https://doi.org/10.17221/60/2026-SWR

Impact of urban soil surface treatments on soil water and thermal regimes in Haplic Chernozem

Bunthorn Thet, Hana Raková, Miroslav Fér, Aleš Klement, Antonín Nikodem, Abdul Majid, Radka Kodešová**

Department of Soil Science and Soil Protection, Faculty of Agrobiology, Food and Natural Resources, Czech University of Life Sciences Prague, Prague, Czech Republic

**Corresponding author: thet@af.czu.cz; kodesova@af.czu.cz*

Citation: Thet B., Raková H., Fér M., Klement A., Nikodem A., Majid A., Kodešová R. (2026): Impact of urban soil surface treatments on soil water and thermal regimes in Haplic Chernozem. Soil & Water Res., 21: 159–168.

Abstract: Although it is known that land cover affects soil water and thermal regimes, the influence of different land covers on soil water content and temperature in urban areas is rarely explored. Five soil surface treatments were selected in this study: bare soil, concrete paving, bark mulch, mown grass, and unmown grass. Soil water contents and temperatures were measured at five depths (5, 10, 25, 50, and 80 cm) over one year. The highest water contents were recorded under mulching. Under grass, water contents were lower and showed greater oscillations due to precipitation and evapotranspiration, while under mown grass, values were higher than under unmown grass. Similarly, near-surface bare soil water contents also fluctuated. The water content under the concrete remained almost constant. While the soil under concrete paving, bare surfaces and even mown grass warmed up considerably during the day because of the absorption of solar radiation and cooled down at night due to the emission of stored heat, the soil under bark mulch and unmown grass cover showed smaller temperature fluctuations, mainly due to the low thermal conductivity of the surface layer and surface shading. The effects revealed throughout the entire soil profiles decreased with depth.

Keywords: bare soil; bark chips; concrete paving; grass; soil temperature; soil water content

Soil water and temperature regimes are very important because they have a direct impact on soil properties and also on microbial activity, plant growth, and nutrient availability. Both regimes are significantly influenced by soil cover. It depends on the type of vegetation, its growth, condition, and density (Niu et al. 2015; Özkan & Gökbulak 2017; Ni et al. 2019; Yang et al. 2021), as well as on the materials that cover the soil surface. For example, these materials can be various mulches, which can be either of organic (bark, wood chips, and post-harvest residues) or inorganic (gravel, sand) origin, or various foils (e.g., Maggard et al. 2012; Kodešová et al. 2014; Hernández et al. 2016; Kader et al. 2017a, b; Pavlů et al. 2021; Zhang et al. 2023, 2024). In urban areas, the soil surface is also covered with various solid materials used in the construction of sidewalks, roads, and parking lots (e.g., concrete pavement, asphalt, and paving stone) (e.g., Asaeda & Ca 2000; Morgenroth & Buchan 2009; Kodešová et al. 2014; Fini et al. 2017). Different soil covers can thus affect the water and temperature regime of soils both positively and negatively. While various mulching materials are expected to have a rather positive ef-

Supported by the European Structural and Investment Funds, project NutRisk No. CZ.02.1.01/0.0/0.0/16_019/0000845 and by the Czech University of Life Sciences Prague, Project No. SV26-1-21130.

https://doi.org/10.17221/60/2026-SWR

fect, a rather negative effect is expected for paved surfaces or bare soils.

In previous studies, soil water and temperature regimes under different surfaces, which may occur in urban environments, e.g., concrete pavement, bark mulch, grass, and bare soil, were usually studied separately for agricultural and horticultural soils and soils with built-up surfaces. In addition, there is limited information on the effect of lawn maintenance on soil regimes. Therefore, the aim of this work was to evaluate how these different soil surface treatments and lawn maintenance can affect the water and temperature regimes in one soil type (Haplic Chernozem). The task was to evaluate data monitored over a period of one year and confirm or refute the above assumptions regarding the positive or negative effects of different soil surfaces.

MATERIAL AND METHODS

Study location and test site parameters. The study was conducted in the experimental site of the Czech University of Life Sciences Prague in Prague – Suchdol, the Czech Republic (50°8'8.9"N, 14°22'49.7"E), elevation of 271 m a.s.l. The soil type was defined as Haplic Chernozem on loess (IUSS 2014). Basic soil properties, hydraulic properties, and thermal properties are shown in Tables S1, S2, and S3 in Electronic Supplementary Material (ESM). Data in Tables S1 and S3 (in ESM) were presented by Kodešová et al. (2013). Soil hydraulic properties (Table S2 in ESM) were measured on the undisturbed 100-cm^3 soil samples using the multistep method that is in detail described for example by Thet et al. (2024). Soil samples for all measurements were taken at the beginning of the experiment. The soil was originally covered with grass. In the fall of 2012, five experimental plots (each measuring 1.5 × 1.5 m) were created (Figure S1 in the ESM). Grass from three plots was removed. One plot was left uncovered where weeds were removed regularly (bare soil – BS). The second plot was covered with concrete tiles (concrete paving – CP). The third plot was covered with layers of bark chips 5 cm thick (bark chips – BC), which were often replenished. The other two plots were covered with grass. On one plot, the grass was regularly mowed to a height of 5 cm (mown grass – MG), and on the other, it was mowed once a year at the end of the growing season to a height of 15 cm (unmown grass – UG).

Climatic conditions (i.e., air temperature, solar radiation, and rainfall intensity) were measured using a Davis Vantage Pro 2 – model 6162 (Davis Instruments Corporation, Hayward, CA, USA). The ECH2O-TE sensors (Decagon Devices Pullman, WA, USA) were installed at depths of 5, 10, 25, 50, and 80 cm on each plot, measuring soil temperature and soil water content at 30-min intervals. Water content sensors were calibrated using the procedure described by Kodešová et al. (2011). The field experiment was described in detail by Thet et al. (2024), who studied the influence of different surfaces on the chemical and physical properties of the soil at a depth of 1–11 cm below individual surfaces.

Data evaluation. This work evaluates data measured during 2020, i.e. during the period when measurements and soil sampling were carried out by Thet et al. (2024). Because the experiment began in 2012, some sensors in 2020 showed temporary outages or errors in measurements, which were removed from the data file. In addition, during January, soil temperatures were often below zero. At such low temperatures, the sensors cannot provide reliable values. Therefore, the measurements obtained in this month were excluded. To compare the effects of different surfaces on the temperature and water regime of the soil, the monthly average values and standard deviations were calculated similarly to the study by Pavlů et al. (2021). To reduce the degree of distortion, days with less than 40 measured data (i.e. 8 or more missing values per day) and then months with five or more missing days were excluded from the comparison. The influence of surfaces on daily temperature fluctuations was also investigated. From the measured data, daily maximum and minimum measured temperatures were selected, and their difference was averaged to monthly average values (according to the same key as before, values for some days and months were excluded). Furthermore, average monthly air temperatures, monthly solar radiation totals, and monthly precipitation totals were calculated to illustrate climatic conditions affecting soil water and temperature regimes. In addition, to determine whether the differences between soil water contents and temperatures measured at individual depths under different surfaces are statically significant, measured data during two months were selected, one with the highest soil temperatures (July) and one with low soil temperatures (December, as complete data sets were not available for the months of February and March) and analysed using Kruskal-Wallis tests and box and whisker plots. Statistical analyses were performed using STAGRAPHICS Centurion XV (Ver.15.2.06.)

https://doi.org/10.17221/60/2026-SWR

RESULTS AND DISCUSSION

Soil water regime. The average monthly soil water contents under individual surface at different depths and their standard deviations are shown in Figures S2 and S3 in the ESM, respectively. Figure S2 in the ESM also includes monthly precipitation totals. The average monthly soil water contents at individual depths below different surfaces and their standard deviations are presented in Figures 1 and 2, respectively. Soil water contents varied most in the upper part of the soil, which confirmed the greatest influence of precipitation and evapotranspiration on soil water content. It was not possible to unambiguously identify the general pattern of the influence of various soil surface treatments on average monthly values in various depths. Statistical analysis performed for data monitored at each depth in both July and December showed statistically significant differences at the 95.0% confidence level between values measured below different surfaces. Which demonstrated a statistically significant effect of various adjustments on the measured values at all depths. However, analyses did not also reveal the same trends in average values (Figure 1) or medians (which are not shown, but they followed similar patterns as average values), affected by various surfaces in different depths.

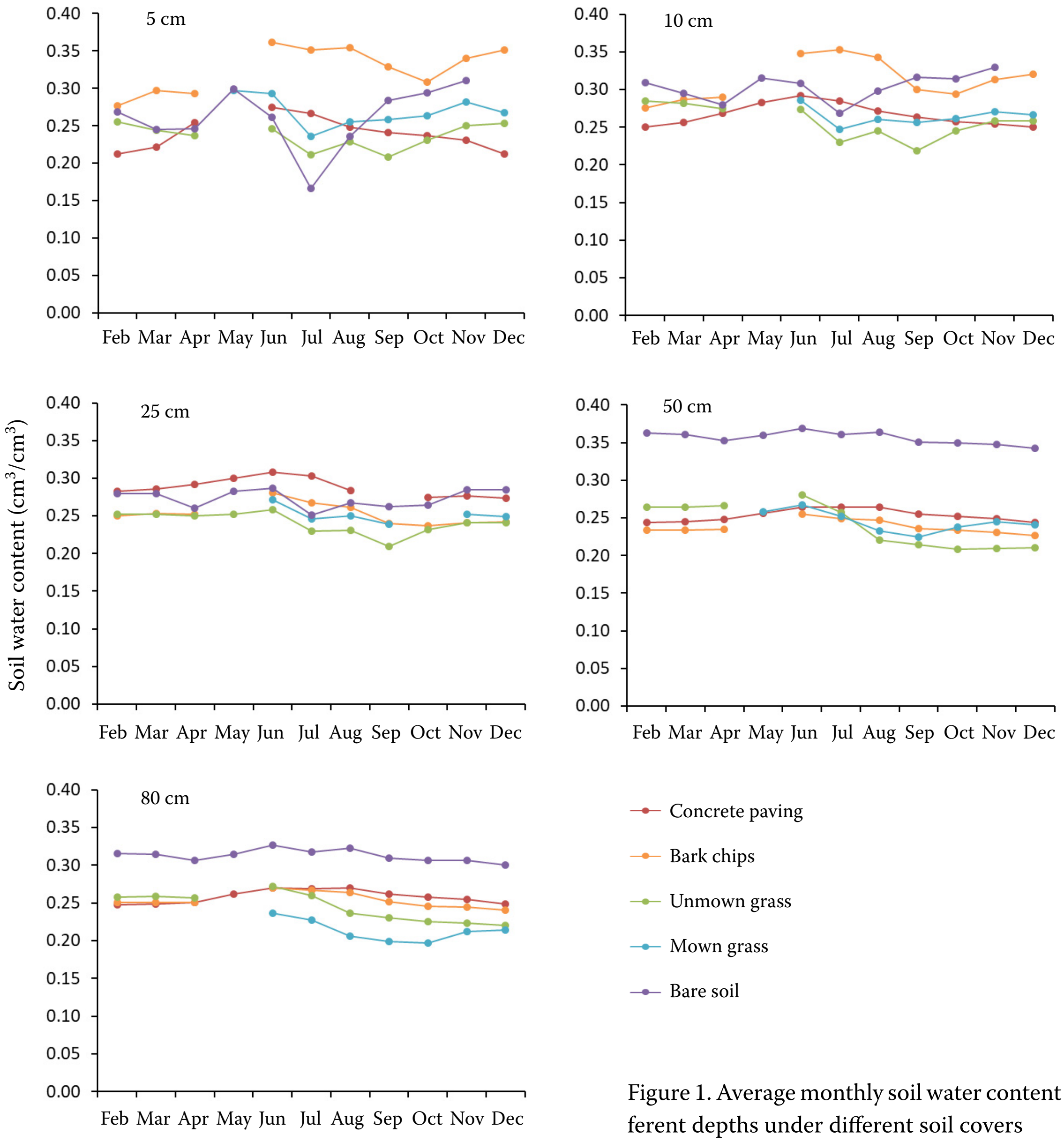

Figure 1. Average monthly soil water content at different depths under different soil covers

https://doi.org/10.17221/60/2026-SWR

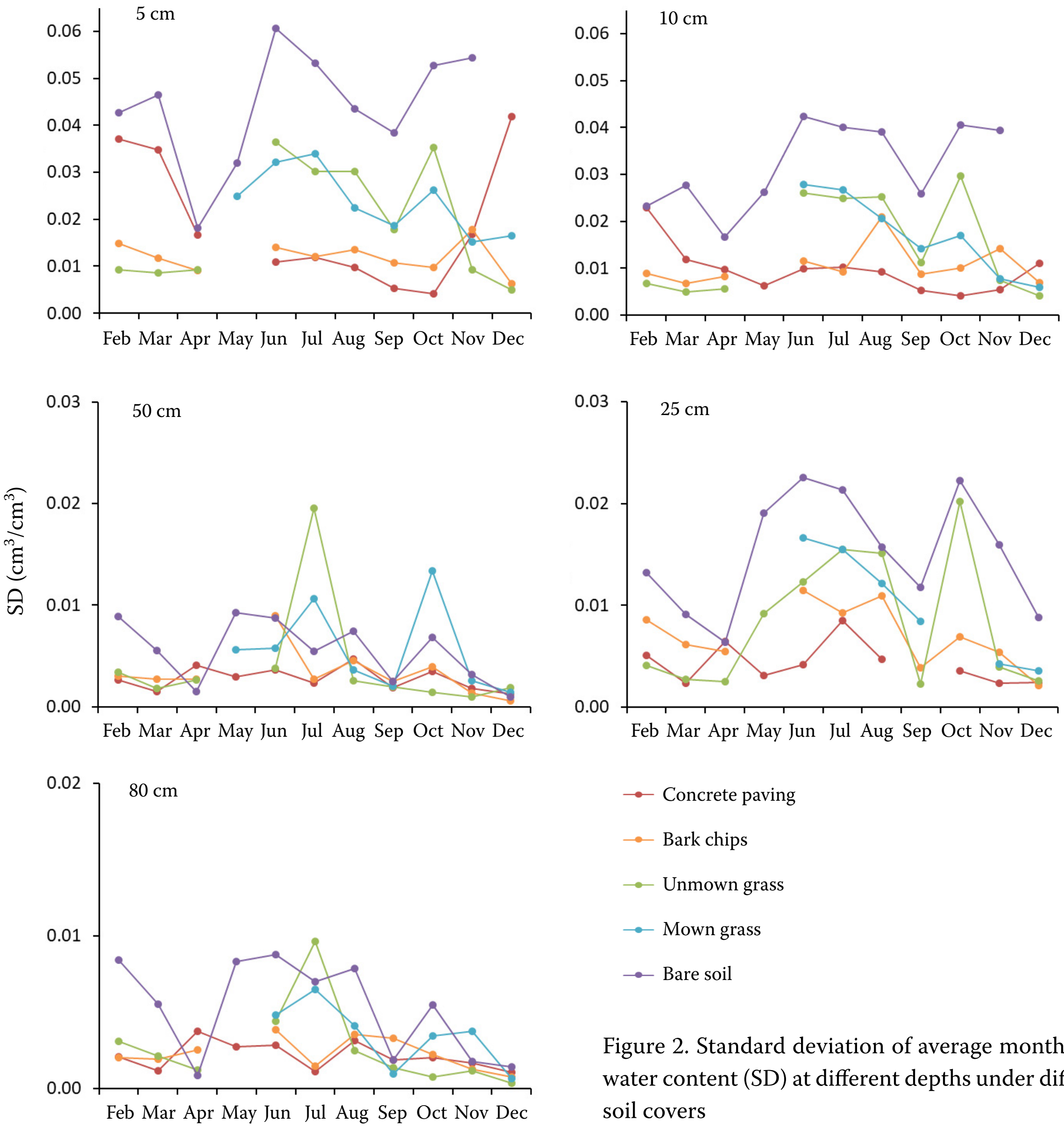

Figure 2. Standard deviation of average monthly soil water content (SD) at different depths under different soil covers

Soil water content under concrete tiles (CP) remained almost constant regardless of the total precipitation, due to the low rate of precipitation infiltration and limited evaporation from the surface. As a result of reduced evaporation, the surface heats up significantly during the day by absorbing solar radiation, and when it cools down in the evening, water vapour condenses on the underside of the surface and moisture returns to the upper soil layers (Asaeda & Ca 2000; Morgenroth & Buchan 2009; Fini et al. 2017). For example, Morgenroth and Buchan (2009) and Kodešová et al. (2014) observed that soil moisture under a concrete pavement was close to field water capacity.

The mulch layer (BC) maintained higher soil water content in the subsurface soil layers, which coincides with the results of Maggard et al. (2012), Kodešová et al. (2014), Hernández et al. (2016), and Kader et al. (2017a, b). However, this effect could not be observed throughout the year by Pavlů et al. (2021), where perennials (*Geranium sanguineum* Ankum's Pride, *Hemerocallis* Stella D'Oro, *Salvia nemorosa* Caradonna, *Echinacea purpurea* Primadonna Deep Rose, *Coreopsis verticilata* Grandiflora, and *Heuchera sanguinea* Leuchtkäfer) were grown on the plots. Mulching materials could thus influence water infiltration and evaporation from the soil surface during spring and autumn, but during the growing

https://doi.org/10.17221/60/2026-SWR

season, the water regime was also influenced by plant transpiration. However, the differences in the effects of various mulches remained.

Soil water content under the grass surface (MG and UG) was lower than under the mulch layer, which is consistent with studies by Byrne et al. (2008) and Kodešová et al. (2014). Soil water contents measured at a depth of 25 cm and below under the grass covers were also often lower than those under other covers. This was again mainly due to plant transpiration. Soil water contents under mown grass (MG) were usually higher (except those at the depth of 80 cm) than under unmown grass (UG), which can be explained by the interception of rainwater on the plants and perhaps also by higher transpiration.

The highest and almost constant soil water content was measured at depths of 50 and 80 cm under the bare surface (BS), where there is no immediate influence of water infiltration or evaporation. The soil water content in the upper layers of the soil fluctuated primarily due to precipitation that percolates relatively quickly into the soil and evaporation from the soil surface (e.g., Morgenroth & Buchan 2009; Kader et al. 2017a, b; Ni et al. 2019).

Soil water content regimes at greater depths below individual surfaces could be partially influenced by the surrounding environment, i.e. regimes under other surfaces, particularly under mowed grass, which was prevalent on a given area, because the flow of water in the soil is not only vertical. However, the statistical analysis performed for both months documenting significant differences between measured values in all depths did not indicate a strong effect. To evaluate the influence of the surrounding environment, i.e. water flow in a three-dimensional space, it would be necessary to monitor the water regimes under larger plots with various surfaces using multiple sensors placed at the same depths at different distances from the centre of the plots. Soil water regimes could also be influenced by changes in soil structure and hydraulic properties of the surface soil layer caused by different water and thermal regimes, the increase in organic matter from mulch and grass cover, root growth and the activity of other organisms that have been described by Thet et al. (2024). For example, X-ray and micromorphological analyses performed in this study revealed distinct differences in soil pore structures. Detected pores of bare soil (BS) were predominantly affected by regular human maintenance, specifically weed removal and soil loosening. Pore structures of grass-covered soils (MG, UG) were primarily shaped by roots and soil organisms. Pores of BC and CP soils of were formed mainly by soil organisms. Furthermore, the bark chip mulch (BC) caused the soil to become more compact due to mulch decomposition and the migration of its components. Detected larger pores increased water percolation into the soil, while finer pores with an appropriate size distribution increased water retention in the soil. The similar effect of mulch decomposition on soil hydraulic properties was documented by Pavlů et al. (2021) and a follow-up study by Fér et al. (2022).

Soil temperature regime. The average monthly soil temperatures under individual surface at different depths and their standard deviations are shown in Figures S4 and S5 in the ESM, respectively. Figure S4 in the ESM also includes monthly average air temperatures and monthly solar radiation totals. The average soil temperatures at individual depth below different surfaces and their standard deviations are presented in Figures 3 and 4, respectively. The average monthly differences between daily maximum and minimum soil temperatures under individual surface at different depths are shown in Figure S6 in the ESM, and the same values at individual depth below different surfaces are presented in Figure 5. The measured values and standard deviations confirmed that the main factor influencing the soil temperature under individual surfaces is solar radiation. In the months with the highest solar radiation, the largest daily temperature fluctuations occurred and the temperature in the upper soil layers exceeded the air temperature. At the same time, there was a gradual heating of the lower soil layers. For most of the year, particularly during the summer months, the highest temperatures were recorded for the CP scenario. Statistical analysis performed for data monitored at each depth in July showed similar decreasing trends in average values (Figure 3) and also medians (not shown) at depths of 5 and 10 cm (CP, BS, MG, BC, and UG), and at depths of 25, 50, and 80 cm (CP, BS, BC, MG, and UG). The differences between the individual variants were mostly statistically significant at the 95% level, except for BC and MG at a depth of 10 cm. During the winter months, the situation was different, e.g., the values at the depth of 5 cm for BC and UG scenarios were slightly higher than those for CP, MG, and BC scenarios. The differences between temperatures measured during December were not as high, which may be one of the reasons why the same trends were not evident at different depths. However, it is important to emphasize that the values measured under various surfaces were again mostly statistically significant. Similarity was found for BC and UG at a depth of 50 cm.

Similar observations were presented by Kodešová et al. (2014). However, with increasing depth, the differences in fluctuations under different covers were smaller compared to the simulated regimes by Kodešová et al. (2014). This difference can be explained by the fact that in the real environment, heat is transferred in three-dimensional space and therefore the temperatures at greater depths were influenced by the surrounding environment, while in the work of Kodešová et al. (2014) only a one-dimensional vertical soil profile was simulated. However, statistical analysis of data monitored in July and December showed that the influence of surrounding areas was probably not as pronounced. To verify the influence of the surrounding environment on the temperature regimes under various ground covers, it would again be necessary to conduct experiments on larger areas and with more sensors at each depth. Significant differences between temperature fluctuations under concrete tiles and grass surfaces were also published by Schaffitel et al. (2020). The highest soil temperature and its oscillation under CP can be attributed to the greater ability of heat exchange of concrete tiles compared to other treatments (Kodešová et al. 2014).

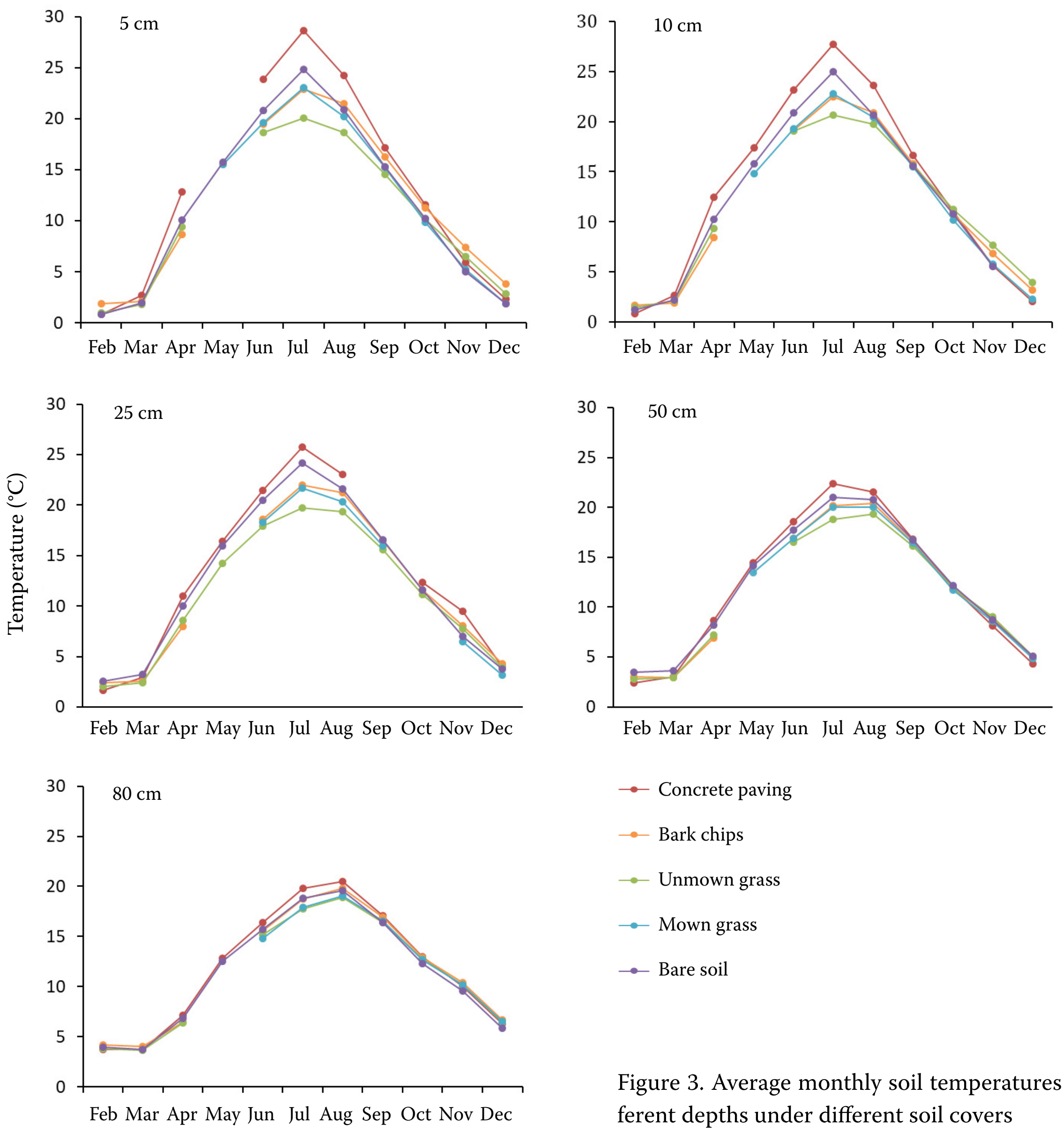

Figure 3. Average monthly soil temperatures at different depths under different soil covers

https://doi.org/10.17221/60/2026-SWR

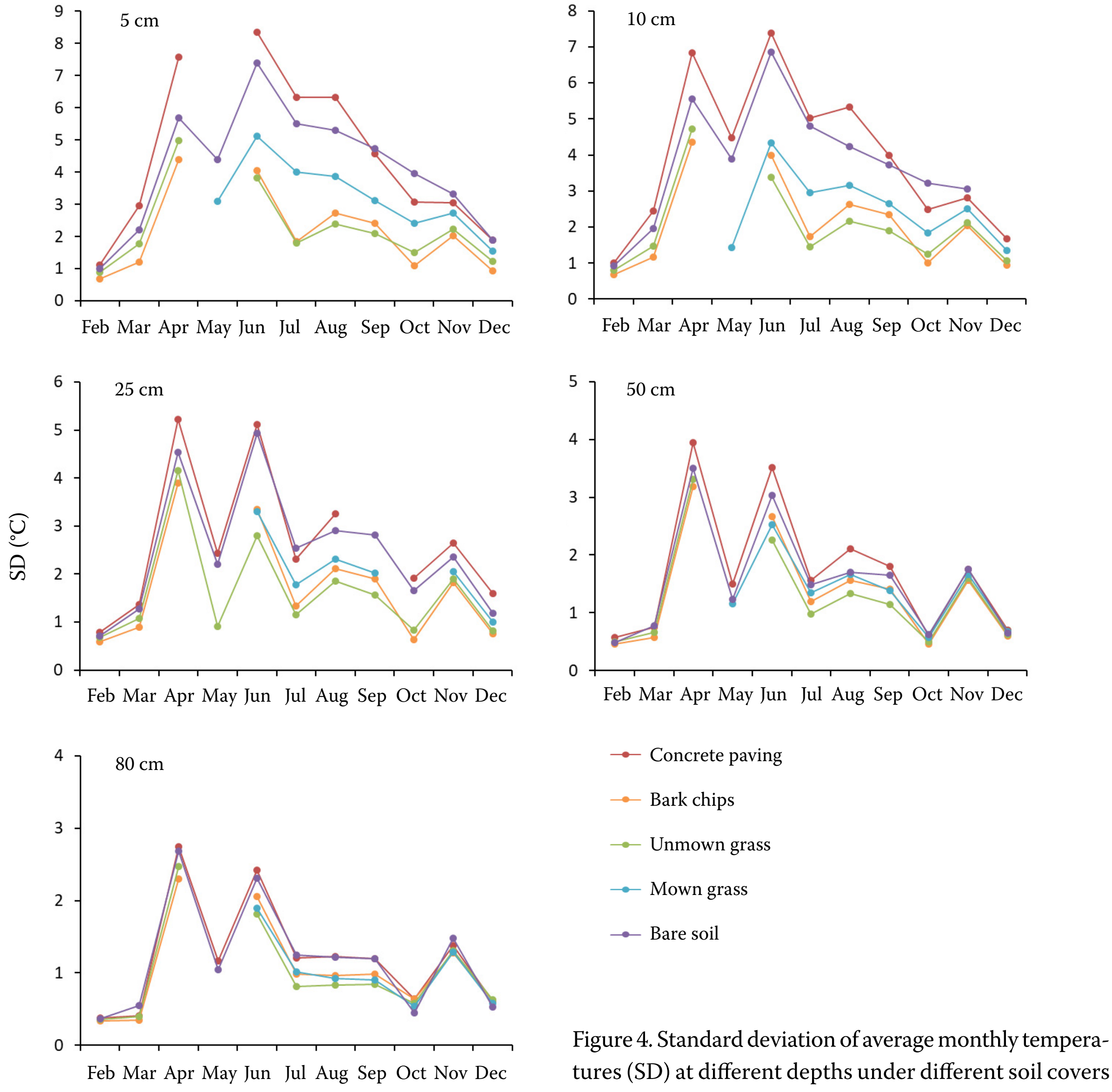

Figure 4. Standard deviation of average monthly temperatures (SD) at different depths under different soil covers

Due to its low thermal conductivity and heat capacity (Table S3 in ESM, Kodešová et al. 2013), and thus slow heat transfer to and from the soil surface, bark chips reduced daily temperature fluctuations, lowered average temperatures during the summer and increased temperature during winter, which was also described by Maggard et. al. (2012), Kodešová et al. (2014), Kader et al. (2017a, b), Pavlů et al. (2021) or Al-Shammary et al. (2024). Similar effect was observed for other organic residues used for soil cover (e.g., Maggard et al. 2012; Pavlů et al. 2021; Rafi & Kazemi 2021; Goettl et al. 2025).

Low temperatures and their low daily oscillations were also recorded in summer under unmown grass. Both were much lower than those under mown grass due to shading of the soil surface in summer, but higher in winter. Vegetation reduces the amount of sunlight falling directly on the soil surface during the day and at the same time these covers prevent the radiation of thermal energy by the soil surface during the night (e.g., Ni et al. 2019). The largest differences up to 10 °C between daily temperature fluctuations for MG and UG scenarios were recorded at the depth of 5 cm during the summer. Similar effect, with smaller differences between these surfaces, was also recorded by Byrne et al. (2008). The effect of shading on soil temperature was also documented by Pavlů et al. (2021), where soil temperature was influenced not only by various mulching materials, but also by the gradual growth of cultivated perennials on individual plots.

On the other hand, high temperatures and their oscillations were measured for the bare soil scenario.

https://doi.org/10.17221/60/2026-SWR

An uncovered or unshaded ground surface allows solar radiation to reach the soil surface and be absorbed. Conversely, during the night, the surface emits the accumulated thermal energy and thus cools down rapidly, which was also documented, for example, by Ni et al. (2019) and Pavlů et al. (2021).

Another possible factor influencing the thermal regimes of soils could be the change in soil properties below individual surfaces. Due to the gradual decomposition of the mulch material and pedoturbation, the organic matter content in the topsoil increased (Thet et al. 2024). Similarly, Thet et al. (2024) noted that the topsoil under unmown grass also showed higher organic matter content, which may be related to the accumulation of organic material at the soil surface that was incorporated into the soil after its decomposition. As documented in Table S3 in ESM (Kodešová et al. 2013), the thermal conductivity (i.e., b_1, b_2, and b_3 values) and capacity (i.e., a value) of bark chips are much lower than those for the studied soils. It can therefore be assumed that the increased organic matter content in the topsoil could have reduced heat transfer in such an amended soil. The increased organic matter content in the soil and the remnants of organic material on the soil surface may therefore have increased the effect of lower thermal conductivity or shading of the soil surface. Heat transfer could be further affected by the grass root system, which could also change the thermal properties. In addi-

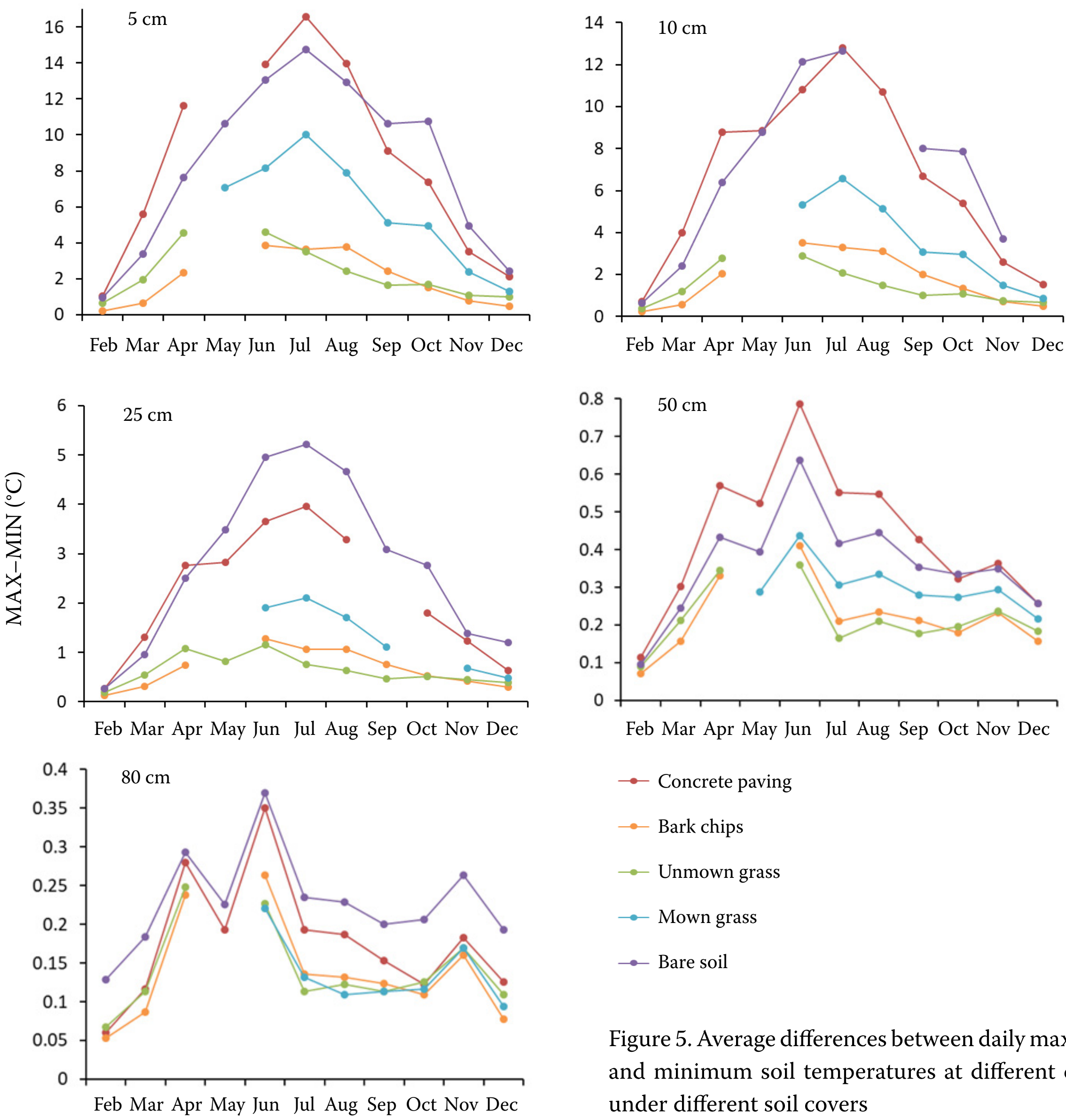

Figure 5. Average differences between daily maximum and minimum soil temperatures at different depths under different soil covers

https://doi.org/10.17221/60/2026-SWR

tion, latent heat flux from plant transpiration could have contributed to soil cooling.

CONCLUSION

The aim of this work was to evaluate the influence of different ground covers, which can occur in an urban environment, on the water and temperature regimes of one selected soil – Haplic Chernozem on loess. The results showed that the soil water contents under concrete pavement showed low oscillations, while the temperature fluctuations were very high, as the surface heated up more during the day. Low soil water oscillations indicated a low rate of precipitation infiltration and thus an increased risk of surface runoff. The high rate of heating of concrete tiles, together with the limitation of evaporation from the soil surface, can contribute to the formation of so-called heat islands. The influence of paved surfaces can therefore be assessed as negative. Similarly, bare soil showed high temperatures and their fluctuations, but also high oscillations in water contents in the 0–25 cm surface layer due to rapid rainwater infiltration and high evaporation. This surface, therefore, also appears to be unfavourable, mainly due to the temperature conditions in the surface layer. Mulched surface has been found to maintain higher water content levels in the subsurface soil layers and reduce temperature fluctuations, with lower temperatures than bare surfaces in the summer months and higher temperatures in the winter months. Since bark mulch is used in urban areas as a cover in flower beds, its positive effect may be greater availability of water for plants in the root zone and at the same time reducing freezing or overheating of roots that can occur when the soil remains bare. The water regime on grassed plots was the most dynamic, as it was directly influenced by precipitation and evapotranspiration. Soil water content under mown grass was usually moderately higher than under unmown grass, probably due to rainwater interception and higher transpiration in the unmown grass plot compared to that in the mown grass plot. A worse temperature regime was recorded on the mown grass plot, i.e. greater heating or cooling of the soil and greater daily oscillations than in the case of the unmown grass plot. The impact of grasslands can be assessed as positive, while not mowing the grass frequently seems to be a more suitable option. The results of this work confirmed the influence of surface type and maintenance on soil regimes, and thus potentially on the microclimate of a given location. Furthermore, although the effects of different soil surfaces decreased with soil depth, they were still evident even at the depth of 80 cm. This suggests that soil properties and soil processes occurring in soils are not only significantly influenced near the soil surface, but throughout the entire soil profile. Although generalising these insights necessitates further study across diverse soil and climatic conditions, the current findings provide valuable applications for urban planning, particularly for mitigating overheating and promoting water retention in the landscape.

REFERENCES

Al-Shammary A.A.G., Al-Shihmani L.S.S., Fernández-Gálvez J., Caballero-Calvo A. (2024): Optimizing sustainable agriculture: A comprehensive review of agronomic practices and their impacts on soil attributes. Journal of Environmental Management, 364: 121487.

Asaeda T., Ca V.T. (2000): Characteristics of permeable pavement during hot summer weather and impact on the thermal environment. Building and Environment, 35: 363–375.

Byrne L.B., Bruns M.A., Kim K.C. (2008): Ecosystem properties of urban land covers at the aboveground–belowground interface. Ecosystems, 11: 1065–1077.

Fér M., Nikodem A., Trejbalová S., Klement A., Pavlů L., Kodešová R. (2022): How various mulch materials can affect the soil hydro-physical properties. Journal of Hydrology and Hydromechanics, 70: 269–275.

Fini A., Frangi P., Mori J., Donzelli D., Ferrini F. (2017): Nature based solutions to mitigate soil sealing in urban areas: Results from a 4-year study comparing permeable, porous, and impermeable pavements. Environmental Research, 156: 443–454.

Goettl B., Da Ros Carvalho H., Heitman J., DeSutter T. (2025): The impact of residue and cover crop management on soil water and temperature regimes in a loam soil in North Dakota. Agrosystems, Geosciences & Environment, 8: e70223.

Hernández J.R., Navarro-Pedreno J., Gómez Lucas I. (2016): Evaluation of plant waste used as mulch on soil moisture retention. Spanish Journal of Soil Science, 6: 133–144.

IUSS (2014): World Reference Base for Soil Resources 2014. World Soil Resources Reports No. 106. Rome, FAO.

Kader M.A., Senge M., Mojid M.A., Ito K. (2017a): Recent advances in mulching materials and methods for modifying soil environment. Soil and Tillage Research, 168: 155–166.

Kader M.A., Senge M., Mojid M.A., Nakamura K. (2017b): Mulching type-induced soil moisture and temperature

https://doi.org/10.17221/60/2026-SWR

regimes and water use efficiency of soybean under rainfed condition in central Japan. International Soil and Water Conservation Research, 5: 302–308.

Kodešová R., Kodeš V., Mráz A. (2011): Comparison of two sensors ECH2O EC-5 and SM200 for measuring soil water content. Soil and Water Research, 6: 102–110.

Kodešová R., Vlasáková M., Fér M., Teplá D., Jakšík O., Neuberger P., Adamovský R. (2013): Thermal properties of representative soil of the Czech Republic. Soil and Water Research, 8: 141–150.

Kodešová R., Fér M., Klement A., Nikodem A., Teplá D., Neuberger P., Bureš P. (2014): Impact of various surface covers on water and thermal regime of Technosol. Journal of Hydrology, 519: 2272–2288.

Maggard A.O., Will R.E., Hennessey T.C., McKinley C.R., Cole J.C. (2012): Tree-based mulches influence soil properties and plant growth. HortTechnology, 22: 353–361.

Morgenroth J., Buchan G.D. (2009): Soil moisture and aeration beneath pervious and impervious pavements. Arboriculture & Urban Forestry, 35: 135–141.

Ni J., Cheng Y., Wang Q., Ng C.W.W., Garg A. (2019): Effects of vegetation on soil temperature and water content: Field monitoring and numerical modelling. Journal of Hydrology, 571: 494–502.

Niu C.Y., Musa A., Liu Y. (2015): Analysis of soil moisture condition under different land uses in the arid region of Horqin sandy land, northern China. Solid Earth, 6: 1157–1167.

Özkan U., Gökbulak F. (2017): Effect of vegetation change from forest to herbaceous vegetation cover on soil moisture and temperature regimes and soil water chemistry. Catena, 149: 158–166._

Pavlů L., Kodešová R., Fér M., Nikodem A., Němec F., Prokeš R. (2021): The impact of various mulch types on soil properties controlling water regime of the Haplic Fluvisol. Soil and Tillage Research, 205: 104748.

Rafi Z.N., Kazemi F. (2021): Effects of planting combinations and mulch types on soil moisture and temperature of xeric landscapes. Urban Forestry & Urban Greening, 58: 126966.

Schaffitel A., Schuetz T., Weiler M. (2020): A distributed soil moisture, temperature and infiltrometer dataset for permeable pavements and green spaces. Earth System Science Data, 12: 501–517.

Thet B., Kodešová R., Fér M., Klement A., Nikodem A. (2024): How different soil surface treatments in urban areas affect soil pore structure and associated soil properties and processes. Journal of Hydrology, 645: 132233.

Yang X.M., Reynolds W.D., Drury C.F., Reeb, M.D. (2021): Cover crop effects on soil temperature in a clay loam soil in southwestern Ontario. Canadian Journal of Soil Science, 101: 761–770.

Zhang L., Wang Z., He Z., Ma X., Ma B., Tian J., He J. (2024): Effects of gravel-sand and plastic film mulching on soil water and temperature retention in cold and arid regions without irrigation. Science of the Total Environment, 934: 173350.

Zhang P., Zhang Z., Xiao M., Chao J., Dai Y., Liu G., Senge M. (2023): Effects of organic mulching on moisture and temperature of soil in greenhouse production of tomato under unheated greenhouse cultivation in the cold zone of China. Food Science & Nutrition, 11: 4829–4842.

Received: May 13, 2026
Accepted: May 28, 2026
Published online: June 8, 2026