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The influence of humidity and temperature upon the rate of soil metabolism in the area of Hornsund (Spitsbergen)

ABSTRACT: Oxygen consumption and carbon dioxide production in some Arctic soils were measured in different thermic and humidity conditions. Testing temperatures was following: 4, 8 and 12 °C. The rate of metabolic processes was temperature and humidity dependent. In the temperature of 4°C the metabolic processes intensity was negatively correlated with humidity, however in higher temperatures the higher was the humidity the higher was also the intensity of metabolic processes.

The interaction of humidity and temperature is probably to great extent responsible for low rate of decomposition processes of organic matter in polar conditions.

Key words: Arctic, Spitsbergen, soil metabolism.

Introduction

The aim of this work was to investigate the dependence of oxygen consumption and carbon dioxide production in chosen Hornsund region soils from their humidity and to study the problem whether these interdependencies are related to temperature. The oxygen consumption and carbon dioxide production were taken as indicators of the intensity of bioenergetic processes occurring in soil, whereas humidity and temperature as leading factors affecting these processes. It is well known that in polar conditions both the temperature and the humidity of soils varies considerably. The temperature close to the ground surface varies from $-30°C$ to $+20°C$ and water content in the soil from several percent during dry summer to 1000% of water capacity in spring at the time of snow cover ablation.

The results obtained by Fischer and Bieńkowski (1987) in the region of Hornsund showed that the dependence of soil oxygen metabolism from the temperature for the majority of soils of this region is of a similar character to that of the soils of moderate climate and that the level of metabolism is not very low. Only structural soil appeared to be an exception. Therefore a very slow rate of decomposition of organic matter in polar regions seemed to be incomprehensible. Thus the intensive studies of only two extremely different soils have been undertaken, aiming at the determination of the role of humidity in metabolic processes intensity.

Material and methods

Two extreme types of soils differing geomorphologically, physically and biologically have been examined. One soil type was close to structural soil, without vegetation, with pH close to neutral, the organic matter content about 3% and water capacity amounting to 39%. Detailed description of this soil is given by Angiel (1990). The second soil was of organic origin totally covered by moss (Calliergon stramineum). It is an acid peat soil (Szerszeń 1965) with the content of organic matter of about 90% and water capacity extremely high; in the place where this soil was taken it amounted to 1000%.

The measurements of oxygen consumption and carbon dioxide production were made in Polish Station laboratory, in volumetric respirometers using the method of Klekowski (1975). Experiments were made in 3 temperatures +4, +8 and +12°C. Soil for each series of measurements was taken from the same place, then samples were put to the bottles (about 10g of wet weight into each) and after the measurement was done the soil humidity from each bottle was examined separately. Higher needed humidity was obtained by adding melted snow water into the bottles. For each temperature about 90 4-hours oxygen consumption measurements were performed and 90 4-hours measurements of carbon dioxide production for each soil examined. In total 540 4-hours measurements of oxygen consumption were done and the same number of carbon dioxide production measurements. For each series the index RQ was calculated, that is the relation of produced carbon dioxide to the oxygen consumed. For each series pH and organic matter contents were also determined.

Results

The dependence of soil metabolism intensity on temperature and humidity was presented as linear regression $Y = a + bx$, where Y was an oxygen consumption or carbon dioxide production per 1g of organic matter in one hour, whereas x was the humidity expressed in percent of water capacity of the examined soil.

The dependencies observed were statistically significant (level of significance 0.001) in temperatures +4°C and +12°C for both soils examined and in temperature +8°C also for organic peat soil. For structural soil in the temperature +8°C both the oxygen consumption and carbon dioxide production were not correlated with changing humidity conditions. It is interesting, however, that the dependence between the intensity of metabolism and humidity in all examined thermic conditions was not unidirectional. In the lowest temperature of +4°C for both soils a decreasing activity of metabolism has been observed along with the increasing amount of water in the soil (Fig. 1); it was manifested both by the oxygen consumption and carbon dioxide production. For organic soil the angle of inclination of the curve of oxygen consumption humidity dependence is similar to the angle of inclination of the curve of carbon dioxide production dependence. Only the levels of curves course are different. Carbon dioxide production curve runs lower than that of oxygen consumption. For structural soil, however, the angle of inclination of such humidity dependence curve for oxygen consumption is greater than that of the humidity dependence curve for carbon dioxide production (Fig. 1). Index RQ, i.e. the quotient of the amount of produced carbon dioxide to the oxygen

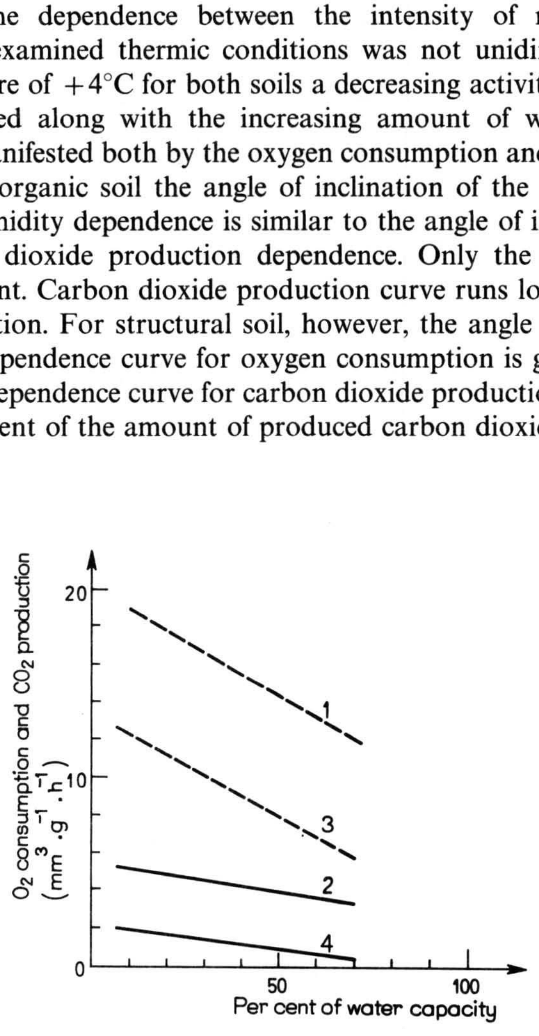

Fig. 1. Dependence of O_2 consumption and CO_2 production on the soil humidity at 4°C:
1, 3 — organic soil; 2, 4 — structural soil;
1, 2 — O_2 consumption; 3, 4 — CO_2 production.
Regression equations:
1. $y = 19{,}880 - 0{,}111x$; 2. $y = 0{,}603 - 0{,}0417x$;
3. $y = 13{,}466 - 0{,}109x$; 4. $y = 2{,}093 - 0{,}0137x$.
Level of significance 0.001

consumption is hardly influenced by the humidity and for structural soil it varies from 0.30 to 0.40 and for peat soil — from 0.50 to 0.80. It is noteworthy, however, that RQ index classically determined for animals and characteristically defining their metabolism, has entirely different meaning in measurements of soil metabolism. It expresses only the proportions between produced carbon dioxide and oxygen consumed. From the presently obtained results we can only conclude that at the temperature of 4°C for peat soil (RQ 0.50—0.80) the difference between produced carbon dioxide and consumed oxygen is bigger than for structural soil (RQ 0.30—0.40).

The relations between oxygen consumption and humidity at the temperatures of +8°C and +12°C is shown in Fig. 2. It should be remembered that this dependence is statistically significant for structural soil at the temperature of +8°C. The course of this curve should be seen as merely a certain tendency. It is possible that the temperature of +8°C for structural soil is a transitory one, where changes of organism communities occur. In structural soils communities of organisms that are intensively active in higher

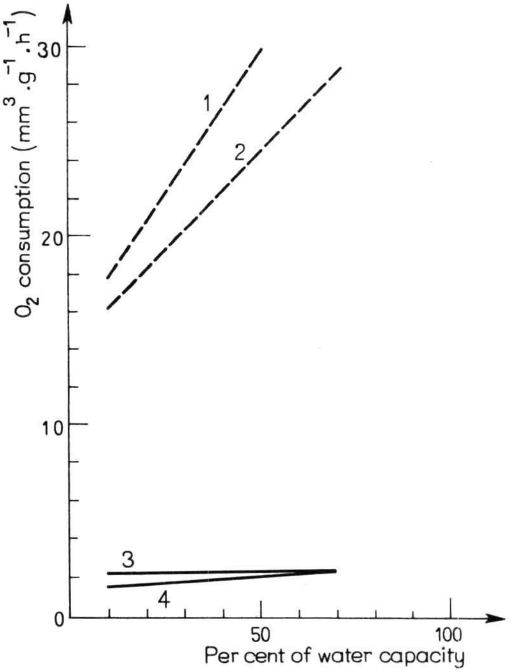

Fig. 2. Dependence of soil O_2 consumption on the soil humidity:
1, 4 — at 12°C; 2, 3 — at 8°C;
1, 2 — organic soil; 3, 4 — structural soil.
Regression equations:
1. $y = 14{,}851 + 0{,}306x$; 2. $y = 14{,}110 + 0{,}2096x$;
3. $y = 2{,}344 + 0{,}0015x$; 4. $y = 1{,}618 + 0{,}00971x$.
Level of significance 0.001

temperatures are probably poorly developed (Fischer and Bieńkowski 1987) and therefore the amount of oxygen used at the temperatures of +8°C and +12°C is about 4 times lower than at +4°C. However, along with the temperature increase the dependence on the humidity also increases (Fig. 2).

The dependence of carbon dioxide production on the humidity appears to be somewhat different (Fig. 3). For structural soil, where metabolism in higher temperatures is also clearly inhibited (the rate was about 3 times lower than at +4°C), at +8°C carbon dioxide production, similarily to oxygen consumption, did not depend on humidity, whereas at +12°C along with the increase of soil humidity slight increase of metabolism intensity was observed. Different processes occur in peat soils. At the temperature of +8°C, although the humidity dependence was statistically significant, but the angle of curve inclination is small, therefore the humidity dependence of carbon dioxide production is low (Fig. 3). In +12°C temperature, however, this dependence is negative — the more water in the soil, the smaller carbon dioxide production. This diversified character of metabolic reactions of soils in different temperatures indicates the existence of different communities of microorganisms whose activity depends on existing thermic conditions. The RQ quotient calculated for all variants of experiment shows the same dependence as for soils studied at +4°C that is — lower RQ for structural soils (by about 0,3) with slight tendency towards an increase at higher temperatures.

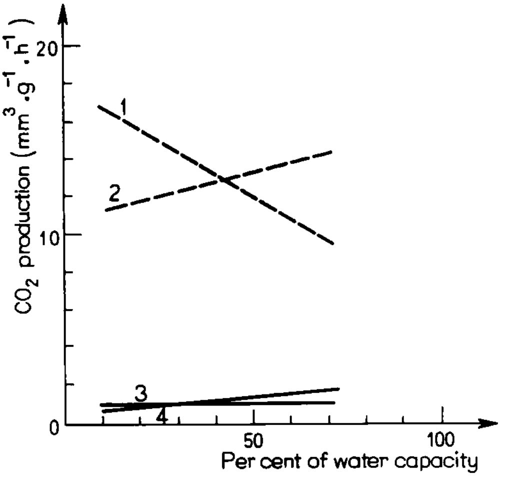

Fig. 3. Dependence of soil CO_2 production on the soil humidity:
1, 4 — at 12°C; 2, 3 — at 8°C;
1, 2 — organic soil; 3, 4 — structural soil.

Regression equations:

1. $-y = 17{,}871 - 0{,}117x$; 2. $y = 10{,}995 + 0{,}047x$;
3. $y = 0{,}924 + 0{,}0021x$; 4. $y = 0{,}728 + 0{,}0078x$.

Level of significance 0.001

Discussion

Spitsbergen is characterized by long, frosty winter, cool, wet spring beginning in May and lasting until the end of June, and short generally dry summer. August is usually chilly and in September snowfalls can be expected. Life processes in soil generally begin in May in temperatures close to 0°C (Fischer and Bieńkowski 1987). It is during that time that melting of snow begins. Spitsbergen as a rule abounds in snow. Melted snow begins to flow down over not fully defrosted soil. This stream of flowing water first under the snow and next, when the snow is gone, on the ground — is an element very significant for biological processes occurring in soil. On the one hand, it is a very significant supply of organic substances for plants because in many cases the water flows through bird colonies situated on the mountain slopes (Krzyszowska 1985). On the other hand it is a nutrients nourishing source for soils. Two extreme soils have been chosen for investigation and data presentation — one was poor in organic substances with small water capacity (39%) the other was of organic origin with extremely big capability of water retention (1000%).

The present study showed that at the temperature of +4°C water is a negative factor. The more water retained in soil, the lower level of metabolic processes expressed both by oxygen consumption and carbon dioxide production (Fig. 1). Experiments carried out with similar soils during previous expedition (Fischer and Bieńkowski 1987) showed the same tendency also at the temperature of 0°C. It can be concluded that in spring, when temperatures of superficial soil strata vary from 0° to about +5°C when snow melts and water floods all slopes and valleys, metabolic processes run slowly not because of low temperature but above all because of high hydration of the terrain. It can be supposed that in this period a community of soil organisms starts its activity; these organisms are adapted to low temperatures but their activity is inhibited by high humidity. It should be stressed here, that such period can last in Spitsbergen relatively long, up to about one month, which constitutes 1/3 of non-winter time, the time when decomposition processes do occur. The period of the duration of zero temperatures in superficial soil strata depends also, to great extent, on the kind of habitat, that is if the area is covered with vegetation and what kind of vegetation, on the sun exposure and the inclination angle etc. (Angiel 1990). Generally after spring time very quick desiccation of the area occurs caused by blowing winds and ground temperature increases significantly (for instance in 1987 average minimal ground temperature at the depth of 5 cm amounted to −6,6°C in May, in June −0,3°C and in July +3,8°C). Probably during that time the set of soil organisms changes; organisms adapted to higher temperatures and hydrophilous ones began their activity (Fig. 2). The present results confirm our earlier observations carried out with slightly different Spitsbergen soils, indicating also that the higher amount of water in the soil the higher intensity of oxygen consumption which increases also with higher temperature (Fischer and Bieńkowski 1987). Thus, in summer, in Spitsbergen natural conditions for bioenergetic processes in soil adverse conditions again begin to prevail. Although the soil temperature increases and organisms positively reacting to the growth of temperature are activated, however, their activity is inhibited due to the low amount of water in the soil. It concerns, in particular, the habitats covered with vegetation because structural soils in higher temperatures show the inhibition of metabolic processes due to other reasons not connected with hydration but rather with temperature (Figs. 2 and 3).

Autumn period is probably most favourable for biological processes occurring in soils. The ground temperature drops again (eg. in 1987 in August average temperature in soil at the depth of 5 cm was +5°C whereas in September it was −0,7°C) and the soil humidity was not as high as during snow ablation. This period, however, is relatively short.

Summarizing one has to conclude that the very cooperation of these two essential factors like water and temperature creates unfavourable conditions for soil processes in polar climate conditions. Although the results of Bieńkowski (1990) indicate that because of large amounts of ornitogenic nitrogen in soils in the region of Polish Polar Station in Hornsund, the rate of cellulose decomposition is higher there than in other polar regions but still these decomposition processes occur more slowly than the existing thermic conditions alone would indicate.

Conclusions

1. Dependence between the humidity and intensity of metabolic processes in soils examined, expressed by oxygen consumption and carbon dioxide production has different character at the temperature of +4°C and at temperatures of +8°C and +12°C.
2. At the temperature of +4°C the intensity of metabolic processes expressed by oxygen consumption and carbon dioxide production decreases along with an increased hydration.
3. At temperatures of +8°C and +12°C the intensity of oxygen consumption by the soil increases together with increasing amount of water in the soil.
4. Structural soil at the temperature of +4°C shows lower level of metabolism then at higher temperatures.
5. The rate of produced carbon dioxide was lower for all examined soils then the rate of oxygen consumption.
6. Index RQ determined for structural soil, independently of thermic conditions, is lower then RQ index determined for organic soil. It may evidence that in structural soil, in comparison to peat soil, processes of oxygen metabolism dominate.

I would like to express my sincere thanks to the Institute of Geophysics of Polish Academy of Sciences for enabling us to carry on the studies in Polish Polar Station in Hornsund; in particular to Professor Jerzy Jankowski, the Director of Institute and to Dr. Maciej Zalewski. I would like also to give my warm thanks to my collaborators from the Department of Ecological Bioenergetics of the Institute of Ecology PAS. I am very much indebted to Mrs. Teresa Biwojno who was responsible for all technical work connected with the presented paper.

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Streszczenie

Wykonano pomiary zużycia tlenu i wydalania dwutlenku węgla przez dwa typy gleb Spitsbergenu: glebę zbliżoną do strukturalnej oraz glebę pochodzenia organicznego, pokrytą całkowicie mchami. Pomiary wykonano z uwzględnieniem zmieniających się warunków wilgotności badanej gleby. Pomiary wykonano w warunkach laboratoryjnych w temperaturach: +4, +8 i +12°C.

Stwierdzono, że zależność intensywności procesów metabolicznych od wilgotności podłoża, wyrażona zużyciem tlenu i wydalaniem dwutlenku węgla przez glebę, ma odmienny charakter w zależności od temperatury. W temperaturze +4°C im większa wilgotność, tym mniejsza intensywność procesów metabolicznych (Rys. 1), natomiast w temperaturach wyższych im wyższa wilgotność, tym większa intensywność procesów metabolicznych (Rys. 2). Poza tym stwierdzono, że ilość wydalanego dwutlenku węgla jest zawsze niższa od ilości zużytego tlenu (Rys. 2 i 3).

Zasugerowano, iż niski poziom procesów rozkładu materii organicznej stwierdzony w warunkach klimatu polarnego można wytłumaczyć nie tylko warunkami termicznymi, ale współdziałaniem ich z niekorzystnymi warunkami wodnymi.