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Research Paper

Recent and future soil temperature regime in the coldest part of Poland

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ABSTRACT

Global climate change is one of the factors changing the thermal regime of soils and thus the conditions of agricultural production. The soil temperature data of two stations (Białystok and Suwałki) of Poland for 40 years (1981-2020) measured at five depths (5, 10, 20, 50, 100 cm) were analyzed. The averaging of the soil temperature for the layers 0-20 cm and 0-50 cm indicated a progressive warming of soils. At the beginning of the 21st century, there was a change in the thermal regime from frigid to mesic, with an average rate of 0.4^0C per decade. In the summer months, rate of increase was twice as high. Soil climate change results in already changing structure of plant cultivation and the need to introduce new elements in the technology of soil cultivation. To ensure a satisfactory yield of plants, it will be particularly important to rationally modify the water management of agricultural areas.

Key words: Soil, temperature regime, climate warming, climate, Poland

Soil is a one place in each land ecosystems where climate, energy, water cycle and biota creating the necessary conditions for plants development from surface rocks or sediments. A huge global soil cover diversity is a result of long time landscapes evolution with important climate role in phenotypic structuring of soil profiles. Climate can create different conditions for plant growth depending on the parent material, relief, hydrology, thus they are named as a main soil factor. All climate changes resulted also in soil functioning by adding or modifying the existing of the soil profile morphology and has an important effect on plant life-history processes, also on seed dormancy and germination (Sinha 2001; Walck *et al.* 2011).

Globally documented climate changes may modify many environmental factors, including mean air temperatures, soil conditions, rainfall patterns and temperature extremes such as heat waves (IPCC 2014). Thermal features of soil profile are common used in their classification like in USDA soil classification. As shown in recent studies, soil temperature is increasing in areas all over the globe (Grillakis *et al.* 2016), influencing subsurface processes under any cover – forests, plantations and urbanized areas. Also some studies in soil temperature regime showed high diversity on short distances, such as in Tenerife, Spain (Shekh *et al.* 2001; Rodríguez *et al*. 2010). More detail study for a topsoil temperature (5 cm depth) in Poland show statistically significant diversification in the territory of Poland with longitudinal orientation in autumn and winter and latitudinal in spring and summer (Rojek, Ussowicz 2018).

A long-term study in SW part of Poland (with highest country mean of air temperature), show slowly increase of soil temperature for period 1961-2000 (Bryś 2004). Estimated rate of soils warming in Czechia and Slovenia are noted, where climate is much warmer than in Poland (Pogacar *et al.* 2018). The progressive climate changes in Central Europe are clear visible in polar and temperate climate zones with a gradual shift of the isotherms to the east and north as well as of climate type areas (Beck *et al.* 2005). In agriculture practice of Central Europe, a climate warming causes gradual changes of crops structure and an increase in the share of plants with higher thermal requirements and a much longer growing season

In the present study the soil temperature regime in the coolest part of Poland are analysed, which can be helpful in agriculture activity planning and management of nature area under protection in global change time.

MATERIAL AND METHODS

The soil temperature data recorded three times a day at

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Table 1: Location and basic climatological data for two investigated stations; a- years 1981-2000, b- years 2001-2020 (Górniak 2021).

Parameters	Periods	Units	Białystok	Suwałki
Elevation		m u.s.l	148	184
Latitude			53°08'N	54°06'N
Longitude			23°10'E	22°56'E
Annual air temperature	a	Celsius degree	7.5	7.0
	b		7.8	7.4
Warmest month mean temperature	a		18.5	18.2
	b		19.2	19.1
Coldest month mean temperature	a		-5.1	-5.7
	b		-5.1	-5.6
Humidity	a	%	80.8	81.9
	b		80.2	81.0
Percipitation	a	mm	596	605
	b		633	623
Rain	a	days with rain	114	118
	b		116	119
Snow	a	days with snow	51	55
	b		48	52
	a	days with snow cover	71	79
	b		68	74
	a	% year precipitation	19.9	18.7
	b		19.5	17.5
Vegetation season	a	days	200	196
	b		205	203

6, 12 and 18 UTC at 5, 10, 20 and 50 cm depths at Białystok and Suwałki meteorological stations, maintained by Polish National Institute of Meteorology and Water Management (IMGW-PIB. Warsaw, Poland), were collected for last 40 years (1981 - 2020). Deep soil thermometer was read from 100 cm only at 12 UTC. Available data for the depth 100 cm started in 1982. During the first 10 years of observations a glass, soil thermometers up to depth 50 cm, with prior validation were used and then electric thermometers were applied. In the Białystok station the soil temperature was measured in humic cambisol developed from sandy loam with ground water level existing on the depth 4-5 meters. Podzoluvisol profile with loamy sand in the top 50 cm soil layers located on the continuous loamy till layer up to 1.5 m depths was analysed in the Suwałki station. Ground water level is stabilized on the depth more than 10 m in this location. Thus, ground water level can be eliminated as a factor effected on thermal soil regime. The basic climatological features of two stations are presented in Table 1.

Monthly and annual average were calculated using a new proposed method of calculating the average values temperature of the two topsoil layers: up to a depth of 20 cm (MT20) and to a depth of 50 cm (MT50). Respecting share of soil volume between measured standard points in soil profile. The following formulas were applied.

For top 20 cm of soil;

$$MT_{20} = 0.25T_5 + 0.25(T_5+T_{10})/2 + 0.5(T_{10}+T_{20})/2$$

For top 50 cm of soil;

$$MT_{50} = 0.1T_5 + 0.1(T_5+T_{10})/2 + 0.2(T_{10}+T_{20})/2 + 0.6(T_{20}+T_{50})/2$$

where T_5, T_{10}, T_{20}, T_{50} are temperature data at depth 5 cm, 10 cm, 20 cm, and 50 cm respectively. It seems that proposed calculation of mean temperature for a topsoil layer (MT20) is much more adequate for a whole ploughed soil layer, mostly used by farming plants in the first growth stages, than single or separate data from depth 5 cm, 10 cm or 20 cm, frequently and separate utilized for a climatological or ecological modeling. Also mean soil temperature in top 50 cm (MT50) show more realistic thermal state of soil habitats for organisms living there. A mean MT50 values for both analyzed stations were 0,5^{0}C higher than mean soil temperature at depth 50 cm (T_{50}) suggested by USDA soil classification. Kruskal-Wallis test for equal medians confirmed significance of their differences with p<0,005.

Air and soil temperature data for vegetation season (April-October) and no plant farming time (November – March) were analyzed. Scenario of future soil temperature was calculated from recent statistical relationships between annual air temperature and yearly mean soil temperature for a top 20 cm and 50 cm layer observed during 1981-2020. Projections of expected air temperatures for both stations data in next decades of 21st century are originated from KLIMADA 2.0 model prepared for all regions in Poland and available on-line www.klimada2.ios.gov.pl/en/. Significance of time series of annual or monthly soil temperature trends were estimated using Mann-Kendall test and Kruskal-Wallis test for equal medians was used for identification of significant differentiations values of soils temperature between analyzed stations, using PAST 4.03 software.

RESULTS AND DISCUSSION

Seasonal and profile differentiation of soil temperature

During past 40 years (1981-2020) absolute soils temperature were noted in the wide range from -14.5°C at 5 cm depth in Bialystok in the winter up to 40.3°C in Suwałki during summertime. Air temperature at 5 cm above soil level was dropping to minimum -39.8 °C in the winter. Soil temperature range was lower than air temperature (2 m), exceeding 70 °C in both stations (from -35.4 °C to 35.5 °C). At the Suwałki station farther north, annual soil temperature was lower than in Białystok, in each measured depth (Table.2). Only at 50 cm depth annual data in soil in Białystok, decrease from 9.6 °C at 5 cm soil depth up to 9.1°C at 100 cm for Suwałki from 9.1 °C to 8.5 °C respectively. Mean annual soils temperature at the depth 50 cm at the analysed location are typical for temperate climate with mesic soil regime, according to USDA soil classification. On the beginning on second half 20 century colder frigic soil temperature regime in the north-eastern Poland was indicated.

Soil temperature differences between presented stations is fully corresponds to the differences in the length of the growing season (Table 2), where warming state of soil in Suwałki during vegetation season was low compared to Białystok. Oppositive situation were present in the coolest part of year, except for a depth of 100 cm with soil parent material (Table 3). The greater winter cooling of soils at the Białystok station, located more to the south, results from the shorter period with snow cover. This is in line with Zanini, Freppaz (2006) results, where decreases of soil temperature were documented when snow cover was absent and then freeze-thaw process was accelerated. Mean soil temperature values in both stations were lowest at the depth 50 cm and difference between mean values were statistically not significant (Table 2).

Soil temperature seasonality in both stations was similar, with minimal monthly values in January and maximal in July only in the soil top 50 cm layer (Fig. 1), but in the deeper part of soil (100 cm) the lowest and highest monthly values were shifted one month later compared to upper soil part. As shown in Fig. 1, an intensive soil warming has a place between April to August with straight soil thermic profile, gradually followed by reverse stratification in period September - March. Start of soil temperature increase have a place usually in middle of May in Central Europe by of ground frosts events. It is connected with arctic air mass movement of from Northeast to Central Europe, when changes of seasonal north to zonal (western) circulation occurred.

The phenomenon of ground frost and cold event of soil temperature in the middle of May is known in European agrometeorology from XIX century in Germany as a “Eismeanner” or Poland as “Cold Sophia Day (15 May). In the course of average daily air temperature is poorly marked (Górniak 2021), but in soils it is distinct in both analyzed stations.

Table 2: Extremal and average soil temperature in five depths in the two stations in period 1981-2020 along with Kruskal-Wallis test (s- significant statistical difference, ns- difference not significant).

Depth (cm)	Białystok Max	Białystok Min	Białystok Mean	Suwałki Max	Suwałki Min	Suwałki Mean	Diff. test chi^2	p
5	39.0	-14.5	9.6	40.3	-9.8	9.1	5.81	0.016 (s)
10	33.6	-13.5	9.4	35.2	-9.0	8.9	6,19	0.013 (s)
20	30.4	-11.8	9.3	29.7	-7.3	8.7	8.76	0.030 (s)
50	26.4	-8.8	8.8	26.4	-3.7	8.6	1.54	0.022(ns)
100	22.8	-0.5	9.1	21.6	-2.2	8.9	5.50	0.019 (s)

Table 3: Mean temperature for annual, vegetation season (April-October VS), non-vegetation season (November- March; NVS) at two stations from years 1981-2020.

Depth	Białystok			Suwałki		
	Annual	April-Oct	Nov-Mar	Annual	April-Oct	Nov-Mar
5	9.6	15.8	1.0	9.1	15.1	2.2
10	9.4	15.3	1.1	8.9	14.6	2.1
20	9.3	14.8	1.5	8.7	14.0	2.3
50	8.8	13.5	2.2	8.6	13.3	2.3
100	9.1	12.7	3.9	8.9	12.6	3.5
Layers						
MT20	9.8	15.1	2.3	9.2	14.4	1.9
MT50	9.3	14.5	2.0	8.9	14.0	1.7

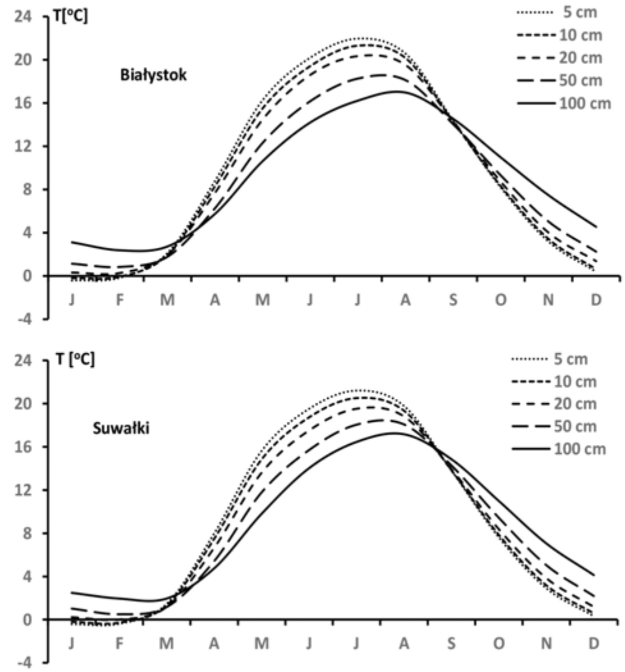

Fig. 1: Mean monthly soil temperature in Białystok and Suwałki stations at the five measured depth in years 1981-2020

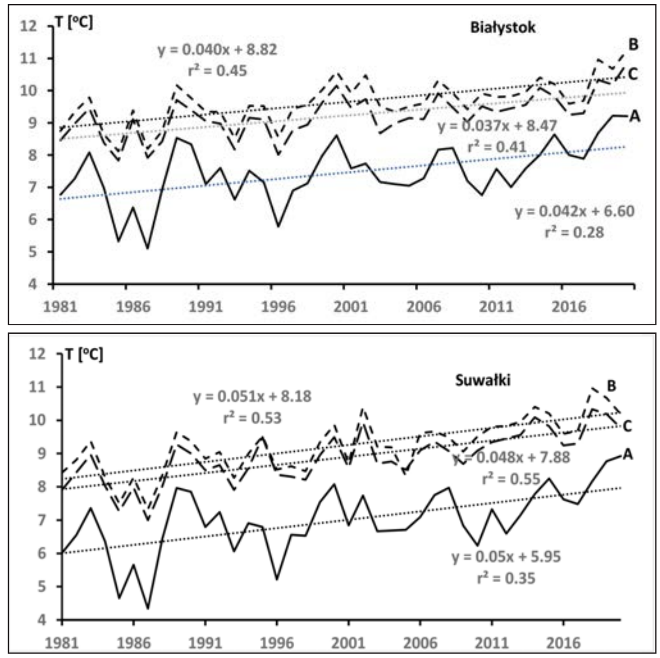

Fig. 2: Annual mean of air (A) and soil 0-20 cm (MT20 – B) and 0-50 cm (MT50 - C) layers temperature in Białystok (upper panel) and Suwałki (lower panel) in years 1981-2020

Multiannual tendency

In last 40 years, dynamic changes of soil temperature were observed (Fig. 2), with longer timing of cold periods, 2-3 years of higher values. In two stations under investigations a statistical significant increase of mean annual soil temperature exists as Mann-Kendall test documented (Table 4). In Białystok station an increase of annual soil temperature have a value near 0.4 and in Suwałki 0.3°C per decade. Observed soil temperature increase was higher than identificated in soils in southern Poland (Bryś 2004) as well as in many stations in Canada or USA in second half of 20 century (Budong *et al.* 2011). The weakest soil warming since the 1970s were detected in winter and spring and the highest in summer in Turkey (Yesilirmak, 2014), as well as in Croatia (Sviličič *et al.* 2016). All earlier researches globally soil warming documented, but the data for order of soil temperature increase in different countries is incomparable practically, caused by different number of daily measurements, its time schedules, and very different depth of soil measurements taken to research. In Australian soils documented that for every 1°C increase in air temperature, associated soil temperature increased by 1.5°C (Knight *et al.* 2018). In my 40 years long data series for both stations in NE Poland, top (0 - 20 cm) and 0 - 50 cm soil layer temperature increased respectively by 1,7°C and 1,6°C.

Multiannual soil warming tendency have a different range with soil depth, much stronger top layer warming has the same order like mean annual air temperature value. The highest level of soil warming was noted in top part of soil profile, except winter months, May and October (Table 4), but in the 100 cm depth was limited only to the vegetation season (April – November). June was detected as a month with the highest topsoil warming during 40 years in both stations, where soil temperature increased 0.8-0.9°C per decade with determination coefficient 42-48%. For soil profile the Suwałki, located more north, this increase was higher than in Bialystok, but difference was not significant statistically. This agrees with the global warming tendency to increase from equatorial zone towards the poles of the earth (Grillakis *et al.* 2016).

Future soil temperature projection and perspectives

Calculated statistically significant relationships entitle to make an attempt to modelling future soil temperature by the end of the 21st century on the basis of predicted changes in air temperature in both stations. Future soil temperature modelling with RCP 4.5 for both stations is difficult to implementation, because air temperature in last decade (2011-2020) was higher than projected in model. Thus, only projection for RCP 8.5 model is presented. By the end of the 21st century in north-eastern Poland, an increase in the average temperature of soils in the surface layer to a depth of 20 cm by more than 2°C can be expected, and at a depth of 50 cm, the average annual temperature of soils will increase by about 1.5 °C (Table 5).

The forecasted warming of the climate, also of soils, will result in numerous changes of processes in the natural environment and the conditions of agriculture and food production. The increase in soil temperature by over 2,5°C by the end of the 21st century is a potential increase in crop productivity and a progressive increase in the area of crops with greater thermal needs.

Pritchard (2011) suggest, climate warming more favour C4 over C3 plants, which is due to their physiological characteristics. In north-eastern Poland, during the first two warm decades of the 20th century, the area of maize cultivation increased several times,

Table 4: Results of Mann-Kendall test for significance of monthly soil temperature positive trend in years 1981-2020 in two analyzed stations in NE Poland; + significance for $p<0.05$, - trends not significant for $p>0.05$.

	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
Białystok													
5 cm	-	+	+	+	-	+	+	-	+	-	+	+	+
10 cm	-	-	+	+	-	+	+	+	+	-	+	+	+
20 cm	-	-	+	+	-	+	+	+	+	-	+	+	+
50 cm	-	+	+	+	+	+	+	+	+	+	+	+	+
100 cm	-	-	-	+	+	+	+	+	+	+	+	+	+
Suwałki													
5 cm	-	-	+	+	-	+	+	+	+	-	+	-	+
10 cm	-	-	+	+	-	+	+	+	+	-	+	-	+
20 cm	-	-	-	+	-	+	+	+	+	-	+	+	+
50 cm	-	-	-	+	-	+	+	+	+	+	+	+	+
100 cm	-	-	-	+	+	+	+	+	+	+	+	-	+

Table 5: Recent (2011-2020) and future soil temperature in Białystok and Suwałki according to projection RCP 8.5 model.

Decades	Białystok			Suwałki		
	MT5	MT20	MT50	MT5	MT20	MT50
2011-2020	10.6	10.7	10.2	9.8	9.8	9.7
2031-2040	10.7	10.8	10.3	8.4	8.4	9.4
2041-2050	10.8	10.9	10.4	8.6	8.6	9.8
2051-2060	11.2	11.3	10.8	9.1	9.1	9.9
2061-2070	11.6	11.6	11.1	9.6	9.6	10.3
2071-2080	12.0	12.1	11.5	10.2	10.2	10.6
2081-2090	12.4	12.4	11.9	10.6	10.6	11.0
2091-2100	12.9	12.8	12.3	11.2	11.2	11.3

with a similar decrease in potato cultivation (Samborski, 2015). With forecasted slight changes in precipitation and an increase in air and soil temperature, there is a substantial risk of a deepening water deficit during the growing season and the need to develop extensive agricultural irrigation. This, in turn, will require the expansion of the retention reservoirs network. In addition, decreasing the share of snowfall in the total annual precipitation will reduce a regional soil water retention. Potential advantages of the lengthening of the thermal growing season in northern and eastern Europe are often outbalanced by the risk of late frost and increased risk of early spring and summer heat waves (Ceglar *et al*. 2019), potentially limiting the increase in agricultural productivity. Higher soil temperatures are found to increase not only root biomass and photosynthetic rate, but also soil respiration as well as shoot, root, and rhizosphere respiration. Thermal soil changes usually stimulate soil microbial activity, net nitrification rates, P and N mineralization rates, and total respiration in soil. Gradual increase of heat transfer from surface to deep soils will lead to greater soil carbon losses than previously and the need to introduce a new plant cultivation technology that limit losses of soil organic matter and water.

CONCLUSION

The above documented changes in the thermal regime of the soils of NE Poland confirm the progressive warming of the soil as a result of global climate change. Thus, they indicate the already changing structure of plant cultivation and the need to introduce new elements in the technology of soil cultivation. In order to ensure a satisfactory yield of plants, it will be particularly important to rationally modify the water management of agricultural areas so as not to endanger the loss of the high natural values of the region, which constitute almost 1/3 of this part of Poland.

Conflict of Interest Statement: The author(s) declare(s) that there is no conflict of interest.

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REFERENCES

Beck, C., Grieser, J., Kottek, M., Rubel, F., Rudolf, B. (2005). Characterizing global climate change by means of

Köppen climate classification. *Klimastatusbericht,* 51: 139-149.

Bryś, K., (2004). Long-term variability of soil temperature in Wroclaw – Swojec and its radiation and circulation conditions. *Acta Agroph*., 3(2): 209-219.

Budong, Q., Gregorich, E.G., Gameda, S., Hopkins, D.W., Xiaolan, L., Wang, X.L., (2011). Observed soil temperature trends associated with climate change in Canada. *J. Geoph. Res.,* 116: D02106, doi:10.1029/2010JD015012

Ceglar, A., Zampieri, M., Toreti, A., Dentener, F., (2019). Observed northward migration of agro-climate zones in Europe will further accelerate under climate change. *Earth's Future*, 7: 1088–1101. https://doi.org/10.1029/2019EF001178

Górniak, A., (2021). Climate of Podlaskie Voivodship during global warming (in polish), University of Białystok Press, Białystok, p.221

Grillakis, M.G., Koutroulis, A.G., Papadimitriou, L.V., Daliakopoulos, J.N., Tsanis, I.K., (2016). Climate-Induced Shifts in Global Soil Temperature Regimes. *Soil Sci.*, 181(6): 1-7, doi: 10.1097/SS.0000000000000156

IPCC (2014). Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri, and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, P.151

Knight, J.H., Minasny, B., McBratney, A.B., Koen, T.B., Murphy, B.W., (2018). Soil temperature increase in eastern Australia for the past 50 years. *Geoderma,* 313: 241–49.

Pogacar, T., Zupanc, V., Bogataj, L., K., Crepinšek, Z. (2018). Soil temperature analysis for various locations in Slovenia. *Italian J. Agrometeorol.*, 1: 25-34, doi:10.19199/2018.1.2038-5625.025

Pritchard, S.G., (2011). Soil organisms and global climate change. *Plant Pathol.*, 60: 82–99.

Rodríguez, M., Neris, J., Tejedor, M., Jiménez, C., (2010). Soil Temperature Regimes from Different Latitudes on a Subtropical Island (Tenerife, Spain). *Soil Sci. Soc. Am. J*., 74:1662-1669.

Rojek, E., Usowicz, B., (2018). Spatial variability of soil temperature in Poland. *Acta Agroph*., 25(3): 289-305, doi: 10.31545/aagr/95026.

Samborski, Andrzej S. (2015). Analysis of length of wheat growing period in southeast part of the Lublin region of Poland. *J. Agrometeorol.*, *17*(2): 244–246. https://doi.org/10.54386/jam.v17i2.1016

Shekh, A.M., V. Pandey, M. Kumar and M.B. Savani (2001). Diurnal variations in soil temperature, momentum and sensible heat fluxes at Anand during LASPEX-97. *J. Agrometeorol.*, *3*(1-2), 97–105. https://doi.org/10.54386/jam.v3i1-2.394

Sinha, S. (2001). Soil temperature and its dependence on soil properties. *J. Agrometeorol*., 3(1&2):161-167. https://doi.org/10.54386/jam.v3i1-2.401

Sviličič, P., Vučetič, V., Filič, S., Smolič, A., (2016). Soil temperature regime and vulnerability due to extreme soil temperatures in Croatia. *Theor. Appl. Clim.*, 126: 247-263.

Walck, J.L., Hidayati, S.N., Dixon, K.W., Thompson, K., Poschlod, P., (2011). Climate change and plant regeneration from seed. *Global Change Biol*., 17: 2145–2161.

Yesilırmak, E., (2014). Soil temperature trends in Büyük Menderes Basin, Turkey. *Met.l Applic.*, 21: 859-866.

Zanini, E., Freppaz, M., (2006). Effetti del cambiamento del regime delle precipitazioni nevose sulla temperatura del suolo e sul ciclo dei nutrienti in pedoambienti alpine. *Ital. J. Agron.*, 3: 577-585.