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The differences in cellulolytic activity of the Arctic soils of Calypsostranda, Spitsbergen

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ABSTRACT. The aim of this study was to determine the differences in cellulolytic activity of soils around the coastal lowlands of the southwestern part of Wedel Jarlsberg Land (west Spitsbergen). Two positions (Calypso and Skilvika) representing typical soil types in this area were chosen for investigation. Within the area of Calypso, arctic brown soils formed from loamy sands with a significant addition of coarser gravel and pebble fractions occur. The Skilvika position represents the arctic gley soils of a loamy texture, with significant content of silt, associated with the occurrence of cell grounds created under the strong influence of cryogenic processes. Cellulolytic activity of the soils was determined by a gravimetric method involving estimation of a weight loss of cellulosic material buried in the surface soil horizons. The investigation showed significant differences in the cellulose decomposition rate between the two research locations. The cellulolytic activity of arctic brown soils –0,412–0,656 $g^*g^{-1*}year^{-1}$ during the vegetation season (Olson's k = 0,231–0,563), was twice higher than the activity in the case of Skilvika gley soils –0,185–0,310$g^*g^{-1*}year^{-1}$ during vegetation season (k = 0,089–0,131). This should be attributed, among other factors, to the grain size distribution, thereby determining more favourable water-air conditions of soils within the area of Calypso.

Introduction

During the past few decades, a distinct change in the Arctic environment may have been seen (Chapman and Walsh 1993; Tynan and DeMaster 1997; Serreze and others 2000). Since the late 19th century, the annual average air temperature in the region has risen by 1.5°C (Overpeck and others 1997). Coverage of the Arctic Ocean sea ice decreases systematically (Serreze 2003; Lindsay and Zhang 2005) with increasing amounts of precipitation (Maxwell 1997). The consequence of these processes is a transformation in the functioning of terrestrial ecosystems: coverage of permafrost (Anisimov and Nelson 1996) and the depth of the active layer (Anisimov and others 1997), an increase in plant biomass (Epstein and others 2000), and changes in stocks of biogenic elements in soils (McGuire and others 2005). It is estimated that the Boreal and the Arctic have between 20% and 60% of global soil carbon (Schlesinger 1977; Post and others 1982; Gorham 1991). The temperature rise, as a result of global warming, will probably increase the rate of soil biological activity of the polar regions, and, as a result, an additional amount of CO_2 can be put into the atmosphere (Luo and Zhou 2006).

The biological activity of the soil is determined by direct and indirect methods. The total number of microorganisms is determined by the direct method (Holding 1981; Simankova and others 2000), while indirect methods are based on the products of their activity, such as released CO_2 or the activity of certain enzymes. One of the methods of assessment of the biological activity of soil is also the determination of the total cellulolytic activity (Russel and others 2005). Gravimetric methods, based on the weight loss of cellulosic material placed in an analysed environment or medium, are often used for the determination of cellulolytic activity. The disadvantage of these methods is getting results that are inflated in relation to the real rate of organic matter decomposition (Niewinna 2009). However, they are widely used due to their low costs and easy implementation (Bieńkowski 1990a; Niewinna 2009). Gravimetric methods are connected with the determination of mass loss of linen fabrics, filter paper or other cellulosic materials buried for a limited time. These methods were applied in determining the influence of acidification of the Silesia, Poland, soils region on their degree of biological activity (Bieńkowski 1990a). Drewnik (1996, 2006) used the method of mass loss of cellulose filter papers for the description of the influence of environmental factors on the differentiated rate of organic matter decomposition in soils of the Carpathian mountains. A gravimetric method was also used for the determination of cellulolytic activity of tundra soils of the Yamal Peninsula and the Ural mountains (Andreyashkina and Peshkova 2001). Fisher and others (2006), on the basis of results obtained by the same method, carried out a comparative study of the biological activity of soils of different ecosystems (desert, steppe, mountain) in Dagestan. Previous studies on cellulolytic activity showed an extremely low rate of organic matter decomposition in arctic soils (Rosswall 1974; Bieńkowski 1990b). Because of the large diversity of soils of polar ecosystems, the current level of knowledge about their functioning is insufficient. This

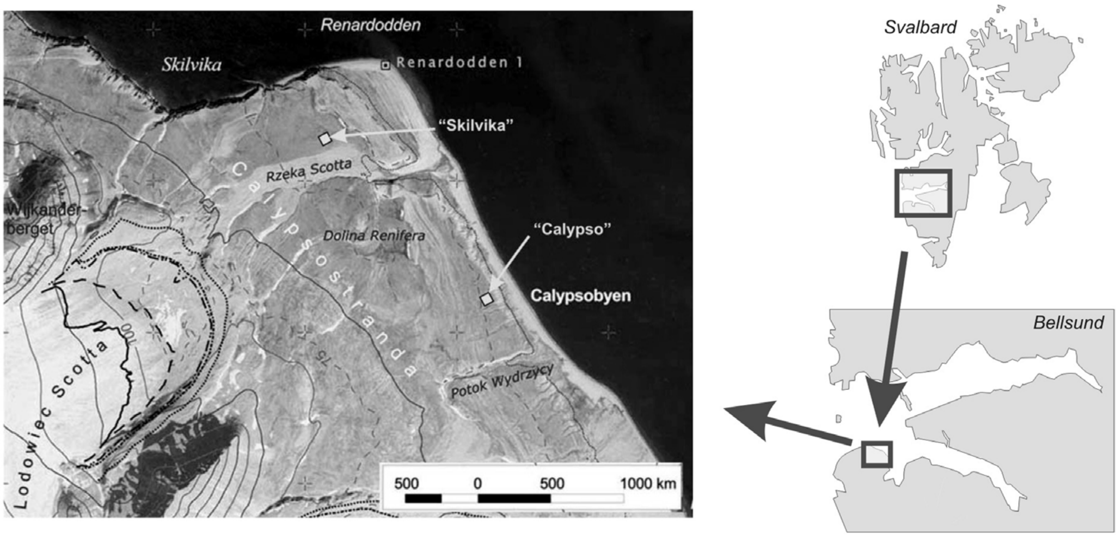

Fig. 1. Location of research positions. Fragment of orthophotomap northwest part of Wedel Jarlsberg Land (Zagórski 2005).

is particularly important in the context of determining the paths of transformation of the soil environment as a result of still changing climate conditions.

The aim of this research is to determine the cellulolytic activity of soils of coastal lowlands of west Spitsbergen. An important aspect of the study was to determine the influence of the basic properties of soils on the rate of cellulose decomposition. This objective was based on a comparative analysis of cellulolytic activity in two locations representing different soil conditions. These studies will be, one hopes, important as a 'reference point' for future teams preparing to study the dynamics of the soil environment of the west Spitsbergen tundra under a changing climate.

Subject and methods

West Spitsbergen is a mountainous region covered extensively (40–60%) by glaciers. The presence of glacial and fluvioglacial relief forms is connected with glaciation: frontal and lateral moraines, outwash plains, fluvioglacial cones and more specific forms are observed.

Along the coast there are coastal plains made up of a system of marine terraces raised as a result of Pleistocene and Holocene glacial isostatic movements (Lindner and others 1991; Landvik and others 1998). One of these plains is covered by the area studied named Calypsostranda lying in the northwest part of Wedel Jarlsberg Land. This plain is located in the southern part of Bellsund and on the western coast of Recherche Fiord. The width of Calypsostranda reaches up to 2 km, and its length is about 5 km. Seven terraces with a height of 2 to 85 m above sea level are distinguished within Calypsostranda (Zagórski 2002). The highest and oldest terraces (VII and VI) are abrasive platforms, created as a result of destructive activity of sea waves, uplifted probably in previstulian period, modified by glacial exaration. The lower, younger terraces (V to I) are accumulative and are covered by Quaternary glacial, fluvioglacial and marine sediments (Pękala and Repelewska-Pękalowa 1990; Salvigsen and others 1991).

The vegetation of Calypsostranda, where research station Calypsobyen is situated is less developed in comparison with the communities described in the proximity of other research stations located on the west coast of Spitsbergen (Hornsund and Kaffiøyra). This is due to lower precipitation and lower average temperatures in the summer which relate to Calypsostranda being sheltered from direct exposure to moist air masses from the Atlantic (Borysiak and Ratyńska 2004). Święs (1988) has identified eight major complex plant communities. Dry lichen-moss tundra is the most common and is typical for the broad, flat marine terraces. It is divided into initial and deflationary tundra**,** with *Dryas octopetala* and grey lichen tundra with *Cladonia sp*. In addition, in Calypsostranda there are also plant communities of arctic deserts, dry moss associations on rock denudation, foothill peat mosses, bog moss, grass and moss community edges of lakes and waterways. The most numerous species present are, among others: *Salix polaris, Salix reticulata, Oxyria digyna, Dryas octopetala, Polygonum viviparum, Cerastium arcticum, Silene acaulis, Saxifraga oppositifolia* and *Saxifraga caespitosa* (Rzętkowska 1987).

Two locations were selected for the study of soil cellulolytic activity, representing the most common soil types of Calypsostranda. The distance between the positions in a straight line is about 2 km (Fig. 1). The first position (Calypso) is situated at a height of 19 m.a.s.l., approximately 200 m from the Bellsund coast near the research station Calypsobyen. Within the position, slightly convex polygons occur which are called tundra 'Jahn' polygons (Fig. 2), resulting from the impact of cryogenic processes of marine sediments, sandy gravels or gravelly sands. These polygons are of considerable size, from a few metres to several metres in diameter, and their occurrence

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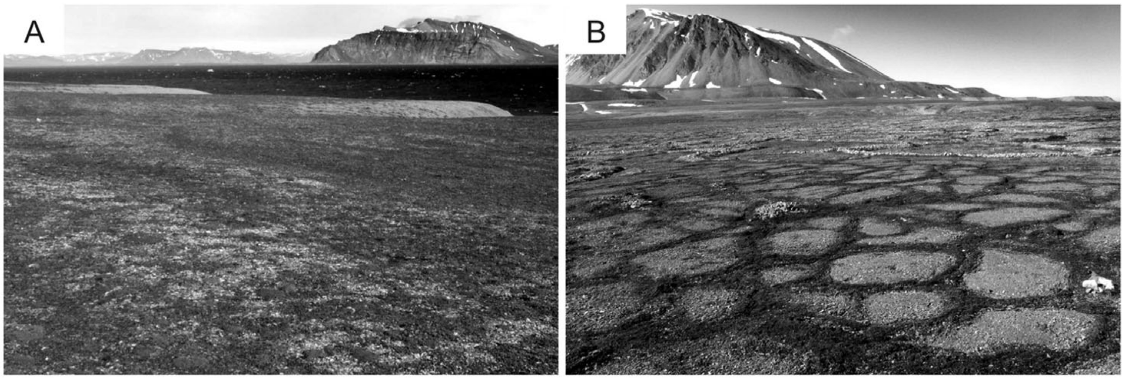

Fig. 2. Research positions: A - Calypso, dry deflation tundra; B – Skilvika – gleyed polygonal soils.

is particularly common in the lower marine terraces of Calypsostranda (Klimowicz and others 2008). The polygons are connected with Arctic tundra brown soils. According to the WRB classification (IUSS-FAO 2007), these soils are classified as Turbic Cryosols (Skeletic) and Turbic Cambic Cryosols (Skeletic). The typical morphology of the arctic brown soil profile (A-Bw-C (r)) is characterised by the presence of both a well-developed surface horizon of humus accumulation (about 2% Corg.) and the horizon of enrichment in the compounds of iron, passing smoothly at the depth of several tens of centimetres into the parent rock, showing gleying properties often associated with the influence of a permafrost ceiling. This position is characterised by a significant degree of coverage (70–100%) by dry tundra vegetation dominated by *Salix polaris, Polygonum viviparum, Cerastium arcticum, Silene acaulis, Saxifraga oppositifolia.*

The second position (Skilvika) is located north of the Scott River outwash plain at a height of 16 m.a.s.l. In terms of geomorphology, it represents remnant depression of the former sea gulf within the terrace III (Szczęsny and others 1989). Skilvika represents the Arctic gleyic soils associated with the occurrence of gleyed polygonal (cell) grounds created in a strong influence of cryogenic processes (Fig. 2). The central part of the cell is a strongly gleyed mineral material with a texture of sandy clay with a significant amount of silt, showing no morphological differentiation into horizons. Particular cells are limited by cracks in the form of polygons with a diameter of 0.5–1.0 m which accumulate very coarse (stony) rock material along with organic matter in varying degrees of decomposition. Crack depth ranges from several centimetres to tens of centimetres. The vegetation coverage rate is about 50%, and vegetation – mosses, *Salix polaris, Polygonum viviparum, Saxifraga oppositifolia* or *Saxifraga caespitosa* – develops mainly within the cracks.

Field studies were conducted during the growing seasons (June–September) in 2007–2009. Cellulolytic activity of the soils was determined by a gravimetric method (Russel and others 2005) based on weight loss of cellulosic material buried in the surface layers of soil. Discs of filter paper (previously weighed and numbered) were buried at a depth of 0–10 cm within each test area in the centre of the tundra Jahn polygons (Calypso) and cell polygons (Skilvika). These discs had a diameter of 90 mm and were attached to glass plates (area of 100 cm^2). The whole set was packed in nylon net, facilitating the removal of partially digested filter paper discs from the soil and protecting them from the sticking of soil peds to the cellulosic substrate. For each of Calypso and Skilvika seven series of determinations were performed (20 repetitions in each series) with different lengths of time and dates of exposure of filter papers (Table 1). The rate of cellulose decomposition was expressed as annual ($g \cdot g^{-1} \cdot year^{-1}$) and daily ($mg \cdot g^{-1} \cdot 24h^{-1}$) fractional weight losses and recalculated to k coefficient using the equation for organic matter decomposition with no production (Olson 1963; Carnevale and Levis 2001):

$k = -$ (ln(W/Wi))/t; where W – weight of partially decayed cellulosic discs, Wi – initial weight of cellulosic discs, t – time (year). Furthermore, the time for 95% (3/k) weight loss was calculated (Olson 1963).

During the course of the study, basic elements of weather were recorded. In order to determine the basic soil properties, soil material was collected from a depth of 0–5 and 10–15 cm, as composite samples (Petersen and Calvin 1996) to provide reliable description of sites. In fine earthy particles (with a diameter <2 mm), the following determinations were made:

Texture by areometric-sieve method, (Casagrande, modified by Prószyński);
Organic carbon content (Corg.) by Tiurin method (Lityński and others 1976);
Total nitrogen content (Forster 1996);
Total phosphorus content (Grimshaw 1987);
Carbonate content by Scheibler volumetric apparatus (Lityński and others 1976);
Soil pH electrometrically in H_2O and 1 M KCl (Thomas 1996);
Exchangeable cations content by Mehlich method (Lityński and others 1976).

Results

Surface humus horizons of arctic brown soils occurring within the Calypso position were characterised by a

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Table 1. Length and period of discs exposure.

Series No.	Name of series	Date of burying	Date of removing	Exposure length [days]	Seasons of exposure				
					Vegetation period 2007	winter 2007–2008	Vegetation period 2008	winter 2008–2009	Vegetation period 2009
				Calypso					
1	spring 2007 – autumn 2007	09.06.07	09.09.07	92	x	–	–	–	–
2	spring 2007 – spring 2008	09.06.07	12.06.08	369	x	x	–	–	–
3	spring 2007 – autumn 2008	09.06.07	04.09.08	453	x	x	x	–	–
4	spring 2008 – autumn 2008	12.06.08	04.09.08	84	–	–	x	–	–
5	spring 2007 – spring 2009	09.06.07	14.06.09	736	x	x	x	x	–
6	spring 2007 – autumn 2009	09.06.07	01.09.09	815	x	x	x	x	x
7	spring 2009 – autumn 2009	14.06.09	01.09.09	79	–	–	–	–	x
				Skilvika					
8	spring 2007 – autumn 2007	11.06.07	09.09.07	90	x	–	–	–	–
9	spring 2007 – spring 2008	11.06.07	17.06.08	372	x	x	–	–	–
10	spring 2007 – autumn 2008	11.06.07	04.09.08	451	x	x	x	–	–
11	spring 2008 – autumn 2008	17.06.08	04.09.08	79	–	–	x	–	–
12	spring 2007 – spring 2009	11.06.07	14.06.09	734	x	x	x	x	–
13	spring 2007 – autumn 2009	11.06.07	01.09.09	813	x	x	x	x	x
14	spring 2009 – autumn 2009	14.06.09	01.09.09	79	–	–	–	–	x

x – period of discs decomposition in soil

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significant content of sand fractions (approximately 80%) and extremely low content of clay fractions (Table 2). Coarse parts in the form of gravel and stones (> 2 mm) constituted over 17%. Gleyed polygonal soils of Skilvika contained far greater amounts of silt fractions (approximately 50%) and clay (7–9%) at a much lower content of sand fractions. The share of coarse parts in these soils was considerable and ranged from 26–30%.

The content of organic carbon and total nitrogen was much higher in the surface horizons of Arctic brown soils in comparison with similar horizons of gleyed polygonal soils. Both test plots contained similar amounts of phosphorus, regardless of the depth of sampling. The humus horizon of arctic brown soils was neutral, while the soils of Skilvika exhibited an alkaline reaction that was connected to the presence of carbonates, which was much higher in the gleyed polygonal soils (Table 3).

Calypso surface soils were characterised by a higher cation exchange capacity when compared to Skilvika soils (Table 4). Regarding the composition of the exchangeable cations of both types of soil dominated by Ca^{2+}, a significant share of the cations Mg^{2+} and H^{+} was observed. The lowest content was noted for K^{+}, Na^{+}, and Fe. Due to the high content of calcium cations, the degree of saturation of the sorptive complex by base cations was significant and equalled or exceeded 90% in all cases.

Despite the very long exposure of the cellulose discs, the degree of decomposition was relatively low (Fig. 3). In addition, there were significant differences in cellulolytic activity between the two research locations. Mean weight losses of cellulose discs for growing the seasons (vegetation periods) 2007, 2008 and 2009 (series of spring–autumn) in the Arctic brown soils were 10.4% (± 2,8 SD), 12.8% (± 5,9 SD) and 14.2% (± 6,7 SD), respectively. In the gleyed Skilvika polygonal soils, weight losses were even two or three times lower: 6.4% (± 1,75 SD), 4.0% (± 1,6 SD) and 6.7% (± 3,1 SD), respectively. The annual fractional weight losses during vegetation periods ranged between 0,412–0,656 in Calypso and 0,089–0,161 ($g \cdot g^{-1} \cdot year^{-1}$) in Skilvika (Table 5). Similar results of the decomposition rate of cellulose discs in the growing seasons of 2008 and 2009 were also obtained from a comparison of their degree of decomposition in the series left for a longer period (Table 6). For this purpose, a series of discs buried in the spring of 2007 and dug out at the beginning and end of growing seasons in successive years (2008 and 2009) were used. The data obtained were used for calculation of the average rate of cellulose decomposition in the resting periods 2007/08 and 2008/09 (snow cover presence besides the growing period). The degree of decomposition of buried filter papers in that period was extremely low and amounted to 0.2 and 2.8% (0,003–0,036 ($g \cdot g^{-1} \cdot year^{-1}$)) in arctic brown soils and 0.1 and 1.1% (0,001–0,014 ($g \cdot g^{-1} \cdot year^{-1}$)) in the gleyed polygonal soils. For purposes of comparison with results obtained by other authors, the degrees of decomposition

Table 2. Grain size distribution of soils analysed.

Genetic horizon	Depth [cm]	Percentage share of fraction [mm]										Granulometric group [PTG 2008]
		>2,0	2,0–1,0	1,0–0,5	0,5–0,25	0,25–0,1	0,1–0,05	0,05–0,02	0,02–0,005	0,005–0,002	< 0,002	
Calypso – Arctic brown soil												
A1	0–5	17,6	18,2	18,9	16,2	17,1	8,6	10	7	2	2	loamy sand (moderately skeletic)
A2	10–15	17,6	19,8	19,7	16,5	16,2	8,8	9	6	2	2	loamy sand (moderately skeletic)
Skilvika – gleyed polygonal soil												
Cr (A)	0–5	26,3	7,6	4,0	6,3	13,2	11,9	17	22	11	7	sandy loam (moderately skeletic)
Cr	10–15	29,8	7,6	4,4	6,4	13,3	11,3	17	21	10	9	sandy loam (moderately skeletic)

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Table 3. Selected chemical and physicochemical properties of soils analysed.

Genetic horizon	Depth [cm]	pH H_2O	pH KCl	$CaCO_3$ [%]	C_{org} [g · kg^{-1}]	N_t [g · kg^{-1}]	P_t [g · kg^{-1}]	C/N
			Calypso – Arctic brown soil					
A1	0–5	7,45	6,76	0,21	18,4	1,66	0,77	11
A2	10–15	7,54	7,06	0,96	22,9	2,19	0,83	10
			Skilvika – Gleyed polygonal soil					
Cr (A)	0–5	8,04	7,92	10,02	7,76	0,85	0,84	9
Cr	10–15	8,20	7,96	11,21	6,15	0,50	0,81	12

in the growing seasons 2007, 2008 and 2009 have been converted to a rate of decomposition of cellulose, expressed in mg · g^{-1} · $24h^{-1}$. These values were, respectively: 1.13, 1.52 and 1.80 for Calypso and 0.71, 0.51 and 0.85 for Skilvika. A comparison of these values shows that the average rate (for all three growing seasons) of cellulose decomposition was higher in the area of Calypso by 2.23 times. Differences in decomposition rate between both sites were tested statistically, for all research periods (Table 7).

Discussion

The soils under study are influenced by similar climatic conditions. Significant differences in cellulolytic activity must therefore be associated with different soil properties in both locations of the research. The main factor determining the biological activity of soil is organic matter content. Surface horizons of Arctic brown soils contained 2.3 times more organic carbon than gleyed polygonal soils, which corresponds to more than double the cellulolytic activity of these soils. It should also be noted that

Table 4. Properties of sorptive complex of soils.

Genetic horizon	Depth [cm]	Ca^{2+}	Mg^{2+}	K^+	Na^+	Fe	H_h	S	T	V [%]
		[cmol(+) · kg $^{-1}$]								
				Calypso – Arctic brown soil						
A1	0–5	9,85	1,09	0,076	0,046	0,108	1,12	11,1	12,3	90,0
A2	10–15	13,4	1,63	0,039	0,028	0,123	0,971	15,1	16,2	93,2
				Skilvika – Gleyed polygonal soil						
Cr (A)	0–5	6,39	1,42	0,068	0,079	0,060	0,449	7,96	8,47	94,0
Cr	10–15	4,63	0,978	0,059	0,030	0,052	0,449	5,70	6,20	91,9

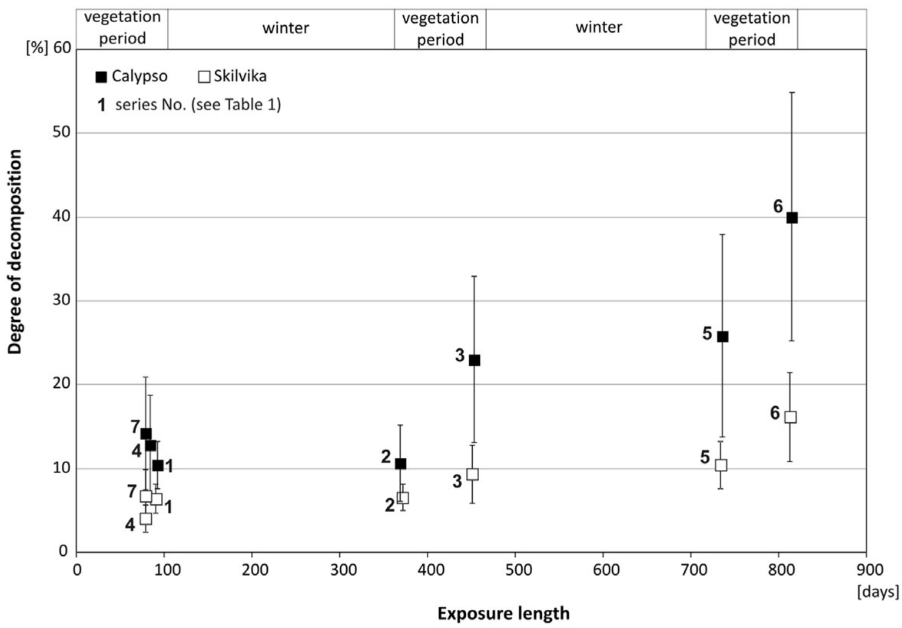

Fig. 3. Comparison of average (± SD) rate of decomposition of cellulose discs.

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Table 5. Cellulose decomposition rate and parameters.

	Study site									
	Calypso					Skilvika				
		decomposition rate					decomposition rate			
Period	Series	g^*g^{-1} $^*year^{-1}$	SD	*k*	95% time *3/k*	Series	g^*g^{-1} $^*year^{-1}$	SD	*k*	95% time *3/k*
Vegetation period 2007	1	0,412	0,11	0,231	13	8	0,26	0,07	0,131	22,9
Vegetation period 2008	4	0,556	0,26	0,353	8,5	11	0,185	0,07	0,089	33,7
Vegetation period 2009	7	0,656	0,31	0,463	6,48	14	0,31	0,15	0,161	18,6
Winter 2007/2008	2–1	0,003	–	0,0013	2308	9–8	0,001	–	0,0004	7500
Winter 2008/2009	5–3	0,036	–	0,016	188	12–10	0,014	–	0,0061	492
Year 2007/2008	2	0,105	0,04	0,048	62,5	9	0,064	0,02	0,029	103
Year 2008/2009	5–2	0,151	–	0,071	42,3	12–9	0,039	–	0,017	176

gleyed polygonal soils have a much lower ratio of humic to fulvic acids in humus compounds which is strongly associated with the mineral part of soil (Klimowicz and others 1999). In gleyed soils, the value of this ratio is only 0.17, while in the Arctic brown soils, it increases to 0.59 (Klimowicz and others 2008). The relatively high content of organic matter in soils of Calypso is the effect of considerable coverage by deflationary tundra vegetation; this, in turn, is a result of the stability of the land and low intensity of cryogenic separation processes (Klimowicz and others 2008). The increased content of organic matter in Arctic brown soils contributed to an increased cation exchange capacity, especially the content of calcium and hydrogen ions which have an impact on soil microbial activity. Another factor that influences the activity of soil microorganisms in arctic brown soils is their better air-water conditions connected to a coarser texture. Gleyed Skilvika polygonal soil contains much higher silt and clay fractions. For this reason, during the period of snow melting and thawing of ceiling parts of the active layer of permafrost, soils are characterised by a moisture content close to the maximum water capacity, hindering the development of higher plants in the central part of the polygon. Previous studies on redox potential have confirmed the dominance of reducing conditions. There is even a strong anaerobiosis in the water-saturated gleyed soils of Calypsostranda (Melke and Uziak 1989).

The results showed that it would take 42,3–62,5 years (Calypso) and 103–176 years (Skilvika) to decompose 95% of organic matter in the studied soils. The results are consistent with the data provided by other authors. In tundra soils it is around 100 years. The time required for 95% of organic matter to decompose in temperate deciduous forests is four times longer whereas in savannah it takes only 1 year (Montagnini and Jordan 2005).

Comparison of the degree of decomposition of cellulose discs in subsequent growing seasons showed significant differences in particular years. These differences may be due to variable climatic conditions. In subsequent seasons of research (6 June 2007–9 September 2007, 16 June 2008–7 September 2008, 11 June 2009–9 September 2009), the average soil temperatures at a depth of 5 cm were, respectively: 5.8, 5.5 and 5.9°C, while precipitation varied as follows: 52.1, 58.8 and 32.7 mm.

Table 6. Influence of exposure length on their degree of decomposition.

	Degree of decomposition [%] (discs left only for one vegetation season./disc left from June 2007)	
Research position	Vegetation season 2008	Vegetation season 2009
Calypso	12,8 / *12,4*	14,2 / *14,2*
Skilvika	4,0 / *2,8*	6,7 / *5,7*

Table 7. Statistics of cellulose decomposition rate ($g^*g^*year^{-1}$) for Calypso and Skilvika, for particular research periods.

	mean (Calypso)	mean (Skilvika)	*t*	*df*	*p*
spring – autumn 2007 (series 1, 8)	0,413500	0,260500	5,153393	38	0,000008
spring 2007 – spring 2008 (series 2, 9)	0,105000	0,063500	3,921612	38	0,000356
spring 2007 – autumn 2008 (series 3, 10)	0,185000	0,076000	5,796302	38	0,000001
Spring – autumn 2008 (series 4, 11)	0,553500	0,182500	6,202337	38	0,000000
spring 2007 – spring 2009 (series 5, 12)	0,127222	0,050714	4,690575	30	0,000056
spring 2007 – autumn 2009 (series 6, 13)	0,179000	0,072500	6,075076	34	0,000001
spring 2009 – autumn 2009 (series 7, 14)	0,656875	0,308889	4,299626	32	0,000150

Table 8. Comparison of cellulose decomposition rate in various ecosystems (Fisher and others 2006, modified).

Landscape type – vegetation	Research area	Cellulose decomposition rate during vegetation period ($mg^*g^{-1}*24h^{-1}$)	Author
High-mountain tundra	Tien-Szan	1,0 – 3,7	Niewinna (not published)
Semi desert	Dagestan	3,5	Fischer and others 2006
Steppe	Dagestan	2,0	
Mixed forest - mountains	Dagestan	5,7	
Mixed forest - foothills	Dagestan	5,1	
Boreal mountain forest	Carpathian Mts.	2,4 – 4,7	Niewinna 2005
Agrostis meadow	Bieszczady Mts.	10,3	Drewnik 1996
Acid beech mountain forest	Bieszczady Mts.	5,8	
Billberry polonina	Bieszczady Mts.	5,3	
Feathered reed-bunting association	Bieszczady Mts.	4,9	
Alpine meadow	Tatry Mts.	4,2	Drewnik 2006
Alpine meadow	Babia Góra Mts.	5,2	
Meadow	Kampinos Forest	5,0 – 10,0	Jakubczyk 1969
Subcontinental deciduous forest	Silesia	4,7	Bieńkowski 1990a
Mixed forest	Silesia	4,5	
Arctic tundra	Spitsbergen	1,3 – 1,6	Bieńkowski 1990b
	Spitsbergen – bird colony	5,4	
Arctic tundra	Spitsbergen – Calypso	1,1 – 1,8	Present survey
	Spitsbergen – Skilvika	0,5 – 0,8	

In gleyed polygonal soils of Skilvika, the annual trend of changes in decomposition of cellulose discs is similar to the changes in average soil temperatures in each season of research. In the Arctic brown soils, a steadily increasing degree of decomposition of cellulose discs was observed (Fig. 3, Table 5). This increase does not reflect changes in average precipitation and soil temperatures calculated for the entire growing seasons. Finding the relationship between changing climatic conditions and cellulolytic activity of these soils therefore requires a more detailed analysis. It is possible that the biological activity of these soils, due to the large amount of organic matter and favourable air-water conditions, is not so sensitive to small changes in weather conditions, as it is in gleyed polygonal soils.

In comparison with the soil ecosystems of lower latitudes, the soils analysed are characterised by low cellulolytic activity resulting from the harsh climatic conditions (Table 8). In the forest and meadow soils in mountain areas of the Carpathians and the Caucasus, the rate of decomposition of cellulose is several times higher (Drewnik 1996, 2006; Niewinna 2005; Fisher and others 2006). A similar or slightly higher rate of degradation was observed in alpine tundra soils of Tien-Szan (Fisher and others 2006 after Niewinna unpublished). In comparison with the results for other areas of Spitsbergen, the rate of decomposition of cellulose in the Arctic brown soils on the area of Calypso was almost identical to the rate of this process in the tundra soils surrounding Horsund (Bieńkowski 1990b). Among the soils of Spitsbergen, the largest cellulolytic activity was found in organic soils under the influence of nutrients flowing from the little auk (*Alle alle*) colony (Bieńkowski 1990b). The lowest rate of cellulose decomposition in the growing season, less than 1 $mg \cdot g^{-1}.24h^{-1}$, was definitely found in gleyed polygonal Skilvika soils.

An additional methodological aspect of the interpretation of results is the possibility to compare the degree of decomposition of filter papers to evaluate the impact of the length of exposure time of filter papers on the rate of their decomposition. In all the analysed cases, the length of time of remaining filter papers in the soil did not significantly change the rate of decomposition. The average degree of decomposition of filter papers buried only for the vegetation periods of 2008 and 2009 was almost identical to the average degree of decomposition calculated from the differences between the respective series of filter papers buried in June 2007 (Table 6).

Conclusions

1. The soils of the study area are characterised by very low cellulolytic activity, as shown by the low degree of decomposition of cellulose discs on both positions of the research.
2. Higher cellulolytic activity was observed in Arctic brown soils. The lower rate of cellulose decomposition in gleyed polygonal soils is probably due to a significantly lower content of organic matter resulting from the coverage of the central part of polygons by vegetation.
3. The indirect factor influencing cellulolytic activity of the soils is the grain size distribution. In the soils of Skilvika, the higher content of silt

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and clay fractions causes unfavourable water-air conditions, thereby reducing the development of higher plants in the central part of the polygon, and affects only a small accumulation of organic matter in surface horizons.

4. Excessive soil moisture of gleyed polygonal soils during snow melting and thawing of ceiling parts of the active layer of permafrost may impede the cellulolytic activity of these soils in relation to the better-aerated Arctic brown soils.
5. The length of exposure of cellulose discs did not affect significant changes in the rate of decomposition.

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