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AERATION AND TEMPERATURE CONDITIONS IN HUMMOCK AND DEPRESSION PEAT IN KIKEPERA BOG, SOUTH-WESTERN ESTONIA

MÄTÄS- JA PAINANNETURPEEN HAPPI- JA LÄMPÖTILAOLOISTA KIKEPERAN SUOLLA LOUNAIS-EESTISSÄ

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Aeration conditions in peat were studied *in situ* with the help of polycarbonate tubes filled with water and inserted into the soil at depths of 3—10, 13—20 and 28—35 cm. The study was carried out during the vegetation period 1986. Aeration conditions were more favourable in hummock peat, where the thickness of the better aerated layer was ca. 10 cm in June and September, and 20—30 cm in July and August. Aeration conditions in the upper 10 cm layer of depression peat only became favourable in July, while in deeper layers aeration conditions remained unfavourable. In September, after heavy rains, aeration conditions deteriorated in both hummock and depression peat. The oxygen content in mire water was higher in depression sites, which may be because of the inflow of surface water rich in oxygen. The temperature in the tubes was higher in upper layers of hummocks and deeper layers of depressions. In comparison with other sites *(Filipendula* forest type on gley soils, drained peat soils, hill pastures, pine forest on podzols), the aeration conditions in bog peat are considerably less favourable.

Key words: peat, bog, hummock-depression variation, aeration, oxygen.

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INTRODUCTION

The complex surface pattern of *Sphagnum* bogs has been examined in a number of studies, but, as mentioned by Sjörs (1976), the ecological mechanism of pattern development is more frequently discussed than actually investigated. Several alternative hypotheses were and are still in force, and comprehensive accounts are given by Auer (1920), Ivanov (1957), Nitsenko (1964), Tallis (1983), Foster et al. (1983), Masing (1984), Pyavchenko (1985 a, b) for example. Concerning pool formation, see Barber (1981). It is important to separate the initiation of surface pattern from the amplification of initial differences in community composition and ecological conditions. To make this separation, differences in ecological conditions of positive and negative parts of bog microrelief should be investigated. Most of such data concern nutrient conditions (e.g. Gorham, 1961; Bellamy and Rieley, 1967; Pakarinen, 1978; Sokol, 1978; Damman, 1978; Westman, 1981; Reinikainen et al., 1984; Yelina et al., 1984). The results of the different authors do not coincide, higher contents of nutrients or several trace elements in peat (water) are reported for both hummocks and hollows.

The results of Pakarinen (1977), Clymo (1978), Ilomets (1981), Vasander (1982), Boatman (1984), and others demonstrate that the productivity of *Sphagna* is similar or even higher in hollows than in hummocks. Therefore several authors have drawn the conclusion that the key factor in determining the net vertical peat growth is decay, not production (see Tolonen et al. 1985). There are some data, however, that show that decomposition rate does not differ between hummocks and hollows (Botch 1978). Loopman (1987) explains the development of bog surface pattern by relating it to the influence of oxygen conditions on decay: the wetter environment of initial (randomly generated) depressions accumulate more solar radiation and the water becomes enriched with oxygen due to the better aeration in the surface layer and also due to moss photosynthesis. Both higher oxygen content and temperature enhance the decomposition and may thus amplify the initial differences in surface pattern.

In this paper I attempt to further characterize the oxygen conditions at the initial stages of hummock-hollow differentiation. To avoid terminological confusion, I use the terms according to Masing (1982, 1984) to describe surface pattern. Hummocks and depressions are considered to be the elementary structural units, the so-called simple microforms. Hollows and hummock ridges are compound microforms, they could be interpreted as "accumulated depressions or hummocks". There are no sharp boundaries between hummocks and ridges (or depressions and hollows), as simple microform can develop towards compound microform. That part of a bog where developed ridges and hollows are absent, and a relatively even mire surface consists of hummocks and depressions at various developmental stages, I have called lawn. In literature, the depressions (smaller, not so wet) and hollows (larger, wetter) are usually not differentiated.

METHODS FOR CHARACTERIZING THE SOIL OXYGEN CONDITIONS

The simplest indirect way to characterize aeration conditions in the upper layer of peat is to measure the water level (e.g. Lopatin, 1972). More precise information about the thickness of aerobic layer is obtained from the distribution of sulphide ions in peat which can be studied with the help of a silver rod or plate (e.g. Urquhart 1966, Lähde 1969). Among the direct methods, the determination of soil redox potential with the help of platinium electrode is used most frequently. Since the work of Pearshall (1938), several studies have been published. For a rewiev see Ponnamperuma (1972) and Sikora and Keeney (1983). Similarly, the measurement of oxygen diffusion in the soil can be carried out (e.g. Lemon and Erickson 1952). An original biological method is offered by Bartlett (1966). Since the classic work of Hesselman (1910), the content of oxygen in mire water has also been directly measured. The number of such data, however, is not large, and the work of Vompersky (1968) may still remain the most comprehensive presentation of oxygen data. Loopmann and Paidla (1981) have reported that the oxygen content of mire water increases from 1—2 mg l^{-1} to 8—10 mg l^{-1} when moving through hollows. Loopmann (1987) presents data about the oxygen content of mire waters of different mire sites: 1.5—1.8 mgl^{-1} in marginal pine bog, 1.5 mgl^{-1} near the upper edge of bog slope, 2.0—2.5 mgl^{-1} in the flat central part. In autumn, more uniform contents were measured.

Rogers and King (1972) offered an improved method for measuring soil aeration conditions. Oxygen content is determinded not directly in soil water, but in polycarbonate centrifuge tubes which are filled with water. These tubes are inserted into the soil. Molecular oxygen is able to diffuse through the membrane in both directions, an equilibrium being attained when the partial pressure of oxygen within the tube is equal to that on the outside of the membrane, both in the gaseous and solution phase.

The measurement of soil redox potential gives us a value which characterizes exactly the time delay studied, but it can change considerably during a few days. The oxygen content of soil water does not vary so much but it is not possible to measure it in dry periods when there is almost no soil water. The oxygen content of water in polycarbonate tubes is an inert parameter, the changes in it are less rapid than is the case with redox potential. It can be used in various sites, enabling mire soils to be compared with mineral soils. But in general, the soil aeration conditions described by the measurement of both redox potential and oxygen content in tubes are quite similar (Lõhmus, 1984). The main disadvantage of the tube method is the freguent breaking of the thin polycarbonate membrane in soil.

STUDY AREA

The investigations were carried out near Tipu, in south-western Estonia during June—September 1986. Climatically Tipu district belongs to the southern boreal zone with an annual mean temperature of +3.1°C (-6.0°C in February, +17°C in July), an annual accumulated temperature (> +10°C) of 1850 dd, an annual mean precipitation of 650 mm and a snow cover duration of 95—100 days. Geobotanically, the Tipu district belongs to the southern part of the Estonia-intermediate region, characterized by abundant swamps and bogs (Laasimer 1965).

Measurements were made at Kikepera bog, the area of which is 4800 ha and the mean depth of peat deposit is 3 m (Raudsepp 1946).

Different mire sites occur, including hollow-ridge bog, hollow-pool-ridge bog, pine bog, lawn bog. The study area was situated at the eastern part of Kikepera bog, where there is lawn bog with sparse pines.

MATERIAL AND METHODS

Polycarbonate tubes (7 cm in length) were inserted into the soil at three depths: 3—10, 13—20, 28—35 cm, with three replications at each depth. First measurements were conducted at the beginning of June 1986 and then repeated with an interval of a month. The oxygen content was measured with the help of an electrochemical oxymeter, designed at Tartu State University (Tenno, 1986). Control tubes were left exposed to the air to imitate the situation of complete aeration.

The oxygen content of mire water, gathered from pits (ca. 20—35 cm deep), was measured three times. Polycarbonate tubes were inserted also into the other types of peat and mineral soils to enable a comparison (Zobel, in preparation). The vegetation was described on 10×10 m plots, each containing four 1×1 m plots. The percentage coverage of different species was estimated. The monthly rainfall was measured *in situ*.

The temperature in the polycarbonate tubes and of the mire water was also determined. These temperature values are dependent on the air temperature at the time of measurement and thus do not characterize the real temperature conditions in soil. However, as the measurements were made simultaneously in both sites, the comparison between them is fully possible.

RESULTS AND DISCUSSION

The differences in species composition between the hummocks and the depressions were not great. *Empetrum nigrum, Vaccinium uliginosum* and *Ledum palustre* do not grow in depressions, and no trees were found there either. Among the *Sphagna*, *S. fuscum* and *S. rubellum* prevail on the hummocks and *S. magellanicum* on the depressions. (Table 1).

Minor differences in aeration conditions were observed in the upper 10 cm peat layer (Table 2). Due to the disturbance of one tube and a suspicious peak in another, the aeration data in June cannot be considered reliable. In July, only minor differences between hummocks and depressions were observed. In August, higher oxygen contents were measured in the tubes located in the depressions, while in September the aeration conditions were better in hummock peat. So there were no reasons to declare that aeration conditions differed significantly in the upper 10 cm peat layer of depression and hummock. In the upper layer the temporal variation in aeration conditions becomes evident in the depression: excluding the extremely wet period at the end of August and at the beginning of September (Table 3), aeration conditions were less favourable in spring when the peat soil was saturated with melt waters and the soil biological activity was high. An analogous situation was reported in case of other soil types (Lõhmus 1984). A clear difference between the two sites becomes evident when the 13—20 cm layers are compared: better aeration conditions are observed in the hummock. In the depression, the rapid decrease of soil aeration in most cases takes place between the upper and intermediate layers, especially in the middle and at the end of summer. When the soil aeration of the upper layer corresponds to 50—60 % of full aeration conditions, it could be less than 10 % in the intermediate layer. Some of the higher values were evidently dependent on the surface microtopography: at somewhat higher spots better aeration conditions can be met in the intermediate layer. In hummocks, the intermediate layer was better aerated, especially

Table 1. The species composition of plant communities (% coverage).
Taulukko 1. Kasviyhdyskuntien lajiston prosenttipeittävyydet.

species, laji	hummock, *mätäs*	depression, *painanne*
Pinus sylvestris	5	-
Picea abies	+	-
Betula pubescens	+	-
Calluna vulgaris	60	25
Eriophorum vaginatum	20	30
Rubus chamaemorus	20	+
Empetrum nigrum	2	-
Drosera rotundifolia	1	1
Vaccinium oxycoccus	3	+
V. uliginosum	+	-
Ledum palustre	+	-
Andromeda polifolia	-	1
Sphagnum fuscum	50	-
S. rubellum	20	70
S. magellanicum	10	30
S. angustifolium	10	-

Table 2. The oxygen content in the water in polycarbonate tubes (mean of three replicates) and aeration conditions in peat (humm. = hummock, depr. = depression).
Taulukko 2. Hapen määrä polykarbonaattiputkissa olleessa vedessä sekä turpeen happitilanne (pain. = painanne).

		abs. cont. *absol. määrä*	oxygen (mgl^{-1}) *hapen (mgl^{-1})*	temperature (°C) *lämpötila (°C)*		satur. level (%) *kyllästysaste (%)*		1) *1)*	(%) *(%)*	2) *2)*	(mgl^{-1}) *(mgl^{-1}*
time, *aika*	depth (cm) *syvyys (cm)*	humm. *mätäs*	depr. *pain.*	humm. *mätäs*	depr. *pain.*	humm. *mätäs*	depr. *pain.*	humm. *mätäs*	depr. *pain.*	humm. *mätäs*	depr. *pain.*
6.—7. 6.	3—10	5.9	2.3	18.0	16.5	62.8	23.0	73.6	27.0	18.3	6.7
1986	13—20	1.7	1.5	13.3	12.8	16.4	14.4	17.9	16.9	4.4	4.2
	28—35	1.3	1.0	9.8	10.5	11.2	9.0	13.1	10.6	3.3	2.6
4. 7.	3—10	4.6	4.9	24.2	20.8	55.1	54.3	64.7	63.7	16.1	15.9
1986	13—20	4.8	2.1	18.5	17.8	44.0	21.5	59.4	25.3	13.7	6.3
	28—35	2.3	0.4	14.0	15.7	21.6	4.4	25.4	5.1	6.3	1.3
2.—3. 8.	3—10	3.2	4.4	29.0	24.3	38.4	53.0	49.4	59.7	12.3	14.9
1986	13—20	2.6	0.6	20.7	20.2	29.6	7.1	34.8	8.4	11.9	2.1
	28—35	0.8	0.5	16.3	17.0	7.8	5.5	9.1	6.5	2.3	1.6
6. 9.	3—10	3.0	1.7	15.8	13.5	29.9	14.6	35.1	19.5	7.3	4.0
1986	13—20	0.8	0.9	14.8	13.8	7.9	8.9	9.3	10.6	2.0	3.2
	28—35	0.8	1.1	13.0	13.2	7.6	7.0	8.9	8.2	1.9	1.2

1) percentage from mean saturation level (85.2 %) in conditions of full aeration.
1) *prosenttinen osuus keskikyllästysasteesta (85,2 %) täysin hapekkaissa olosuhteissa.*
2) mean oxygen content in soil air (hypothetical, for dry soil only).
2) *hapen keskimääräinen määrä maan ilmatilassa (hypoteettinen arvo ainoastaan kuivalle maalle).*

Table 3. Precipitation during the vegetation period in 1986 at Tipu (measured under sparse tree canopy).
Taulukko 3. Kasvukauden 1986 aikainen sademäärä Tipun alueella (mittaus harvan latvuskerroksen alapuolella).

period, aika	precipitation (mm) *sademäärä (mm)*
7. V.—6. VI.	50.0
6. VI.—4. VII.	8.3
4. VII.—2. VIII.	78.3
2. VIII.—6. IX.	118.2

in the middle and at the end of summer. Only in the extremely wet September were the aeration conditions in the intermediate and lower layer of the depressions and hummocks quite similar.

Here one should evaluate the influence of rainfall on aeration conditions. At the beginning of June, when rainfall was high and the peat was saturated with spring waters, the aeration of upper layers was weaker than in other months. After the prolonged drought in June the results of July were somewhat different: in hummock peat aeration conditions considerably improved, in the depressions such improvement took place only in the upper layer. Rainfall in July was high, but most of it fell in the first half of the month, and the aeration conditions changed more considerably in the depression than in the hummock. The upper layers, however, remained quite well aerated in both sites.

Here one can observe a somewhat different reaction of aeration conditions to rainfall in case of hummock and depression. In the case of high rainfall the difference in aeration conditions between the intermediate (13—20 cm) and the lower (28—35 cm) layers was negligible in both sites. In the case of intermediate rainfall the differences between the intermediate and lower layer were remarkable in hummock peat, but little in depression peat. But when there was very little rainfall (the results of July), the intermediate layer was considerably better aerated in both cases. Considering the oxygen saturation level of the soil environment at the depth of 28—35 cm, it was evident that aeration conditions were better in hummocks in all cases. Consequently, depending on rainfall, the aeration conditions in the upper 10 cm layer can be relatively favourable in both sites, but in case of hummocks the thickness of the better aerated layer exceeds that of depressions.

The last column in Table 2 gives the oxygen content of the soil air. These values enable us

Table 4. Oxygen content, temperature and pH of mire water, gathered from soil pits of 20...35 cm deep (mean of three replicates).

Taulukko 4. Suoveden happitilanne, lämpötila ja pH. Keräys 20...35 cm syvyisistä kuopista (kolmen toiston keskiarvo).

	absolute content (mgl^{-1}) *absol. määrä (mgl^{-1})*		saturation level (%) *kyllästysaste (%)*		temperature (°C) *lämpotila (°C)*		pH *pH*	
time *aika*	hummock *mätäs*	depression *painanne*	hummock *mätäs*	depression *painanne*	hummock *mätäs*	depression *painanne*	hummock *mätäs*	depression *painanne*
8.—9. 5. 1986	4.1	5.7	34.5	49.0	8.2	8.5	3.6	3.7
14. 7. 1986	2.3	3.2	25.0	33.4	14.7	16.8	n.d.	n.d.
6. 9. 1986	2.7	3.2	26.0	30.6	13.2	13.3	n.d.	n.d.

to make comparisons with the results of Rogers and King (1972) and Lõhmus (1983, 1984), but are meaningless in case of water saturated peat soil. In comparison with the soils of hill pastures, drained peat soils and gley soils the aeration conditions in bog depressions and hummocks are more unfavourable. For example, in drained peat soil the minimal oxygen content of soil air at the depth of 30 cm was 12.2 % (in tube water 6.3 mgl^{-1}, saturation level 60.7 %). In dry podzolic soil under pine forest the tubes at all depths indicated full aeration throughout the summer (Zobel, in preparation).

The oxygen content in mire water, both absolute content and saturation level, was higher in the depressions (Table 4). At first it would seem that more oxygen in the depressions enables more intense decomposition but, evidently, the problem is more complex. Vompersky (1968) demonstrated that the oxygen content in the soil water of fens is lower than of bogs. Similar results have been obtained by Lõhmus (1983) and Zobel (1987), e.g. in an alder swamp the oxygen content of soil water was considerably lower than in the soil of transitional pine bog. So the oxygen content, measured directly in soil water, seems not to characterize soil aeration conditions, but instead the intensity of decomposition. In the case of high microbiological activity, soil oxygen is intensively consumed and the content of free oxygen is low. Here the results, obtained on the June 6th, 1986 are presented as an example (Toom and Zobel, in preparation): eutrophic alder swamp with some *Sphagna:* 0.6 mgl^{-1}, mesotrophic swamp with alder, pine and *Sphagna:* 1.1 mgl^{-1}, mesotrophic swamp with pines, birches and abundant *Sphagna:* 2.4 mgl^{-1}, meso-oligotrophic transitional pine bog: 3.0 mgl^{-1}. It is thus evident that in eutrophic sites, where the decay rate is higher in soil, the oxygen content in soil water is lower than in meso- or oligotrophic sites. As the oxygen content was higher in the soil water of depressions than in that of hummocks one can draw the conclusion that the decomposition rate is higher in hummocks. But it should be taken into account that the water samples compared here originate from different peat layers. When the 25 to 35 cm deep pit was made in the bog surface, it would be filled with the water from the surface and upper peat layers in the case of depressions. In hummocks there was usually no surface water and the upper layers were also low in water. The water in pits on hummocks thus originated mostly from deeper layers. The high oxygen content in the water of bog surface depressions thus partly indicates "input conditions", because free surface water contains considerably more oxygen (4—5 mgl^{-1}). Consequently, it is difficult to interprete the results: the values received partly characterize input of the oxygen into soil environment and partly output (oxygen consumption due to decomposition) conditions. In July there was no surface water in the depressions but the oxygen content remained higher. In the hummock situation (Table 2), the well aerated layer was thicker but the soil water originated from different peat layers.

The differences in soil temperature, as measured in the polycarbonate tubes, were similar throughout the vegetation period (Table 2). In the upper peat layers the temperature was higher in hummocks but the temperature of the deepest (28—35 cm) layer was higher in the depressions. Considering the water gathered in the soil pits, the temperature was always higher in depressions (Table 4).

The results of measured aeration and temperature conditions in hummock and depression peat indicate that cause and effect combine in a complex manner. Aeration conditions were more favourable in the soil environment of hummocks but the influence on decay remains unclear. Clymo (1978) claims that in bogs, the decay rate is highest in the aerobic zone. Ryden et al. (1980) drew the conclusion that the lower soil moisture content of elevated microsites is more favourable for decomposition than the wet conditions of depressions. Still, considering that the peat accumulation is (or at least has been) more intense in hummocks, aeration conditions seem to be not the only determinator of production and decay. It is also possible that the better aeration conditions in hummock enhance the growth of several dwarf shrubs (e.g. *Calluna, Andromeda, Empetrum*) and the hummock structure is reinforced by their repeated branching. There are few data about nutrition conditions in hummocks (ridges) and depressions (hollows). The content of certain ions in mire water or peat does not indicate adequately the conditions of mineral nutrition. Thus, in order to evaluate more precisely the differences in ecological conditions between different mire sites, input rates (oxygen, nutrients) and consumption rates should be further studied and estimated.

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TIIVISTELMÄ:

MÄTÄS- JA PAINANNETURPEEN HAPPI- JA LÄMPÖTILAOLOISTA KIKEPERAN SUOLLA LOUNAIS-EESTISSÄ

Rahkasoille on tyypillistä kuivien mätäs- ja märempien välikkö-, painanne- ja kuljupintojen vuorottelu. Näiden synnystä ja erilaistumisesta on esitetty useita hypoteesejä, mutta kuten Sjörs (1976) on todennut, asiaa on kokeellisesti selvitetty hyvin vähän.

Tässä työssä on pyritty luonnehtimaan turpeen happiolosuhteita mätäs-kulju -vaihtelun muodostumisen alkuvaiheessa. Työ on tehty Lounais-Eestissä Kikeperan kohosuolla, jonka kokonaispinta-ala on 4800 ha ja turpeen keskipaksuus 3 m. Tutkimusalue sijaitsi suon harvapuustoisella osalla, jota luonnehtii mättäiden ja painannepintojen mosaiikki. Kasvilajisto erosi lähinnä pohjakerroksen osalta. Painanteiden valtalajeja olivat *Sphagnum rubellum* ja *S.magellanicum* kun mättäitä luonnehti *S.fuscum* (Taul. 1).

Kokeissa käytettiin 7 cm:n pituisia polykarbonaatista valmistettuja sentrifuugiputkia (Rogers ja King 1972). Happimolekyylit pystyvät diffuntoitumaan putken ohuen membraanin lävitse. Hapen määrä putkissa olevassa vedessä mitattiin Tarton yliopistossa kehitetyllä sähkökemiallisella mittauslaitteella (Tenno 1986). Menetelmä on hitaampi kuin redoxpotentiaalin mittaus. Myös ohuet polykarbonaattikalvot rikkoontuvat maassa helposti.

Sentrifuugiputket täytettiin vedellä ja asetettiin turpeeseen kolmelle syvyydelle: 3—10, 13—20 ja 28—35 cm. Tutkimus tehtiin kasvukauden 1986 aikana n. kuukauden välein siten, että ensimmäiset mittaukset olivat kesäkuussa ja viimeiset syyskuussa. Myös veden lämpötila mitattiin sekä putkista että turpeeseen kaivetuista kuopista.

Hapen määrä oli suurempi mättäillä kuin painanteissa. Kesä- ja syyskuussa hapekkaan turpeen paksuus oli mättäillä n. 10 cm ja heinäelokuussa 20—30 cm (Taul. 2). Painanneturpeessa oli hapen määrä suurehko ainoastaan pintakerroksessa heinäkuussa: syvemmissä kerroksissa oli silloinkin happipitoisuus pieni. Kostean syyskuun aikana (Taul. 3) heikkenivät happiolosuhteet sekä mätäs- että painanneturpeessa. Lämpötila oli mättäiden pintaosissa korkeampi kuin painanteissa, mutta tilanne oli päinvastainen painanteiden syvemmissä turvekerroksissa (Taul. 2). Hapen määrä kaivetuista kuopista kerätyssä vedessä oli suurempi painanteissa (Taul. 4). Tämä saattoi aiheutua hapekkaiden pintavesien virtaamisesta painanteihin. Myös suoveden lämpötila oli painanteissa korkeampi kuin mätäspinnoilla (Taul. 4).

Turpeen happi- ja lämpötilaolot ovat esimerkki siitä, miten monimutkaisella tavalla syyt ja seuraukset kietoutuvat suoekosysteemeissä toisiinsa. Happitilanne oli parempi mätäspinnoilla, mutta sen vaikutus hajotustoimintaan jäi vielä epäselväksi. Clymon (1978) mukaan hajotus on suurinta turpeen hapellisessa pintakerroksessa (akrotelm), johon liittyy myös alhaisempi vesipitoisuus. Kuitenkin turpeen kertymä on ollut suurempaa mätäspinnoilla. Näin ollen happiolot eivät ilmeisesti pelkästään määrää tuotannon ja hajotuksen suhdetta. Myös esim. kasvillisuuden erot (mätäsvarvikko) voivat omalla toiminnallaan olla vaikuttamassa. On vielä vähän tutkimuksia mättäiden ja märempien pintojen ravinne-eroista. Jotta pystyttäisiin arvioimaan paremmin eri suotyyppien ja osakasvustojen ekologisia eroja, pitäisi lisätä happi- ja ravinneolojen ja hajotuksen vuorovaikutuksen tutkimista.

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