	4.68	5.72	0.76
			100.00	19.42	0.00	19.42	4.23	19.71	1.60	25.54	44.96	55.04	
	A	4–13/19 cm	7.30	1.47	0.00	1.47	0.36	1.53	0.07	1.96	3.43	3.87	0.75
			100.00	20.14	0.00	20.14	4.93	20.96	0.96	26.85	46.99	53.01	
	(B)	13/19–50 cm	2.02	0.34	0.00	0.34	0.20	0.29	0.10	0.59	0.93	1.09	0.58
			100.00	16.83	0.00	16.83	9.90	14.36	4.95	29.21	46.04	53.96	
	(B)	50–70 cm	0.81	0.09	0.00	0.09	0.08	0.09	0.07	0.24	0.33	0.48	0.38
			100.00	11.11	0.00	11.11	9.88	11.11	8.64	29.63	40.74	59.26	
Douglas fir	O_{LF}	0–1/2 cm	36.17	3.27	0.00	3.27	0.50	4.67	0.00	5.17	8.44	27.73	0.63
			100.00	9.04	0.00	9.04	1.38	12.91	0.00	14.29	23.33	76.67	
	O_H	1/2–2 cm	14.53	2.18	0.00	2.18	0.38	3.14	0.00	3.52	5.70	8.83	0.62
			100.00	15.00	0.00	15.00	2.62	21.61	0.00	24.23	39.23	60.77	
	A	2–8 cm	5.35	0.98	0.00	0.98	0.39	1.15	0.15	1.69	2.67	2.68	0.58
			100.00	18.32	0.00	18.32	7.29	21.50	2.80	31.59	49.91	50.09	
	(B)	8–50 cm	0.90	0.15	0.00	0.15	0.12	0.20	0.00	0.32	0.47	0.43	0.47
			100.00	16.67	0.00	16.67	13.33	22.22	0.00	35.56	52.23	47.77	
	(B)	50–103 cm	0.39	0.06	0.00	0.06	0.05	0.08	0.00	0.13	0.19	0.20	0.46
			100.00	15.38	0.00	15.38	12.82	20.51	0.00	33.33	48.71	51.29	

Table 2. Composition of 0.1 M H_2SO_4 extract from samples of soil under beech and Douglas fir

Plot	Horiz.	Depth cm	pH H_2O	Fulvic acid 1a (Cx2)	R_2O_3 %	Fe_2O_3 %	Al_2O_3 %	R_2O_3 : FK	Al_2O_3 : Fe_2O_3	Fe (B)hor : Fe A hor
Beech (control)	O_{LF}	0–4 cm	5.06	1.02	0.20	0.15	0.05	0.20	0.33	
	A	4–9 cm	4.86	0.88	1.30	0.42	0.88	1.48	2.10	
	A	4–13/19 cm	4.79	0.72	1.29	0.47	0.82	1.79	1.74	
	(B)	13/19–50 cm	5.27	0.40	1.19	0.37	0.82	2.98	2.22	0.79
	(B)	50–70 cm	5.54	0.16	0.86	0.28	0.58	5.38	2.07	0.60
Douglas fir	O_{LF}	0–1/2 cm	4.95	1.00	0.48	0.28	0.20	0.48	0.70	
	O_H	1/2–2 cm	4.60	0.76	1.58	0.48	1.10	2.07	2.28	
	A	2–8 cm	4.55	0.78	2.17	0.40	1.77	2.78	4.43	
	(B)	8–50 cm	5.15	0.24	1.44	0.39	1.05	6.00	2.69	0.98
	(B)	50–103 cm	5.36	0.10	1.34	0.33	1.01	13.40	3.06	0.83

the most present. There was no regularity in its increase or decrease through the profile, as already concluded by several authors (Avdalović, 1971; Pavlović, 1992, 1998; Pavlović et al., 1997; Kostić, 2007). The proportion of fraction 1 of the fulvic acids was higher at the Douglas fir stand through the whole depth of the profile, apart from in the litter horizon. This difference was most pronounced in the cambic horizon, where it amounted to 20.51–22.22 % at the Douglas fir stand, while at the control area of beech it was 11.11–14.36% (Table 1). This fraction was higher than the content of the aggressive fraction 1a throughout almost the whole profile, while its increase with depth was more marked in the soil under Douglas fir than under beech (13.33% : 9.90%; 12.82 : 9.88 in the cambic horizon, Table 1). As expected, the highest content of insoluble residue, due to the highest content of resistant material of lignin, was found in the litter horizon at both study sites. The proportion of humins in the humus was higher under Douglas fir than under the control beech (76.67% : 72.51%; Table 1). On the basis of these results, it can be seen that the humus matter formed in the soil under Douglas fir has a less favourable chemical composition than that at the control site in the autochthonous beech stand, which is reflected in the greater proportion of insoluble residue in humus, a lower proportion of humic acids, a higher proportion of fulvic acids and fraction 1a in the soil horizons, and a narrower Ch:Cf ratio at the Douglas fir stand. Specifically, soils which develop under coniferous vegetation are richer in fulvic acids than those formed under broadleaf vegetation (McKeague et al., 1986; Stefanović and Pavlović, 1991; Pavlović et al., 1997). An analysis of the parameters of the composition of soil extract in 0.1M H_2SO_4 revealed a dynamic that is characteristic of Dystric Cambisol (Table 2), i.e. there was not found a translocation of fulvic acid 1a and the organomineral complex of iron from the surface layers into the lower parts of the profile (Avdalović, 1971). This can be explained by the fact that the level of sesquioxides was enough to bind the aggressive fraction of fulvic acid 1a to the organomineral complex of iron and accumulate it from the very surface of the profile. This was supported by both the ratio of R_2O_3 to fulvic acid 1a, which was always higher than one, and also the Fe (B) hor./FeAhor. ratio, which was less than one. As far as aluminium is concerned, its migration was noted only in the area of the Douglas fir stand, and only within the humus-accumulative horizon.

Through an analysis of litter decomposition intensity, it was determined that beech organic matter decomposed more quickly than that from Douglas fir during the whole experiment (Figures 3 and 4). The greatest difference in decomposition intensity was found 6 months after the start of the experiment ($p < 0.001$) (Figure 3).

At this point, beech organic matter was 18.2% decomposed, while that from Douglas fir was 9.48% decomposed; however, after a year, the ratio was 32.76% : 24.98%. The slower decomposition of conifer litter is a result of the lower concentrations of nutrients and higher levels of lignin and polyphenols in coniferous organic matter, and of the specific microclimate (lower light intensity and lower moisture content) characteristic for coniferous ecosystems (Millar, 1974; Flanagan and VanCleve, 1983; Pavlović, 1992; Mudrik et al., 1994; Cornelissen, 1996; Pavlović, 1998; Prescott et al., 2000, 2004; Kostić et al., 2003; Pavlović et al., 2003; Kostić, 2007; Kostić et al., 2016).

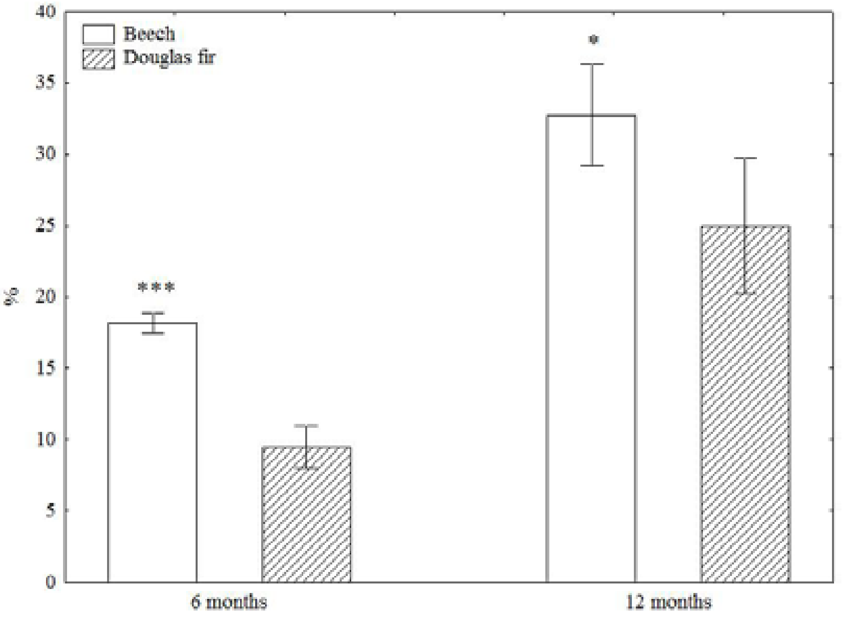

Figure 3. Decomposition intensity of organic matter from beech and Douglas fir (ANOVA, n=5; ***p<0 .001, * p<0.05) (Kostić et al., 2016).

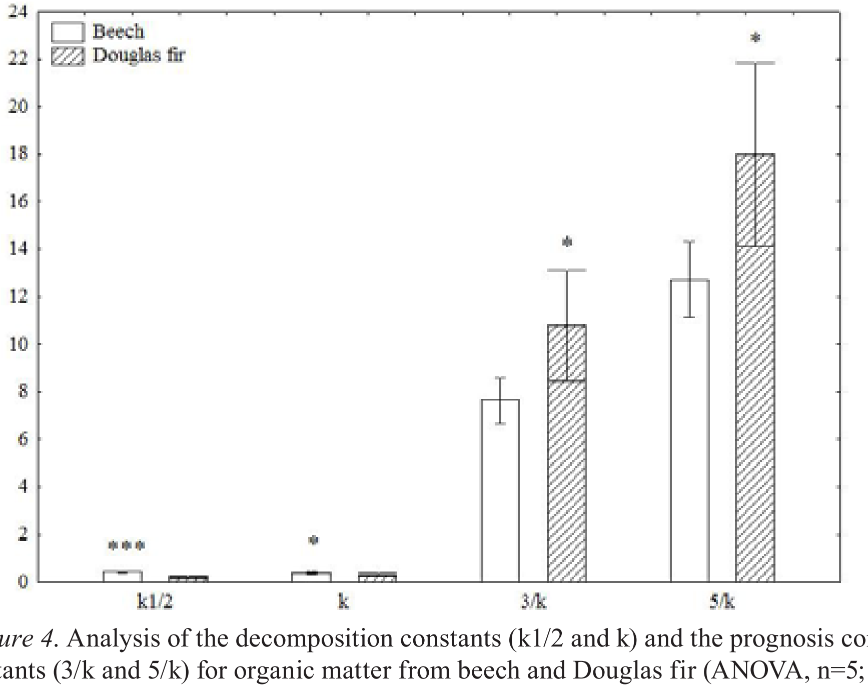

Figure 4. Analysis of the decomposition constants (k1/2 and k) and the prognosis constants (3/k and 5/k) for organic matter from beech and Douglas fir (ANOVA, n=5; ***p<0.001, *p<0.05) (Kostić et al., 2016).

A prognosis of the decomposition intensity of the organic matter from the studied species based on Olson's decomposition model suggested that 95% of organic matter from beech will decompose after 7.6 years and from Douglas fir after 10.8 years, while for 99% decomposition, 12.7 years will be necessary for beech organic matter and almost 18 years, i.e. an additional 5 years, for Douglas fir organic matter (Figure 4).

CONCLUSION

On the basis of the results of this study, it can be concluded that there is a difference in the amount and composition of humus in the soil of the examined ecosystems, as well as in the decomposition intensity of the organic matter of the edificators. The results of the spatial and temporal analysis of soil humus levels lead us to the conclusion that the clearcutting of beech and the organic matter from Douglas fir have contributed to a reduction in the amount of humus in beech forests on Mt. Maljen. A qualitative analysis of humus indicates that the chemical composition of the humus substances that form in the soil under Douglas fir is unfavourable compared to that under beech, which may in the future lead to the destruction of acid brown soil through further acidification and a reduction in its productivity. Specifically, the slower decomposition of Douglas fir organic matter and its more modest requirements for nutrients compared to beech will mean a significant amount of nutrients will be excluded from the cycling process for a lengthy period of time. In this way, the processes of beech habitat degradation, which began with the clearcutting of beech trees and the removal of large amounts of beech organic matter, will continue and will probably culminate after the cutting of the Douglas fir.

ACKNOWLEDGEMENTS

This work was supported by the Ministry of Education, Science and Technological Development of Republic of Serbia, Grants 451-03-68/2020-14/200007

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УТИЦАЈ ДУГЛАЗИЈЕ НА ДИНАМИКУ И САСТАВ ХУМУСА У ЗЕМЉИШТУ АУТОХТОНЕ ШУМЕ БУКВЕ У ЗАПАДНОЈ СРБИЈИ

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РЕЗИМЕ: У раду је истраживан утицај органске материје дуглазије (*Pseudotsuga menziesii* [Mirb.] Franco) на количину и састав хумуса киселог смеђег земљишта климарегионалне букове шуме (*Fagetum moesiacae montanum* B. Jov. 1967 s.l.) на Маљену. За постизање наведеног циља обављен је једногодишњи *in situ* експеримент, коришћењем “litter bag” методе/технике са стељом букве (*Fagus moesiaca*) и дуглазије (*Pseudotsuga menziesii*). Анализиран је квантитативан и квалитативан садржај хумуса и интезитет процеса разлагања органске материје букве и дуглазије. Утврђена је нижа количина хумуса, уочен је тренд смањивања количине хумуса током истраживања и опадање квалитета хумуса (неповољнији хемијски састав) у култури дуглазије у односу на контролну површину под аутохтоном буквом. Закључено је да ће ове промене, изазване ефектима чисте сече букве и у будућности дуглазије, и успорено разлагање органске материје дуглазије, допринети даљој деградацији буковог станишта у погледу продуктивности на планини Маљен.

КЉУЧНЕ РЕЧИ: нарушени екосистеми, *Fagus moesiaca*, *Pseudotsuga menziesii* силвикултура, хумус, хуминске и фулво киселине, разлагање стеље