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EFFECT OF LAND USE AND SOIL PROPERTIES ON SOIL TEMPERATURE DISTRIBUTION OF CAMBISOLS IN MOUNTAIN REGIONS

Milena KERCHEVA[1*], Maria GLUSHKOVA[2], Katerina DONEVA[1], Stanimir STOINOV[1], Emiliya VELIZAROVA[3]

[1]Department of Physics, Erosion, Soil Biota, Institute of Soil Science, Agrotechnology and Plant Protection "N. Poushkarov", Sofia, Bulgaria
[2]Forest Research Institute, Bulgarian Academy of Sciences, Sofia, Bulgaria
[3]Ministry of Environment and Water, Sofia, Bulgaria
*Corresponding author: mkercheva@abv.bg

ABSTRACT

The aim of this study was to assess the effect of land use, location, and soil properties on the distribution and dynamics of the soil temperature, the accumulated heat and the apparent thermal diffusivity of Cambisols in three mountain regions in Bulgaria. Annual distribution of the soil temperature (Ts) of Cambisols was registered under different land use (grassland, bare soil, deciduous and coniferous vegetation) during period June 2018-May 2021. Every day measurements were realized at 0, 2, 5, 10, 20, and 50 cm depths in 11 plots within the territory of the experimental stations Gabra (~920 m.), Govedartzi (~1540 m.), and Igralishte (~850 m) of the Forest Research Institute, situated in the Lozen, Rila and Maleshevska Mountains, respectively, in the South-Western part of Bulgaria. The experimental stations differ in climatic conditions and soil physical and chemical properties. The heat accumulated in 0-50 cm soil layer was assessed by the sum of Ts for the period with Ts > 5^{o}C. The heat accumulated in bare soil was the highest (4067-3544^{o}C), followed by the sums under grassland (3849-3453 ^{o}C) and forest (3096-3300 ^{o}C) in Gabra and Igralishte. The relative decrease of the accumulated heat under woodland in comparison to grassland was 18-20% in Gabra and 4-7% in Igralishte. At the higher elevation in Govedartzi the heat accumulated under grassland was 10-12% less than under woodland. The apparent thermal diffusivities (~) were estimated using annual amplitudes of Ts at depths 0.02 and 0.20 m. The data showed that the values of ~ under grass in Gabra 0.212 $mm^2\ s^{-1}$ and in Igralishte 0.535 $mm^2\ s^{-1}$ were higher than under forest vegetation 0.061-0.133 $mm^2\ s^{-1}$ and bare soil 0.049-0.071 $mm^2\ s^{-1}$. In Govedartzi the thermal diffusivity was higher 0.118 $mm^2\ s^{-1}$ under Norway spruce than under grassland 0.070 $mm^2\ s^{-1}$ and Scots pine 0.079 $mm^2\ s^{-1}$.

Keywords: *Soil temperature distribution, Cambisols, Mountains, Land use, Bulgaria.*

INTRODUCTION

Soil temperature is important pedoclimatic characteristic and influences a lot of physical, chemical, and biological processes in soils (Paul et al., 2004). Soil temperature is determined by the intercept of solar radiation and hence depends on the geographical location, vegetation cover and meteorological conditions. Soil temperatures are more affected by the presence woodland canopy than air temperatures (Morecroft et al., 1998). The canopy shading and the presence of litter layer lead to reduction of daily and annual soil temperature amplitudes (Morecroft et al., 1998; Andrade et al., 2010). The temperature distribution along the soil depth depends on the soil properties (texture, soil water and air content, soil organic carbon content, bulk density, etc.) and can be predicted by combining energy balance with heat flux equation or empirical relationships (Kang et al., 2000). The apparent thermal diffusivity which is a measure of the heat dissipation increases with the soil water content and bulk density (Ochsner et al., 2001), but it is less sensitive to water content in comparison to thermal conductivity and heat capacity (Morecroft et al., 1998). The information of soil temperature characteristics under adjacent woodland (coniferous, deciduous forest) and open site (bare soil/grassland) in the mountain regions was not found.

The aim of this study was to assess the effect of land cover, location and soil properties on the distribution and dynamics of soil temperature, the accumulated heat, and the apparent thermal diffusivity of Cambisols in three mountain regions in Bulgaria.

MATERIALS AND METHODS

The soil temperature of Cambisols was measured under different land use in the experimental stations of the Forest Research Institute: Gabra in the Lozen Mountains (grassland, bare soil, deciduous and mixed forest); Govedartzi in the Rila Mountains (grassland, Scots pine, Norway spruce); Igralishte in the Maleshevska Mountains (grassland, bare soil, deciduous – oak forest, and Scots pine forest), all situated in South-Western Bulgaria. The geographic coordinates of the stations are presented in Table 1. The daily registrations of soil temperature were performed by mercury thermometers in the morning and at noon at 0, 2, 5, 10, 20, and 50 cm soil depths in 11 plots during the period June 2018 - May 2021. The daily sums of precipitation were measured at grassland plots in all stations and at forest plots in Govedartzi station.

The obtained soil temperature data for the studied period were used for determining the following characteristics: mean, maximum and minimum monthly temperatures, heat accumulation in 0-50 cm soil for the period with $T_s > 5^oC$; mean apparent thermal diffusivity (**~**, $mm^2\ s^{-1}$). The procedure for determination of the apparent thermal diffusivity using the annual soil temperature wave at two depths was described in detail by Marinova (1993) and applied by Doneva and Kercheva (2017) for Alluvial-meadow soil. In the current study the 3-years average daily temperature data were approximated with 5th-order polynomial curve to determine the position of the annual maximum and minimum and then the amplitudes attenuation method was applied for determining of ~ (Horton et al., 1983). The term “apparent” means that both processes – conduction and convection – are performed in heat transfer in moist soil and in the presence of a temperature gradient.

RESULTS AND DISCUSSION

Some of the main soil characteristics of the studied Cambisols are presented in Table 1. The highest contents of soil organic carbon (SOC) 4.2-6.8% were obtained for Govedratzi station, situated at the highest altitude – above 1500 m in the Rila Mountains. The soils in the other two stations were with lower SOC and coarser texture, especially in Igralishte where the soils were classified as loamy sand. The content of coarse fragments at 0-5 cm soil depth varied from 6 to 26% by mass in Gabra and Govedartzi, and from 1 to 18% by mass in Igralishte. The profiles are shallow and the content of rock fragments increased significantly below 25-30 cm soil depth. Additional information on the soil hydraulic properties of these profiles can be found in Kercheva et al. (2019).

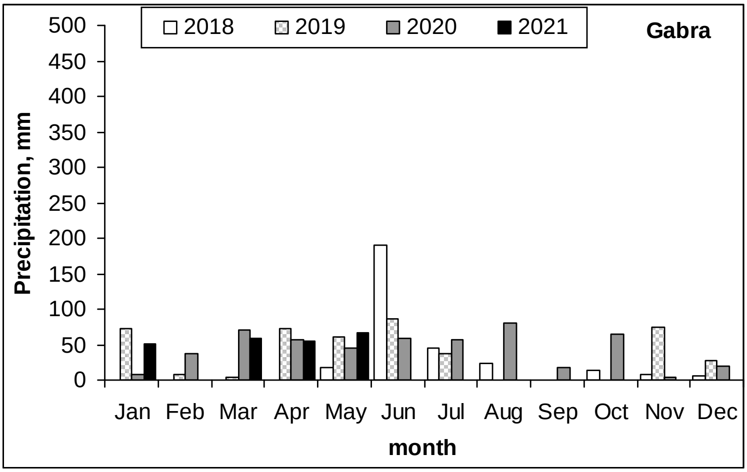
The sites differed according to the amount and distribution of precipitation during the studied period (Fig. 1). The southernmost experimental station Igralishte (Fig. 1b) was characterized with winter maximum of precipitation which is typical for the Mediterranean climate. During the studied period the monthly sums varied significantly in Govedartzi (Fig. 1c). The complete annual records obtained for 2019 and 2020 showed that the annual precipitation was higher in 2020. The annual sums of these years were 442 and 520 mm in Gabra (Fig. 1a), 446 and 505 mm in Igralishte (Fig. 1b), and 356 mm and 910 mm in Govedartzi (Fig. 1c). The highest monthly sums 346-435 mm were registered in June 2020 in Govedartzi.

The monthly average soil temperatures of the coldest month (January) and the hottest month (July or August) are presented in Table 2. The soil temperature slowly increased with depth in the coldest month which indicated the direction of heat flux towards the surface. The average winter temperatures were negative only at Govedartzi. The soil freezing and wetter climate at these high altitudes influence lot of soil properties through their effect on biological activity and physical disruption of soil aggregates. The monthly soil temperatures below 20 cm soil depth under forest were higher than under grass and bare soil. The lower temperatures under Norway spruce than under Scots pine and grassland at Govedartzi is resulting from the higher altitude (Table 1). The differences between the studied vegetation covers were well pronounced in the summer and at the lower altitudes (Gabra and Igralishte). These results coincide with finding of Morecroft et al. (1998) regarding soil temperature under woodland and open site registered at low altitude. The bare soil in our study was characterized with the highest surface temperature and this effect was preserved till 20 cm soil depth where the temperature equalized that under grass. The soil temperatures under woodland were lower than under grass by 2.2 to 3.6 ^{o}C in Igralishte and by 4 to 5.5 ^{o}C in Gabra. In Govedartzi such effect was less pronounced (1 to 2.2^{o}C) and was observed only in the surface 0-5 cm soil layer. The soil temperatures under grass in

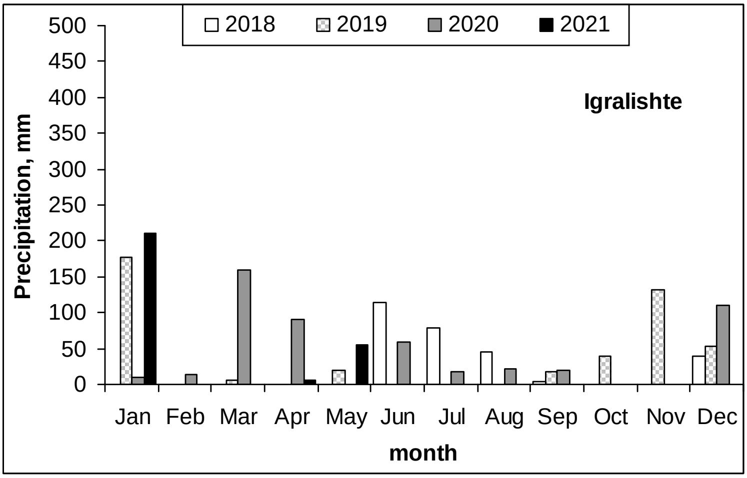
Govedartzi was 7-8 ^{o}C lower than those in Igralishte and 8-9 ^{o}C than in Gabra, which can be explained beside the difference in elevation with the dryer conditions in Igralishte.

Table 1. Location of soil profiles and basic properties: SOC – soil organic carbon content, pH, soil textural fractions and classification according to IUSS Working Group WRB (2015).

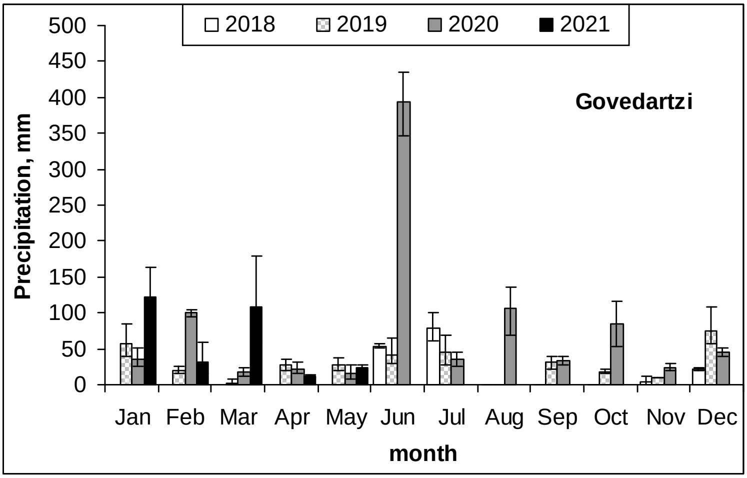
Location	Land use	Depth (cm)	SOC (%)	pH (H_2O)	Sand (%)	Silt (%)	Clay (%)	Texture class
Gabra	Grassland	0-5	1.5	5.2	32	47	21	loam
23.63E	Deciduous forest	0-5	2.7	3.9	52	29	20	sandy loam
42.53N		15-20	0.9	3.8	52	31	17	sandy loam
916-937 m	Mixed forest	0-5	1.5	4.0	54	32	14	sandy loam
Govedartzi	Grassland	0-5	5.9	4.1	46	34	20	loam
23.46-23.42E	Scots pine	0-5	4.2	4.2	43	37	19	loam
42.22N	Norway spruce	0-5	6.8	3.7	48	32	20	loam
1503-1579 m								
Igralishte	Grassland	0-5	2.9	4.6	72	21	7	sandy loam
23.13E		10-20	0.4	4.1	82	15	3	loamy sand
41.57N	Deciduous	0-5	2.4	4.5	73	25	2	loamy sand
848-869 m	forest	10-15	1.1	3.9	74	21	5	loamy sand
	Scots pine	0-5	0.3	4.5	82	14	4	loamy sand



a)



b)



c)

Fig. 1. Monthly sums of precipitation during the studied period (June 2018-May 2021) in Gabra (a), Igralishte (b) and Govedartzi (c)

Table 2. Average monthly soil temperature for the coldest (January) and hottest (July or August, the latter marked with "*") months.

a) Gabra

Depth	Grassland		Bare soil		Deciduous		Scots pine	
cm	Jan	Aug	Jan	Aug	Jan	Aug	Jan	Aug
0	0.3	23.3	0.2	24.7	0.8	19.3	0.0	20.2
2	0.2	22.9	0.2	24.2	0.9	17.5	0.2	19.1
5	0.3	21.7	0.3	23.4	1.2	17.1	0.5	17.9
10	0.6	21.0	0.5	22.1	1.5	16.8	1.0	17.6
20	1.5	21.6	1.5	22.2	2.4	16.5	1.9	17.7
50	2.6	20.4	2.7	21.3	3.4	15.8	3.0	16.2

b) Igralishte

Depth	Grassland		Bare soil		Deciduous		Scots pine	
cm	Jan	Jul/Aug*	Jan	Jul/Aug*	Jan	Jul/Aug*	Jan	Aug
0	0.0	23.2	0.1	25.3	0.3	21.0	0.8	19.7
2	0.4	20.9	-0.1	25.4	0.4	20.2	1.0	18.3
5	0.2	20.9	-0.2	24.1	0.6	18.2	1.1	18.1
10	0.3	20.0	0.3	22.3	1.2	17.8*	1.5	17.6
20	0.8	19.7*	0.6	19.5*	2.0	17.4*	2.7	17.2
50	2.5	18.7*	2.5	19.0*			3.5	16.4

c) Govedartzi

Depth	Grassland		Scots pine		Norway spruce	
cm	Jan	Jul/Aug*	Jan	Aug	Jan	Aug
0	-1.7	15.3	-2.0	13.2	-2.2	13.1
2	-1.4	14.2	-1.9	12.8	-1.8	12.7
5	-1.2	13.4	-1.6	12.3	-1.5	12.0
10	-0.9	12.7*	-1.2	12.6	-1.1	12.2
20	-0.6	12.2*	-0.6	12.0	-0.6	11.7
50	-0.4	11.1*	0.6	10.9	0.5	10.8

The heat accumulated in 0-50 cm soil layers was expressed as sum of weighed temperatures along the whole layer for the period with Ts > 5^{o}C (Table 3). The mean sums under bare soil were the highest (4067-3544 ^{o}C), followed by the sums under grassland (3849-3453 ^{o}C) and forest (3096-3300 ^{o}C) in Gabra and Igralishte. The decrease of the accumulated heat between woodland and grassland were best pronounced in Gabra by 18-20% and by 4-7% in Igralishte. The latter were in agreement with the reported decrease of 0-10% in woodland by Morecroft at al. (1998). At the higher elevation in Govedartzi the heat accumulated under grassland 1617 ^{o}C was 10-12% less than under woodlands (Scots pine and Norway spruce) which was 1800 ^{o}C in average.

Table 3. Soil heat accumulation (Ts, °C) for 0-50 cm soil layer, period with Ts_{0-50} > 5°C.

Land use	Gabra		Igralishte		Govedartzi	
	ΣTs, °C	days	ΣTs, °C	days	ΣTs, °C	days
Grassland	3849	268	3453	255	1617	160
Bare soil	4067	272	3544	250		
Deciduous	3175	285	3227	249		
Scots pine	3096	255	3300	286	1810	197
Norway spruce					1782	188

The annual soil temperature amplitudes at two depths 0.02 and 0.20 m are presented in Table 4. The reduction of the annual amplitude at 0.20 m under deciduous and coniferous vegetation in comparison to grassland was 6.3 °C and 4.6 °C in Gabra. In Igralishte these reductions were 3.8 and 5 °C correspondingly under deciduous and coniferous vegetation. The differences can be explained with thickness of litter layer and soil properties, creating different moisture conditions. Andrade et al. (2010) reported that removal of litter layer in Mediterranean conditions can lead to 2.5 °C higher annual amplitude at depth 0.16 m. The amplitudes at 0.02 m of bare soil were 3-4 °C higher than under grass (Table 4).
Based on the approximated annual soil temperature waves at 0.02 and 0.20 m depths the apparent thermal diffusivity was estimated. The relatively short-term period of observations and the variability of moisture conditions among the stations and years (Fig. 1) allowed to regard the obtained estimates for the apparent thermal diffusivity (Table 4) as preliminary. The highest values of ~ were obtained under grassland in Igralishte and Gabra, respectively 0.535 to 0.212 mm^2 s^{-1} (Table 4). The values under bare soil were lower within the range 0.049 to 0.071 mm^2 s^{-1}, which can be attributed to the lower soil water content due to the higher evaporation rates. Most of the values of ~ under woodland were medium within the range 0.075 to 0.133 mm^2 s^{-1}. The exceptions of these ranges were found under grass in Govedartzi (0.070 mm^2 s^{-1}) and under deciduous forest in Igralishte (0.061 mm^2 s^{-1}).

Table 4. Annual amplitudes of soil temperature at 0.02 ($A_{0.02}$) and 0.20 m ($A_{0.20}$) soil depths and apparent thermal diffusivity (~, mm^2 s^{-1}) of 0.02-0.20 m soil layer.

Land use	Gabra			Igralishte			Govedartzi		
	$A_{0.02}$ °C	$A_{0.20}$ °C	***a*** mm^2 s^{-1}	$A_{0.02}$ °C	$A_{0.20}$ °C	***a*** mm^2 s^{-1}	$A_{0.02}$ °C	$A_{0.20}$ °C	***a*** mm^2 s^{-1}
Grassland	22.8	20.2	0.212	21.4	19.8	0.535	17.1	13.8	0.070
Bare soil	25.8	20.8	0.071	25.5	19.7	0.049			
Deciduous	16.9	13.9	0.085	20.1	16.0	0.061			
Scots pine	19.2	15.6	0.075	17.3	14.8	0.133	15.8	12.9	0.079
Norway spruce							16.0	13.5	0.118

CONCLUSIONS

The obtained data and characteristics of the soil temperature in the studied mountain regions in Southwestern Bulgaria, allowed to evaluate the influence of vegetation cover, geographic position, and soil properties on the profile distribution and dynamics of Ts, the accumulated heat and the apparent thermal diffusivity of Cambisols. The information can serve as pedoclimatic characteristics, for predicting the heat exchange and soil temperature under bare soil, grassland, and forest and for describing the interrelations with other soil properties and processes.

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