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Chapter III

Tomasz Gnatowski, Bogumiła Pawluśkiewicz, Ryszard Oleszczuk,
Sławomir Chrzanowski

Analysis of temperature distribution changes and moisture contents of moorsh soil under permanent grassland

INTRODUCTION

Two processes dominate in organic soils. One of them is related to the accumulation of organic matter during the formation of peat soils. The second process, which is mainly dependent on human activities, causes the dehydration of these soils through the lowering of ground water levels. After drainage the peat material in the top layer changes into a new soil formation called, in the Polish terminology, a moorsh (OKRUSZKO, ILNICKI 2003). The moorsh and the underlying peat deposits are two distinct materials which are characterized by different structures as well as different physical properties and which have contrasting dry bulk densities. The moorsh material is of a much more grainy structure which is dependent on the degree of advancement of the moorsh forming process. During this process, the structure of the peat material is changing from fibric (moss peat) to humous (herbaceous and alder peats) and is modified by different degree of decomposition (OKRUSZKO, ILNICKI 2003). Intensive drainage causes mineralization of organic matter which results in subsidence and a decrease in surface elevation of peatlands (ILNICKI 1972). The lowering of the water level enhances the release of nitrogen and the emission of the greenhouse gases nitrous oxide, N_2O, and carbon dioxide, CO_2 (GOTKIEWICZ 1987; CRILL et al. 2000; SZANSER 1991a,b). The release of nitrogen is damaging to the ground water as well as open water resources. The proper management of peat-moorsh soil is required in order to protect these types of ecosystems from degradation.

The primary factor that strongly influences the degradation process is moisture content and water storage in moorsh soils, especially in the top layer, and has been studied extensively under Polish conditions by Mioduszewski et al. (1996); Oleszczuk et al. (2001), Brandyk et al. (2001, 2006) and Szatyłowicz et al. (2006). The second factor, which affects the intensification of the soil processes, is the temperature. Peat soils with high volumetric heat capacities slowly increase their temperature which has an influence on delaying the beginning of growing season. The soil thermal properties, which controlled the thermal status of the peat soils, are rather poorly recognised. Studies related to thermal properties tend to concentrate on thermal diffusivity of peat soils or soil organic substrates (HORTON et al. 1983; GNATOWSKI et al. 2006, 2008; USOWICZ 1996). Thermal status of the soil is also an important factor which is applied for quantification the soil energy transport. Horton and Wierenga (1983) indicated that soil heat flux can be estimated using soil temperature gradient method. Soil temperature distribution influences hourly heat balance and therefore should be accurately quantified as a part of surface energy balance. This is especially important for agricultural area where the proper measurement of this kind of soil flux can influence better understanding of a crop's energy and water use (VERHOEF 2004).

The temperature and moisture content of the soil influence the peat decomposition rate (KIRCHBAUM 1995; FANG, MONCRIEFF 2001) but they are also important for plant development and soil microorganisms existence (RICHARD, CELLIER 1998). Hence, the main objective of this study was to analyse the interrelationship between soil temperature distribution, water content and plant botanical composition.

DESCRIPTION OF INVESTIGATED SITE

The investigated site is located in the Middle Biebrza Basin within the Kuwasy drainage and sub-irrigation systems (SZUNIEWICZ, CHRZANOWSKI 1995). The drainage of these areas was carried out using open channels (1933-1939) and a network of drainage and sub-irrigation ditches (1951-1960). In 1977-1988 the ditches were deepened due to the high rate of peat subsidence following drainage. Later on drainage and sub-irrigation pipe systems were also installed in order to achieve appropriate levels of capillary rise from groundwater. The Kuwasy Channel (about 15 km long) is the main part of land reclamation system, which connects the Rajgrodzkie Lake with the Rudzki Channel. The Rajgrodzkie Lake is the main reservoir of water used for irrigation of the Kuwasy peatlands.

After drainage of these peatlands, the area was ploughed and various grass species were sown. The productivity of this new ecosystem during the first five years of use as permanent grassland was relatively high and equal to approximately 7-8 ton of dry mass per hectare (KOWALCZYK et al. 1974). The cultivation practices and the drainage contributed to the formation of peat-moorsh soils with different rate of moorsh forming processes.

The descriptions of the soil temperature distribution as well as the moisture content on top layers of soil profiles are presented in this study. The measurements of physical properties were performed on an area of 495 m^2 at 29 points (randomly selected). The soil profile at this site was classified as a peat-moorsh soil formed from alder peat with moderate state of moorsh forming process (MtII bc) according to Okruszko (1994) classification. The soil temperature measurements were conducted at hourly intervals during sunshine hours on the 11th of August 2008 and also during sunshine hours on the 12th of August (on this date the last measurement of soil temperatures was recorded at 2 pm). The temperature values were obtained from standard thermometers every one hour. In addition, at each of the 29 points, the moisture content in the top 10 cm layer was measured in triplicates using the TDR method. The measurement probes were installed vertically from the surface. The detailed botanical composition of the plants cover was determined using gravimetrical method for representative area of about 6 m^2. For each of the 29 measurement points, the plant species were determined visually. The heights of the plants were also measured.

TEMPERATURE DISTRIBUTION AND MOISTURE CONTENT OF MOORSH SOIL

The energetic status of the soil is characterized by its moisture content and temperature. Both of these physical properties are related to water and nutrient movements in the soil profile and the influence of soil microbiological activity as well. Monitoring of soil temperature and moisture regimes can be useful for better understanding of the physical and biological processes dominated in energy and mass balance at the soil surface.

The soil temperature is changing according to a diurnal cycle, within an annual cycle. One of the simplest ways used for expressing the soil temperature distribution at the surface in a fundamental cycle is the following sinusoidal function (HORTON et. al 1983):

$$T(0,t) = T_a + A \cdot \sin(\omega \cdot t) \tag{1}$$

where: T_a – average temperature at soil surface (^oC), A – the amplitude of temperature changes (^oC) and ω represents the radial frequency equal to $2\pi/\tau$ with τ representing the period of the fundamental cycle, and t is time.

This equation (1) expresses the basic boundary condition which is required for the solution of the heat transfer equation (HUBRECHTS 1998; JURY et al. 1991) which allows the prediction of temperature changes at different depths in the soil profile (KOSSOWSKI, SIKORA 1978; VERHOEF et al. 1996). Under field conditions the temperatures of the soil and the surface are usually characterised by non-sinusoidal changes which are mainly related to atmospheric conditions. Therefore the soil temperature near the soil surface can be often described by a series of sine terms (HORTON et al. 1983). In these cases the temperature as a periodic function of time can be described in the form of sinusoidal waves oscillating around an average daily temperature T_a. These are known as a Fourier series expressed in the following form (CENIS 1989):

$$T(t) = T_a + \sum_{n=1}^{M} A_n \cdot \sin(k \cdot \omega \cdot t + \phi_n) \tag{2}$$

where: A_n and ϕ_n are amplitude and phase angle of k^{th} harmonics, respectively.

Equation (2) can be physically interpreted as the sum of a constant value T_a and values of k^{th} order of sinusoidal changes called harmonics. Based on the research conducted by Cenis (1989) it may be concluded that daily temperature variation can be described using only two-harmonic series. Therefore the basic equation which can be developed from series of soil temperature measured with hourly interval can be written as follows:

$$T(t) = T_a + A_1 \cdot \sin\left(\frac{2\pi}{\tau} \cdot t + \phi_1\right) + A_2 \cdot \sin\left(\frac{4\pi}{\tau} \cdot t + \phi_2\right) \tag{3}$$

This means that the soil daily temperature variation can be modelled using only the following five parameters: T_a, A_1, A_2, ϕ_1, ϕ_2.

The soil temperatures, which were recorded at the 29 measurement points, are presented in Figure 1. For the measurement period, the lowest and highest temperatures were measured on the 11th of August. The minimum temperature was observed at 9 am and was equal to 15.8°C. The highest temperature was recorded at 5 pm and was equal to 22.3°C.

For all the recorded data presented in Figure 1, the parameters of equation (3) were identified using a least squares optimisation procedure. The formula which was developed as the average temperature distribution for the investigated period at the field scale takes the form:

$$T(t) = 18.40 + 1.682 \cdot \sin[(2\pi/24) \cdot t + 3.205] + 0.295 \cdot \sin[(4\pi/24) \cdot t + 0.008] \tag{4}$$

Based on the parameters obtained, the average soil temperature distribution for the analysed period was also plotted in Figure 1. Additionally, the values of the first and second harmonics are also included in this figure. From the data it can be seen that soil temperature variations between the measurement points were the highest during the afternoon. In between 2 and 5 pm, the temperature change was about 4°C whereas in the morning the variation was not more than 2°C. From the observed trend in temperature variations, it can be reasonably argued that the distribution of soil temperature does not depend solely on meteorological conditions. The influence of the soil cover represented by the height of the vegetation as well as the exposition to the sun energy of the measurement points should be taken into consideration. Hence the status of the soil surface will influence soil conditions.

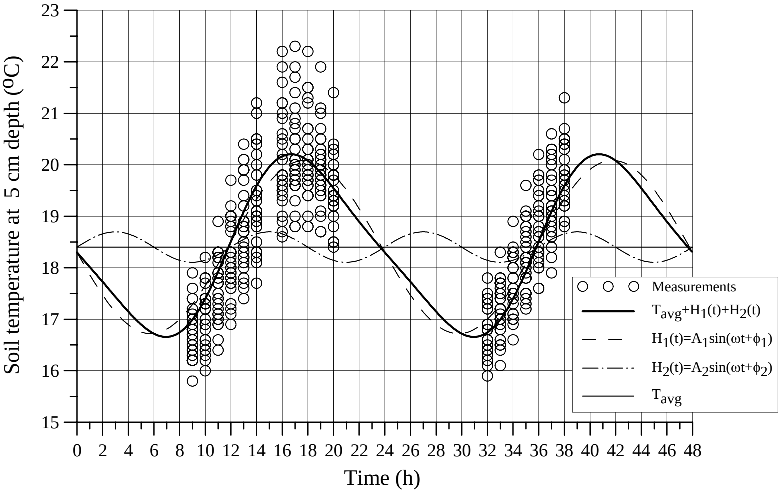

Fig. 1. Soil temperature distribution measured at the 29 points of the investigated plot between 11 and 12th August 2008

The Fourier series with two harmonics were fitted to the measured temperature data for each of the 29 points of the area. It means that, for each of the 29 points, the parameters T_a, A_1, A_2, ϕ_1, ϕ_2 were determined separately using a least squares optimisation procedure. The coefficients of determination that describe the quality of the fitting between measured and calculated values of the soil temperatures were varied between 91 and 99%. In order to visualize the results of the statistical calculation the average, minimum and maximum temperatures for each measurement point are plotted in Figure 2.

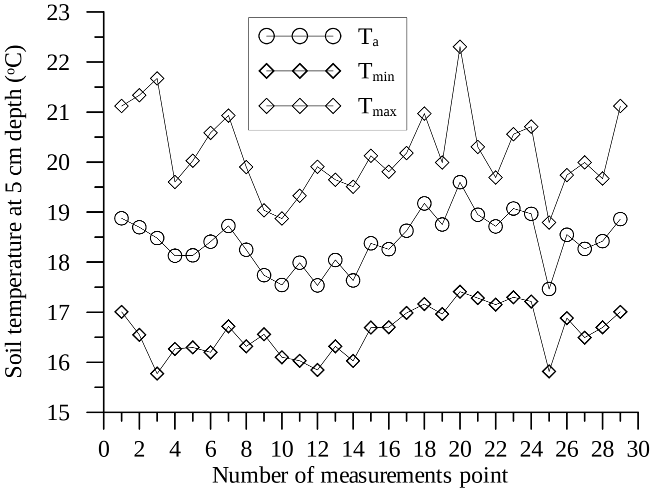

Fig. 2. Average, minimum and maximum temperatures calculated using Fourier series

The data plotted in this figure show that the average temperatures calculated for the 29 points of the area was oscillating between 17 to 19.5^{o}C. The range of temperature variation (values between maximum and minimum temperatures) at each point was changing from 3 to 6^{o}C. The data clearly show that the range of temperature variation is individual for different measurement points in the study area. It shows again that soil temperature distribution is probably related also to vegetation which covers the soil surface.

The soil water content is the basic property measured in soil profile. For monitoring purposes, the water content is measured using the TDR method, where the dielectric properties of the soil are used to calculate the moisture status of soil using calibration curves. For mineral soils one of the typical calibration equations used for moisture content calculation was proposed by Topp et al. (1980). The application of the TDR method for organic soil layers located in the Biebrza River Valley was studied by Oleszczuk et al. (2007). The moisture content of peat deposit can be calculated on the basis of dielectric constant measurements using the following expression:

$$\theta_v = 0.174 + 0.013 \cdot K_a - 0.000045 \cdot K_a^2 \qquad (5)$$

where: θ_v – volumetric moisture content (cm^3 cm^{-3}), K_a – dielectric constant (-).

The main advantage of this calibration equation for the TDR method is the requirement of only one measurement parameter represented by the dielectric constant. Additionally the coefficient of determination which measures the quality of prediction of the dependent variable was relatively high and equal to 93.6%. However most of the reported investigations (MALICKI 1993; OLESZCZUK et al. 2004) in these types of curves also include the basic soil physical properties. Unfortunately the physical properties were not measured for the purpose of this study. It was assumed that moisture content may be predictable with sufficient accuracy using equation 5. The average values of the dielectric constant (measured in triplicates) for each point of the selected area are presented in Figure 3.

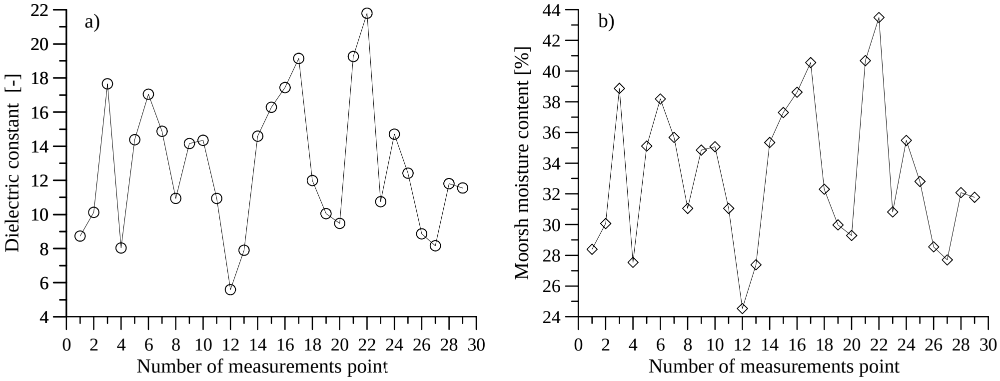

Fig. 3. Average dielectric constant values measured in moorsh layer 0-10 cm (a) and moisture contents calculated using equation 5 (b)

The measurements show that dielectric constants are characterised by rather low values and that they vary for the different points investigated. The variation in the measured data is characterised by a relatively high coefficient of variability equal to 31%. The corresponding volumetric moisture content varied from 24 to 44%. This indicates that during the measurement period the soil was relatively dry.

The low moisture content of the top soil layer was probably caused by the high evapo-transpiration rates of the cultivated plants in the summer. The measurements in this study were performed at the beginning of August which was approximately two months after the first cutting of the plants. The soil moisture status at each point of the investigated area indicates that physical properties of moorsh material are spatially variable. But on the other hand the influence of the plant covers should be taken into account.

The analysis of plant botanical composition indicates that 65% of cover biomass is occupied mainly by grasses: *Festuca rubra* and *Poa pratensis*. Supplementary plant species are represented by grasses: *Deschampsia caespitosa*, *Holcus lanatus* as well as *Poa trivialis*. Participation of *Dactilis glomertata* and other cultivated tall grasses was less than 1% of total dry mass. Approximately 18% of the plant soil covers are occupied by herbaceous species. There are mainly rosette and stoloniferous plants, i.e. *Taraxacum* sp., *Ranunculus repens*, *Cardaminopsis arenosa*, *Leontodon autumnalis* and *Potentilla anserina*. The detailed botanical composition as well as heights of plants for each of the analyzed point of the area are presented in Table 1.

Table 1

Plant botanical composition at the measurement points

Measure-ments point	Dominant plants	Height of plants – H [cm]	
		H1	H2
1	*Cardaminopis arenosa, Trifolium repens*	9	16
2	*Festuca rubra, Trifolium repens, Ranunculus repens*	13	13
3	*Trifolium repens*	6	6
4	*Deschampsia caespitosa*	25	25
5	*Taraxacum sp, Ranunculus repens*	25	25
6	*Potentilla anserina, Cerastium holosteoides*	26	26
7	*Festuca rubra, Trifolium repens*	12	26
8	*Ranunculus repens, Potentilla anserina*	19	19
9	*Festuca rubra, Potentilla anserina, Ranunculus repens*	22	22
10	*Potentilla anserina, Poa pratensis*	28	28
11	*Ranunculus repens, Potentilla anserina*	27	27
12	*Festuca rubra, Trifolium repens*	28	20
13	*Festuca rubra, Ranunculus repens* (+)*	24	24
14	*Festuca rubra, Leontodon autumnalis*	29	32
15	*Festuca rubra, Leontodon autumnalis* (+)	30	30
16	*Potentilla anserina, Taraxacum sp.*	25	25
17	*Poa pratensis, Trifolium repens*	27	27
18	*Deschampsia caespitosa*	23	23
19	*Festuca rubra, Leontodon autumnalis*	17	23
20	*Poa pratensis, Carex hirta*	20	9
21	*Deschampsia caespitosa*	18	21
22	*Potentilla anserina, Festuca rubra, Poa pratensis, Deschampsia caespitosa*	24	24
23	*Festuca rubra, Potentilla anserina* (+)	23	18
24	*Deschampsia caespitosa, Trifolium repens*	21	21
25	*Phalaris arundinacea, Potentilla anserina*	67	53
26	*Festuca rubra, Poa pratensis*	34	34
27	*Festuca rubra, Achillea millefolium, Leontodon autumnalis, Trifolium repens*	30	30
28	*Deschampsia caespitosa, Festuca rubra* (+)	26	33
29	*Deschampsia caespitosa, Festuca rubra*	28	24

* (+) – not significant part

HIERARCHICAL STRUCTURE OF PHYSICAL PROPERTIES OF MOORSH SOIL COVERED BY GRASS COMMUNITY

Cluster analysis was used to classify the measurement points of the investigated site into groups based on their similarities. The input data for this analysis were represented by 29 sets of parameters describing the harmonic equations of soil temperature distribution. These parameters are represented by average soil temperature (T_a), amplitudes (A_1 and A_2) and phase angles (ϕ_1 and ϕ_2) of first and second harmonics. Based on the 29 vectors of the above mentioned parameters, a matrix of variables (5 columns and 29 rows) was prepared and standardisation of input data was performed. Application of the cluster agglomerative technique as proposed by Marek (1989) enables on establishment of independent groups. Each group was established on the basis of the similarity between individuals. These individuals are represented by a vector of observations (parameters of harmonic equations) determined for each point of the investigated area. A dendrogram which shows the groups of similar measurement points is presented in Figure 4.

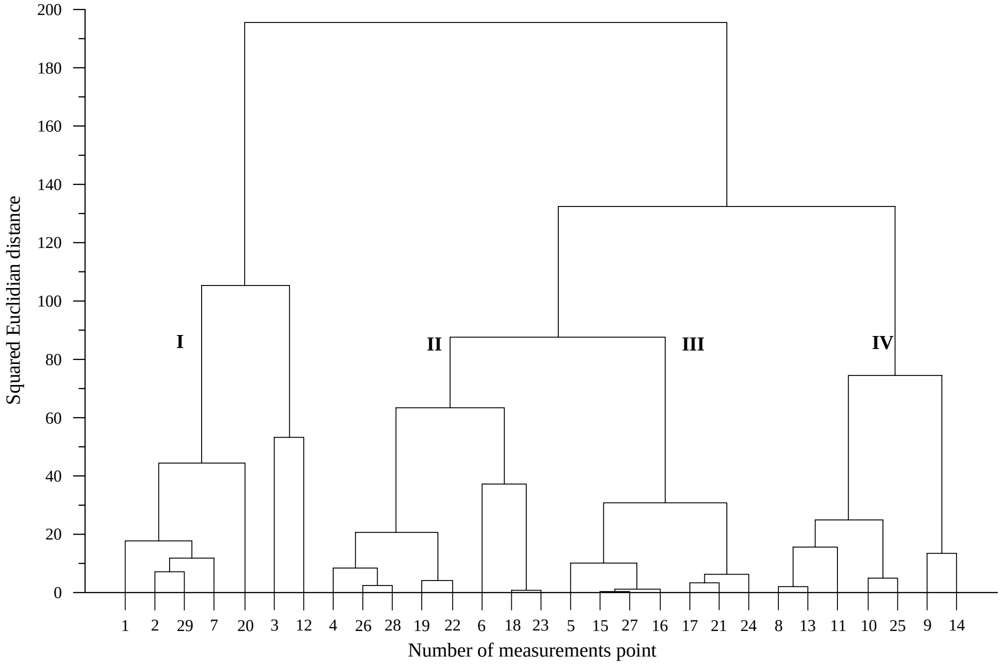

Fig 4. Dendrogram for parameters of harmonic equations determined for each of the 29 measurement point

The data presented in figure 4 clearly show that the agglomerative technique enables to distinguish two clusters. One group is agglomerated within one cluster which includes 7 measurements points. The second cluster can be divided into three homogenous groups. Based on these agglomerations, the average parameters of the Fourier series which describe the temperature distribution were determined for each group. The calculated values of T_a, T_{min}, T_{max}, A_1, A_2, ϕ_1 and ϕ_2 are presented in

Table 2. The mean dielectric constants, the mean capacity and the height of the plant are also included. The analysis of the results suggests that the average temperature T_a in each group is dependent on the height of the plant. It means that a decrease in the height of the plant causes a decrease in the average temperature in the upper soil layer (5 cm depth). The average values of the first main harmonic indicate that soil temperature oscillations are also different between established groups. In case of lower plants these changes are equal to approximately 2.1^{o}C whereas in the case of higher plants, the soil temperature oscillates by about 1.5^{o}C around the average T_a.

Table 2

The average values of the physical parameters of moorsh material as well as description of the plants for established groups

Group	T_{min}	T_{max}	T_a	A_1	A_2	ϕ_1	ϕ_2	K_a	Water storage* [mm]	Basic species	H [cm]
I	16.62	21.20	18.84	2.145	0.415	3.331	-0.364	11.15	31.2	*Trifolium repens, Festuca rubra*	16
II	16.83	20.10	18.68	1.602	0.505	3.011	0.318	12.54	32.9	*Deschampsia caespitosa, Festuca rubra*	25
III	16.81	20.16	18.54	1.580	0.243	3.142	0.242	15.63	36.5	*Festuca rubra, Deschampsia caespitosa, Trifolium repens, Taraxacum* sp.	25
IV	16.17	19.30	17.83	1.476	0.236	3.042	0.180	12.19	32.5	*Potentilla anserina, Ranunculus repens, Festuca rubra*	30

* water storage in the 10-cm top layer of the moorsh

The influence of the height of the plants on the dielectric constant and soil water storage was rather moderate. The soil water storage is more dependent on the plant botanical composition of the soil cover. The lowest value of water storage in the 10 cm layer is observed in group I where the plants with stoloniferous roots system dominate. Relatively low water storage is also observed in group IV. This is probably due to large transpiration apparatus of the plants which belong to this group. These plants are higher than the ones belonging to other analysed groups. From the data presented in Table 2, it can generally be concluded that the height of the plant community affects the thermal status of the soil which can also be influenced by the lower value of water storage of the moorsh soil.

The average parameters of the Fourier series which describe groups II and III were not significantly different, except for the values of the second harmonics. This may suggest that these groups should be treated as one group. However the analysis of the water storage and dielectric constant data show a clear difference between these groups. This tendency is also confirmed by Figure 5 where the average temperature distribution for both groups is presented. The difference between temperature variations is especially pronounced for hours between 20 and 24. The higher water storage belongs to the group III of more diverse botanical composition of the grass community (grass, and perennial rosette plants). These plant species have a deeper root system and water consumption occurs from deeper layers of the soil profile. Although there is a difference between the two groups, a more detailed study is required to corroborate the results.

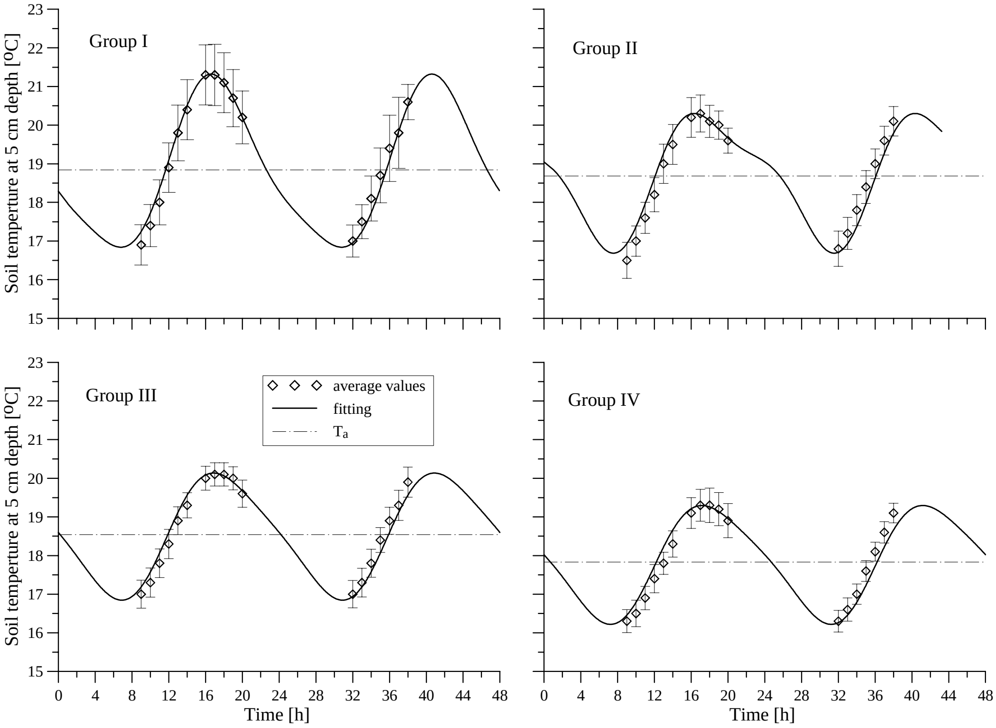

Fig. 5. Soil temperature distributions at 0-5 cm depth in establishing moorsh groups

SUMMARY AND DISCUSSION

The obtained results lead to the conclusion that soil temperature distribution in the moorsh material can be described using Fourier series with two harmonics. Statistical analysis represented by hierarchical agglomerative technique enables to divide the 29 observed points into four homogenous groups of the investigated area. These groups are characterized by different thermal and moisture status of the moorsh material. The experimental results and the statistical analysis of the data indicate that variability in the physical properties can be related to spatial variability of plant botanical composition of grass community. Simultaneously with increases in the height of the plants the average temperatures (measured at 5 cm depth) of moorsh layer decrease. The heights of the plants are related to oscillation of the temperatures around their averages. Higher variations in the soil temperatures were observed in the places where the lower plants were dominant. However, height of the plant species was not the main factor influencing water storages in the moorsh layer. Rather, the variations in water storage at different points within the study area were dependent on botanical composition of the grass community. Appearance of the stoloniferous root system plants as well as the plants with large assimilation apparatus caused the decrease of water storage in the upper 10 cm soil layer considered in this study. Higher water storage in the moorsh layer was observed at locations where plant species with a deep root system were dominant. The analysis of the moisture and thermal status of the moorsh layer at the field scale performed in this study can be used for assessing the intensity of the mineralization of organic soils and devise strategies to help protecting these kinds of ecosystems. The results presented in this study need to be complemented by a more detailed investigation in order to analyze the interrelation between plant, soil, water and thermal conditions under various atmospheric and water regimes.

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Tomasz Gnatowski[1], Bogumiła Pawluśkiewicz[1], Ryszard Oleszczuk[1],
Sławomir Chrzanowski[2]

[1] Department of Environmental Improvement
Warsaw University of Life Sciences
Nowoursynowska 159; 02-776 Warszawa
e-mail: tomasz_gnatowski@sggw.pl

[2] Institute of Land Reclamation and Grassland Farming
Experimental Station Biebrza
19-200 Grajewo