POLISH POLAR RESEARCH	14	4	345-354	1993

Zofia FISCHER[1] and Stefan SKIBA[2]

[1] Department of Ecological Bioenergetics,
Institute of Ecology
Polish Academy of Sciences
Dziekanów Leśny
05-092 Łomianki, POLAND
[2] Pedological Laboratory and Soil Geography
Institute of Geography
Jagiellonian University
Grodzka str., 64
31-044 Kraków, POLAND

Some remarks about bioenergetic aspects of tundra soil

ABSTRACT: Physical and chemical properties (granulometric composition, pH, carbonates, organic carbon, nitrogen etc.) as well as bioenergetic activity of Spitsbergen tundra soils were studied at three chosen stations situated near Polish polar station "Hornsund". It was found that biological activity of Arctic tundra soils depended mainly on its physical properties, whereas the chemical composition of organic matter did not effect directly the bioenergetics of these soils. This bioenergetic activity depends mainly on the richness of micro- and mesofauna communities inhabiting the soil

Key words: Arctic, Spitsbergen, tundra soils, bioenergetic activity.

Introduction

The biological activity of Arctic tundra soils of all polar regions is rather low (Tedrow and Douglas 1959, Bliss et al. 1973, Lag 1980, Ugolini and Edmonds 1983, Dziadowiec 1984, Bieńkowski 1990). When comparing this activity with the metabolic activity of the soils of other regions, despite the fact that the strict comparison is methodically impossible, it is evident that the differences can be counted by quantity (Edwards 1975, Focht 1990 a, b).

Recent studies carried out on Spitsbergen show that the dependence of the metabolic activity of the soils on climatic conditions (e.g. temperature and humidity) is rather insignificant (Fischer and Bieńkowski 1987, Fischer 1990). Because of these results a question can be raised to what extent the intensity of bioenergetic processes depends on the features of the researched soils. Therefore an attempt was undertaken to link the bioenergetic factors (the consumption of oxygen and the excretion of carbon dioxide) with the characteristics of the researched soils.

Investigation area

The research was carried out in the southern part of Spitsbergen, in the Hornsund Fiord area (Wedel — Jarlsberg Land) near the Polish polar station of Polish Academy of Sciences, in the drainage area of the Fuglebekken stream (Fig. 1).

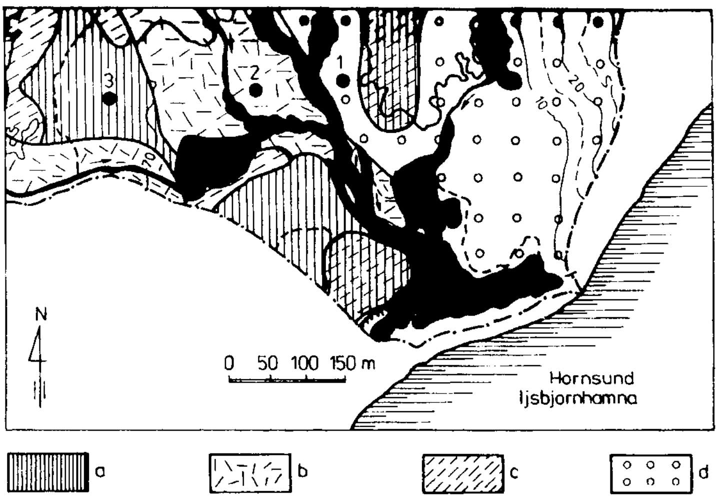

Fig. 1. Investigated stations in the lower part of the Fugleberget drainage area (Hornsund) and the vegetation assemblages: 1 — Site No. 1, 2 — Site No. 2, 3 — Site No. 3; a — *Sphaerophorus globosus*, b — *Calliergon stramineum*, c — *Cladonia mitis* — *Cetraria nivalis* — *Rhacomitrium languinosum*, d — stony tundra.

This drainage area amounts to about 1.5 km^2 (Klekowski, Opaliński and Fischer 1988). It is situated nearby the alluvial cones of Ariekammen and Fugleberget. To the west it is limited by the high inselberges of the old sea terrace, to the east — the lateral moraine of the Hans Glacier, to the south it is closed by the old storm ridge of the Hornsund Fiord.

The bed-rock of the described drainage area is constituted by the rocks of the Ariekammen and Fugleberget formations of the Isbjornhamna group (Birkenmajer 1960). These are: paragneisses, mica shales with the addition of carbonate shales. These rocks weathered by frost and water together with the moraine and sea sediments constitute the basis of the soils occurring there. The climatic conditions of the described region can be characterized by changing weather, low temperature, rather low precipitation and strong foehn type winds. According to the data provided by Polish station of PAS in Hornsund for 1978–1983 (Rodzik and Stepko 1985), the average annual temperature was −5.6°C, the warmest month was July (average temperature +4°C), the coldest — January (average temperature −14.2°C). The average annual precipitation was 406.2 mm, the highest, observed in August — 63.3 mm, the lowest (in December) — 16.2 mm.

The vegetation occurring in the researched area is constituted by the Arctic-polar assemblages (Dubiel and Olech 1989 and unpubl. data). The drainage area of Fuglebekken is dominated by three main types of tundra in which the present research was carried out:

(1) Cryogenically deformed the so-called patterned ground, poorly covered with plants of *Saxifraga aizodes* assemblage.

(2) Humid mossy tundra of the *Caliergon stramineum* community, formed in the central part of the drainage area (in the Fuglebekken Stream area).

(3) Dry tundra with *Sphaerophorus globosus* communities on the stony-gravel formations.

The soil cover in the researched drainage area is also fairly differenciated (Szerszeń 1968) and it refers to the bed-rock and humidity relations. All the soils, because of the permafrost, are marked by the cryogenic processes.

Methods

The pedological research was carried out in three sites representing main types of tundra. The profiles were dug out and described, and samples were taken for the laboratory analyses. In the description the Arctic tundra soil units of the classification of Tedrow (1977), Wilding, Smeck and Hall (1983) and FAO Classification (1988) were taken into consideration.

In the samples following parameters were analysed: granulometric composition — using the areometric method (fractions 2.0–0.05 mm were sieved out wet on the sieves proper to these fractions); pH of the soil — potentiometrically; the content of carbonates — using the Scheibler volumetric method; organic carbon — using the Tiurin–Walkley–Black oxidometric method; humus — calculated as follows: $C_{org.} \times 1.724$; total nitrogen — using the Kjeldahl method; the chemical composition of the soil — in the alloys with Na_2CO_3.

The bioenergetic activity analysis, oxygen consumption and the excretion of carbon dioxide were determined basing on the sample material taken during the expedition of 1989 (Fischer 1990). Analyses were carried out on the soil taken from the 5 cm upper layer. Analyses were made in the laboratory with the use of Klekowski respirometer (Klekowski 1975) in the glasses of 25 ml with the temperature and humidity controlled. The temperature of the surveys carried out from May to September 1989 was controlled with the factual soil temperature in the field and it varied from 0°C to +8°C. Each analysis lasted three hours and was interpreted as the average of the results read every half an hour. The received data were indices characterizing only relative differences by which the comparison of soils (taking into account the anomalies caused by collecting samples) was possible.

Results

Site No. 1 was situated on cryogenic (polygonal) gleysols. Earthy space in the middle of the polygons is constantly saturated, and the average saturation during the summer season of 1989 was 93.4%. They do not show the colour differentation into the diagnostic horizons which is caused by the strength of the processes of frost sorting and mixing of the weathered material (Skiba 1991, Skiba and Kuczek 1993). The colour of the soil was olive green (5Y 4/3), which points to the predominance of the reduction processes connected with the relative anaerobiosis that can be found there (Melke and Uziak 1989). In the granulation the silt fractions (0.05 – 0.02 mm) prevail and the amount of these fractions was more than 50% (Tab. I). In the upper horizon a small impoverishment can be observed which may be the result of the eolic processes because those formations were poorely covered with vegetation. They were periodically covered with very thin layer of algae which are the major supplier of the organic matter into these soil formations (Plichta and Luścińska 1988).

Table I

Soil profile and granulometric composition

Depth [cm]	Horizon	Colour (moist)	Skeleton 2.0 %	Earth particle %	%% fraction in earth particle in mm							
					2.0 – 1.0	1.0 – 0.5	0.5 – 0.25	0.25 – 0.10	0.10 – 0.05	0.05 – 0.02	0.02 – 0.002	<0.002
SITE No 1 — Gelic gleysol												
1 – 0	O	blue-green	algae									
0.20	ACgg	5Y 4/3	30	70	10	9	10	12	11	23	21	4
20 – 40	ACgg	5Y 5/6	20	80	4	4	6	16	11	27	25	7
<40	Cgg	5Y 5/6	30	70	4	5	7	15	10	28	28	7
SITE No 2 — Gelic histic-gleysol												
9 – 3	Oi	moss										
3 – 0	Oe	moss	raw humus									
0 – 40	ACgg	5Y 5/6	40	60	7	4	6	5	17	30	28	3
SITE No 3 Gelic regosol												
2 – 0	O		raw humus									
0 – 30	AC	10YR 3/2	70	30	30	22	8	10	13	10	6	1

The reaction of the researched soil was rather constant throughout the profile (Tab. II). It was about 6.0–6.4 demonstrating considerable content of the alcalic elements (Tab. III).

Table II

Some chemical properties

Depth [cm]	Horizon	pH H_2O	pH KCl	$CaCO_3$ %	Organic matter %	C org. %	N total %	C:N
SITE No 1 — Gelic gleysol								
1–0	algae							
0–20	ACgg	6.0	5.8	–	0.8	0.46	0.03	15
20–40	ACgg	6.3	5.8	–	0.6	0.35	–	–
<40	Cgg	6.4	5.8	–	0.6	0.35	–	–
SITE No 2 — Gelic histic-gleysol								
9–3	Oi	5.8	5.4	–	48.18	27.95	0.93	30
3–0	Oe	6.0	5.8	–	35.08	20.35	0.70	29
0–40	ACgg	6.5	6.2	–	–	–	–	–
SITE No 3 — Gelic regosol								
2–0	O	6.8	6.4	–	18.29	10.61	0.09	20
0–30	AC	7.4	6.9	5.20	2.25	1.30	0.08	16

Table III

Basic chemical composition

Profile No	Depth [cm]	SiO_2	R_2O_3	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	P_2O_5
1	0–20	57.15	23.40	18.20	5.20	1.75	2.65	3.25	1.70	0.19
	20–40	58.80	24.08	18.70	5.38	1.82	2.47	2.95	1.80	0.17
2	0–40	56.10	22.40	17.30	5.10	2.36	3.72	3.12	1.65	0.20
3	0–30	60.12	21.60	18.65	3.15	5.18	2.60	2.43	1.13	0.16

Organic matter was formed by rather primitive plant organisms and in the soils studied the amount of the organic matter was about 0.6–0.8% with very low nitrogen content — 0.03%.

The intensity of metabolic processes (Tab. IV) in the organic matter of this soil was relative high. The amount of the consumed oxygen per gram of the

Table IV

Oxygen consumption and carbon dioxide production in soil and in organic matter, related to its basic chemical character

Site No	In soil					In organic matter					
	subst. org. %	C %	N %	O_2 %	CO_2 %	C %	N %	O_2 %	CO_2 %	C:N	O_2:N
1	0.8	0.46	0.03	0.037	0.015	57.5	3.7	4.69	1.87	15	1.26
2	35.08	20.35	0.50	0.266	0.098	58.1	1.99	0.76	0.28	29	0.38
3	2.25	1.30	0.08	0.028	0.0126	57.77	3.55	1.26	0.56	16	0.35

matter in this site was about 4.69 μl/h, SD was being 1.7 μl/h for n=490. The amount of excreted CO_2 was respectively 1.87 μl/h with SD amounting 0.8 for n=451.

Relatively high intensity of bioenergetical processes of the organic matter is not contradictory to the low activity of the soil as a whole. Because of the small quantity of the organic matter in this soil, 1 gram of the soil during one hour period consumes only 0.028 – 0.037 μl of O_2 and excretes 0.011 – 0.015 μl of CO_2.

Site No. 2 was represented by gelic histic gleysols. Such formations can be found in the bottom of the Fuglebekken stream valley. The characteristic feature of these soils is the duality of the profile. The upper horizon was constituted by the mossy-peat organic layers of various thickness, but not exceeding 20 cm. In the case of sample No. 2 this horizon was 0 – 9 cm thick, and consisted of the living tissues of mosses and other vascular plants (0-6 cm) and of the decaying tissues (0 – 9 cm). Below the organic horizon there was a layer about 1 cm thick of frozen angular gravel and below there was the mineral clayey silt horizon of the olive green colour (5Y 5/6). Mossy-peat layer "hung" over the mineral horizon, over which water is flowing, makes an isolation preventing stronger cryogenic deformations.

The reaction of the organic matter was about 5.8 – 6.0 and in the mineral horizon it was 6.5.

The amount of the organic matter for the mossy horizon was 48.18% and for the decaying humus horizon — 35.08%. The content of nitrogen was much higher (0.9 – 0.7%) and probably it was the result of ornithogenic enrichment.

The intensity of bioenergetic processes of the decaying layer (6 – 9 cm) was far lower than in the site No. 1. One gram of the organic matter used on the average 0.7 μl/h of oxygen (SD was 0.2 for n=390), excreting on the average 0.28 μl/h of carbon dioxide (SD was 0.1 for n=394). The intensity of the bioenergetic processes calculated for the whole soil was higher than at the site No. 1 and its consumption was 0.266 μl of oxygen and its excretion — 0.098 μl of CO_2 per gram per hour.

Site No. 3 was situated on gelic regosols. The profile of this soil was composed of a lichen horizon several centimeters thick, covering the loose gravel formation of the lifted sea terrace.

The granulometric composition of this soil (Tab. I) contains in 70% gravel pebbles of the diameter larger than 2 mm on the average about 5 – 10 mm. Earthy parts (fraction below 2 mm) were composed mainly of the sand fraction (2.0 – 0.05) and their amount was about 83%; silt fraction (below 0.002) occurred in insignificant amount — about 1%. Therefore this formation was fairly penetrable and periodically dry; only in the thaw season or after heavy rains gravitation water can occur.

The reaction of this soil (Tab. II) was weakly alcaline in the mineral part (pH=7.4) which was due to the limestone gravel. In the lichen organic matter pH was 6.8.

The amount of calcium carbonate in earthy parts was 5.2 to 6.0%. Organic matter content was about 18.29% in the lichen layer, and in the organic humus layer 2.25% with total nitrogen content of 0.08 – 0.09%.

The intensity of bioenergetic processes in the organic matter of the 0 – 5 cm layer was a bit higher than in the site No. 2. Oxygen consumption per gram was on the average 1.26 μl/h (SD = 1.2, n = 240). The excretion of CO_2 was 0.56 μl/h per 1 gram (SD = 0.6, n = 234). Respective data for 1 gram of the soil were: oxygen consumption — 0.03 μl/h and CO_2 excretion — 0.01 μl/h.

Discussion

The common feature of the researched soils is the presence of permafrost and its contribution to the soil forming processes. Differences in the biological activity are caused by the geomorphology of the area, floristic composition and humidity relations.

In the humid area poorly covered with plants in the earthy material contemporary regelation processes take place (patterned ground). In the bottom of the valley covered with the mossy-peat carpet, these processes are weakened and gelation can be shown only as a thin layer of refrozen gravel, occurring only in the upper mineral horizon. Gravel formations show only surface crushes.

Chemical properties of the soils studied are related to the mineral composition of the bed rock, and in the bottom of the valley also with the ornithogenic fertilization. Basic chemical composition of these soils (Tab. III) does not shows serious differences, only at the site No. 2, containing considerable amount of limestone gravel, more calcium and magnesium compounds did occur.

When comparing the bioenergetic activity of the researched soils against the background of their physico-chemical properties two pictures can be seen: one for soils as a whole, another one for the organic matter alone (Tab. IV).

The soils studied show tenfold differences in the metabolic activity. The soil of the site No. 2 is characterized by the highest biological activity, far higher than of the other sites. In this soil the higher amount of nitrogen (Tab. IV) was found (twenty times than in other soils). This was caused by the high content of organic matter in this soil and the environment of decaying mosses. Very important is here the fact that these decaying plants are strongly hydrophilic (maximum water capacity 1000). Soils of other sites — cryogenic gleysols and gelic regosols have the nitrogen content lower of one order of magnitude. At the polygonal site (1) the content of the organic matter is almost three times lower than at the site 3 of gelic regosols. On the other hand the comparison of the metabolic activity of these two last soils shows that the differences are not connected with the amount of nitrogen in the soil (Tab. IV).

The biological activity of the polygonal soils is a bit higher than that of the soils of the site No. 3; it should be expected that this phenomenon is caused by the quality and quantity of plants communities inhabiting these soils. This question can be answered by the estimation of the metabolic activity of the organic matter alone (Tab. IV). It can be seen that the activity of the organic matter of the soils studied is different. The lowest was found at the site No. 2 that is at the peat-gley site, where the soil was the most active. At this site, during the major part of summer, the temperature was lower than at the other sites; also the humidity was considerably high (Fischer 1990). It is also the environment where the organic matter is relatively poor in nitrogen. So the question may be raised: whether nitrogen could be the motive power of the biological activity of organic matter of the researched Arctic soils?

The analysis of Table IV does not prove the hypothesis. Organic matter of sites No. 1 and No. 3 contained almost equal amount of nitrogen and also the proportion of carbon to nitrogen was similar, yet their bioenergetical activity was totally different. This is shown by the relation of nitrogen to the oxygen consumed (Tab. IV). The activity of organic matter at the polygonal site was more than three times higher than at the gelic regosol of the third site. The cause of such differences should be due to the differences in the settlement of the soils by the organisms which in turn seems to be the result of different physical structure of the environments inhabited by micro- and mezofauna. The comparison of the soil of the site 1 (polygonal) at the depth 0–20 cm with that of the site 3 (gelic regosol) at the depth 0–30 cm (Tab. I) shows contrasted situation. The cryogenic gley-polygonal soil consists mainly of earthy parts (about 70%), the rest are the gravel parts — 30%. In the initial regosol the granulometric composition is completely different, 70% are parts of the diameter above 2.0 mm. Therefore the soil of the site 1 is of a rather compact structure, retaining water for considerably long time and containing small amount of air. Parallel research carried out by Fischer (1990) proved also that this soil melted faster in spring and the temperature of their upper layers during summer was higher than that of the soils of other sites. The mentioned above physico-structural features may provide specific conditions for the life of micro- and mezofauna. Organic matter did not occur in large amount here, as a result of low density of vegetation possibly due to wind action (Plichta and Luścińska 1988), however it seems that this organic matter is rather active, permanently settled by the community of microorganisms. On the other hand the cryogenic initial soil of loose structure, large amount of air and constantly penetrated by water is settled by smaller number of organisms or by less active organisms. This biotope is exposed to changing environmental conditions, of course in the scale of needs of microorganisms. May be that these features cause more than three times lower biological activity of the organic matter of regosols when compared to cryogenic gley — soil.

Conclusions

1. Biological activity of the researched Arctic soils depends mainly on their physical properties.
2. Chemical composition of the organic matter of Arctic soils studied does not effect directly the intensity of bioenergetic activity.

References

BIEŃKOWSKI P., 1990. The rate of cellulose decomposition in soils of Spitsbergen tundra. — Pol. Polar Res., 11: 39–45.

BIRKENMAJER K., 1960. Raised marine features of the Hornsund area, West Spitsbergen. Geological results of the Polish 1957–1958 Spitsbergen Expedition. — Studia Geol. Polon., 5: 33–73.

BLISS L.C., COURTIN G.M., PATTIE D.L., RIEWE R.R., WHITEFIELD D.W.A., WIELDEN P., 1973. Arctic tundra ecosystem. — Adv. Rev. Ecol. Syst., 4: 359–399.

DUBIEL E., OLECH M., 1989. Plant communities of NW Sörkapp Land (Spitsbergen). — Zesz. Nauk. U.J., Pr. Bot., 21: 33–73.

DZIADOWIEC H., 1984. Preliminary studies on carbon dioxide evolution from tundra soils of Spitsbergen (Kaffiora, Oscar II Land). — Acta Univ. Nicol. Copernic., Geografia, 28: 159–169.

EDWARDS N.T., 1975. Effects of temperature and moisture on carbon dioxide evolution in a mixed deciduous forest floor. — Soil Sci., Soc. Am. Proc., 39: 361–365.

Food and Agriculture Organization of the United Nations. 1988. FAO/UNESCO Soil Map of the World. Revised Legend. — World soil recources, Report 60, Rome FAO: 119 pp.

FISCHER Z., 1990. The intensity of soil metabolic processes in Spitsbergen tundra. — Pol. Polar Res., 11: 17–24.

FISCHER Z. and BIEŃKOWSKI P., 1987. The effect of temperature on oxygen consumption by Arctic soil of the fiord Hornsund (Spitsbergen) region. — Ekol. Pol., 35: 159–171.

FOCHT U., 1990a. Seasonal changes in oxygen metabolism of soil subject to artifactial acidification. — Pol. Ecol. Stud., 16: 219–228.

FOCHT U., 1990b. The effect of acidification on oxygen metabolism of soil at various thermal conditions. — Pol. Ecol. Stud., 16: 229–234.

KLEKOWSKI R.Z., 1975. Constant — pressure volumetric microrespirometer for terrestrial invertebrates. In.: W. Grodziński, R.Z. Klekowski & A. Duncan (eds.), Methods for ecological bioenergetics. Oxford, Blackwell Sci. Publ., IBP Handb. 24; 212–225.

KLEKOWSKI R.Z., OPALIŃSKI K.W. and FISCHER Z., 1988. Polish bioenergetical studies in Spitsbergen tundra. — Arctic and Nordic Count. on Coordin. Res. Arctic., Leningrad; 1–34.

LAG Z., 1980. Special peat formation in Svalbard. — Acta Agric. Scand., 30: 205–210.

MELKE J. and UZIAK S., 1989. Dynamics of moisture, redox potential and oxygen diffusion rate on some soils from Calypsostranda, Spitsbergen. — Pol. Polar Res., 10: 91–104.

PLICHTA W. and LUŚCIŃSKA M., 1988. Blue-grey algae and their influence on development of surface horizon of tundra soils in Kaffiora, Oscar II Land, Spitsbergen. — Pol. Polar Res., 9: 475–484.

RODZIK J. and STEPKO W., 1985. Climatic conditions in Hornsund, 1978–1983. — Pol. Polar Res., 6: 561–576.

SKIBA S., 1991. The soil cover in north-west Sörkapp Land, Spitsbergen, Svalbard. — XVIII Sympozjum Polarne, Szczecin, Materiały, Komitet Badań Polarnych PAN; p. 81.

SKIBA S. and KUCZEK M., 1993. Preliminary studies of the soil cover in north-west Sörkapp Land SW Spitsbergen. — Zesz. Nauk. U.J., Pr. Geogr., 94: 93–103.
SZERSZEŃ L., 1968. Preliminary investigations of soil cover in the region of Hornsund. In: K. Birkenmajer (ed.), Polish Spitsbergen Expeditions 1957–1950. Wyd. Geol.; 217–227.
TEDROW J.C.F., 1977. Soils of the Polar Landscapes. — Rutger Univ. Press; 638 pp.
TEDROW J.C.F. and DOUGLAS L.A., 1959. Organic matter decomposition rates in Arctic soils. — Soil Sci., 88: 305–309.
UGOLINI F.C. and EDMONDS R.L., 1983. Soil Biology. 1. Concepts and Interactions. In: L.P. Wilding, N.E. Smeck & G.F. Hall (eds.), Soil Taxonomy and Pedogenesis. Elsevier Sci. Publ., Amsterdam; 193–231.
WILDING L.P., SMECK N.E. and HALL G.F. (eds.), 1983. II. The orders. Pedogenesis and Soil Taxonomy. Amsterdam, Elsevier Sci. Publ.; 410 pp.

Revised and accepted December 7, 1993

Streszczenie

Stanowiska badawcze zlokalizowane były w trzech różnych geomorfologicznie i florystycznie terenach, na trzech różnych genetycznie utworach glebowych (kriogeniczne gleby glejowe, gleby organiczno-glejowe i regosole).

Z wykonanych badań wynika, że o aktywności biologicznej tych gleb decydują w głównej mierze ich właściwości fizyczne, które wytwarzają konkretne warunki środowiska życia dla zespołów organizmów żywych. Na warunki środowiskowe życia składają się stosunki wodne w glebie, termiczne, intensywność penetracji wodnej i powietrznej itd. Nie bez znaczenia jest oczywiście zawartość substancji organicznej w glebie, gdyż jest ona źródłem energii dla pedosfery, jednakże aktywność biologiczna tej substancji organicznej może być zróżnicowana i zależna właśnie od właściwości fizycznych gleby. Skład chemiczny substancji organicznych badanych gleb arktycznych nie wydaje się limitować intensywności przemian bioenergetycznych zachodzących w górnej warstwie glebowej. Być może, iż wpływa na to stosunkowo duża zasobność badanych gleb, co może być spowodowane dużymi wpływami w tym rejonie substancji ornitogennych.