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Dynamics of moisture, redox potential and oxygen diffusion rate of some soils from Calypsostranda, Spitsbergen

ABSTRACT: The dynamics of some features of arctic soils and their connection with air-water relations are presented. Investigations of 5 selected profiles were carried out in 1987. Considerable dynamics of moisture, redox potential (Eh) and oxygen diffusion rate (ODR) during the summer season were confirmed. Oscillations of these features in individual profiles and sometimes in their horizons were distinguished.

Key words: Arctic, Spitsbergen, soils.

Introduction

Arctic soils are formed due to different processes, among which complete or partial anaerobiosis plays an important role. It is true for most soils in this zone but mainly for gley and organic ones. Studies of Ivanov and Bogatyriev (1970), Szerszeń (1974), Tedrov (1977), Cypanova (1978), Låg (1980), Everett *et al.* (1981) and many others demonstrate it distinctly.

Permanent or periodic anaerobic soil conditions depend on air-water relations and they could be characterized, among other things, by redox potential (Eh) and oxygen diffusion rate (ODR). These conditions of the arctic soils are studied in this paper.

Materials and methods

Studies were carried out during the scientific expedition of the Institute of Earth Sciences, Maria Curie-Skłodowska University (Lublin, Poland).

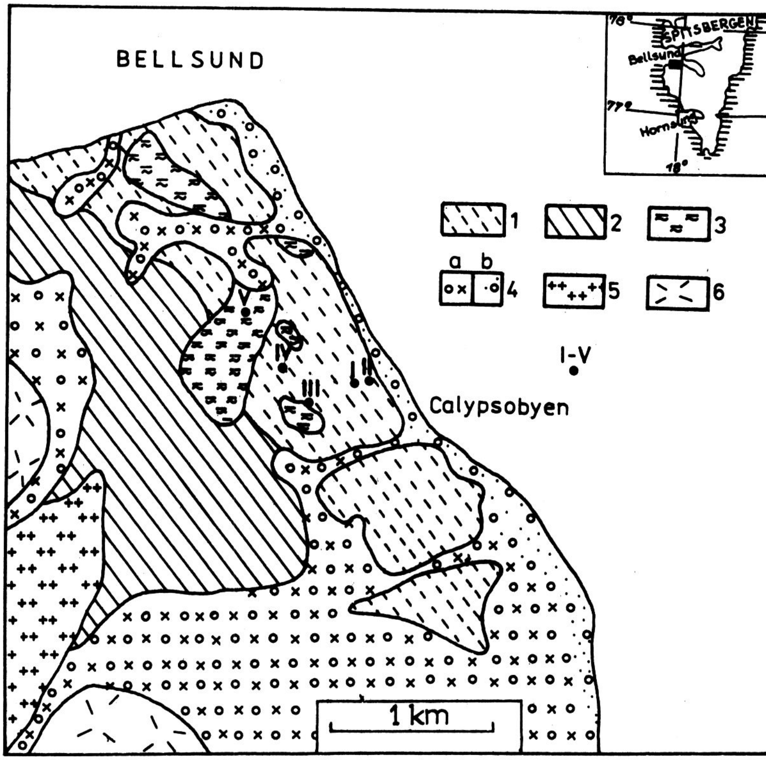

Fig. 1. Schematic distribution of soils and the profiles studied in Calypsostranda
1 — complex of weakly developed and brown soils mostly derived from weak-loamy and loamy sands, 2 — soils derived from medium and light loams, in majority gleyed and weakly gleyed and locally lithosols, 3 — soils derived from medium and heavy loams and clays, in majority gleyed, and locally peaty and peat soils, 4 — areas without soil (a — stony-gravel materials, b — gravel-sandy materials) and locally regosols, 5 — mountain rocky materials, 6 — glaciers; I—V — profile nos

Measurements were made in 5 soil profiles in Calypsostranda, the Bellsund region. Reconnaissance investigations were made in 1986 (Klimowicz and Uziak 1988). The studied profiles were located on a marine terrace 20—30 m a.s.l., covered by dry, and partly wet tundra. The main field studies were conducted from June to August 1987. In selected places (Fig. 1), the redox potential (Eh) as well as oxygen diffusion rate (ODR) were determined every few days. Measurements were made at depths of 5, 10, 15 and 20 cm, using the universal device for measuring electrochemical soil properties, constructed by the Institute of Agrophysics, Polish Academy of Sciences in Lublin and the Lublin section of the Polish Pedological Society (Gawlik, Malicki and Stępniewski 1977, Malicki and Walczak 1983). Eh and ODR determinations were done by using 10 platinium electrodes against a calomel electrode.

The principles of the method for redox potential measurements are described in many papers, for example by Serdobolski (1954), whereas those of ODR measurements in paper of Lemon and Erikson (1952).

Eh and ODR measurements were accompanied by collecting soil samples at a depth of 5 cm for determination of moisture dynamics by the oven--drying method. Samples from deeper horizons could not be collected due to limited return luggage.

Samples for a general description of soils were collected from the same places in which Eh and ODR determinations were made. In these samples granulometric composition, the content of $CaCO_3$, total nitrogen and organic matter, and reaction were determined by the methods commonly used in pedological laboratories.

The results are summarized in a table and presented in figures. Figure 2 presents dynamics of the moisture at a depth of 5 cm from 5 profiles, and temperatures at 5, 10 and 20 cm close to the profile 1. Soil temperatures were taken from the paper by Gluza, Repelewska-Pękala and Dąbrowski (1988). Eh dynamics is presented in figures 3—7 while that of ODR in figures 8—12.

Description of the soils studied

Profile 1 (located within a polygon) represents brown polygonal soil formed from silty light and skeletal sand. A frost fissure in the polygon was another profile of studies. The top layer in this profile was rich in organic matter. Much of it was also distinguished in lower horizons, translocated by water from the top layer. The other features of the fissure soil were the same as in the profile 1.

Profiles 3 and 4 were located within two different stone rings; they belong to gley soils. The former was formed from a light and skeletal clay, while the latter from a medium strongly skeletal clay.

Profile 5 located on a loamy outflow represents a gley soil too but formed from a heavy and skeletal clay.

The basic features of the studied profiles are shown (Table 1). They are strongly and very strongly skeletal. $CaCO_3$ is present in all profiles, but especially rich (up to 40%) are the soils of the stone rings. Light sandy soils have neutral reaction while loamy soils are alkaline. The soils in the polygons and loamy outflow are richer in organic matter than those in the stone rings.

Results and discussion

Moisture dynamics (Fig. 2) was quite different in the soils of the stone rings than in the loamy outflow *i.e.* in gley and polygonal soils. The smallest

Table 1

Some properties of the soil profiles studied

Profile No.	Soil horizon, depth in cm	Grain sizes in %				$CaCO_3$ %	$pH_{[KCl]}$	Organic matter %	C %	N total %	C:N
		skeleton [$\phi > 1$ mm]	1–0.1 mm	0.1–0.02 mm	< 0.02 mm						
1	A_1:1—3	28	47.6	39.4	13	9.0	6.9	4.07	2.37	0.18	13
	(B):5—17	24	50.3	38.7	11	10.4	6.7	2.20	1.28	0.07	18
	D:29—42	73	60.9	25.1	14	1.2	6.8	1.99	1.16	0.10	12
2	A_{FH}:3—8	0	40.4	47.6	12	1.4	6.6	18.18	10.53	0.61	17
	A_1:11—13	40	50.5	38.5	11	8.4	6.9	3.73	2.17	0.17	13
	(B):17—24	24	39.6	49.4	11	7.8	6.8	3.31	1.92	0.16	12
	D:32—43	72	49.4	27.6	23	1.2	6.9	3.73	2.17	0.19	11
3	(A_1):0—5	62	40.8	27.2	32	39.8	7.5	1.08	0.63	0.06	10
	G/C:15—25	55	39.7	27.3	33	39.8	7.6	0.29	0.17	0.02	8
	CG:42—55	55	38.2	28.8	33	37.0	7.5	0.43	0.25	0.03	8
4	(A_1)G:0—5	36	34.8	27.2	38	32.5	7.6	1.19	0.69	0.07	10
	G/C:15—25	33	37.1	23.9	39	35.6	7.7	0.47	0.27	0.03	9
	CG:30—40	39	35.0	26.0	39	35.6	7.6	0.47	0.27	0.02	13
5	(A_1)G:0—5	27	9.3	33.7	57	13.0	7.4	2.78	1.62	0.14	12
	G/C:20—39	39	13.7	33.3	53	14.2	7.3	1.71	0.99	0.08	12
	CG:52—61	25	7.5	32.5	60	20.5	7.3	0.83	0.48	0.06	8

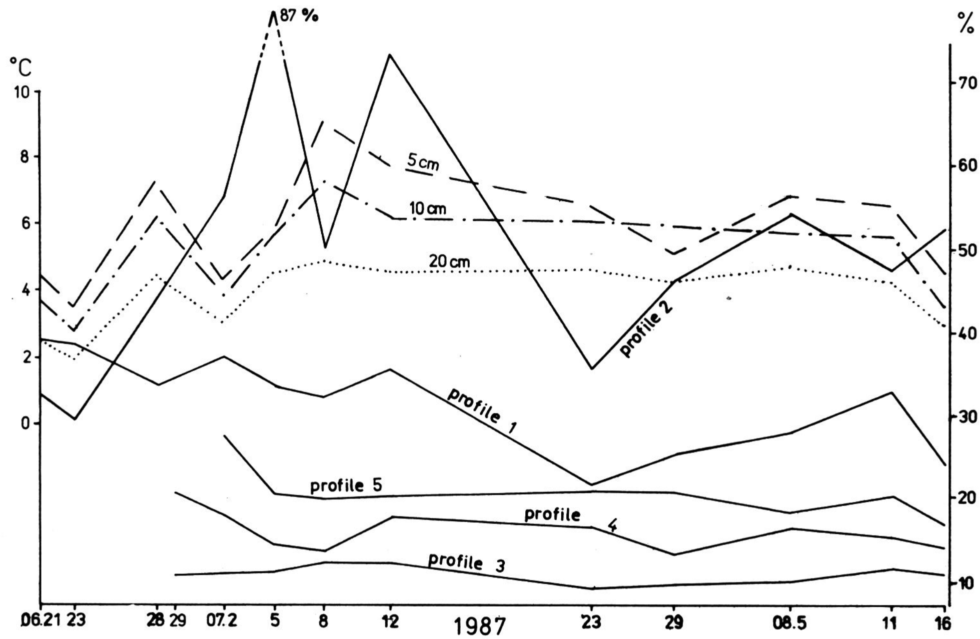

Fig. 2. Soil moisture of profiles 1—5 (at a depth of 5 cm) and soil temperature at depths of 5, 10 and 20 cm

moisture oscillations were recorded in profile 3 at the beginning of the arctic summer (on the turn of June and July). A similar phenomenon was observed in profile 4 and 5 but their moisture oscillations were higher than in profile 3. In soils in the polygon and in the frost fissure big differences in their moisture were recorded, however both diagrams were similar. Moisture oscillations in the polygonal soil were equal 21—38%, while in the fissure they were extremely gib and reached 29—87%.

Soil temperatures (Fig. 2) in the individual horizons were similar. The smallest differences were recorded at a depth of 20cm, while the biggest at 5 cm (3.5—9.0°C).

In the profiles studied the redox potential varried widely from 90 to 550 mV, but mostly from 220 to 420 mV (Figs 3—7). Considering the particular profiles separately, these oscillations were smaller, from 120 mV in profile 5 to 330 mV in profile 2.

Eh changes were generally similar and regular in the individual soil horizons. In deeper horizons the values of Eh were higher. Only in lighter polygonal brown soil (profiles 1 and 2) increasing moisture was connected with decreasing Eh, and *vice versa*. In other soils, *i.e.* in gley soils such dependences occurred occasionally.

Similar Eh dynamics, but the strongest at the beginning of the observation period were recorded in profiles 3 and 4. From the end of July the values

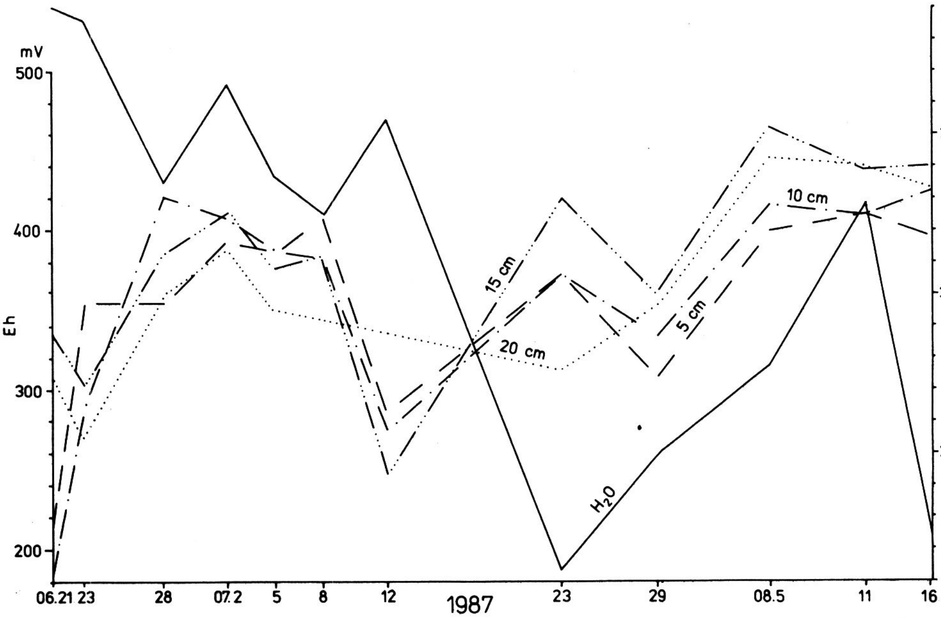

Fig. 3. Redox potential (Eh) of profile 1 at depths of 5, 10, 15 and 20 cm and soil moisture at depth of 5 cm

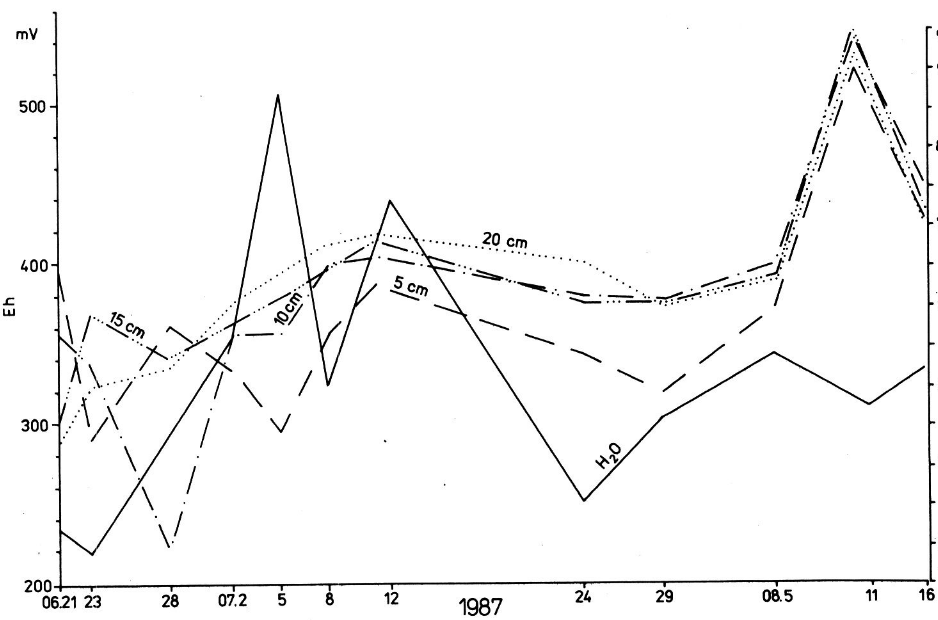

Fig. 4. Redox potential (Eh) of profile 2 at depths of 5, 10, 15 and 20 cm and soil moisture at depth of 5 cm

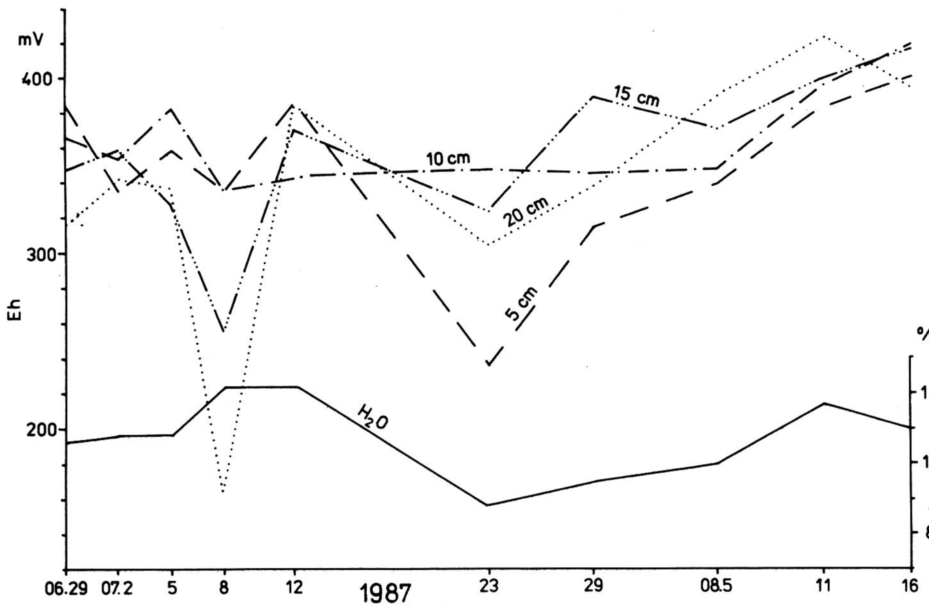

Fig. 5. Redox potential (Eh) of profile 3 at depths of 5, 10, 15 and 20 cm and soil moisture at depth of 5 cm

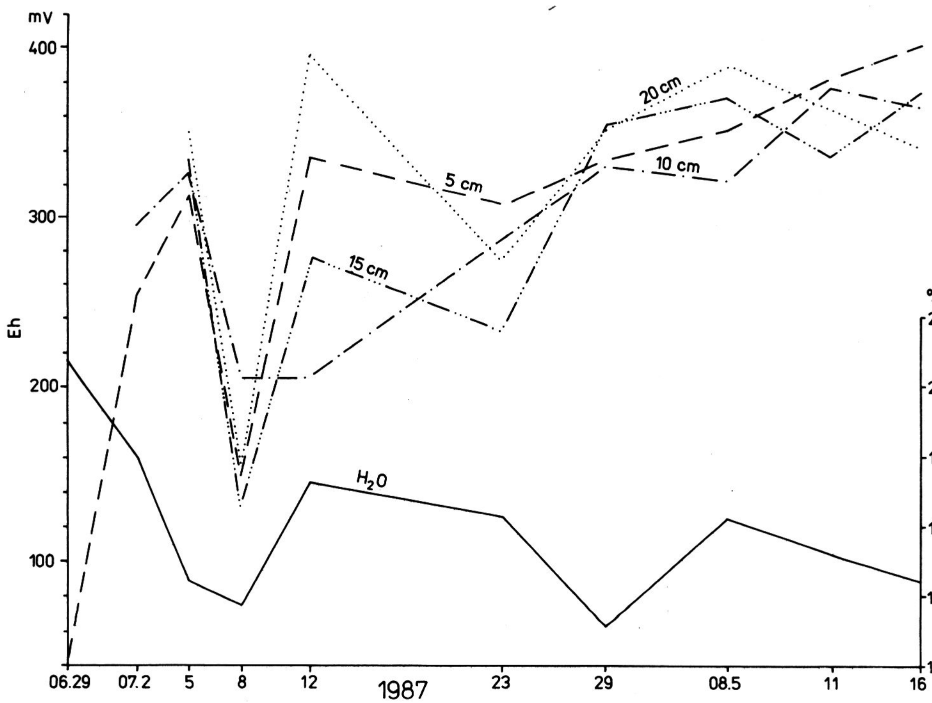

Fig. 6. Redox potential (Eh) of profile 4 at depths of 5, 10, 15 and 20 cm and soil moisture at depth of 5 cm

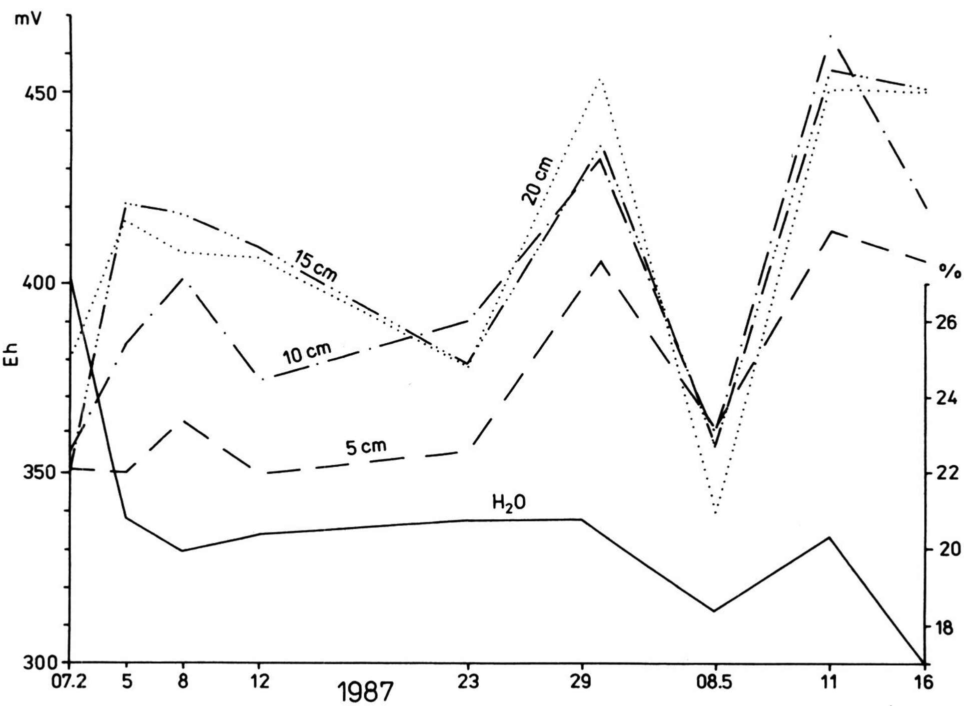

Fig. 7. Redox potential (Eh) of profile 5 at depths of 5, 10, 15 and 20 cm and soil moisture at depth of 5 cm

of Eh increased and at the same time their oscillations became lower. In the polygonal soil (profile 1) Eh oscillations persisted during the summer season. In profile 5 the dynamics of Eh was higher from mid July, whereas in the frost fissure (profile 2) at the beginning and by the end of the research period.

The redox potential indicates distinctly that in the soils studied, mainly in gley soils, reduction processes occur. According to the literature data Eh values of 200—400 mV are good evidence of it (Serdobolsky 1954, Ponnamperuma 1972, Kaurichev and Orlov 1982). When Eh values drop below 200 mV at the turn of June and July in profile 4 (Fig. 6), it indicates a strong anaerobiosis and active reduction processes. In some terms, *e.g.* in the early August, the values of the potential increased over 400 mV in profiles 1 and 2 (Figs 3 and 4), reaching 550 mV, that indicates normal air-water conditions.

A comparison of the obtained data and of the results of other authors is difficult, because there are only few papers on soils from Spitsbergen or similar geographic conditions (Cypanova 1978, Everett *et al.* 1981). These papers also show that redox potential changes greatly during the individual seasons, even in the same place.

The oxygen diffusion rate (ODR) in the soils studied oscillated between 5 and 200 $\mu g\ m^{-2}\ sek^{-1}$ (Figs 8—12). In the individual profiles the differen-

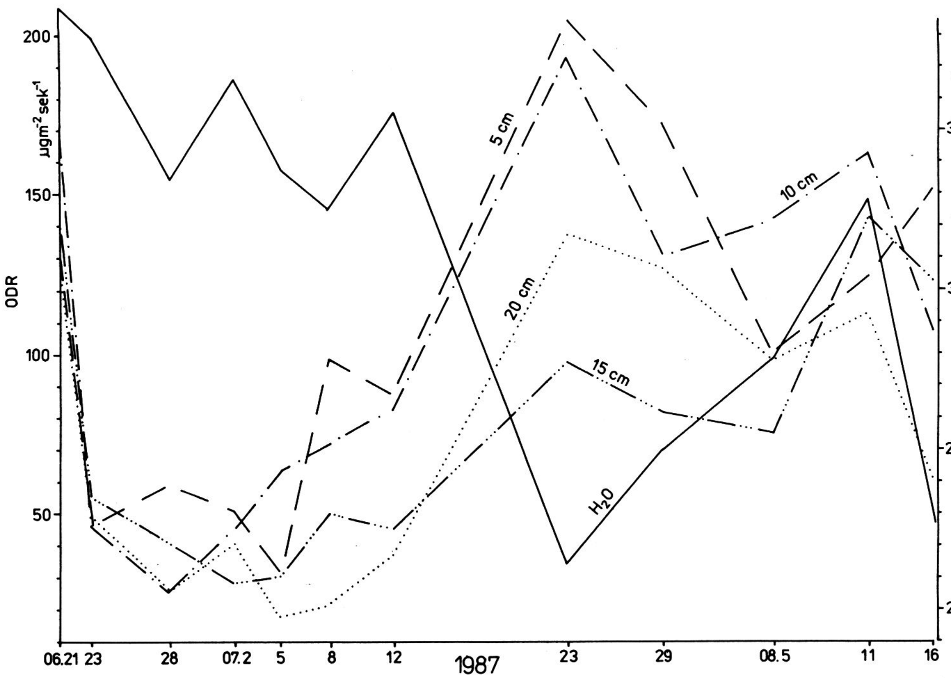

Fig. 8. Oxygen diffusion rate (ODR) of profile 1 at depths of 5, 10, 15 and 20 cm and soil moisture at depth of 5 cm

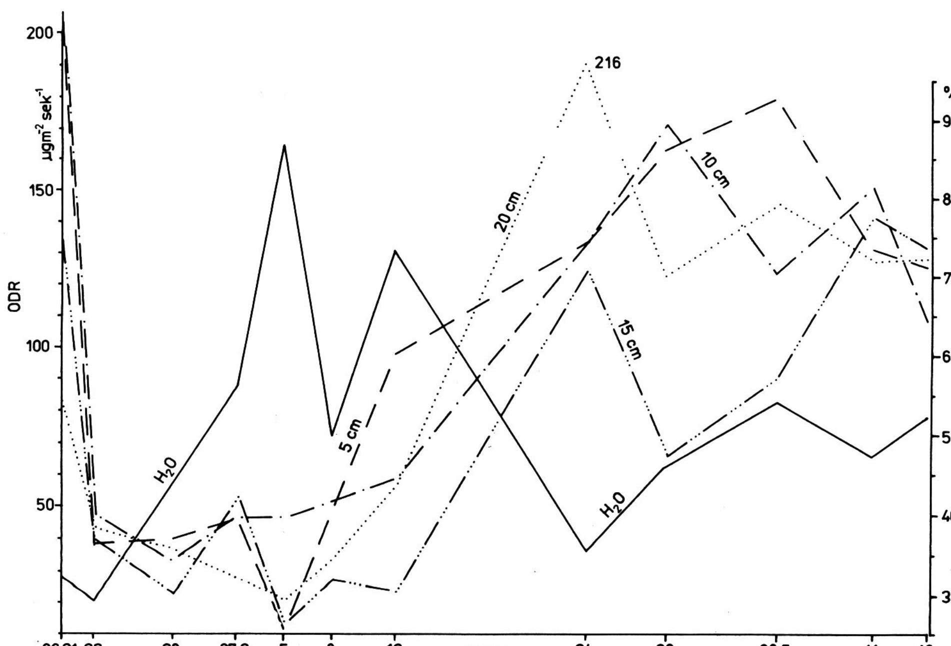

Fig. 9. Oxygen diffusion rate (ODR) of profile 2 at depths of 5, 10, 15 and 20 cm and soil moisture at depth of 5 cm

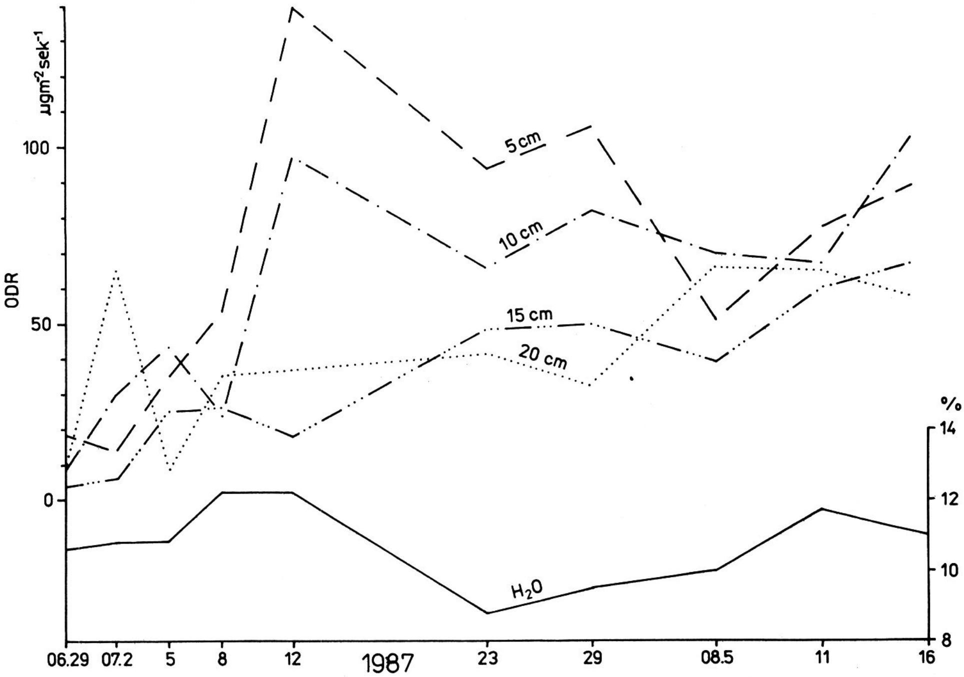

Fig. 10. Oxygen diffusion rate (ODR) of profile 3 at depths of 5, 10, 15 and 20 cm and soil moisture at depth of 5 cm

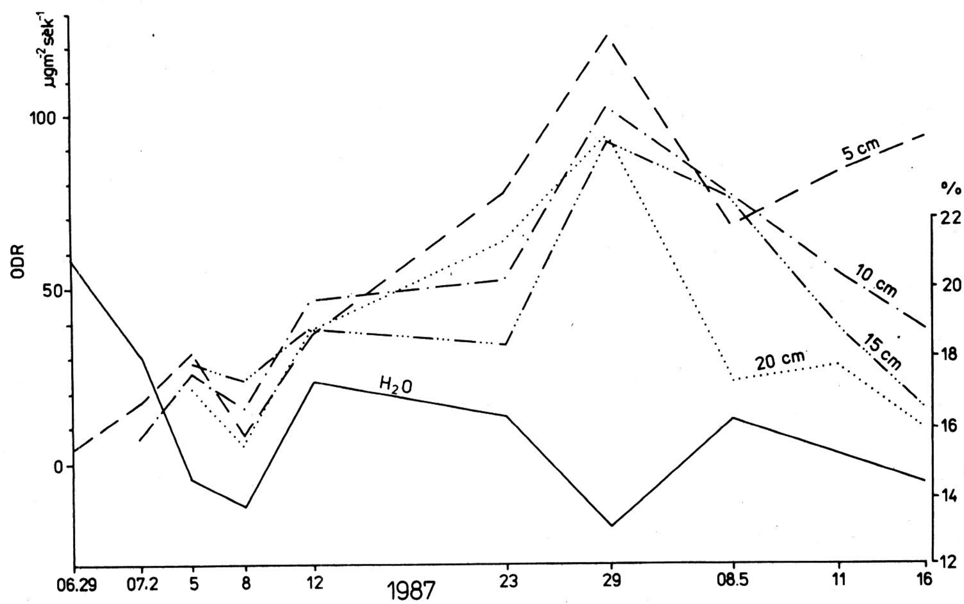

Fig. 11. Oxygen diffusion rate (ODR) of profile 4 at depths of 5, 10, 15 and 20 cm and soil moisture at depth of 5 cm

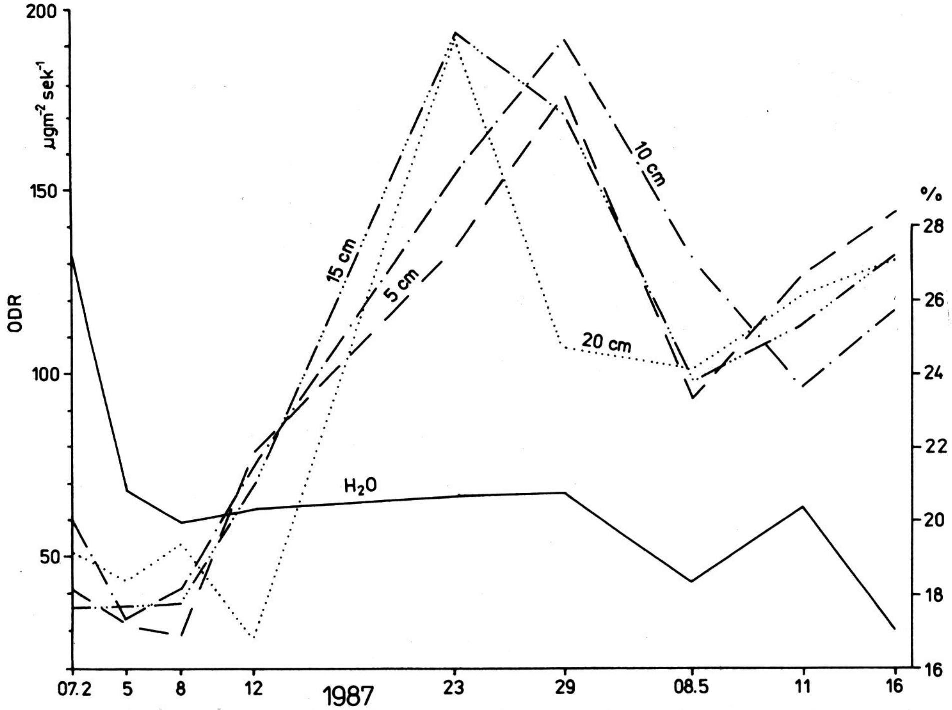

Fig. 12. Oxygen diffusion rate (ODR) of profile 5 at depths of 5, 10, 15 and 20 cm and soil moisture at depth of 5 cm

tiation of ODR was smaller and equal 115—190 $\mu g\ m^{-2}\ sek^{-1}$. Like the Eh graphs, those of ODR are also similar in the individual horizons but no regular decrease in ODR with the depth was observed. The ODR graphs of the individual horizons often alternate.

Low ODR values (under 50 μg, often between 10 and 30 μg) form another clear feature, especially at the beginning of the studied period (*i.e.* end of June and the first decade of July). It is due to increased moisture of the ground. Later, ODR values become higher but in gley soils (profiles 3 and 4) they do not exceed 100 μg. In brown soils (profiles 1 and 2) and in a loamy outflow (profile 5), the values of ODR reached 200 μg. Sometimes lower soil moisture was connected with higher ODR and *vice versa* (profiles 1, 2 and 4).

In profile 1 and 3 ODR oscillations were high, especially at depths of 5 and 10 cm. It was due to variable soil aeration conditions in top horizons. In profiles 1 and 2, the strongest dynamics of ODR was recorded at the end of June and July, while in profile 3 such dynamics was observed during whole of July. The ODR graphs in profiles 4 and 5 are similar and show bigger differences in the second half of July.

A comparison of Eh and ODR indicates some regularities, however not in all terms of measurements. In the studied soils (except profile 2) low values of ODR (under 50 μg) are connected with medium Eh values (300—400 mV). In other terms, particularly the second half of July and in August the values of Eh and ODR become greater. In profile 2 such relations do not occur.

The results of ODR measurements do not permit a precise description of the oxygenation conditions, the more so as the optimum and critical values of ODR were determined for selected plants from a temperate climatic zone. The known lowest value for grass is to 25 μg m ^{2} s ^{1}, while for cultivated plants 33 μg m ^{2} s ^{1} (Lately *et al.* 1966, Gawlik 1987). Optimal values are considerably higher. However, the ratios mentioned are controversial because they are not accepted by all authors. Similar coefficients based on ODR measurements have not been determined for the arctic conditions yet, while the coefficients useful in a temperate zone cannot be used here. The ODR values obtained in the arctic tundra seem to be higher than those in a temperate zone due to a higher solubility of oxygen. The existence of tundra with moss, lichens, grass and bushes depends on ecologic conditions in different quantitative relations. Individual plant groups could possess different oxygen requirements.

Despite the lack of ODR norms, the preliminary results of ODR prove that at the beginning of summer the content of oxygen in the studied soils is very low. At present no generalization on the oxygen conditions in arctic soils can be presented, therefore the studies should be continued.

Conclusions

1. The moisture of the investigated soils shows a considerable dynamics (in terms of percentage and time), especially in polygonal soils. Soil temperatures have similar curves in the individual horizons. The highest oscillations were found in the top layer (5 cm).

2. Redox potential (Eh) demonstrates strong dynamics. Eh values confirm that in the soils investigated (mainly in gley soils) the reduction conditions and sometimes a strong anaerobiosis predominate.

3. ODR values demonstrate considerable dynamics but varying in the individual profiles. Full evaluation of the oxygenation conditions on the basis of the obtained ODR values is still difficult due to the lack of ODR norms for the arctic tundra.

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Streszczenie

Praca dotyczy dynamiki niektórych właściwości, związanych ze stosunkami wodno-powietrznymi gleb arktycznych. Badania przeprowadzono w lecie 1987 r. w 5 wybranych profilach.

Pomiary potencjału oksydo-redukcyjnego (Eh) i wydatku dyfuzji tlenu (ODR) przeprowadzono w terenie przy użyciu uniwersalnego miernika z elektrodą platynową (pomiarową) i kalomelową (porównawczą). Pobrano również próbki w terenie do oznaczania w laboratorium wilgotności i podstawowych właściwości badanych gleb (skład granulometryczny, zawartość $CaCO_3$, substancji organicznej, azotu ogólnego i odczynu). Wyniki badań przedstawiono w tabeli (podstawowe właściwości) oraz na rycinach (fig. 2 — dynamika wilgotności i temperatury gleb, fig. 3—7 — dynamika Eh na tle wilgotności, fig. 8—12 — dynamika ODR na tle wilgotności). Wyniki można uogólnić następująco:

1. Wilgotność badanych gleb wykazuje znaczną dynamikę, zwłaszcza w glebach poligonalnych, zarówno pod względem jej procentowej zawartości jak też w czasie. Temperatura gleb ma podobny przebieg w poszczególnych poziomach, jednak największe wahania wykazuje warstwa powierzchniowa (5 cm).

2. Potencjał oksydo-redukcyjny (Eh) wykazuje dużą dynamikę jego wartości. Eh potwierdza, że w badanych glebach, zwłaszcza w glejowych, panują przeważnie warunki redukcyjne, a niekiedy nawet silna anaerobioza.

3. Również ODR odznacza się wyraźną dynamiką, przy czym w poszczególnych profilach ma ona zróżnicowany przebieg. Pełna ocena warunków natlenienia na podstawie uzyskanych wartości ODR jest na razie trudna ze względu na brak odpowiednich wskaźników dla warunków tundry arktycznej.