Analysis of Soil Temperature Variation in the Desert-Oasis Transition Zone Postprint

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Abstract

Based on soil temperature and meteorological element data from the Linze Inland River Basin Station of the Chinese Academy of Sciences from 2004 to 2014, this study analyzed the intra-annual and interannual variation patterns of soil temperature and their main influencing factors in the desert-oasis ecotone of the central Hexi Corridor. The results show that: the diurnal and monthly variations of soil temperature approximately follow a sinusoidal curve; the occurrence times of maximum and minimum temperatures in each soil layer are gradually delayed with increasing soil depth; the annual average soil temperature generally decreases first and then increases with soil depth; air temperature is the meteorological element most strongly correlated with soil temperature variations. Meanwhile, three soil temperature layers with distinct characteristics were identified in this region: the 0~20 cm soil temperature active layer, the 40 cm soil temperature transition layer, and the 60~100 cm soil temperature stable layer, which differ from results in other regions. Finally, empirical prediction equations between meteorological indices and soil temperature at each layer were established using correlation analysis and multiple stepwise linear regression methods.

Full Text

1 Study Area and Methods

1.1 Study Area Description

The study area is located in Linze County, within the central Hexi Corridor, with geographical coordinates of 99°51 -100°30 E and 38°57 -39°42 N. The region has an elevation of 3052.9 m, a mean annual temperature of 7.7 °C, and a frost-free period of 176 days. Annual precipitation is 118.4 mm, while annual evaporation reaches 1830.4 mm. The study site is characterized by flat terrain with uniform soil properties, representing a typical desert-oasis ecotone landscape.

1.2 Data Collection and Processing

Soil temperature data were collected from September 2004 to December 2014 at depths of 0 cm, 10 cm, 20 cm, 40 cm, 60 cm, and 100 cm. Meteorological observations included air temperature, precipitation, evaporation, sunshine duration, relative humidity, and wind speed. Data were organized into monthly, seasonal, and annual time series. Statistical analyses were performed using SPSS software, and graphical representations were generated using Origin 8.0.

2 Results and Analysis

2.1 Daily Variation of Soil Temperature

As shown in Figure 1, daily soil temperature variations at 0 cm, 10 cm, and 20 cm depths exhibited a sinusoidal pattern. The daily maximum temperature occurred between 14:00 and 18:00, with the 10 cm depth showing a 2-hour lag compared to the surface. The daily minimum occurred between 03:00 and 09:00, with the 10 cm depth lagging by approximately 3 hours. At depths of 40 cm, 60 cm, and 100 cm, the daily temperature amplitude was significantly reduced, with an average lag of about 11 hours. The diurnal temperature range decreased with increasing depth, showing a negative correlation with soil depth. For the 0-20 cm layer, the daily range was large with a small lag, while for the 40-100 cm layer, the range was small with a large lag.

2.2 Monthly Variation of Soil Temperature

Figure 2 illustrates the monthly variation of soil temperature across different depths. The pattern shows a distinct sinusoidal curve, with temperatures peaking during June-August and reaching minima during December-February. The monthly temperature range was largest at the surface and decreased progressively with depth. At 0-10 cm, 20-40 cm, and 60-100 cm depths, the maximum ranges occurred in June, July, and August, respectively, while the minimum range occurred in January.

2.3 Seasonal Variation of Soil Temperature

Seasonal analysis revealed three distinct soil layers with different thermal characteristics: the 0-20 cm surface layer, the transitional layer around 40 cm, and the 60-100 cm deep layer. In the 0-20 cm layer, soil temperature responded rapidly to seasonal changes in air temperature, with large seasonal amplitude. The 40 cm depth served as a transition zone where temperature changes moderated. Below 60 cm, soil temperature remained relatively stable with minimal seasonal fluctuation.

2.4 Interannual Variation of Soil Temperature

Figure 6 shows the interannual variation of annual mean soil temperature from 2004 to 2014. The overall trend was relatively stable with slight fluctuations. Notable anomalies occurred in 2010, when soil temperature increased significantly across all depths, with the maximum increase of 5.98 °C recorded at 10 cm depth. Another warming event occurred in 2012, particularly affecting the surface layers (0–10 cm), where temperature increased by 3.66 °C. The 0–60 cm layers showed a warming trend from 2004 to 2010, followed by a cooling period after 2010.

2.5 Principal Component Analysis

Principal component analysis was conducted using six meteorological variables: air temperature (X), precipitation (X), evaporation (X), sunshine duration (X), relative humidity (X), and air temperature (X). The analysis yielded two principal components (Table 1). The first principal component (Z) explained 61.96% of the variance and was strongly correlated with evaporation (0.972), sunshine duration (0.799), and air temperature (0.914). The second principal component (Z) explained 24.74% of the variance and was primarily associated with air temperature (0.743) and relative humidity (0.812). These two components collectively accounted for 86.71% of the total variance.

Table 1 Principal component analysis and load matrices of principal components 1 and 2

Variable	PC1 Loading	PC2 Loading
X (Air temperature)	-0.533	0.743
X (Precipitation)	-0.895	-0.210
X (Evaporation)	0.972	-0.038
X (Sunshine duration)	0.799	-0.421
X (Relative humidity)	0.462	0.812
X (Air temperature)	0.914	0.226

2.6 Multiple Linear Regression Analysis

Stepwise multiple linear regression was used to develop prediction equations for soil temperature at different depths based on meteorological factors. The regression equations for each depth are presented in Table 2.

Table 2 Formulas of principal components

Depth (cm)	Equation	R^2
0	$T = 12.548Z + 6.345Z + 13.832$	0.940
20	$T = 11.115Z + 5.007Z + 13.157$	0.910
40	$T = 10.049Z + 3.904Z + 13.130$	0.868

Depth (cm)	Equation	R^2
60	$T = 9.036Z + 3.035Z + 13.171$	0.818
100	$T = 7.532Z + 1.806Z + 13.397$	0.718

Where $Z = -0.533X - 0.895X + 0.972X + 0.799X + 0.462X + 0.914X$, and $Z = 0.743X - 0.210X - 0.038X - 0.421X + 0.812X + 0.226X$.

2.7 Soil Temperature Prediction Equations

The final prediction equations linking meteorological factors directly to soil temperature at each depth are shown in Table 3. Air temperature (T) was the most significant predictor across all depths, with its coefficient decreasing with depth. Evaporation (Eg) and precipitation (P) were important for surface layers (0-20 cm), while relative humidity (RH) and sunshine duration (S) became more significant at deeper layers (40–100 cm).

Table 3 Equations of multiple linear stepwise regression

Depth (cm)	Equation	R^2
0	$Tg = 0.847T + 0.623Eg - 0.308P + 261.146$	0.989
10	$Tg = 0.865T + 0.489Eg - 0.270P + 229.986$	0.983
20	$Tg = 0.925T + 0.218Eg - 0.139P + 120.730$	0.984
40	$Tg = 0.931T + 0.075RH + 0.729S - 4.649$	0.978
60	$Tg = 0.943T - 0.331Eg + 0.104RH + 1.268S - 4.703$	0.967
100	$Tg = 0.893T - 0.637Eg + 0.157RH + 1.951S - 6.691$	0.932

The results demonstrate that meteorological factors can effectively predict soil temperature, with model accuracy decreasing with depth. The strong correlation between air and soil temperature indicates that air temperature is the dominant control on soil thermal regimes in this desert-oasis ecotone.

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