Caspian Journal of Environmental Sciences
Online ISSN: 1735-3866
Print ISSN: 1735-3033

Influence of time conditions on the soil temperature indicators in Kazakhstan

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ABSTRACT

Interest in studying the influence of the conditions of the year and time of day on the soil temperature indicators has been increasing in recent years to develop new adaptive strategies in agriculture and provide scientific substantiation for making decisions on the sustainable use and protection of natural resources. No research in this direction has been conducted in Kazakhstan to date. The presented studies were carried out in 2021-2023 in the dry network of the Ili Alatau in the Almaty region. The soil temperature was measured at 10 cm depth with CS107 thermocouples, and the average temperature was recorded every hour using the CR-10 datalogger. The data analysis was carried out using RStudio. The purpose of this study was to analyze the influence some factors such as the year, month, and time of day on the soil temperature indicators. It was found that the year, month, and time of day have a significant impact on the indicators of the variable temperature. This indicator amounted to -1.6, 7.5, and -5.2 °C in 2021, 2022, and 2023, respectively. The soil temperature warmed up most significantly between 12 PM and 6 PM (8.6-17.3 °C). The average soil temperature by 9 PM, 12 AM, 3 AM, 6 AM, and 9 AM decreased to 3.8, -0.6, 2.9, -4.0, and -2.9 °C, respectively. The average monthly temperature indicators were 4.3-8.3 °C in March and October. They were higher in April and September (11.7-14.6 °C). They were the highest in June, July, August, and September (20.3-25.8 °C). The results of the study are of fundamental importance for developing new adaptive strategies in agriculture and providing scientific substantiation for making decisions on the sustainable use and protection of natural resources.

Keywords: Soil temperature, Factors, Season, Time of day, Kazakhstan.
Article type: Research Article.

INTRODUCTION

It is proven that global warming is taking place (Solomon 2007; Qian, *et al.* 2011). Climate warming is widespread around the world and is more pronounced at higher latitudes (Yang & Chenghai 2019; Li *et al.* 2021; Fang *et al.* 2019). This phenomenon leads to the degradation of frozen soils, the retreat of glaciers, the decrease in snow cover, and the increase in the number of glacial lakes. In turn, this causes the release of large reserves of carbon absorbed by permafrost, leading to an elevation in net sources of atmospheric carbon, creating positive feedback and accelerating warming (Fang *et al.* 2019; Xu *et al.* 2022). The retreat of glaciers also has a serious impact on the water resources in arid regions (Su *et al.* 2022). Unfortunately, it is expected that the degradation of ecosystems and the loss of biodiversity caused by climate change are irreversible (Pörtner *et al.* 2022) and will continue in the future and beyond (Solomon 2007). The soil temperature reflecting the thermal regime is an indicator of the reaction to climate change. Knowledge of soil temperature trends in long time series through the soil profile is considered as an effective approach to accurately reflecting the degree of climate change (Zhu *et al.* 2019; Chen *et al.* 2020). New reports have appeared recently about variations in soil temperature associated with climate

Caspian Journal of Environmental Sciences, Vol. 21 No. 5 pp. 1117-1122 Received: Aug. 17, 2023 Revised: Oct. 01, 2023 Accepted: Nov. 26, 2023
DOI: 10.22124/CJES.2023.7399

Publisher: University of Guilan,

change in various parts of the world (Leach & Dan Moore 2019; Yang *et al.* 2020). The study area is located in the foothills of the dry network of the Ili Alatau, Talgar district, Almaty region, Kazakhstan. This area is characterized by a harsh continental climate with hot summers, severe drought, as well as abundant sunlight and cold winters. Seasonal changes in soil temperature are caused by a complex of factors, including solar radiation, atmospheric conditions, duration of day and night, and physicochemical properties of the soil (Fang *et al.* 2019a; Argüello *et al.* 2019). Studying the influence of seasonal and time of day conditions on temperature is an important task for agroecology and soil science (Tang *et al.* 2020; Blahušiaková *et al.* 2020; Meili *et al.* 2021). It is a key factor that has a significant impact on the growth, development, and productivity of plants occurring in the soil environment (Yang & Chenghai 2019; Liebelt *et al.* 2019). Understanding the mechanisms that determine changes in soil temperature in different seasons and times of day is important for optimizing and forecasting agricultural practices, including the selection of plant varieties, the optimal time of sowing and harvesting, as well as assessing the risks and opportunities associated with climate change (Li *et al.* 2021). No research in this direction has been conducted in Kazakhstan to date. This calls for a deeper understanding of the relationship between factors affecting soil temperature, the development of new adaptive strategies in agriculture, and the provision of scientific substantiation for decision-making on the sustainable use and protection of natural resources. The purpose of this study was to analyze the influence of the conditions of the year and time of day on the soil temperature indicators in corn, rye, and wheat crops in the Almaty region. We established that such factors as year, month, and time of day have a significant impact on the indicators of the variable soil temperature.

MATERIALS AND METHODS

Soil and climatic characteristics of the region under study

The study area is located in the foothills of the dry network of Ili Alatau (Fig. 1). This area is characterized by a harsh continental climate with hot summers, severe drought, as well as abundant sunlight and cold winters. The soil cover of the studied area consists of light-dark chestnut soils and depends on the complexity and humidity of the soil layers (Kussainova *et al.* 2020; Chen *et al.* 2022).

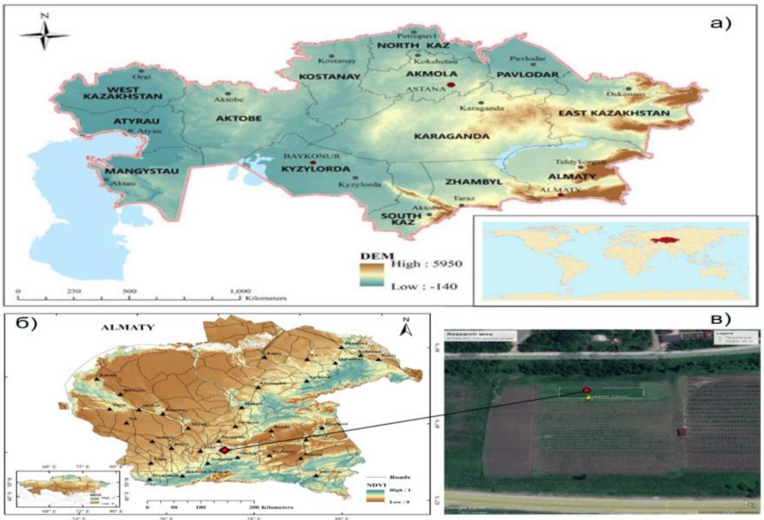


Fig. 1. The location of the research site in the Almaty region: a) the elevation map of Kazakhstan; b) the elevation map of the Almaty region; c) the research site (Google Earth snapshot).

Description of the site

Soil temperature measurements were carried out during 2021-2023 on a pilot plot of light-dark chestnut soils at the Baibulak educational and experimental farm of the Kazakh National Agrarian Research University (N 43.2899766; E 77.1805571). A total of 24,800 measurements were taken at the experimental plot measuring 100 × 15 m divided into three sectors in the horizontal plane, each was planted with a different crop popular in Kazakhstan (corn, wheat, rye). Primary meteorological data for this farm during the study period were obtained.

Measurements

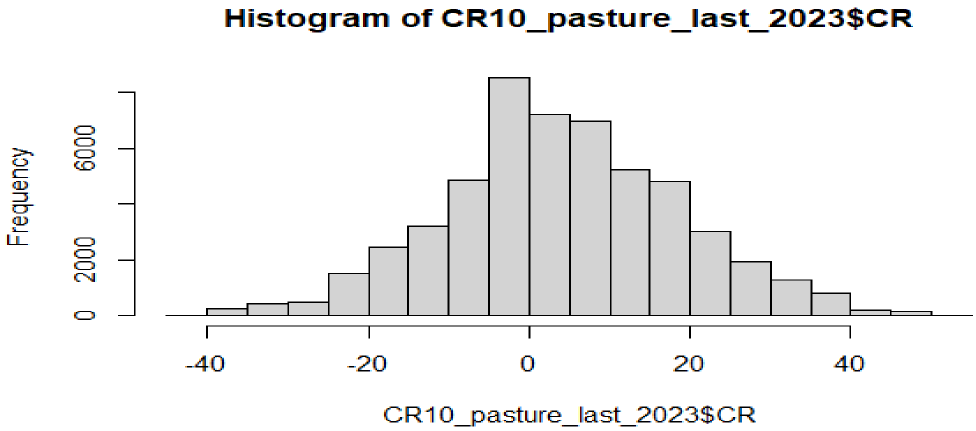
The soil temperature was measured at 10 cm depth with CS107 thermocouples (Campbell Scientific) and the average temperature was recorded every hour using the CR-10 datalogger (Campbell Scientific). A total of 27 temperature sensors (nine sensors in three sectors each) were installed at the experimental section. The datalogger was powered by 100 Ah deep-cycle marine batteries charged by solar panels (2 × 100 W). The received data was synchronized using LoggerNet (Campbell Scientific).

Statistical analysis

We used RStudio and performed a variance analysis of Student's t-test for statistical analysis. The critical significance level was determined using the p-value < 0.05 (Dutbayev *et al.* 2022; Kuldybayev *et al.* 2023; Zhumatayeva, *et al.* 2022). The factors of year, month, and time of day were evaluated for indicators of variable soil temperature.

RESULTS

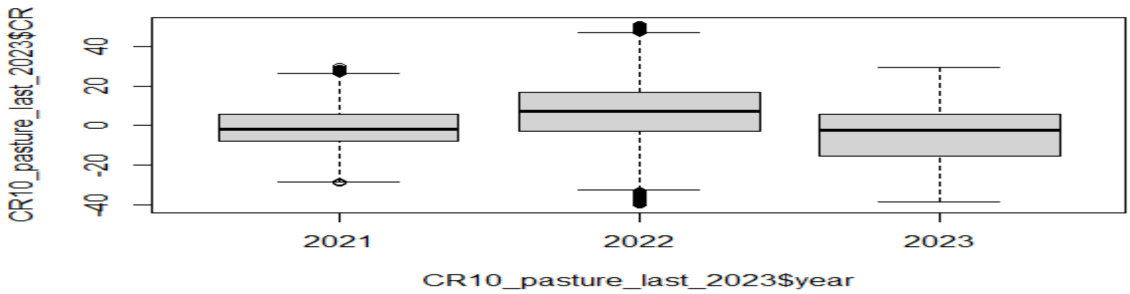
The distribution of the general population of the variable soil temperature was abnormal. We applied parametric analysis of variance (Student's t-test; Fig. 1). By analyzing 53,406 measurements of the variable soil temperature, we found that the minimum value, first quantile, median, mean value, third quantile, and the maximum values were -40.2 °C, -4.9 °C, 3.5°C, 4.1°C, 13.7°C and 50.8 °C respectively (Fig. 2).



Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
-40.2	-4.9	3.5	4.1	13.7	50.8

Fig. 2. Distribution of the general population of the variable soil temperature.

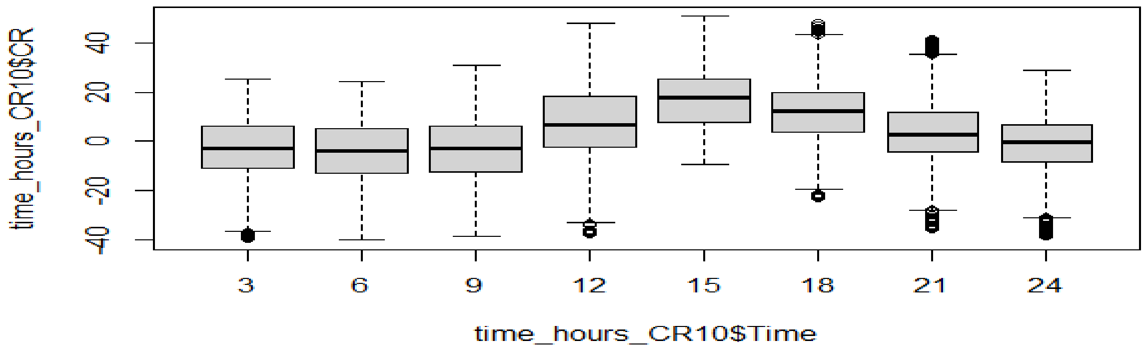
We found that the factor of year (2021, 2022, and 2023) exhibited a significant impact on the indicators of the variable soil temperature (p-value < 0.001***). Thus, 24,800 measurements of soil temperature were estimated in 2021 and 2022, and 3,807 in 2023. The annual averages of this indicator by year were -1.6, 7.5, and -5.2°C, respectively (Fig. 3).



Year	2021	2022	2023
Number of measurements	24,800	24,800	3,807
Average value	-1.6	7.5	-5.2
P-value<0.0001***			

Fig. 3. The influence of the year factor on the variable soil temperature.

It was also found that the factor of the time of day displayed a significant effect on the indicators of the variable soil temperature (p < 0.001***). By analyzing the measurements, we found that the soil temperature warmed up the most at 12 PM, 3 PM, and 6 PM, averaging 8.6, 17.3, and 12.7 °C respectively. This indicator values were 3.8, -0.6, 2.9, -4.0, and -2.9 at 9 PM, 12 AM, 3 AM, 6 AM, and 9 AM, respectively. Negative average soil temperatures were observed in January, February, November, and December (-5.1, -2.7, -3.1, and -3.5 °C, respectively). The average monthly temperature indicators were 8.3 and 4.3°C in March and October respectively. They were higher in April and September (11.7-14.6°C), and the highest in June, July, August, and September (21.7, 23.9, 25.8, and 20.3°C, respectively; Fig. 4).



Hours per day	3	6	9	12	15	18	21	24
Number of measurements	6,675	6,675	6,675	6,675	6,675	6,675	6,675	6,675
Average value	2.9	-4.0	-2.9	8.6	17.3	12.7	3.8	-0.6
P-value<0.0001***								

Fig. 4. The influence of the hour of day factor on the variable soil temperature.

The month factor revealed a significant impact on the indicators of the variable soil temperature (p-value < 0.001***). Negative average soil temperatures were observed in January, February, November, and December (-5.1, -2.7, -3.1 and -3.5 °C, respectively). The average monthly temperature indicators were 8.3 and 4.3 °C in March and October respectively, and higher in April and September (11.7-14.6 °C), while the highest in June, July, August, and September (21.7, 23.9, 25.8, and 20.3°C, respectively; Table 1).

Table 1. Influence of the month factor on the variable soil temperature.

Months	January	February	March	April	May	June	July	August	September	October	November	December
Average value	-5.1	-2.7	8.3	11.9	21.7	23.9	25.8	20.3	14.6	4.3	-3.1	-3.5
p-value < 0.0001***												

DISCUSSION

The soil reacts to climate change on a regional scale. By the phenomenon of freezing and thawing of the soil, the phase of water and atmosphere changes, affecting the soil-vegetation and atmosphere system. In the phenomenon of freezing and thawing of the soil, the water phase and the energy balance of the soil change, which can affect the soil-vegetation-atmosphere system. Li *et al.* (2021) calculated that the interannual cycles of freezing and thawing of the soil in the middle zone of Eurasia are sharper than in North America. Due to the delay of the beginning of soil freezing by 0.1 days/year and the early completion of the beginning of freezing by 0.15-0.2 days/year, the duration and average annual area of frozen soil over the past 40 years in the Northern Hemisphere have significantly decreased at rates of 0.13 and 4 km^2/year. Studies conducted on the Tibetan Plateau in 1960-2014 showed that soil temperature, air temperature, and precipitation upraised by 0.36-0.47 °C and 7.36 mm every decade. The maximum depth of frozen soil and the depth of snow cover declined at a rate of 5.58 and 0.07 cm/decade. When the soil freezes and thaws, monthly changes in its temperature occur. Xu *et al.* (2022) found that the state of freezing and thawing of the soil has changed significantly in the last 60 years in the Heilongjiang Province, China [6]. The maximum depth of seasonal freezing decreased by 48 cm and was lasted for about 10 days. The start and end dates of thawing have shifted by 6 and 27 days. According to our data, some factors such as the year, month, and time of day display a significant impact on the indicators of the variable soil temperature in the Almaty region. The soil temperatures were -1.6, 7.5, and -5.2 °C in 2021, 2022, and 2023, respectively. The lowest negative soil temperatures were observed in January, February, November, and December (-2.7-5.1°C). The average monthly temperature indicators were in the range of 4.3-8.3 °C in March and October. They were higher in April and September (11.7-14.6 °C). These indicators were the highest in June, July, August, and September (20.3-25.8 °C).

CONCLUSION

We achieved the research goal and analyzed the influence of the conditions of the year and time of day on the soil temperature indicators in grain crops in the Almaty region. We established that such factors as year, month, and time of day have a significant impact on the indicators of the variable temperature. These indicators amounted to -1.6, 7.5, and -5.2 °C in 2021, 2022, and 2023, respectively. The temperature of the soil warmed up most strongly between 0 PM and 6 PM (8.6-17.3 °C). The average soil temperature at 9 PM, 12 AM, 3 AM, 6 AM, and 9 AM decreased by 3.8, -0.6, 2.9, - 4.0, -2.9 °C, respectively. The lowest negative soil temperatures were observed in January, February, November, and December (-2.7-5.1°C). The average monthly temperature indicators were 4.3-8.3 °C in March and October. These indicators were higher in April and September (11.7-14.6°C), and were the highest in June, July, August, and September (20.3-25.8 °C). The results are of fundamental importance for developing new adaptive strategies in agriculture and providing scientific substantiation for making decisions on the sustainable use and protection of natural resources.

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Bibliographic information of this paper for citing:

Kussainova, M, Toishimanov, M, Syzdyk, A, Tamenov, T, Nurgali, N, Chen, J 2023, Influence of time conditions on the soil temperature indicators in Kazakhstan. Caspian Journal of Environmental Sciences, 21: 1117-1122.