THE ACCUMULATION AND PROPERTIES OF SURFACE HUMUS LAYER IN MIXED SELECTION FORESTS OF FIR ON DIFFERENT SUBSTRATES

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Abstract

Pernar N., Matić, S., Bakšić D., Klimo E.: The accumulation and properties of surface humus layer in mixed selection forests of fir on different substrates. Ekológia (Bratislava), Vol. 27, No. 1, p. 41–53, 2008.

The accumulation of organic matter in the surface, organic horizon (forest floor) has been investigated in two plant communities, *Blechno-Abietetum* (B-A) and *Omphalodo-Fagetum* (O-F) in the same climate. The dominant soil type in the community B-A is Podzol. Dystric Cambisol occurs in the inclusions, whereas the dominant soil type in the community O-F is Calcocambisol with Melanosol (Mollic Leptosol) in the inclusions. The results showed significant differences in the organic matter accumulation between these two communities. In the community B-A the accumulation of organic matter varies from 46,614 to 90,299 kg ha^{-1} on average, and in the community O-F it is from 7.536 to 16.651 kg ha^{-1}. The structure of the forest floor in the community B-A is dominated by over 80% of humified organic matter in the form of the Oh subhorizon. According to the analysis of the forest floor quality, the forest floor in the community O-F contained a higher concentration of Ca and Mg compared to the community B-A. No differences were found in terms of other nutrient concentrations; however, due to high organic matter accumulations in the forest floor of the community B-A, it accumulated significantly more analysed nutrient elements, with the exception of Ca. High accumulations of organic carbon and total nitrogen are particularly distinct. High total nitrogen accumulation in the Oh subhorizon indicates its relative immobilisation in the community B-A.

Key words: forest floor, surface humus layer, nutrient cycling, nutrient immobilisation

Introduction

The quantity and quality of organic sediment in the forest soil is an important link in the cycle of biogenic elements in an ecosystem. This material (leaves and needles, twigs, fruits) reaches the forest floor in the form of dead organic matter mainly in annual cycles. Biological cycling of mineral elements and nitrogen is one of the most important issues in the relationship of forest vegetation and soil (Cole, Rapp 1981; Waring, Schlesinger, 1985; Tamm, 1995; Harris, Safford, 1996; Johnson et al., 2000; Klimo, 2000; Martinović, 2003; Tesar et al., 2004). In dependence on their biological properties and ecological requirements (Mudrick et al., 1994), forest trees show different behavioural patterns in the process of biological nutrient cycling, which largely takes place in the soil – plant – forest floor – soil system. Research by Tesar et al. (2004) points to significant differences in the accumulation of surface humus in spruce, beech and fir stands, where high humus accumulation in a spruce stand (126 t ha^{-1}) is particularly distinct, especially in the Oh subhorizon (106 t ha^{-1}). Klimo (1992) states changes in the humus form and surface humus mass arising from a changed species composition in the conversion of a beech stand into a spruce stand (Table 1).

T a b l e 1. Change in surface humus mass (t ha^{-1})after the change in forest stand species composition (Klimo, 1992).

Layer	Beech stand	Norway spruce stand
L	10.0	11.5
F	12.6	15.8
H	0.5	22.3
Total	23.1	49.6

Notes: The L subhorizon is composed of fresh floor of an almost unchanged colour. The F subhorizon is composed of the weakly to strongly altered organic matter containing a multitude of mycelia and thin roots, while the H subhorizon consists of humified amorphous matter.

Forest floor has a strong influence on acidification and soil acidity. Acidification affects the transformation and cycle of biogenic elements (Bolan et al., 2005; Ulrich, Sumner, 1991). In a stable forest ecosystem the annual accumulation of organic matter and its mineralization coincides with the properties of soil. These properties may be determined by the soil type, the position in the forest and the forest floor.

This paper will present the results of research in two plant communities of fir and beech in Gorski Kotar in Croatia and analyse them in the light of the results of similar research. The subject of research is the surface humus layer. Research was aimed at analysing the relationships between organic matter parameters vital for the understanding of nutrient cycle and organic matter transformation in the soil. The results of these analyses will provide a starting point for better understanding of specific features of forest ecosystems developed above the pedogenetically and physiographically contrasting soils. This is particularly important in the current worsened ecological conditions affecting the fir (acid rains, changed climate), which is declining throughout its range.

Materials and methods

Research was conducted in the Teaching Experimental Forest Site of Zalesina, located in the mountain area of western Croatia called Gorski Kotar. Research encompassed two forest communities – the forest of fir with hard fern (*Blechno-Abietetum* Ht. 1950) (B-A) in the management unit (MU) Belevine and the forest of beech and fir (*Omphalodo-Fagetum* Marinček et al. 1992) in the MU Kupjački Vrh. To illustrate the structure of the studied stands, the results of research by Matić (1983) are given, which he obtained when he studied structural properties of selection forests of beech and fir in Gorski Kotar. According to his research (Table 2), in the community B-A in the southern exposition the frequency curve of tree number for each tree species has a regular shape of Liocourt's curve, which reflects the character of a single tree selection structure. In the northern exposition the frequency of tree number indicates a stand of group structure. The growing stock in the northern exposition exceeds that in the southern exposition by 15%.

Research was done in transects established 30 years ago (Matić, 1972, 1983), in which structural stand properties were studied on several occasions. Five localities were chosen (BEL1 – BEL 5) in the transect established in the community B-A, of which two were in the southern exposition and three in the north-eastern one (Table 3). In the transect in the community O-F six localities were chosen (KV1 – KV5), of which three were in the south-western exposition and three in the north-western exposition.

Climatic features can briefly be illustrated with annual temperature and precipitation means. The temperature mean is 6.5-7 °C and the precipitation mean is ~2,100 mm.

The forest of fir with hard fern (B-A) (Fig. 1) is developed on silicate substrate (sandstone) with Dystric Cambisol and Podzol. These are very acid soils with pH values of water solution across the profile less than 4.5. In terms of texture these are sandy to clayey loams. Saturation of the adsorption soil complex with basic cations is very low (mainly lower than 15%). The organic matter content in the A-horizon amounts to 80–180 g kg^{-1} C org. and of nitrogen 4–10 g kg^{-1}.

Fig. 1. Forest of fir with hard fern (left) and Dinaric beech-fir forest (right).

The forest of beech and fir (O-F) is developed on limestones and dolomites with Melanosol, Calcocambisol and Luvisol. These are shallow and skeletal soils. Melanosol prevails on steeper slopes and tops, while Luvisol occurs in sinkholes. Calcocambisol is the most represented soil. All soils are non-carbonate. They differ significantly in other parameters. Melanosols in the A-horizon as a rule contain > 250 g kg^{-1} C org., their reaction is weakly acidic and the adsorption complex capacity for basic cations is high. Calcocambisols are texturally heavier soils than

T a b l e 2. The structure of the stand by tree species, thickness class, number of trees (N) and wood mass (M (m^3)) (Matić, 1983).

Diameter (cm)	Fir and hardfern community – aspect south, Compt. 10, 12, 13								Fir and hardfern community – aspect north, Compt. 8, 10, 13							
	fir		spruce		beech		total		fir		spruce		beech		total	
	N	M	N	M	N	M	N	M	N	M	N	M	N	M	N	M
0–10	317	6.44	135	2.62	267	3.05	719	12.11	95	2.06	20	0.28	205	2.01	320	4.35
11–20	127	17.11	24	3.02	122	16.54	273	36.67	46	5.97	3	0.38	105	10.60	154	16.95
21–30	79	43.26	17	6.47	19	9.32	115	59.05	27	11.53	2	1.20	27	12.15	56	24.88
31–40	66	86.00	12	13.22	11	12.30	89	111.52	28	33.92			3	4.20	31	38.12
41–50	49	115.21	5	10.94	2	4.74	56	130.89	40	95.97	6	12.49			46	108.46
51–60	29	108.42					29	108.42	54	195.39	5	16.68			59	212.07
61–70	15	75.83	1	4.95			16	80.78	28	142.83	3	14.85			31	157.68
71–80	1	6.35					1	6.35	10	72.35					10	72.35
Σ	683	458.62	194	41.22	421	45.95	1298	545.79	328	560.02	39	45.88	340	28.96	707	634.86
Diameter (cm)	Beech and fir community – aspect south, Compt. 2								Beech and fir community – aspect north, Compt. 7							
	fir		beech		maple		total		fir		beech		maple and elm		total	
	N	M	N	M	N	M	N	M	N	M	N	M	N	M	N	M
0–10	149	3.80	258	5.86	19	0.54	426	10.20	52	0.91	274	2.75	9	0.14	335	3.80
11–20	68	8.34	149	20.99	39	6.26	256	35.59	62	8.48	77	8.26	17	2.50	156	19.24
21–30	33	16.87	73	44.50	56	36.89	162	98.26	36	18.70	38	19.81	30	15.80	104	54.31
31–40	23	28.96	37	51.74	43	57.45	103	138.15	33	40.63	25	31.20	28	35.26	86	107.09
41–50	17	35.77	5	14.89	16	40.02	38	90.68	33	72.23	4	10.81	16	34.90	53	117.94
51–60	7	26.49	1	3.96	2	8.29	10	38.74	5	16.00			1	3.20	6	19.20
61–70	14	78.30					14	78.30	15	72.72					15	72.72
71–80									12	74.11					12	74.11
81–90									3	25.93					3	25.93
Σ	311	198.53	523	141.94	175	149.45	1009	489.92	251	329.71	418	72.83	101	91.80	770	494.34

Melanosols. Their reaction is acid to weakly acid. Luvisols are the deepest soils on limestones and dolomites. In the illuvial horizon they have a heavy texture (predominantly clay), and their reaction in the A- and E-horizon is very acid. The lowest adsorption complex capacity for basic cations is in the E-horizon. In terms of tree number frequency (Table 2), stands of beech and fir have a single tree selection structure in the southern and northern exposition, with sporadic occurrences of sycamore and wych elm.

The studied community of fir with hard fern on Podzol and Dystric Cambisol is characterised by a mor humus form, while the community of beech and fir is characterised by a mull-moder humus form. Mor humus in the studied stands has a characteristic stratigraphy, with powerful F and H subhorizons.

Field investigations were undertaken in June 2004. A semi-profile was opened in each locality for purposes of pedotaxonomic determination and soil sampling from the A-horizon. Samples of the forest floor were collected below a square plot of 625 cm^2. The forest floor was sampled in 5 randomly chosen points in each locality.

The subhorizons L, F and H were identified in every sample (Fig. 2). The L subhorizon is composed of fresh floor of an almost unchanged colour. The F subhorizon is composed of the weakly to strongly altered organic matter containing a multitude of mycelia and thin roots, while the H subhorizon consists of humified amorphous matter.

In the community B-A, all three subhorizons were identified in all the cases, whereas in the community O-F only the L and F subhorizons were identified.

T a b l e 3. Basic features of the studied localities.

Locality	Soil	Location WGS 84 (°)		Height above sea level	Relief		Plant community	Horizon	pH (susp. H_2O)	pH (susp $CaCl_2$)	C org.	N tot.
		Geogr. latitude	Geogr. longitude		Slope	Exposition						
		N	E		(°)	(°)					(g kg^{-1})	
BEL 1	Podzol	45.38623	14.87131	795	8	190	*Blechno-Abietetum*	A	3.73	2.63	126.3	5.7
BEL 2	Podzol	45.38762	14.87392	825	8	180		A	3.79	3.15	101.1	5.7
BEL 3	Dystr. Cambisol	45.38989	14.87565	850	5	60		A	3.85	2.86	107.1	5.2
BEL 4	Podzol	45.39164	14.87678	815	12	40		A	3.67	2.66	165.0	9.1
BEL 5	Podzol	45.39313	14.87762	800	4	25		A/E	4.01	2.80	172.5	6.7
KV 1	Mollic Leptosol	45.41387	14.86523	970	10	330	*Omphalodo-Fagetum*	A	5.85	5.11	107.7	4.6
KV 2	Mollic Leptosol	45.41452	14.86505	945	20	355		A	5.64	4.84	82.5	6.3
KV 3	Mollic Leptosol	45.41614	14.86568	920	19	335		A	4.96	4.12	88.8	5.2
KV 4	Mollic Leptosol	45.40831	14.86086	810	28	240		A	6.39	5.98	101.2	6.6
KV 5	Cambisol	45.40672	14.86192	800	31	250		A	7.27	6.68	101.1	5.6
KV 6	Cambisol	45.40602	14.86222	780	35	240		A	6.77	6.13	84.0	4.9

Fig. 2. Procedure of organic matter sampling by subhorizons in the O-horizon.

The samples of the forest floor were dried at 50 °C until they reached constant mass. To determine the nutrient content in the floor subhorizons and in the A-horizon, a composite sample of the subhorizons and the A-horizon was made for three localities of the community B-A and for three localities of the community O-F (Table 5). Prior to analysis, the samples were ground in a mill and sifted through a stainless steel sieve.

The carbon content was determined according to the 10694 ISO Norm, the nitrogen content using Kjehldal's method and the P, K, Ca and Mg according to the 14869-1 ISO Norm.

The values of pH and carbon and nitrogen content in the A-horizon were determined in individual samples from the semi-profile taken in each plot. The pH value was determined according to the 10390 ISO Norm, while carbon was determined using the bichromatic method (Tjurin) and nitrogen using Kjehldal's method.

Descriptive statistical processing was done in Statistica 7.0 package.

Results and discussion

A-horizon

The A-horizon of the soil in all plots in the community B-A is of ochric character, while in the community O-F it is of mollic character, except in the plot KV3 where the A-horizon is ochric.

The organic carbon and total nitrogen content, as well as the pH value were measured in the A-horizon (Table 3). The organic carbon content in the soil A-horizon in the community B-A varies from 101 to 172 g kg^{-1}.

The highest organic carbon content in the A-horizon was recorded in Podzol in the plot BEL 5. It is a plot characterised by the accumulation relief type – a flattened terrain at the foot of a mild slope.

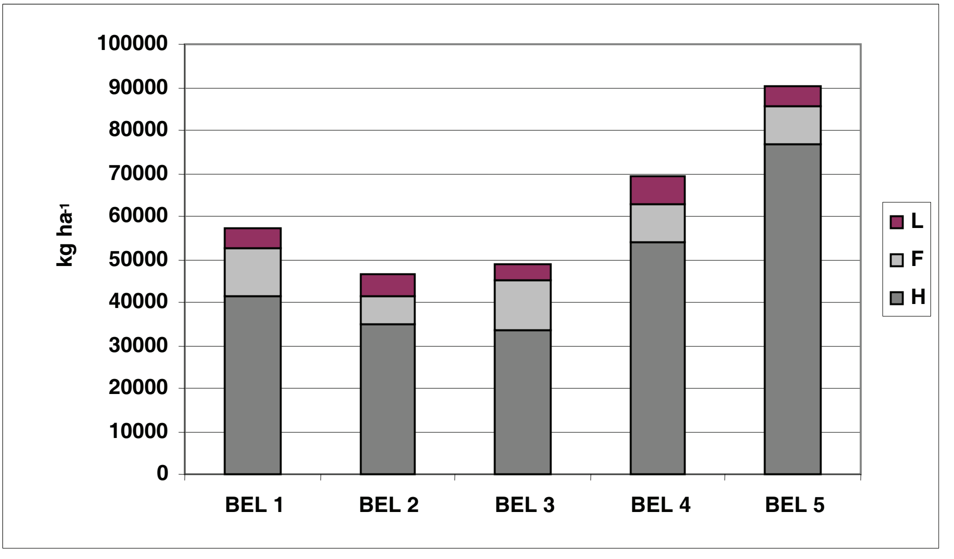

Fig. 3. Mean values of organic matter content in the soil O-horizon in the community B-A.
Notes: purple – L subhorizon, light gray – F subhorizon, dark gray – H subhorizon.

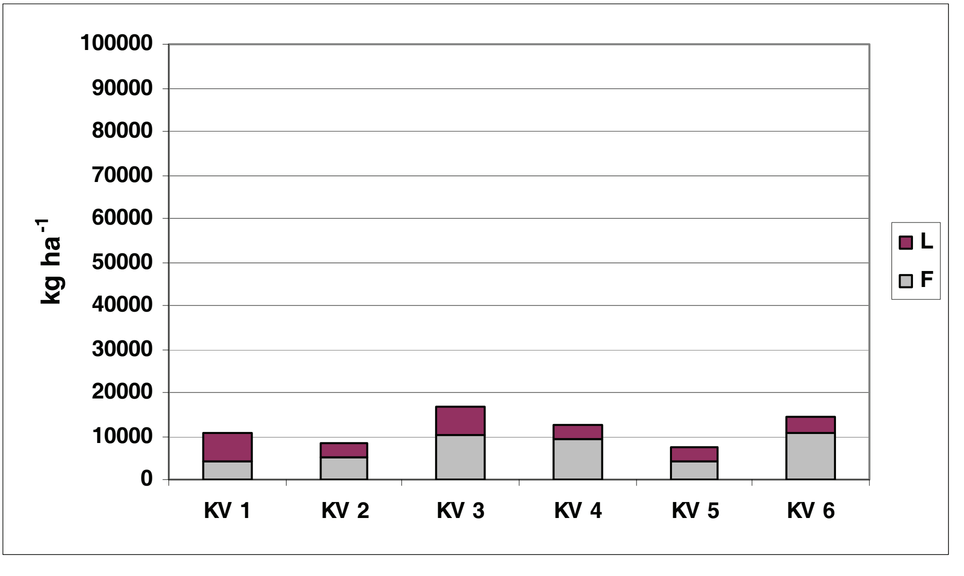

Fig. 4. Mean values of organic matter content in the O-horizon in the community O-F.
Notes: purple – L subhorizon, light gray – F subhorizon.

The nitrogen content in this community ranges from 5.2 to 9.1 kg^{-1}. In the community O-F, the organic carbon content in the A-horizon is 82–108 kg^{-1} and the nitrogen content is from 4.6 to 6.3 kg^{-1}.

The values of pH in water suspension in B-A is from 3.67 to 4.01 and in O-F from 4.96 to 7.27. Variations of pH values in O-F are much higher, which can be attributed to tiny limestone particles in the surface humus layer at higher inclinations, as for example in plots KV5 and KV6. In this spectre, the lowest value (Table 3), recorded in the ochric A-horizon of Calcocambisol in plot KV3 is also prominent.

Forest floor

A) Accumulation of organic matter

There are statistically significant differences in the accumulation of organic matter in the forest floor of these two forest ecosystems (Figs 3, 4). In the community B-A, it varies from 46.614 to 90.299 kg ha^{-1} on average, with a minimal value of 31.493 kg ha^{-1} and a maximal value of 115.338 kg ha^{-1}. In such a mass the completely humified organic matter – the Oh subhorizon, participates the mostly, and its quantity varies from 34.727 to 76.890 kg ha^{-1} on average. It is this, completely humified organic matter that is responsible for significant differences in the accumulation of organic matter between these two ecosystems. This layer (subhorizon) is absent in the community O-F. In the latter community the quantity of organic matter in the forest floor is 7.536 kg ha^{-1} to 16.651 kg ha^{-1} on average, with a minimal value of 3.336 kg ha^{-1} and a maximal of 35.609 kg ha^{-1}. Such a large difference in the quantity of organic matter in the forest floor should be attributed to the difference in the quality of leaf litter (McClaugherty et al., 1985). The decomposition rate of fir needles is slower than that of beech leaves, especially in later stages of decomposition. This is reflected on leaf litter decomposition in the stand as well, depending on the participation of a given species in the leaf litter accumulation. According to research by Kavvadias et al. (2001) on the example of Macedonian fir (*Abies borisii-regis,* M a t t f.) and common beech, it takes 17 years for a beech leaf and 32 years for a fir needle to decompose. Apart from plant species, the decomposition rate was also affected by the specific microclimate, as well as the nutrient status of two different sites in which research was done.

The content of fresh or partially humified organic matter in the Ol and Of subhorizons does not differ significantly in these two ecosystems. The community B-A shows a distinct dominant layer of humified organic matter.

Due to high variability of organic matter in the O-horizon (Table 4), this sample size was not statistically sufficiently large to test the correlation between individual subhorizons. The results of our analysis indicate a correlation ($r = 0.5–0.8$) between the quantity of organic matter in the Ol- and Of-soil subhorizon in the community B-A. As an exception, positive correlation is absent in plot 5, which occupies a flat position and has an exceptionally high accumulation of organic matter, and in plot 1. Correlation is

T a b l e 4. Variability coefficients for the organic matter content in the O-subhorizons.

Locality	L	F	H
	Variability coefficients (CV)		
BEL 1	24.7	33.3	66.6
BEL 2	32.8	22.1	69.6
BEL 3	14.1	49.8	30.2
BEL 4	47.6	26.7	23.5
BEL 5	33.0	45.1	28.1
KV 1	80.5	61.5	
KV 2	29.5	66.1	
KV 3	50.9	35.4	
KV 4	38.9	17.8	
KV 5	53.6	58.1	
KV 6	63.8	99.8	

also absent between the Of- and Oh-subhorizons and between the Ol- and Of-subhorizons in the community O-F.

Nutrients in the forest floor

The nutrient content in the forest floor was analysed in three plots in the community B-A, and in three plots in the community O-F. The forest floor in the community O-F contains higher Ca and Mg concentrations than that in the community B-A. There are no differences with regard to other nutrient concentrations. Despite this, due to the high accumulation of the forest floor in the community B-A, significantly more analysed nutritive elements, except Ca, have been accumulated in it. High accumulations of organic carbon and total nitrogen are particularly prominent (Table 5). As for the accumulation of Ca in the forest floor, there are no significant differences between these two communities. The nitrogen cycle in the community B-A is evidently characterised by its relative immobilisation with regard to the accumulation in the Oh-subhorizon to more than 1.400 kg ha^{-1}. Berg, Ekbolm (1983) attribute this phenomenon to the C: N relationship, which, according to our research, is considerably broader in the L subhorizon in the community B-A than in the community O-F. In models of organic matter dynamics in forest ecosystems of boreal and temperate climatic belt, Chertov et al. (2001), Komarov et al. (2003) rank nitrogen and ash content in the first place in terms of organic matter properties.

T a b l e 5. Concentration and accumulation of biogenic elements in the O- and A-horizon.

		Element (g kg^{-1})						Element (kg ha-1)					
No.	Sample	C org.	N	P	K	Ca	Mg	C org.	N	P	K	Ca	Mg
1	BEL 1 L	475.0	13.6	1.1	1.2	10.7	0.8	2156	62	5	5	49	4
2	BEL 1 F	432.0	15.5	1.3	1.8	8.8	1.0	4924	177	15	20	100	11
3	BEL 1 H	348.0	16.5	1.3	2.8	2.4	0.8	14364	681	54	117	98	33
4	BEL 1 A	126.3	5.7	1.0	3.2	0.4	0.7	21443	919	74	142	247	48
5	BEL 3 L	467.0	15.2	1.3	1.4	10.1	0.8	1781	58	5	5	38	3
6	BEL 3 F	405.0	15.3	1.4	2.1	5.4	0.9	4749	179	16	25	63	10
7	BEL 3 H	328.0	15.9	1.3	2.5	2.3	0.7	10990	533	45	84	75	24
8	BEL 3 A	107.1	5.2	0.9	3.3	0.6	0.6	17521	770	66	115	177	37
9	BEL 5 L	474.0	13.1	1.0	1.1	11.6	0.7	2135	59	4	5	52	3
10	BEL 5 F	459.0	15.8	1.3	1.6	7.2	0.8	4087	141	12	14	64	7
11	BEL 5 H	412.0	18.7	1.2	2.4	3.2	0.8	31679	1438	95	187	242	61
12	BEL 5 A	173.0	6.7	1.2	6.3	0.6	0.6	37901	1638	111	206	359	71
13	KV 1 L	435.0	15.5	1.3	2.3	15.8	1.2	2762	98	8	15	100	8
14	KV 1 F	430.0	15.3	1.2	2.6	18.9	1.2	1847	66	5	11	81	5
15	KV 1 A	107.7	4.6	1.6	9.6	10.0	5.0	4609	164	14	25	181	13
16	KV 3 L	465.0	14.8	1.4	1.6	19.8	1.0	2986	95	9	10	127	6
17	KV 3 F	426.0	15.4	1.4	2.2	24.6	1.5	4358	158	14	22	252	16
18	KV 3 A	88.8	5.2	1.2	8.2	3.1	5.2	7344	253	23	32	379	22
19	KV 6 L	453.0	15.0	1.0	2.1	20.7	1.3	1674	55	4	8	77	5
20	KV 6 F	376.0	11.1	1.1	3.7	29.7	2.3	4097	121	12	40	323	25
21	KV 6 A	84.0	4.9	1.2	14.9	7.9	6.5	5771	176	16	47	400	30

These results should be linked to internal and external factors that affect the cycle of biogenic elements in the forest ecosystem. A set of internal factors include soil and its properties determined by the constellation of pedogenetic factors. External factors relate to bioclimatic conditions that determine the conditions of organic matter decomposition. In combination with internal factors, external factors determine the quality of organic matter that reaches the forest floor. Individual factor which does not differenciate these communities is macroclimate. However, in this case the physiognomy of the ecosystem and the cycle of matter in it are strongly affected by the parent substrate, or the mineral soil component as a source of nutrients (except N). The nature of the parent substrate is evidently a key factor in the debasification process and the profile acidification trend. In their study of different factors of soil acidification, Augusto et al. (1998) put the parent substrate in the first place.

An increase in soil moisture contributes to an increased accumulation of surface humus (Tesar et al., 2004).

Regardless of nutrient accumulation in the forest floor and a high degree of organic matter humification, the production of organic acids and the slow mineralization rate are crucial negative features of the forest floor in the community B-A. Raulund-Rasmussen, Vejre (1995) point to significant differences in nutrient immobilisation in the forest floor of different stands, arising from species of trees or from soil properties, while Klimo (1992) points to an increase in the accumulation of surface humus from 23 t ha^{-1} in a beech stand to 50 t ha^{-1} in a spruce stand (in the period of one spruce generation), and to the transformation of humus nature from a moder form to a mor-moder form. Slow nutrient release and low pH values that are adverse to the uptaking of certain nutrients have negative effects on young plants. In his study of stand regeneration in this community, Matić (1972) emphasises that high mortality of young fir growth is a limiting factor for successful regeneration. He attributes this to unfavourable properties of the surface humus layer. Of the initial number of seedlings, only 6% survive in the first three years. In later developmental stages the dieback trend is milder.

Matić (1983) investigated the correlation between the number of seedlings and young fir growth and ecological factors in the same localities in which the present research was done. He proved that the survival of seedlings and one-year-old plants was significantly dependent on pH values in the surface humus layer. Interestingly, the number of seedlings was higher in places where the soil reaction was lower, the thickness of raw humus smaller and the humus content lower. In the community O-F the number of seedlings was higher where the soil reaction was higher, the soil humidity regime more favourable and the quantity of raw humus lower.

It is the accumulation of raw humus (Oh-subhorizon) that characterises the community B-A.

Conclusion

Based on research of organic matter accumulation in the surface humus horizon and its properties in two mixed fir stands on silicate and limestone substrate, the following conclusions can be drawn:

1. In the community B-A the dominant soil type is Podzol, while Dystric Cambisol occurs in the inclusions. In the community O-F the dominant soil type is Calcocambisol, with Melanosol and Luvisol occurring in the inclusions.
2. In the community B-A, the accumulation of organic matter is between 46.614 and 90.299 kg ha^{-1} on average, while in the community O-F it is from 7.536 to 16.651 kg ha^{-1}.
3. The organic matter in the forest floor of the community B-A is almost completely humified in the form of the Oh-subhorizon. Its quantity varies from 34.727 to 76.890 kg ha^{-1}.
4. The forest floor in the community O-F contains higher concentration of Ca and Mg compared to the community B-A, but does not differ in the concentration of other nutrients.

5. Due to high accumulations of the forest floor in the community B-A, this floor has accumulated considerably more analysed nutrient elements, except Ca. High accumulations of organic carbon and total nitrogen are particularly distinct.
6. There are no significant differences between these two communities in terms of Ca accumulation in the forest floor. The nitrogen cycle in the community B-A is evidently characterised by its relative immobilisation with regard to the accumulation in the Oh-subhorizon and to more than 1.400 kg ha^{-1}.
7. The community B-A is characterised by the nature of the parent substrate as a passive acidification factor, as well as the accumulation of raw humus in the forest floor as an active factor of soil acidification.

Translated by the authors

Acknowledgements

Research was realised within scientific cooperation between Faculty of Forestry in Zagreb, Croatia and Faculty of Forestry and Wood Technology in Brno, Czech Republic, project MSM 6215648902.

References

Augusto, L., Bonnaud, P., Ranger, J., 1998: Impact of tree species on forest soil acidification. Forest Ecology and Management, *105*: 67–78.

Berg, B., Ekbolm, G., 1983: Nitrogen immobilization in decomposing needle litter at variable carbon: nitrogen ratios. Ecology, *64*: 63–67.

Bolan, N.S., Curtin, D., Adriano, D.C., 2005: Acidity. In Hillel, D. (ed.), Encyclopedia of soils in the environment. Vol. 1. Elsevier A.P., Amsterdam, p. 11–17.

Chertov, O.G., Komarov, A.S., Nadporozhskaya, M.A., Bykhovets, S.S., Zudin, S.L., 2001: ROMUL–model of forest soil organic matter dynamics as a substantial tool for forest ecosystem modelling. Ecol. Modell., *138*: 289–308.

Cole, D.W., Rapp, M., 1981: Elemental cycling in forest ecosystems. In Reichle, D.E. (ed.), Dynamic properties of forest ecosystems. Cambridge University Press, Cambridge, p. 341–410.

Harris, M.M., Safford, L.O., 1996: Effects of season and four tree species on soluble carbon content in fresh and decomposing litter of temperate forests. Soil Science, *161*, 2: 130–135.

Johnson, D.W., Song, T., Kvindesland, S., 2000: The nutrient cycling model: lesson learned. Forest Ecology and Management, *144*: 113–127.

Kavvadias, V.A., Alifragis, D., Tsiontsis, A., Brofas G., Stamatelos, G., 2001: Litterfall, litter accumulation and litter decomposition rates in four forest ecosystems in northern Greece. Forest Ecology and Management, *138*, 1–3: 91–106.

Klimo, E., 1992: The spruce forest ecosystems in Czechoslovakia. In Teller, A., Mathy , P., Jeffers, J.N.R. (eds): Responses of forest ecosystems to environmental changes. Elsevier, Applied Sciences, p. 503–511.

Klimo, E., 2000: Stress factors in the ecosystems of norway spruce monocultures, induced by changed soil properties and nutrient cycling. Ekológia (Bratislava), *19*, Suppl. 1: 113–129.

Komarov, A., Chertov, O., Zudin, S., Nadporozhskaya, M., Mikhailov, A., Bykhovets, S., Zudina, E., Zoubkova, E., 2003: EFIMOD 2–a model of growth and cycling of elements in boreal forest ecosystems. Ecol. Modell., *170*, 2–3: 373–392.

Martinović, J., 2003: Gospodarenje šumskim tlima u Hrvatskoj (Management of forest soils in Croatia). Forest Research Institute Jastrebarsko, 525 pp.

Matić, S., 1972: Natural regeneration – the factor of stand structure in the fir and hardfern forests (*Blechno-Abietetum* Horv.). Master thesis. Faculty of Forestry, University of Zagreb, 77 pp.

Matić, S., 1983: The impact of ecological and structural factors on natural regeneration of fir and beech selection forests in Gorski Kotar. Glasnik za Šumske Pokuse, *21*: 233–400.

McClaugherty, C. A., Pastor, J., Aber, J.D., Melillo, J.M., 1985: Forest litter decomposition in relation to soil nitrogen dynamics and litter quality. Ecology, *66*: 266–275.

Mudrick, D.A., Hoosein, M., Hicks, R.R., Jr., Townsend, E.C., 1994: Decomposition of leaf litter in an Appalachian forest: effects of leaf species, aspect, slope position and time. Forest Ecology and Management, *69*: 231–250.

Raulund-Rasmussen, K., Vejre, H., 1995: Effect of tree species and soil properties on nutrient immobilization in the forest floor. Plant and Soil, *168–169*: 345–352.

Tamm, C.O., 1995: Towards an understanding of the relations between tree nutrition, nutrient cycling and environment. Plant and Soil, *168–169*: 21–27.

Tesar, V., Klimo, E., Kraus, M., Souček, J., 2004: Long-term transformation of a coniferous forest at Hetlín – the Kutná Hora forest management. Mendel University of Agriculture and Forestry, Brno, 60 pp.

Ulrich, B., Sumner, M.E., 1991: Soil acidity. Springer-Verlag, Berlin, 224 pp.

Waring, R.H., Schlesinger, W.H., 1985: Nutrient cycling trough forests. In Forest ecosystems. Concepts and Management. Academic Press, Orlando, p. 121–156.