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Soil Genesis

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PROPERTIES OF HUMUS HORIZONS OF SOILS DEVELOPED IN THE LOWER MONTANE BELT IN THE TATRA MOUNTAINS**

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Abstract. The aim of the study is to evaluate differences occurring in the soil humus horizons between different types of forests. Soil samples were collected from spruce monoculture and natural beech sites within the lower montane zone in the Tatra Mountains. They were analyzed for organic carbon (OC), loss on ignition in ectohumus horizons, pH, fractional composition of organic matter and cellulose decomposition rate. The objects of investigation are two profiles representing Rendzic Leptosols under spruce and beech, one profile formed on cover bed, which can be classified as Haplic Leptosol under spruce forest and one Haplic Cambisol under the beech site. It is shown that different tree species strongly affect features of both ectohumus and endohumus horizons. This is visible in morphology of humus horizons as well as humus fraction composition which leads to acidification and to a descending cellulose decomposition rate. Another factor controlling features of humus horizons is parent material. It seems to be possible to separate effects which are results of vegetation and parent material features.

This paper is a part of wider investigations continuing estimating the influence of spruce on the soil properties in the Tatra Mountains. A part of that investigation is to compare the humus horizons developed under spruce monoculture and natural beech forest. Many authors claim that coniferous trees affect the soil properties leading to their acidification [1, 2, 12, 20] and intensify weathering processes [2]. The depth and intensity of those processes depend on the parent material features and the time of duration.

The humification rate and humus features depend on the plant material. The chemical composition of a plant remnants leads to releasing different amounts of humus substances to the soil's environment. Needles of coniferous trees which

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contain more lignins and less nitrogen release more humus acids in comparison to broadleaf trees [6, 11]. On the other hand, decomposition of needles causes a slowdown of the mineralization processes which leads to development of thick row humus horizons [10]. Production of humic acids is claimed to be the main process causing acidification [1, 4, 12]. The depth of the acidification depends on the type of parent material and age of the monoculture [1, 2, 12]. In some cases acidification by coniferous trees can lead to development podzolization processes [5].

The fractional composition of humus substances is strongly connected with the type of parent material [15, 17]. Generally speaking, in soil developed on limestone, the ratio of humic acids to fulvic acids is relatively high in comparison to soils formed on other materials, which is connected with higher biological activity in Rendzic Leptosols. The mentioned authors reported that fractional composition of humus substances differs within similar limestone parent material. Binding humic acids by abundant active carbonates protect them from further transformation and decreases the humic to fulvic acids ratio [15, 17].

The aim of this paper is to compare the humus horizons developed under spruce monoculture and natural beech sites in the lower forest belt in the Tatra Mountains. The second question is whether it is possible to determine these differences from the influence of parent material.

MATERIAL AND METHODS

Forest soil samples from under natural beech (*Fagus silvatica*) sites and spruce (*Picea abies*) monocultures were taken into consideration. Four profiles are located in the lower montane belt of the Tatra Mountains in Dolina Chochołowska and Dolina Białego. Characteristics of the profiles are given in Table 1. Profiles Nos 5 and 6 are classified as Rendzic Leptosols with a high amount of $CaCO_3$. Profile No. 3 is classified as Haplic Leptosol and profile No. 1 is classified as Cambisol, both developed on sediments with a relatively small amount of $CaCO_3$ covering limestone. The analyzed soils are representative of the lower montane belt in the West part of the Tatra Mountains [14].

The following were assayed in the soil samples:

– pH in water and 1M KCl (1:2.5);
– organic carbon content (OC), with the Tiurin method modified by Oleksynowa;
– loss on ignition at 550°C;
– fractional composition of organic with the Duchafour and Jacquin method modified by Skłodowski [22, 24] in endohumus horizons (A) and adjacent ectohumus subhorizons (Of, Ofh). This method allows dividing density fractions: free humus fractions (the light one) and bound with mineral particles (the heavy one). It enables measuring insoluble fraction content represented by

humines and non-extracted strong mineral-organic complexes as well as non-humus material (residuum) [16]. In following extractions, the humus acids with different polymerization index and degree of binding with the mineral part of soil are released. These are the most active fulvic and humic acids which are claimed to be responsible for podzolization processes in some kind of soils [22] in the first extraction (I). In the second and third extraction (II, III) there are more stable acids (Table 4). As unbound with mineral particles, humic acids released from free fraction, especially the fulvic ones, can be treated as relatively moveable;

– cellulose decomposition using cellulose filters method. As an accurate factor of biological activity, the cellulose filter method was used for the ectohumus horizons [3]. Cellulose filter decomposition was measured in 10 replicates in two analyzed soils – Cambisol under the beech site and Haplic Leptosol under the spruce forest. Cellulose filters were placed in fermentation sub-horizon (Of) in profile No. 1, and fermentation-epihumus sub-horizon (Ofh) in profile No. 3.

TABLE 1. POINTS OF INVESTIGATION

Profile No.	Location	Soil (WRB, 2006)	Parent material	Vegetation	Type of humus horizon
1	Dolina Białego, 980 m a.s.l., slope 10-15°N	Haplic Cambisol (Dystric)	Shales and sandstones on limestones	*Dentario glandulosae-Fagetum*	Moder-mull
3	Dolina Chochołowska, 960 m a.s.l., slope 8-10°N	Cambic Leptosol (Calcaric, Skeletic)	Shales and sandstones on limestones	*Piceetum* (adm. *Abies alba*)	Protomor
5	Dolina Białego, 970 m a.s.l., slope 20-25°W	Rendzic Leptosol (Eutric, Skeletic)	Dolomites, limestones	*Dentario glandulosae-Fagetum*	Moder-mull
6	Dolina Białego, 1 070 m a.s.l., slope 30° W	Rendzic Leptosol (Eutric, Skeletic)	Dolomites, limestones	*Piceetum* (*adm.Acer pseudoplatanus, Fagus silvatica, Picea abies, Sorbus aucuparia*)	Moder-mor

RESULTS

Basic features of soils

Basic features of analyzed soils with humus horizons are given in Table 2. The thickness of ectohumus horizons is comparable to profiles 1,3,5 and 6 irrespective of the tree species and measure 6 cm in profiles 1, 3, 5 and 9 cm in profile 6.

Differentiation between analyzed horizons is visible in the sequence of ectohumus sub-horizons as well as morphology of endohumus horizons.

The organic matter content within ectohumus horizons ranges from approx. 90% in the uppermost weakly decomposed leaf and fermentation sub-horizons (Ol, Of) of all profiles to approx. 30% in well-humificated fermentative-humic (Ofh) sub-horizons in Rendzic Leptosols (Table 2). Organic carbon content within endohumus horizons Ah ranges from approx. 3% to approx. 4%.

Morphological features and pH of the ectohumus and endohumus horizons presumed classifying them as moder-mull (profiles 1, 5), moder-mor (profile 6) and protomor (profile 3) [13].

Cellulose decomposition

The amount of decomposed cellulose within a 10 week period during the growing season (VI-X) was measured. The results are given in Table 3: in the Cambisol under beech on average (from 10 replicates) 64% of all cellulose was decomposed; in the profile no. 3 under spruce that amount was on average 47%.

Fractional composition of humus

The results of fractional composition of humus are given in Table 4. In Table 5 the main indexes of humification process are given.

Ectohumus horizons

Humification index in analyzed ectohumus horizons range from 2.27 to 19.50%. The fulvic acids prevail on humic acids in all analyzed profiles among the humus acids extracted from ectohumus horizons. The Ch/Cf ratio range from 0.32 to 0.64 and is higher under spruce forest (0.44-0.64) than under the beech site (0.32-0.35).

There are more humus acids released from spruce litter than from beech leaves. The important fact is that fulvic acids of the first and the second extraction in the light fraction prevailed (Fig. 1). This means that higher amounts of movable reactive fractions are released from spruce litter than from the beech litter. Fulvic acid content ranges from 0.56 and 0.58% under beech and 0.70 and 0.86% under spruce. Humic acid content was the same in both soils under beech (0.19%) and higher in soils under spruce (0.29 and 0.50%).

TABLE 2. SELECTED PROPERTIES OF SOILS

Profile No.	Horizon	Depth (cm)	Total organic carbon (%)	Organic matter (%)	$eqCaCO_3$ (%)	pH	
						Water	1M KCl
1	Ol	0-1		95.2		5.3	4.5
	Of	1-6		82.9		5.0	4.3
	Ah	6-15	3.02		0.16	4.8	3.6
	AB	15-30	0.56		0.24	5.1	3.7
	Bw	30-55	0.34		0.24	5.2	3.9
	B2	55-80	0.33		0.44	5.4	4.0
	BC1	80-100	0.24		0.21	5.5	4.0
	BC2	100-120	0.37		0.35	5.6	4.2
3	Of	0-2		90.9		4.0	3.1
	Ofh	2-6		56.3		3.6	2.8
	Ah	6-10	4.15		0.56	4.3	3.3
	B1w	10-20	1.58		1.10	4.9	3.7
	B2w	20-35	1.17		0.92	6.7	5.8
	BC1ca	35-50	1.38		2.42	7.4	6.9
	BC2ca	50-(70)	1.35		11.15	7.6	6.9
5	Ol	0-2		92.3		6.4	5.7
	Of	2-5		89.5		6.6	5.9
	Ofh	5-6		37.0			
	A1h	6-20	4.42		54.57	7.9	7.5
	A2	20-28	2.81		57.80	7.8	7.3
	AC1ca	28-35	1.96		62.97	7.9	7.6
	AC2ca	35-(45)	0.67		76.95	8.2	7.9
6	Olf	0-2		88.1		5.6	4.6
	Of	2-4		75.4		4.8	4.2
	Ofh	4-9		33.5		6.0	5.7
	A1h	9-15	4.38		29.25	7.7	7.0
	A2	15-25	1.86		46.31	7.9	7.2
	A3	25-35	1.36		38.18	8.0	7.2
	AC1Ca	35-40	0.90		48.66	8.1	7.3
	AC2Ca	40-(45)	0.85		57.97	8.0	7.3

TABLE 3. THE RATE OF CELLULOSE DECOMPOSITION

Profile No.	Rate of cellulose decomposition within 10 weeks - average (%)
1	63.80
3	46.83

TABLE 4. FRACTIONS OF HUMUS COMPOUNDS

Horizon (depth, cm)	Organic carbon (%)	Free fraction						Bound fraction								Σ Kh	Σ Kf	Humines	Residuum
		Humic acids (Kh)			Fulvic acids (Kf)			Humic acids (Kh)				Fulvic acids (Kf)							
		I	II	Σ	I	II	Σ	I	II	III	Σ	I	II	III	Σ				
In relation to carbon content (%)																			
Profile No. 1. Haplic Cambisol (Dystric), beech forest																			
Of 1-6	48.05	0.28	0.07	0.35	0.45	0.54	0.99	0.00	0.00	0.04	0.04	0.03	0.02	0.08	0.13	0.39	1.12	0.75	97.74
Ah 6-15	3.02	0.91	1.11	2.02	1.42	0.83	2.25	0.93	0.65	2.32	3.90	6.49	3.18	5.10	14.77	5.92	17.03	49.82	27.23
Profile No. 3. Cambic Leptosol (Calacaric, Skeletic), spruce forest																			
Ofh 2-6	32.68	0.19	0.70	0.89	0.77	1.19	2.07	0.00	0.00	0.00	0.00	0.03	0.00	0.02	0.05	0.89	2.02	0.57	96.52
Ah 6-10	4.15	1.69	1.10	2.79	1.69	1.44	3.13	2.26	1.76	2.66	6.71	11.39	4.73	8.41	24.53	9.49	27.67	42.00	20.84
Profile No. 5. Redzic Leptosol (Eutric, Skeletic), beech forest																			
Ofh 5-6	21.48	0.22	0.34	0.56	0.70	1.14	1.84	0.05	0.07	0.17	0.29	0.32	0.16	0.36	0.84	0.86	2.67	3.30	93.17
Ah 6-20	4.42	0.00	0.00	0.00	4.09	2.60	6.69	0.77	0.77	1.52	3.06	3.52	1.52	2.93	7.97	3.05	14.66	57.08	25.21
Profile No. 6. Rendzic Leptosol (Eutric, Skeletic), spruce forest																			
Ofh 4-9	19.41	0.24	1.05	1.29	1.65	0.12	1.77	0.37	0.00	0.79	1.16	0.79	0.77	0.71	2.27	2.58	4.03	12.88	80.51
Ah 9-15	4.39	4.82	0.00	4.82	0.80	0.40	1.20	1.44	0.00	1.92	3.36	4.48	3.31	1.36	9.15	8.22	10.36	61.13	20.29

TABLE 4. CONTINUATION

Horizon (depth, cm)	Organic carbon (%)	Free fraction						Bound fraction								Σ Kh	Σ Kf	Humines	Residuum
		Humic acids (Kh)			Fulvic acids (Kf)			Humic acids (Kh)				Fulvic acids (Kf)							
		I	II	Σ	I	II	Σ	I	II	III	Σ	I	II	III	Σ				
In relation to soil mass (%)																			
Profile No. 1. Haplic Cambisol (Dystric), beech forest																			
Of 1-6	48.05	0.14	0.03	0.17	0.22	0.26	0.48	0.00	0.00	0.02	0.02	0.01	0.01	0.04	0.06	0.19	0.54	0.36	46.96
Ah 6-15	3.02	0.03	0.03	0.06	0.04	0.03	0.07	0.03	0.02	0.07	0.12	0.20	0.10	0.15	0.45	0.18	0.52	1.50	0.82
Profile No. 3. Cambic Leptosol (Calacaric, Skeletic), spruce forest																			
Ofh 2-6	32.68	0.06	0.23	0.29	0.25	0.39	0.64	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.02	0.29	0.66	0.19	31.54
Ah 6-10	4.15	0.07	0.05	0.12	0.07	0.06	0.11	0.09	0.07	0.11	0.27	0.47	0.20	0.35	1.02	0.39	1.15	1.74	0.87
Profile No. 5. Redzic Leptosol (Eutric, Skeletic), beech forest																			
Ofh 5-6	21.48	0.05	0.07	0.12	0.15	0.24	0.39	0.01	0.02	0.04	0.07	0.07	0.04	0.08	0.19	0.19	0.58	0.71	20.00
Ah 6-20	4.42	0.00	0.00	0.00	0.18	0.12	0.30	0.03	0.03	0.07	0.13	0.16	0.07	0.13	0.36	0.13	0.65	2.53	1.11
Profile No. 6. Rendzic Leptosol (Eutric, Skeletic), spruce forest																			
Ofh 4-9	19.41	0.05	0.20	0.25	0.32	0.02	0.34	0.07	0.03	0.15	0.25	0.15	0.15	0.14	0.44	0.50	0.78	2.50	15.63
Ah 9-15	4.39	0.21	0.00	0.21	0.04	0.02	0.06	0.06	0.00	0.08	0.14	0.20	0.15	0.06	0.41	0.35	0.47	2.68	0.89

TABLE 5. SELECTED INDICATORS

Horizon (depth cm)	Total organic carbon (%)	Humification index	Ch/Cf ratio	Rate of carbon in fraction	
				Free	Bound
Profile No. 1. Haplic Cambisol (Dystric), beech forest					
Of 1-6	48.05	2.27	0.35	0.65	0.10
Ah 6-15	3.02	72.77	0.35	0.13	0.57
Profile No. 3. Cambic Leptosol (Calacaric, Skeletic), spruce forest					
Ofh 2-6	19.41	3.65	0.44	0.99	0.02
Ah 6-10	4.39	79.15	0.34	0.33	1.29
Profile No. 5. Rendzic Leptosol (Eutric, Skeletic), beech forest					
Ofh 5-6	32.68	6.84	0.32	0.51	0.26
Ah 6-20	4.15	74.79	0.20	0.30	0.42
Profile No. 6. Rendzic Leptosol (Eutric, Skeletic), spruce forest					
Ofh 4-9	21.48	19.50	0.64	0.59	0.66
Ah 9-15	4.42	79.71	0.74	0.27	0.55

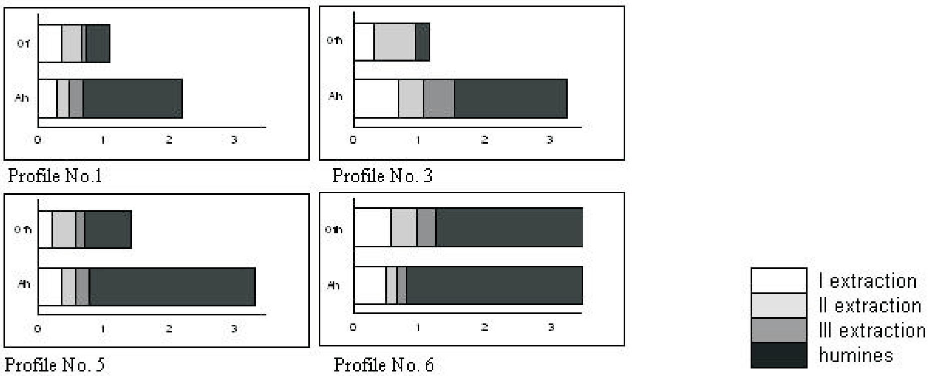

Fig. 1. Carbon content of following extractions in relation to soil mass (%).

Humines content is less than 1% in ectohumus horizons of soils developed on parent material with a small amount of $CaCO_3$. In both Ofh horizons of Rendzic Leptosols it is higher. Humines content in Ofh subhorizon in profile 6 is on average 13% of organic carbon content (Table 5) and is significantly higher in comparison to other analyzed ectohumus subhorizons.

Endohumus horizons

In the endohumus horizons the humification index ranges from 72.77% in Cambisol formed under the beech site to 79.71% in Rendzic Leptosol under spruce (Table 5).

The amount of the most movable humus acids dissoluted in the first extraction (I) is significantly higher in A horizons of profiles developed under spruce than under beech. The amount of those fractions range from 0.70% in Haplic Leptosol and 0.51% in Rendzic Leptosol under spruce to 0.30% in Haplic Cambisol and 0.37% in Rendzic Leptosol under beech (Fig. 1). Fulvic acid content is the highest in Haplic Leptosol under spruce – 1.15% in soil mass compared to less than 0.8% in other soils. Fulvic acids prevailed on humic acids.

The amount of humines ranges from 57-61% of organic carbon content in Rendzic Leptosols to 42-49% in Cambisol and Rendzic Leptosol (Table 4).

DISCUSSION

The presented results confirm early observations demonstrating specific features of organic and humus horizons in the mountain soils [9, 19, 21].

In the ectohumus horizons, pH is clearly connected with tree species. It can be observed that the spruce litter is significantly more acid than the beech litter independently on parent material. The acidification effect is also visible in endohumus horizons (Table 2).

Results of cellulose decomposition show that one kind of biological activity under spruce is noticeably lower than under beech. The results for spruce are more comparable to those from a higher montane belt in the Tatra Mountains – 41-44%, while those from under beech are similar to beech forest in the Gorce Mountains – 61% and just slightly lower than in the mixed stand in the Carpathian Foothills – 71% [7].

Humification indexes in analyzed profiles in both ectohumus and endohumus horizons are significantly lower than in comparable forest soils in the Świętokrzyskie Mountains for both Rendzic Leptosols and Cambisols [16,21]. This is probably the result of the harsh climate slowing down the organic matter decomposition processes in the Tatra Mountains [8].

Within ectohumus horizons a higher Ch/Cf ratio under spruce than under beech can be observed. Our investigations confirmed that needle decomposition leads to the production of more humic acids than leaves [10, 11]. This could be partly explained by the fact that coniferous' needles produce more bitumines than leaves, which increase the humic acid amount in the Douchafour and Jacquin method.

In endohumus horizons, the Ch/Cf rate in analyzed Rendzic Leptosols is significantly higher under spruce than under beech. In Rendzic Leptosol under spruce the Ch/Cf rate is 0.74 and is similar to values in some rendzinas with a high amount of calcium carbonate [15, 17, 19]. In Rendzic Leptosol under beech the Ch/Cf rate is 0.20 and is relatively low, but quite similar to AC horizons in Rendzic Leptosols from the Tatra Mountains [19]. Active carbonate content was not measured, but the content of calcium carbonate in this profile is extremely high (on average 55%) and comparable to AC horizons analyzed by the mentioned author. The low Ch/Cf ratio can be explained by binding humus acids, especially humic ones with clay minerals with the presence of a high amount of $CaCO_3$, which was reported by many authors [15, 17]. This can be supported by the fact that in comparison to ectohumus horizons, the amount of humic acids in endohumus horizons is significantly lower in both soils classified as Rendzic Leptosols, while in soils with a low amount of calcium carbonates differences are rather small with no visible tendency. On the other hand, the amount of humic acids under beech is lower than under spruce which can shape the Ch/Cf ratio.

Some authors [11, 15, 17] observed a decrease in the Ch/Cf ratio in transition to mineral horizon in the forest soils. Gonet *et al*. [11] claim that it is connected with displacement of movable fulvic acids into deeper soil horizons. In our investigation a decreasing Ch/Cf rate with a simultaneous increase in fulvic acids was observed in the one profile – Haplic Leptosol under spruce. Besides this profile, there is no visible tendency in transition from ectohumus to endohumus horizons. In relation to whole carbon content, the fulvic acid content is higher in Haplic Leptosol and Haplic Cambisol than in Rendzic Leptosols, which is connected with lower amounts of humines in those profiles.

As mentioned before, there is more humus acid release from spruce litter than beech litter, and fulvic acids of the first and the second extraction in the free fraction prevailed. This means that higher amounts of movable reactive fractions are released from spruce litter than from the beech litter. Licznar *et al*. [18] did not observe any differences in the amount of free fractions between different land use (arable land and meadows). They just observed a significant decrease in its amount with increasing contents of calcium carbonates and clay minerals. Our observations suggest that in contrast to those agricultural soils, vegetation type has first-rate meaning in free fraction content in the forest soils. It should be mentioned that those authors used the Kononowa and Bielczikowa method.

According to Gonet *et al*. [11], fulvic acids have a tendency to move down through the soil profile. Our observation suggests that the acids of fraction release in the first extraction (both humic and fulvic) move down the profile. The amount of humus acids dissoluted in the first extraction is significantly higher in A horizons of profiles developed under spruce than under beech.

Humines content in ectohumus horizons is relatively low. Higher humine content in both Rendzic Leptosols is probably a result of limestone admixture in those sub-horizons. Within endohumus horizons, humines content is significantly higher in Rendzic Leptosols than under Haplic Leptosol or Cambisol. Values of humines content are comparable to A horizons of Rendzic Leptosols from the Świętokrzyskie Mountains and are even higher than humines content in forest soils, but similar to arable soils [17]. Values for Haplic Leptosol and Cambisol are similar to Cambisols from the Świętokrzyskie Mountains. This can be explained by binding humus acids (especially humic acids) with clay minerals with an abundance of calcium cation [16, 17, 18]. A higher amount of humines in Rendzic Leptosol under spruce than under beech can be caused by a higher amount of humic acids released from spruce litter.

Our observations allow claiming that fractional composition of both ectohumus and endohumus horizons are determined primarily on the type of organic matter (litter). The key difference between spruce and beech is the amount of humus acids, especially moveable fraction which is higher under spruce than under the beech site. The most moveable acids containing both humic and fulvic ones migrate down the profile from O to A horizons causing acidification in both Rendzic Leptosols and soils with small amounts of carbonates in their uppermost parts. Differences observed between a similar type of litter, visible in different amounts of humines and humus acids of third extraction, can be the result of an admixture of calcareous material in Ofh subhorizons in both soils classified as Rendzic Leptosols. In endohumus horizons the influence of parent material is more significant than in ectohumus horizons and is especially visible in high amounts of humines content. The release of moveable humic acids leads to acidification visible in ectohumus and endohumus horizons. Biological activity in spruce litter is lower than in beech litter which results in the analyzed profiles to form ectohumus horizons with more features in its preliminary stage.

CONCLUSIONS

1. Tree species strongly affect properties of both ecotohumus and endohumus horizons in analyzed soils independent of the type of parent material.

2. One index of biological activity under spruce is significantly lower than under beech. The rate of cellulose decomposition under spruce is approx. 15% lower than under beech.

3. Soils under beech and spruce differ in humus fractional composition. The most important difference is the amount of humus acids, especially moveable fraction which is higher under spruce than under the beech site. This leads to acidification humus horizons under spruce.

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WŁAŚCIWOŚCI POZIOMÓW PRÓCHNICOWYCH GLEB REGLA DOLNEGO W TATRACH

Celem badań było określenie różnic pomiędzy poziomami próchnicowymi wykształconymi w glebach pod różnymi lasami. Próbki gleb zostały pobrane pod monokulturą świerka i naturalnym zbiorowiskiem buczyny karpackiej w reglu dolnym Tatr. Przeprowadzone zostały analizy następujących właściwości gleb: zawartość węgla organicznego, strata żarowa w poziomach nadkładowych, odczyn, skład frakcyjny połączeń próchnicznych oraz tempo rozkładu celulozy w poziomach próchnicowych. Obiekt badań stanowią cztery profile glebowe: dwa profile wykształcone na skałach węglanowych (Rendzic Leptosols) pod bukiem i świerkiem, oraz dwa wykształcone z utworów pokrywowych – Haplic Leptosol pod świerkiem i Haplic Cambisol pod bukiem. Wyniki badań wskazują na to, że gatunek drzewa silnie wpływa na cechy poziomów ekto- i endohumusowych. Jest to widoczne w morfologii poziomów humusowych oraz składzie frakcyjnym połączeń humusowych. Prowadzi to do zakwaszenia tych poziomów oraz spowolnienia tempa rozkładu celulozy. Czynnikiem, którego wpływ na cechy poziomów próchnicowych da się wyodrębnić, pomimo silnego wpływu roślinności, jest skała macierzysta.