Determination of Soil Temperature Regimes in Croatia

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Summary

Determination of soil temperature regimes is important to establish the diagnostic horizons that are used for classification of soils. Temperature regimes are determined according to Soil Taxonomy, and soils are allocated into six regimes. From the agricultural aspect, Croatia is divided into three regions: Pannonian, Mountainous and Adriatic and into nine sub-regions. The present analysis shows the average annual cycle of soil temperatures in the period 1981 - 2010 at depths of 10 and 50 cm. According to the average annual soil temperatures, the soils in Middle and South sub-region of the Adriatic region belong to the category of soils with the Thermic temperature regime, and the soils in other seven sub-regions are classified as soils with the Mesic temperature regime. Furthermore, differences between air temperature and soil temperature have been established. Theory that states that the average annual soil temperature can be roughly determined by adding 1°C to the average annual air temperature, was tested on depths of 10 cm and 50 cm and has not proven to be entirely correct.

Key words

soil temperature regime, soil, soil temperature, air temperature, agricultural regions, Croatia

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Introduction

Soil temperature is of vital importance for solving many theoretical and practical problems in different scientific areas (Sellers, 1965). Pedogenesis along with the processes that take part in it (physico-chemical, biochemical and biological) would not be possible without heat (Kaučić, 1989, Vukov, 1971). Understanding of soil temperature regime is important in plant production because it effects seed intergrowth, germination, growth and the activity of the root, blooming, maturation, end of the vegetation etc. (Racz, 1981). Temperature regime influences both directly and indirectly processes in pedogenesis (Yli-Halla and Mokma, 1998, Yli-Halla et al., 2001). Taking into account the increasing trend in air temperatures on a global level, it is necessary to determine the correlation between soil temperature and air temperature in recent period. Soil temperature regime is in close connection with the cycling of elements in nature as well as processes in plants and ecosystems. It is also important to determine the annual cycle of soil temperatures (Zhang et al., 1993). Because of its importance temperature regime is also used as criteria in different soil classification systems, (Husnjak et al., 2010, FAO, 1998). For instance, Cryic diagnostic horizon is based on soil temperature, and based on that horizon soils are systematized in the group Cryosols (Cline, 1979). Furthermore, in 1998 Soil Survey Staff introduced new soil rank – Gelisol, which includes soils with Pergelic temperature regime (Smith, 1986). World trend shows that this matter has received a lot of attention in the last 20 years. In Croatia, a soil classification system, which would include temperature regime as stated in Soil taxonomy (Soil survey Staff, 1975, Soil Survey Staff, 1998) or in World Reference Base for Soil Resources (IUSS Working group WRB, 2006), has not been made yet. The reason for this could be found in the lack of researches on this subject. Due to its geographical position we can find a great diversity among soil types in Croatia (Table 1). When indentifying temperature regimes it is important to take into account the relation between average annual air temperature and average annual soil temperature (Penzar, 1971, Pleško, 1987). Several researches have shown strong correlation between daily soil temperatures and daily air temperatures (Zhebg et al., 1993). It is common theory that the average annual soil temperature can be estimated by adding 1°C to the annual average air temperature (Yli- Halla and Mokma, 1998).

Table 1. Soils in Croatia and their fraction in land mass

Soil type	Percentage (%)
Luvisol	12.6
Pseudogley	10.4
Eugley	9.1
Calcocambisol	8.5
Rendzina	7.5
Distric Cambisol	5.7
Calcomelanosol	4.6
Terra rosa	4.4

Material and methods

From the agricultural point of view Croatia is divided into three regions: Pannonian, Mountainous and Adriatic. Each of these regions are divided further into sub-regions: East (P1), Central (P2), West (P3), and Northwest (P4) sub-region in the Pannonian region, Sub-mountain (G1) and Mountain (G2) sub-region in the Mountainous region and North (J1), Central (J2), and South (J3) sub-region in the Adriatic region. For each of the nine sub-regions a meteorological station from the operational network of Meteorological and Hydrological Service of Croatia (DHMZ) was selected: Osijek (P1), Požega (P2), Bjelovar (P3), Varaždin (P4), Karlovac (G1), Gospić (G2), Pazin (J1), Zadar (J2) and Opuzen (J3). The monthly and annual air temperature as well as soil temperature data at the depths of 10 and 50 cm for the period from 1981 to 2010 were grouped by sub-regions and depth. The ten soil temperature regimes were used to determine temperature regimes for the soils in the sub-regions: Cryic, Frigid, Hyperthermic, Isofrigid, Isohyperthermic, Isomesic, Isothermic, Mesic, Pergelic and Thermic.

The Cryic soil temperature regime has mean annual soil temperatures greater than 0°C, but less than 8°C, with a difference between mean summer and mean winter soil temperatures greater than 5°C at 50 cm below the surface and cold summer temperatures.

The Frigid soil temperature regime has mean annual soil temperatures greater than 0°C, but less than 8°C, with a difference between mean summer and mean winter soil temperatures greater than 5°C at 50 cm below the surface. The Hyperthermic soil temperature regime has mean annual soil temperatures of 22°C or more and a difference between mean summer and mean winter soil temperatures less than 5°C at 50 cm below the surface. The Isofrigid soil temperature regime has mean annual soil temperatures greater than 0°C, but less than 8°C, with a difference between mean summer and mean winter soil temperatures less than 5°C at 50 cm below the surface. The Isohyperthermic soil temperature regime has mean annual soil temperatures of 22°C or more and a difference between mean summer and mean winter soil temperatures less than 5°C at 50 cm below the surface. The Isomesic soil temperature regime has a mean annual soil temperatures of 8°C or more, but a difference between mean summer and mean winter soil temperatures less than 5°C at 50 cm below the surface. The Isothermic soil temperature regime that has mean annual soil temperatures of 15°C or more but 5°C difference between mean summer and mean winter soil temperatures at 50 cm below the surface. The Mesic soil temperature regime has mean annual soil temperatures of 8°C or more but less than 15°C, and the difference between mean summer and mean winter soil temperatures is greater than 5°C at 50 cm below the surface. The Pergelic soil temperature regime has mean annual soil temperatures of less than 0°C at 50 cm below the surface. In this temperature regime permafrost is present. The Thermic soil temperature regime has mean annual soil temperatures of 15°C or more, but less than 22°C; and a difference between mean summer and mean winter soil temperatures greater than 5°C at 50 cm below the surface.

The relationship between air temperature and soil temperature was determined by using 30-year average air temperature data series and soil temperature data series at both 10 and 50 cm depth. The data that was analyzed was grouped by regions, and for comparing the data, the difference between soil temperatures at both depths and air temperature was determined.

Results and discussion

In the Pannonian region the lowest average monthly soil temperature at a depth of 10 cm was measured in P3 and P4 sub-regions in January (1°C), and the highest in P2 sub- region in July (24.7°C). At a depth of 50 cm the lowest average monthly soil temperature was recorded in P3 sub-region in February (3.1°C) and the highest in P1 sub-region in August (22.6°C). Based on the annual average at the depth of 10 cm soil temperature varied from 11.7°C in P4 sub-region to 13.0°C in P2 sub-region. At a depth of 50 cm soil temperature varied from 12.1°C in P4 sub-region up to 13.3°C in P1 sub-region (Table 2). Average mean winter soil temperatures at the depth of 50 cm varied from 3.8°C in P3 sub-region to 4.9°C in P1 sub-region, whereas the mean summer soil temperatures at the same depth varied from 20.0°C in P4 sub-region to 21.7°C in P1 sub-region. The highest difference between mean summer and mean winter soil temperatures was recorded in P3 region (17.2°C) (Table 3). The highest monthly soil temperature (25.3°C) at the depth of 50 cm was recorded in August 1993 in P1 sub-region. On the other hand the lowest monthly soil temperature, at the same depth, was recorded in February 1981 in P3 sub-region (0.4°C).

Table 2. Monthly and annual averages of air and soil temperatures (°C) in the period 1981-2010

Regions	Sub-regions	Soil depth/air	Months												Average
			I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Pannonian	P1	10 cm	1.4	2.5	6.5	12.1	18.4	22.0	24.3	23.6	18.5	12.9	6.9	2.8	12.7
		50 cm	4.1	4.3	7.1	11.3	16.7	20.2	22.4	22.6	19.2	15.0	10.2	6.2	13.3
		Air	-0.1	1.6	6.5	11.8	17.1	20.1	22.0	21.3	16.7	11.6	5.7	1.3	11.3
		| 10 cm – Air |	1.5	0.9	0.0	0.3	1.3	1.9	2.3	2.3	1.8	1.3	1.2	1.5	1.4
		| 50 cm – Air |	4.2	2.7	0.6	0.5	0.4	0.1	0.4	1.3	2.5	3.4	4.5	4.9	2.0
	P2	10 cm	2.0	3.2	7.2	13.6	18.7	22.3	24.7	23.4	18.0	12.5	7.3	3.3	13.0
		50 cm	4.0	4.2	6.7	11.3	15.4	18.6	21.1	21.1	18.0	14.0	9.8	6.0	12.5
		Air	0.3	2.1	6.9	11.2	16.5	20.0	21.5	20.9	16.2	11.6	5.8	1.5	11.4
		| 10 cm – Air |	1.7	1.1	0.3	2.4	2.2	2.3	3.2	2.5	1.8	0.9	1.5	1.8	1.6
		| 50 cm – Air |	3.7	2.1	0.2	0.1	1.1	1.4	0.4	0.2	1.8	2.4	4.0	4.5	0.9
	P3	10 cm	1.0	1.8	5.8	11.3	17.3	21.1	23.3	22.8	17.6	12.3	6.6	2.5	12.0
		50 cm	3.2	3.1	5.8	10.4	15.5	19.4	21.7	22.0	18.6	14.3	9.3	5.2	12.4
		Air	0.0	2.0	6.8	11.7	16.8	19.9	21.8	21.0	16.2	11.1	5.5	1.2	11.2
		| 10 cm – Air |	1.0	0.2	1.0	0.4	0.5	1.2	1.5	1.8	1.4	1.2	1.1	1.3	0.8
		| 50 cm – Air |	3.2	1.1	1.0	1.3	1.3	0.5	0.1	1.0	2.4	3.2	3.8	4.0	1.2
	P4	10 cm	1.0	1.9	5.9	11.2	17.1	20.7	22.9	22.1	17.0	11.7	6.1	2.2	11.7
		50 cm	3.6	3.8	6.4	10.5	15.2	18.5	20.7	20.9	17.6	13.5	8.8	5.2	12.1
		Air	-0.1	1.6	6.1	10.9	16.0	19.1	20.9	20.1	15.6	10.7	5.3	1.1	10.6
		| 10 cm – Air |	1.1	0.3	0.2	0.3	1.1	1.8	2.0	2.0	1.4	1.0	0.8	1.1	1.1
		| 50 cm – Air |	3.7	2.2	0.3	0.4	0.8	0.6	0.2	0.8	2.0	2.8	3.5	4.1	1.5
Mountainous	G1	10 cm	1.9	3.4	7.3	14.6	20.7	24.1	26.7	24.5	19.4	13.6	8.1	3.4	14.0
		50 cm	4.2	4.4	7.1	12.1	17.2	20.6	23.5	23.2	20.0	15.5	11.1	6.5	13.8
		Air	0.2	2.0	6.7	11.4	16.5	19.7	21.7	20.9	16.2	11.2	5.6	1.3	11.1
		| 10 cm – Air |	1.7	1.4	0.6	3.2	4.2	4.4	5.0	3.6	3.2	2.4	2.5	2.1	2.9
		| 50 cm – Air |	3.0	2.4	0.4	0.7	0.7	0.9	1.8	2.3	3.8	4.3	5.5	5.2	2.7
	G2	10 cm	0.4	0.9	4.1	9.1	15.1	19.4	22.0	21.2	15.9	11.0	5.6	1.7	10.5
		50 cm	3.1	2.4	4.2	8.3	13.2	16.8	19.3	19.8	16.6	13.0	8.6	4.8	10.8
		Air	-0.9	0.3	4.3	8.6	13.7	17.0	19.3	18.7	13.9	9.7	4.5	0.4	9.1
		| 10 cm – Air |	1.3	0.6	0.2	0.5	1.4	2.4	2.7	2.5	2.0	1.3	1.1	1.3	1.4
		| 50 cm – Air |	4.0	2.1	0.1	0.3	0.5	0.2	0.0	1.1	2.7	3.3	4.1	4.4	1.7
Adriatic	J1	10 cm	2.9	3.4	7.0	11.6	16.9	20.7	23.1	22.6	18.5	13.9	8.8	4.6	12.8
		50 cm	5.1	4.8	7.1	10.7	15.0	18.5	21.0	21.6	19.1	15.5	11.4	7.2	13.1
		Air	2.8	3.2	6.6	10.4	15.3	18.9	21.4	20.6	16.1	12.1	7.4	4.0	11.6
		| 10 cm – Air |	0.1	0.2	0.4	1.2	1.6	1.8	2.7	2.0	2.4	1.8	1.4	0.6	1.2
		| 50 cm – Air |	2.3	1.6	0.5	0.3	0.3	0.4	0.4	1.0	3.0	3.4	4.0	3.2	1.5
	J2	10 cm	6.4	7.0	10.5	14.8	20.2	24.5	27.3	26.9	21.8	17.0	11.5	7.7	16.3
		50 cm	8.8	8.7	11.0	14.5	18.7	22.6	25.6	25.9	22.8	18.9	14.2	10.5	16.9
		Air	7.3	7.3	9.9	13.4	18.1	21.8	24.6	24.2	20.1	16.3	11.8	8.5	15.3
		| 10 cm – Air |	1.1	0.3	0.6	1.4	2.1	2.7	2.7	2.7	1.7	0.7	0.3	0.8	1.0
		| 50 cm – Air |	1.5	1.4	1.1	1.1	0.6	0.8	1.0	1.7	2.7	2.6	2.4	2.0	1.6
	J3	10 cm	6.4	7.1	10.4	14.5	19.3	22.9	25.9	25.8	21.0	17.0	11.9	7.6	15.8
		50 cm	8.8	9.1	10.6	14.4	18.3	22.0	25.4	25.9	22.7	18.2	14.2	9.7	16.6
		Air	7.0	7.9	11.1	14.4	19.2	22.9	25.5	25.1	20.9	16.9	11.7	8.1	15.9
		| 10 cm – Air |	0.6	0.8	0.7	0.1	0.1	0.0	0.4	0.7	0.1	0.1	0.2	0.5	0.1
		| 50 cm – Air |	1.8	1.2	0.5	0.0	0.9	0.9	0.1	0.8	1.8	1.3	2.5	1.6	0.7

Table 3. Seasonal average soil temperatures (°C) at 50 cm depth (DJF - winter, MAM - spring, JJA - summer, SON - autumn) and difference between DJF and JJA mean soil temperatures at 50 cm depth in the period 1981-2010

Sub-region	DJF	MAM	JJA	SON	JJA - DJF
P1	4.8	11.7	21.7	14.8	16.9
P2	4.7	11.1	20.2	13.9	15.5
P3	3.8	10.5	21.0	14.0	17.2
P4	4.2	10.7	20.0	13.3	15.8
G1	5.0	12.1	22.4	15.5	17.4
G2	3.4	8.5	18.6	12.7	15.2
J1	5.7	10.9	20.3	15.3	14.6
J2	9.3	14.7	24.7	18.6	15.4
J3	9.2	14.4	24.4	18.3	15.2

In the Mountainous region the lowest average monthly soil temperature at a depth of 10 cm was measured in G2 sub-region in January (0.4°C) and the highest in G1 sub-region in July (26.7°C). At a depth of 50 cm the lowest average monthly soil temperature was recorded in G1 sub-region in February (2.4°C) and highest in G2 sub-region in July (23.5°C). Annual soil temperature at the depth of 10 cm was 14.0°C in G1 sub-region and 10.5°C in G2 sub-region. On the other hand at the depth of 50 cm the average soil temperature in G1 was 13.8°C and 10.8°C in G2 sub-region (Table 2). Average mean winter soil temperatures at the depth of 50 cm varied from 3.4°C in G2 sub-region to 5.0°C in G1 sub-region whereas the mean summer soil temperatures at the same depth varied from 12.7°C in G2 sub-region to 15.5°C in G1 sub-region (Table 3). The highest monthly soil temperature (24.8°C) at the depth of 50 cm was recorded in July 2010 in G1 sub-region. On the other hand the lowest monthly soil temperature, at the same depth, was recorded in February 2006 (0.7°C) in G2 sub-region.

In the Adriatic region the lowest average monthly soil temperature at a depth of 10 cm was measured in J1 sub-region in January (1.4°C), and the highest in J2 sub- region in July (27.3°C). At a depth of 50 cm the lowest average monthly temperature was recorded in J1 sub-region in January (4.1°C) and the highest in J2 sub-region in July and August and in J3 sub-region in August (25.9°C). Based on the annual average at the depth of 10 cm soil temperature varied from 12.7°C in J1 sub-region to 16.3°C in J2 sub-region. At a depth of 50 cm soil temperature varied from 13.3°C in J1 sub-region up to 16.9°C in J2 sub-region (Table 2). Average mean winter soil temperatures at the depth of 50 cm varied from 5.7°C in J1 sub-region to 9.3°C in J2 sub-region whereas the mean summer soil temperatures at the same depth varied from 20.4°C in J2 sub-region to 24.7°C in J2 sub-region (Table 3). The highest monthly soil temperature (29.0°C) at the depth of 50 cm was recorded in August 2003 in J2 sub-region. On the other hand the lowest soil temperature, at the same depth, was recorded in February 1981 in J1 sub-region (1.7°C).

The results shown in Table 2 and Figure 1 indicate that soils in seven out of nine sub-regions (P1, P2, P3, P4, G1, G2, J1) have Mesic temperature regime and soils in two subregions (J2, J3) have Thermic temperature regime. The reason for this partition is that the soils in J2 and J3 have an average annual soil temperature in the temperature range above 15°C and less than 22°C at the depth of 50 cm and the difference between mean summer and mean winter soil temperatures greater than 5°C at 50 cm below the surface, while soils in other sub-regions have the average annual soil temperature between 8°C and 15°C at 50 cm below the surface and for all regions a difference between mean summer and mean winter soil temperatures is greater than 5°C (Table 2, Table 3, Figure 1).

In eight out of nine observed sub-regions the difference between the average annual air temperature and average annual soil temperature at depth of 10 cm was not 1°C, but it rather

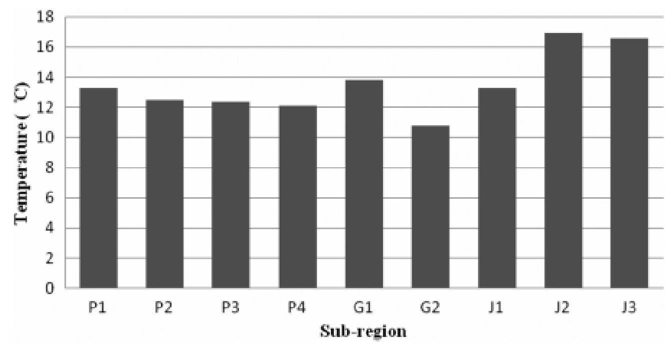

Figure 1. Average annual soil temperatures at 50 cm bellow the surface in agricultural sub-regions in the period 1981-2010

varied from 0.1°C to 2.9°C . The exception was the J2 sub-region. The difference between the average annual air temperature and average annual soil temperature at depth of 50 cm varied from 0.7°C to 2.7°C (Table 2). In the Pannonian region the largest difference between average year air temperature and average soil temperature at 10 cm was 1.6°C in P2 sub-region. The bigest difference between average year soil temperature at 50 cm and average year air temperature was in P1 sub-region (2.0°C). In the Mountainous region the bigest difference between average year soil temperature at 10 cm and annual air temperature was 2.9°C in G1 sub-region, whereas the difference between the average year soil temperature at 50 cm and average year air temperature was 2.7°C in G1 sub-region. The bigest difference between average year soil temperature at 10 cm and average year air temperature in the Adriatic region was 1.2°C in J1 sub-region and the largest difference between average year air temperatures and average year soil temperatures at 50 cm depth was 1.6°C in J2 sub-region (Table 2).

Conclusions

We can conclude that due to its geographical position and climate conditions that occur in this area, soils in Croatia have different temperature regimes depending on the area. As far as the relation between average annual air temperature and average annual soil temperature in both 10 and 50 cm depths are concerned the general rule of adding 1°C to the air temperature in order to estimate the soil temperature has proven to be incorrect in this research. Again, this result could be due to the geographical position and climate condition of the observed area. If the observed area was smaller the results would perhaps differ.

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