FOREST SOIL SCIENCE

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CELLULOSE DECOMPOSITION RATE AND FEATURES OF ORGANIC MATTER IN FOREST SOILS IN THE TATRA MOUNTAINS

Abstract. The cellulose decomposition rate measurement and soil micromorphology have been used to determine the influence of parent material and tree species on mechanisms responsible for organic matter form differentiation in woodland soils in the Tatra Mountains in Poland.

The study area is located in the lower montane belt of the Tatra Mountains. Investigated soils are developed on dolomites and shale. In the past, beech and beech-fir forests had been the dominant form of vegetation in the study area. Since the 16th century, these areas were deforested until the 19th century, when reforestation efforts were undertaken. Reforestation efforts provided mainly spruce; hence, it is the dominant species in the lower montane belt at the moment, although in some areas, natural or semi-natural beech and beech-fir forests have survived.

Four plots were compared – two with soils developed on calcareous material (Rendzic Leptosols), one under beech forest and one under spruce forest, and two developed on shale (Haplic Cambisols), one under beech forest and one under spruce forest.

Cellulose filters were placed in organic O-horizons and humus A-horizons in every plot to measure the cellulose decomposition rate. Before being placed in the soil, cellulose filters were boiled in KOH, rinsed in distilled water, dried, weighed, and set on glass plates in a nylon bag (1.5 mm mesh). The bags were placed in the soil vertically at approx. 15 cm intervals. After taken up, the filters were boiled in KOH, rinsed, dried, and weighed. The amount of ash was determined via combustion. The research was carried out during a period of 10 weeks between June and August as well as during a period of 1 year. Measurements were repeated ten times. A weighted average and standard deviation were calculated for every plot.

The cellulose filter method is useful because of the homogeneity of the substrate, which helps to exclude differences connected with the chemical composition of the plant material, a factor that affects the decomposition rate.

Undisturbed soil samples were taken from humus A-horizons in every soil profile. The thin sections were prepared and features of organic matter were described.

It was concluded that the presence of calcarous material negatively affects organic matter decomposition rates which is pronounced in both: higher amount of organic matter residues in humus-A horizons and slower cellulose decomposition rates in Rendzic Leptosols than in Haplic Cabisols. The influence of tree species on organic matter features is observed only in Haplic Cambisols, where

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the cellulose decomposition rate under spruce is lower than under beech. This suggests that tree species indirectly affect the cellulitic microflora only in acidic soils.

Keywords: *cellulose decomposition rates, mountain soils, parent material, calcareous bedrock, beech, spruce, Tatra Mountains.*

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СКОРОСТЬ РАЗЛОЖЕНИЯ ЦЕЛЛЮЛОЗЫ И ОСОБЕННОСТИ ОРГАНИЧЕСКОГО ВЕЩЕСТВА В ЛЕСНЫХ ПОЧВАХ ТАТР

Для определения влияния почвообразующего материнского материала и вида деревянистой растительности на целлюлозолитическую активность микрофлоры измерялась скорость разложения целлюлозы и особенности микроморфологического строения органических остатков в лесных почвах Татр Польши.

Район исследований расположен в нижних горных поясах. В прошлом, на територии исследования, буковые и буково-еловые леса были доминирующей формой растительности. После лесовостановительных мероприятий в XIX веке, на территории исследования в основном доминируют ельники, хотя в некоторых районах, сохранилась первичная лесная растительность.

Сравнивались четыре участка. Два из них представлено почвами, что образовались на карбонатных породах (Rendzic Leptosols), один из которых покрыт буковым лесом, а второй – еловым. Почвы других двух участков образованы на сланцах (Haplic Cambisols) и покрыты такими же двумя аналогичными типами леса.

Скорость разложения целлюлозы определяли по интенсивности распада фильтров. Также было проведено микроморфологическое изучение растительных остатков в тонких шлифах. Исследование проводилось на протяжении 10 недель в период с июня по август, а также на протяжении 1 года. Измерения повторялись десять раз и обрабатывались статистически. В результате проведенных исследований был сделан вывод, что присутствие кальцийсодержащего материала отрицательно влияет на скорость разложения целюлозы, что проявлялось в значительно меньшей потере массы целлюлозы в Rendzic Leptosols, в сравнении с Haplic Cambisols. Влияние типа леса на свойства органического вещества наблюдалась только в Haplic Cambisols, где скорость разложения целлюлозы под ельником была ниже, чем под буковым лесом. Это косвенно говорит о влиянии типа древесных пород на целлюлозолитическую микрофлору только в кислых почвах.

Ключевые слова: *скорость разложения целлюлозы, горные почвы, материнский материал, карбонатные породы, бук, ель, Татры.*

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ШВИДКІСТЬ РОЗКЛАДАННЯ ЦЕЛЮЛОЗИ І ОСОБЛИВОСТІ ОРГАНІЧНОЇ РЕЧОВИНИ В ЛІСОВИХ ҐРУНТАХ ТАТР

Для визначення впливу грунтотворного материнського матеріалу та виду дерев'янистої рослинності на целюлозолітичну активність мікрофлори визначалася швидкість розкладу целюлози і особливості мікроморфологічної будови органічних залишків у лісових грунтах Татр Польщі.

Район досліджень розташований в нижніх гірських поясах. У минулому, на території дослідження, букові та буково-смерекові ліси були домінуючою формою рослинності. Після лісовідновлювальних заходів у XIX столітті, в основному на території дослідження домінують ялинники, хоча в деяких районах, збереглася первинна лісова рослинність.

Порівнювалися чотири ділянки. Дві з них представлено грунтами, що утворилися на карбонатних породах (Rendzic Leptosols), одна з яких під буковим лісом, а друга – під ялиновим. Грунти інших двох ділянок утворились на сланцях (Haplic Cambisols) і вкриті такими ж двома аналогічними типами лісу.

Швидкість розкладу целюлози визначали за інтенсивністю розпаду фільтрів. Також було проведено мікроморфологічне вивчення рослинних залишків у тонких шліфах. Дослідження проводилося протягом 10 тижнів в період з червня по серпень, а також протягом 1 року. Вимірювання повторювалися десять разів і оброблялися статистично. В результаті проведених досліджень було зроблено висновок, що присутність кальційвмісного матеріалу негативно впливає на швидкість розкладу целюлози, що проявлялося в значно меншій втраті маси целюлози в Rendzic Leptosols, в порівнянні з Haplic Cambisols. Вплив типу лісу на властивості органічної речовини спостерігалася тільки в Haplic Cambisols, де швидкість розкладання целюлози під ялинником була нижчою, ніж під буковим лісом. Це є непрямим свідченням впливу типу деревних порід на целюлозолітичну мікрофлору тільки в кислих грунтах.

Ключові слова: *швидкість розкладу целюлози, гірські грунти, материнський матеріал, карбонатні породи, бук, ялина, Татри.*

INTRODUCTION

The problem of the development of soil humus-A horizons and organic-O horizons (humus forms) has been studied by many researchers all over the world since the beginning of soil-science (e.g. Müller, 1889 ; Kubiena, 1953).

Organic matter content as well as its form depend on many factors. The most important factors are climate, bedrock, topography, land use and, in the case of forest soils – tree species, age of trees, and forest management (Lousier and Parkinson, 1976; Dziadowiec, 1990; Bernier, 1996; Kurka and Starr, 1997; Drewnik, 2006; Ponge et al., 2011). The listed factors influence environmental conditions such as soil temperature, humidity, and the availability of nutrients, which control microbial activity in the soil, and in consequence, the rate of organic matter decomposition that shapes the features of humus-A horizons and organic O-horizons. (Drewnik, 2006; Ponge et al., 2011). Niemyska-Łukaszuk, 1977 and Miechówka and Ciarkowska, 1998 described some micromorphological features of organic matter in soils developed in the Tatra Mountains.

Pine needle decomposition rates provided by Kurz-Besson et al. (2006) suggest that on the macro-scale, the organic matter decomposition rate depends mainly on climate conditions (humidity and average temperature). Drewnik (2006) found a similar relationship for cellulose decomposition rates in mountain soils in selected mountain climate zones, but was able to show that climate factors are also affected by plant communities. Drewnik's results show that the cellulose decomposition rate is slower under dwarf pine communities than under alpine meadows developed in a harsher climate. Results obtained by Donnely et al. (1990), McClellan et al. (1990), Beier and Rasmussen (1994), Kim (2000) and Withington and Sanford (2007) show that on the micro-scale, the cellulose decomposition rate depends mainly on micro-climate conditions such as humidity and sunshine. Donnely et al. (1990) and Beier and Rasmussen (1994) claim that pH is a negligible factor in comparison with soil moisture and temperature. In contrast, Vanhala et al. (2005) found that respiration of organic-O horizons depends mainly on the fertility of these horizons, e.g. factors such as the C/N ratio and pH. A significant positive correlation between pH and the cellulose decomposition rate was also found by Drewnik (2006).

The role of the calcium ion in organic matter transformation has often been discussed, but remains unclear. Results obtained by Howard et al. (1998), Reich et al. (2005) and Hobbie et al. (2006) suggest that the calcium ion accelerates the decomposition of soil organic matter in the initial stages e.g. affects soil fertility. On the other hand, it is known that the calcium ion causes aggregation of soil material, which protects organic matter from leaching and facilitates its binding with the soil mineral fraction (Muneer and Oades, 1989; Sollins et al, 1996; Baldock and Skjemstad, 2000; Kloster et al., 2012).

The purpose of this research study was to determine the effect of parent material and forest type on organic matter features including micromorphology features and cellulose decomposition rates in four soil profiles in the Tatra Mountains (Poland).

DATA AND METHODS OF THE RESEARCH

The study area is located in the lower montane belt of the Tatra Mountains in Poland. The mean annual air temperature (data for the nearest weather station: Zakopane) is 5,3 °C. The mean annual precipitation depth is 1115 mm, with a predominance in the warmer half of the year (data for the period 1951–2006) (Bokwa et al, 2013).

The part of the Tatra Mountains, where the study was carried out (Western Tatras), is mainly formed of metamorphic rocks in its upper part, and calcaric rocks and shale in the lower part. In the study area, layers of Mesozoic and Tertiary calcaric rocks (dolomite and limestone) alternate with layers of shale (Sokołowski S., Guzik K., 1958–1980).

In the past, beech and beech-fir forests had been the dominant form of vegetation in the study area (Myczkowski et al., 1985b). Since the 16^{th} century, these areas were successively deforested until the 19^{th} century, when reforestation efforts were undertaken. At the turn of the 20^{th} century, reforestation efforts provided mainly spruce; hence, it is the dominant species in the lower montane belt at the moment (Fabijanowski, Dziewolski, 1996). In some areas, natural or semi-natural beech and beech-fir forests have survived, while in other areas, these forest have been renewed because of the succession process (Myczkowski et al., 1985a).

The research study was conducted on four plots located in the lower montane belt in Białego Valley and Strążyska Valley at an elevation of 970–1080 meters. Two soils developed on shale parent material (one under beech forest and one under spruce forest) and two soils developed on dolomite (one under beech forest and one under spruce forest).

Cellulose filters were placed in organic O-horizons and humus A-horizons in every plot to measure the cellulose decomposition rate. Before being placed in the soil, cellulose filters (ø7 cm or half of circle) were boiled in 2% KOH, rinsed in distilled water, dried at 105º, weighed, and set on glass plates in a nylon bag (1.5 mm mesh). The bags were placed in the soil vertically at approx. 15 cm intervals. After taken up, once collected, the filters were boiled in 2 % KOH, rinsed, dried, and weighed. The amount of ash was determined via combustion (Drewnik, 2006). The research was carried out during a period of 10 weeks between June and August of 2012 as well as during a period of 1 year between June of 2012 and June of 2013. Measurements were repeated ten times. A weighted average and standard deviation were calculated for every plot.

The cellulose filter decomposition rate has been used widely to compare the effect of microbial activity in different environments (e.g. Beatty and Stone, 1986; Bieńkowski, 1990; McCllelan et al., 1990; Kurka et al., 2000; Kurka, 2001; Drewnik, 2006; Withington and Sanford, 2007). This method is useful because of the homogeneity of the substrate, which helps to exclude differences connected with the chemical composition of the plant material, a factor that affects the decomposition rate (Dziadowiec, 1990).

Undisturbed soil samples (6×8 cm) were taken from humus A-horizons in every soil profile. The thin sections (30µm thick) were prepared with the application of a standard procedure Fitzpatrick (1993).Terminology by Fitzpatrick (1993) was used to describe the organic matter features.

Soil profiles were excavated in every plot and described and sampled according to their genetic horizons. Bulk soil samples taken from mineral horizons were air-dried, gently crushed using a wooden rolling pin, and sieved using a 2 mm sieve. Live roots were removed. Soil samples obtained from organic horizons were milled after the living parts of plants in the samples had been removed. The texture was determined by wet sieving (sand fractions) and the hydrometer method (silt and clay fractions) (Gee and Bauder, 1986). The calcium carbonate equivalent was determined using the volumetric calcimeter method. Each sample's pH was measured in 1M KCl (1:2.5 soil/1M KCl ratio) (Thomas, 1996). The concentration of organic carbon in humus A-horizons was determined using the Tiurin method, modified by Oleksynowa (Oleksynowa et al., 1987). In organic-O horizons, loss on ignition (LOI) in 400°C for 16 h was determined (Nelson and Sommers, 1996).

Soil profiles were classified according to the WRB system (IUSS Working Group WRB, 2006). Humus forms were classified according to Jabiol et al. (2013).

RESULTS AND THEIR DISCUSSION

According to the WRB system (IUSS Working Group WRB, 2006), soil in plot no.1 was classified as Haplic Cambisol (Hyperdystric, Endoskeletic), soil in plot no. 2 as Haplic Cambisol (Epidystric, Episkeletic), and soil in plots no. 3 and no. 4 as Rendzic Leptosols (Hypereutric, Episkeletic) (Table 1).

According to Jabiol et al. (2013), humus forms were classified as follows: in soil in plots no.1 and no. 3 – Dysmull, in soil in plot no. 4 – Pachyamphi, and in soil in plot no. 2 – Eumor (Table 1).

Table 1

Site location, soil classification

Profile no.	Parent material	Dominant tree species	Elevation (m a.s.l.)	Humus form	Soil type
1	Shales	*Fagus silvatica*	970	Dysmull	Haplic Cambisol (Hyperdystric, Endoskeletic)
2	Shales	*Picea abies*	990	Eumor	Haplic Cambisol (Epidystric, Episkeletic)
3	Dolomites	*Fagus silvatica*	990	Dysmull	Rendzic Leptosol (Hypereutric, Episkeletic)
4	Dolomites	*Picea abies*	1080	Pachamphi	Rendzic Leptosol (Hypereutric, Episkeletic)

The basic properties of the organic-O horizon and humus-A horizons of the examined soils are shown in Table 2.

Table 2

Basic properties of organic-O horizons and humus-A horizons

Depth	Soil horizon	OC (%)	LOI (%)	$eqCaCO_3$ (%)	Texture	pH KCl
1	2	3	4	5	6	7
Profile no.1						
0–1	Oi	n.a.	95,22	n.a.	n.a.	4,5
1–6	Oe	n.a.	82,85	n.a.	n.a.	4,3
6–15	A	3,02	n.a.	0,0	loam	3,6
Profile no. 2						
0–1	Oe	n.a.	70,48	n.a.	n.a.	3,6
1–5	A1	7,17	n.a.	0,0	loam	3,0
5–8	A2	4,98	n.a.	0,0	loam	3,1
Profile no. 3						
0–2	Oi1	n.a.	92,26	n.a.	n.a.	5,7
2–5	Oi2	n.a.	89,49	n.a.	n.a.	5,9
5–6	Oe	n.a.	37,04	n.a.	n.a.	n.a.
6–20	Ah	4,42	n.a.	54,6	loamy silt	7,5
20–28	A2	2,81	n.a.	57,8	clay loam	7,3
28–35	A3	1,96	n.a.	63,0	loamy silt	7,6

Ending of table 2

1	2	3	4	5	6	7
Profile no. 4						
0–2	Oi	n.a.	88,07	n.a.	n.a.	4,6
2–4	Oe	n.a.	75,39	n.a.	n.a.	4,2
4–9	Oa	n.a.	33,47	n.a.	n.a.	5,7
9–15	Ah	4,39	n.a.	29,2	clay loam	7,0
15–25	A2	1,86	n.a.	46,3	clay loam	7,2

n.a. – not analyzed.

The micromorhological features of humus-A horizons were shown on figures 1–6.

The mean cellulose decomposition rate differs between soil profiles as well as soil horizons (Table 3). The highest cellulose decomposition rate was noted in plot no. 1, where in the organic-O horizon, filter mass loss was noted at 87.73 % and 97.95 % after 10 weeks and 1 year, respectively. In the humus-A horizon, it was 77.97 % and 96.95 %, respectively. In plot no. 2 after 10 weeks in the organic-O horizon, 84.95 % of the cellulose had decomposed and after 1 year it was 96.72 %. In humus-A horizons, it was 52.72 % and 94.00 %, respectively. Significantly lower decomposition rates were noted in soils in plots no. 3 and no.4. In plot no. 3, in the organic-O horizon, filter mass loss was noted at 36.66 % and 86.33 % after 10 weeks and 1 year, respectively. In the humus-A horizon, it was 39.01 % and 88.08 %, respectively. In plot no. 4, after 10 weeks, in the organic-O horizon, 48.08 % of the cellulose had decomposed, and after 1 year, it was 83.79 %. In humus-A horizons, it was 39.59 % and 89.49 %, respectively.

Table 3

Cellulose decomposition rate after 10 weeks and 1 year

Cellulose decomposition rate after 10 weeks								
	No. 1		No. 2		No. 3		No. 4	
	O-horizon	A-horizon	O-horizon	A-horizon	O-horizon	A-horizon	O-horizon	A-horizon
WA	87,73	77,97	84,95	52,72	36,66	39,01	48,08	39,59
SD	7,71	13,76	8,19	18,50	10,18	10,92	12,16	11,30
Cellulose decomposition rate during 1 year								
	No. 1		No. 2		No. 3		No. 4	
	O-horizon	A-horizon	O-horizon	A-horizon	O-horizon	A-horizon	O-horizon	A-horizon
WA	97,96	96,95	96,72	94,00	86,33	88,08	83,79	89,49
SD	2,02	2,39	0,95	3,01	10,24	3,20	8,83	7,97

WA – weighted average.
SD – standard deviation.

Micromorphology of organic matter in humus-A horizons differs between soil profiles. In all profiles residual organic matter in form of fresh and slightly and moderately decomposed prevailed. Usually tissues structure is retained, and in some parts of residues interference colors are visible. Organic matter residues are only slightly fragmented (Fig. 1–4). In humus-A horizons of profiles no.1 and 2 organic matter residues exist inside the soils aggregates, but there is also quite large amount of free residues (Fig. 1, 2). In profiles no. 3 and 4 the amount of residual organic matter higher than in profiles no. 3 and 4 and it exists mainly inside the aggregates (Fig. 3, 4). In profiles no.

1 and 3, the feaces of mesofauna living in the soil have been observed (Fig. 5), while in profile no. 4 the feaces of *Oribatei* feeding on needles have been observed (Fig. 6). Cellulose decomposition rates in most of the analyzed soils are higher in organic-O horizons than in humus-A horizons, which creates better conditions for cellulitic microorganism development in these horizons. This is most likely the result of better microclimate conditions including a higher temperature with relatively high moisture levels in the well-developed and partly decomposed material of organic-O horizons. It is assumed that, because of the C/N ratio (data not published), and pH (Table 2) that could affect the cellulose decomposition rate in similar conditions (Kurka and Starr, 1997; Vanhala et. al., 2005; Drewnik, 2006), organic-O horizons are less favorable for microorganism development than humus-A horizons. A similar correlation (decrease in cellulose decomposition rate with depth) has been observed by most researchers – e.g. McClellan et al. (1990), Kurka and Starr (1997), Kurka et al. (2000), Beier and Rassmusen (1994); (but see Withington and Sanford, 2007). An opposite trend was observed in plot no. 3, where the cellulose decomposition rate was slightly lower in the organic-O horizon versus the humus-A horizon. This may be the effect of organic-O horizon features. This horizon is composed of weakly-decomposed litters (Oi layers – see Table1), which can result in poor water retention, and make this horizon susceptible to seasonal droughts, which can consequently inhibit microbial activity (Beier and Rasmussen, 1994).

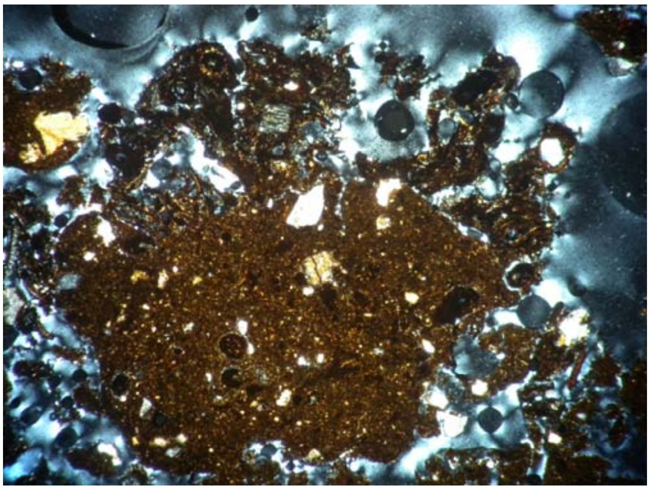

Fig. 1. **Structure of aggregate in humus-A horizon of Haplic Cambisol under spruce forest, XPL, 5 mm wide**

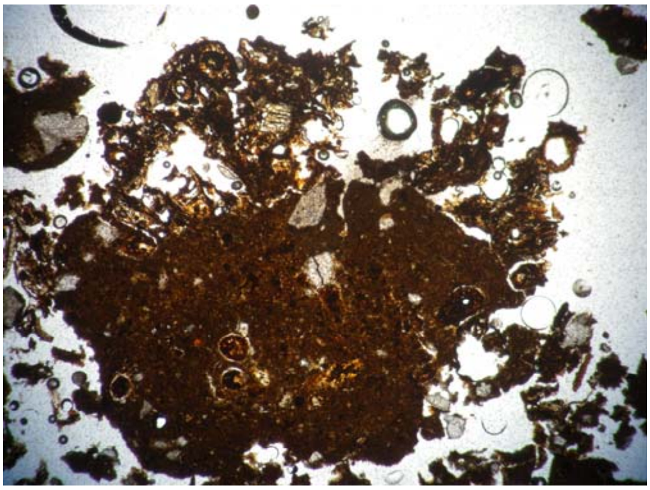

Fig. 2. **Structure of aggregate in humus-A horizon of Haplic Cambisol under spruce forest, PPL, 5 mm wide**

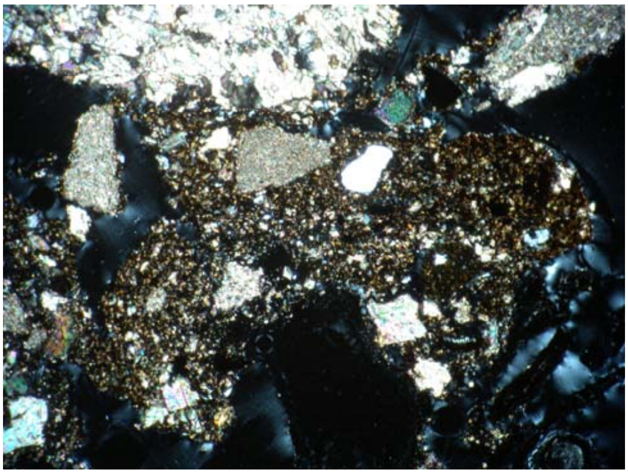

Fig. 3. **Structure of aggregate in humus-A horizon of Rendzic Leptosol under beech forest, XPL, 5 mm wide**

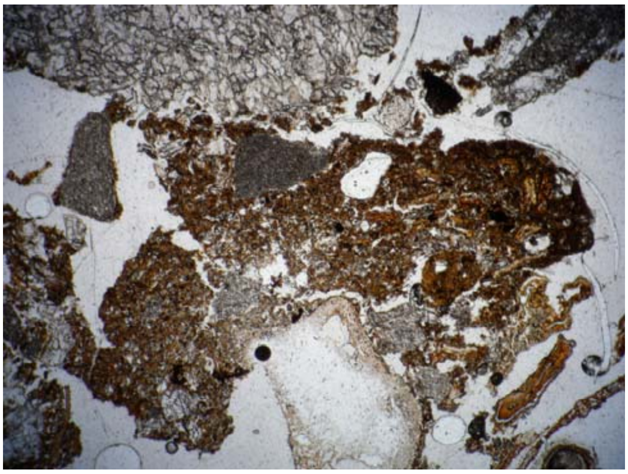

Fig. 4. **Structure of aggregate in humus-A horizon of Rendzic Leptosol under beech forest, PPL, 5 mm wide**

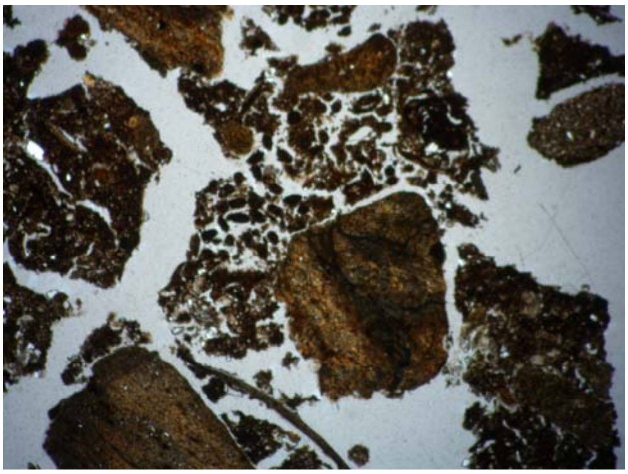

Fig. 5. **Feaces of soil mezofauna in humus-A horizon of Haplic Cambisol under beech forest, PPL, 5 mm wide**

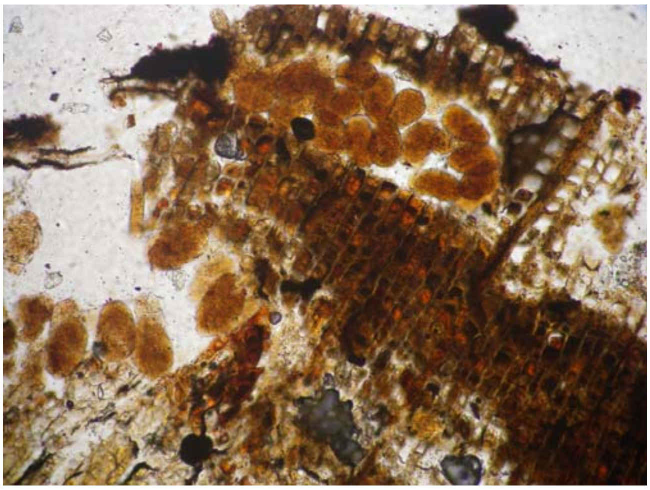

Fig. 6. **Feaces of *Oribatei* in humus-A horizon of Rendzic Leptosol under spruce forest, PPL, 1 mm wide**

The cellulose decomposition rate is significantly lower in Rendzic Leptosols developed on dolomite than in Haplic Cambisols developed on shale. This pattern is observable regardless of the type of forest in both organic-O horizons and humus-A horizons.

Slower decomposition of organic matter is confirmed in the micromorphology of humus-A horizons. In Rendzic Leptosols there is higher proportion of organic matter residues in comparison to Haplic Cambisols. Those organic matter exists mainly inside well-developed soil aggregates. This observation itself would suggest that aggregation play an important role in protection organic matter from decomposition. Such mechanisms has been already observed by Muneer and Oades (1989), who claim that aggregation supported by Ca^{2+} ions protects particulate organic matter against fast decomposition. Slower decomposition of cellulose filters in the examined calcarous soils shows, that although aggregation seems to be better developed in calcarous soils, it cannot be the only process responsible for slow down decomposition, as cellulose strips cannot bind with the soil structure. Duchafour (1976) observed that thin carbonate coatings on weakly-decomposed material protected it against microbial attack. Microscope observations of particulate organic matter in this soil exclude the possibility of the formation of carbonate crusts on cellulose filters in examined soils. Therefore, Ca^{2+} ions seem to inhibit microorganism activity in a more direct way. This effect is observable not only in humus-A horizons, but also in organic-O horizons.

The relationship between the organic matter decomposition rate and vegetation type seems to be less pronounced than that in the case of climate or microclimate conditions (Donnely et al., 1990; Beier and Rasmussen, 1994). In our study, the elevation and slope are similar, which reduces the effect of such differences. Furthermore, the stands' age and canopy cover are similar. Although the effect of tree species on the cellulose decomposition rate in the examined soils is much less significant than the effect of the parent material (Table 3), it is observable in Haplic Cambisols, where the mass loss of cellulose is smaller under spruce than under beech forest in both the organic-O horizon and humus-A horizon after 10 weeks, as well as after 1 year. In Rendzic Leptosols, differences between forest sites are less significant, without any clear pattern. Results obtained by Shmidt and Rushenmayer (1958), Valhala et al. (2005) and Drewnik (2006) suggest that a pH decrease can inhibit microbial activity. Spruce undoubtedly causes a decrease in soil pH (Rozędowska and Skiba, 1995), but this decrease is smaller in calcareous soils with high buffer capacity than in more acidic Cambisols (Table 2). These findings are in agreement with the experimental findings of Shmidt and Rushmeyer (1958), who found that the cellulose decomposition rate's dependence on pH is most pronounced at very low pH.

CONCLUSIONS

Presence of calcarous material cause negatively affects cellulose decomposition rates in soils. Slower decomposition in this soils seems to be responsible for organic matter preservation in this soils.

The cellulose decomposition rate under beech is higher than that under spruce, but only in Haplic Cambisols, which suggests that in acidic soils, tree species affect the composition and/or activity of cellulitic microflora in the soil.

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