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ORIGINAL ARTICLE

The significance and relationships among substitutive climatic proxies in the Holocene at the middle Loess Plateau in China

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Abstract The substitutive climatic proxies contain climate data, including temperature, rainfall, monsoon, and so on. However, the environmental significance and relationships among climatic proxies remain uncertain. In this research, soil samples from three soil profiles in the Holocene at the middle Chinese Loess Plateau were studied to analyze the change of seven substitutive climatic proxies. The rescaled range analysis method and Pearson correlation coefficient were employed to determine the significance and relationships among these proxies. The results indicated that the magnetic susceptibility of soil, total ferrum content, and pH can reflect changes in both temperature and rainfall during soil formation. In addition, calcium carbonate content and total organic carbon were mainly affected by the rainfall and temperature, respectively. Particle size composition (clay fraction <0.005 mm and coarse silt 0.01–0.05 mm) is an effective means by which to describe the effects of the East Asian winter monsoon. The results of this study provide theoretical basis and scientific reference for further paleoclimate evolution research.

Keywords Heilu soil · Climate · The Holocene · ^{14}C · Loess Plateau

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Introduction

Understanding past climate changes is essential in determining the congruent relationships between climatic and stratigraphic characteristic proxies through an analysis of the biological, physical, and chemical properties of sedimentary formations (Huang et al. 2003; Knorr and Schnitzler 2006; Wu and Lu 2012). Information on climatic and environmental changes can be analyzed by these proxies. Although such proxies can be measured directly and can indicate the characterizations of the biological, physical, and chemical properties in the strata, they generally cannot describe the characteristics the climate directly; thus they are not accurate climatic proxies. These proxies, also called substitutive climatic proxies, are associated with the climate formed by the stratum, and thus, the changes in these proxies can generally reflect the climate changes to some extent. Considering that many new research methods have been applied in the study of climate evolution, an increasing number of substitutive climatic proxies have been introduced with successful results. Many kinds of proxies, including geochemistry (e.g., carbon oxygen isotopes, ^{10}Be, weathering proxy, etc.), geophysics (e.g., magnetic susceptibility, granularity, etc.), and biology (e.g., sporopollen, silicate in plant, snail fossils, etc.), have been used as substitutive climatic proxies. However, the effects of the whole environmental system on these proxies are very complex. Previous works have shown the definite environmental significance of some proxies (Huang et al. 2002; Wu and Lu 2012). However, the relationships among proxies and their environmental significance remain uncertain, despite the fact that such proxies have been proven to present information about temperature, rainfall, monsoon, and other climatic aspects in different degrees. Understanding the climatic evolution process in the Holocene necessitates a detailed analysis of the relationships among the different substitutive climatic proxies and their environmental significance.

The Chinese loess profile contains the most abundant information about the geologic evolution during the Quaternary period. This sediment profile records the change progress of the paleoclimate, neotectonism, paleogeography, and other important geological events in the Quaternary period in Mainland China, as well as the synchronous evolution process of the paleoclimate and paleoenvironment all over the world. Therefore, the Chinese loess is one of the best geological information carriers for global change research, because it provides precious and valuable conditions in spatial and temporal dimensions (Heller and Liu 1982; Kukla et al. 1990). Heilu soils are the main soil components found in the gently rolling or undulating land surfaces of the Chinese Loess Plateau, where limited past erosion occurred. The well-preserved Heilu soil provides important information about the climatic evolution on the Loess Plateau in the Holocene (Liu 1985; Tang and He 2004). In this paper, changes in the climatic proxies in the Heilu soils from three profiles located at the middle of the Chinese Loess Plateau were analyzed. The rescaled range analysis method was used to discuss the relationships among the different climatic proxies and their environmental significance. These results provide theoretical basis and scientific reference for further paleoclimate evolution research.

Materials and methods

Study area

The Loess Plateau in northwest China covers an area of 530,000 km^2, larger than Spain and almost as large as France; the loess cover largely ranges in thickness from 30 to 80 m. The Loess Plateau is conveniently divided into three zones: sandy loess in the northern part, typical loess in the middle, and clayey loess in the south (Liu 1985). Three soil chronosequences LC, YC, and HS were located in Luochuan (N35°42.561′, E109°23.952′), Yanchang (N36°36.836′, E109°56.125′), and Hengshan (N37°36.992′, E109°12.040′), where the landform are a loess tableland, in the middle of Chinese Loess Plateau (Fig. 1). The climatic

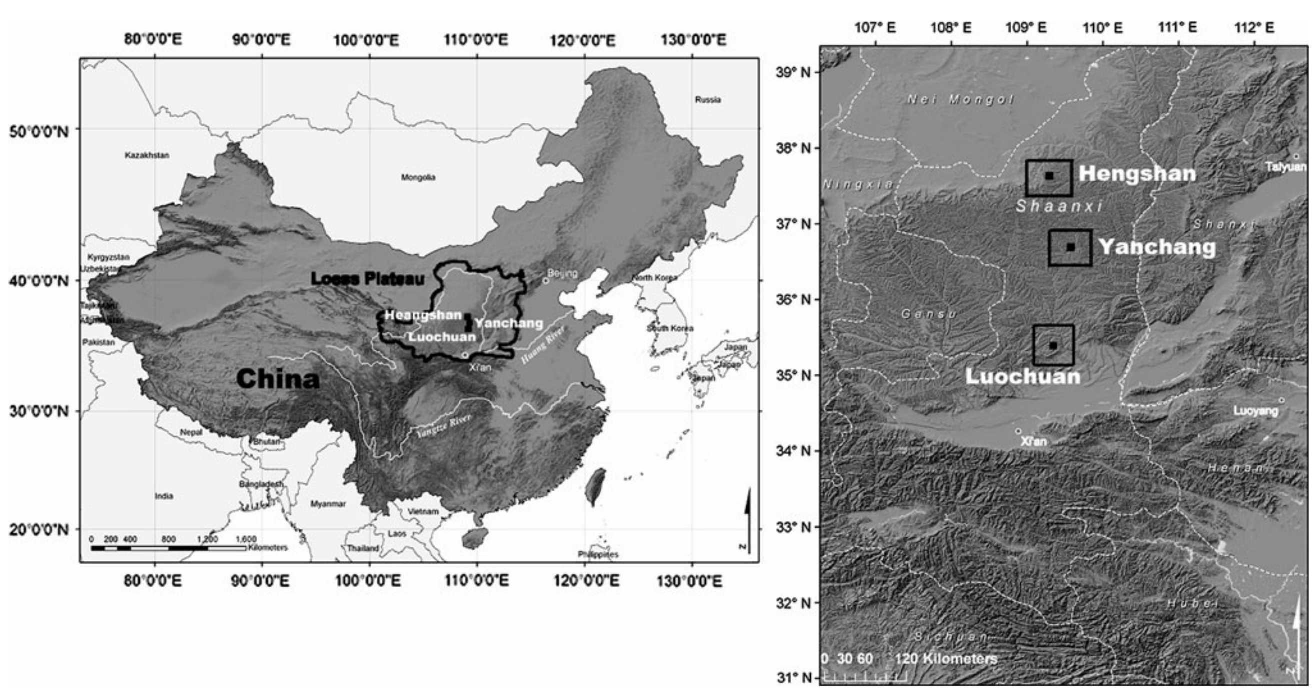

Fig. 1 Location of three soil chronosequences LC, YC, and HS in Luochuan, Yanchang, and Hengshan within the study area at the middle Loess Plateau in China

conditions of this area are characterized by warm and semi-humid continental monsoon climate. Mean annual rainfall in Luochuan, Yanchang, and Hengshan are about 622, 523, and 399 mm concentrated in the summer (July–September). Conversely, the climate is cold and dry in winter, with low rainfall. The mean annual temperature in three locations was 9.2, 9.0, and 8.6 °C, respectively. The present-day vegetation in the study area is dominated by grasses and shrubs (Poaceae, Leguminosae, Labiatae, Rhamnaceae, and Compositae).

Field work and laboratory analyses

The soil layers of the LC, YC, and HS profiles were, respectively, sampled from the face wall of three hand-dug pits, approximately 50 × 200 cm at the top for all three samples, and about 200 cm deep for the LC and YC profile and 150 cm deep for the HS profile. The samples were uniformly obtained from the pit walls at 5 cm intervals, and the soil morphology was routinely described. The interval was occasionally adapted to avoid sampling across a horizon boundary. A total of 110 samples were obtained for all three profiles.

In the laboratory, after air-drying and picking out visible roots and stone fragments, samples were passed through a 2-mm sieve. The amounts of organic carbon were determined by a carbon analyzer with stepped heating routine (LECO RC 412). After pretreatment to remove organic matter, particle size analysis was carried out by a laser granulometer (Mastersizer 2000, Malvern Instruments, Malvern, UK). Magnetic susceptibility was measured with a Bartington MS2 Magnetic Susceptibility System. The pH was determined in deionised water using a soil:water ratio of 1:2.5 (Schlichting et al. 1995). The total ferrum content was determined by X-ray fluorescence analysis (XRF) of fused discs. The calcium carbonate content was measured using the calcimeter method (Bascomb 1961).

For all 110 soil samples, the extraction of humin and radiocarbon dating were carried out at the AMS ^{14}C laboratory of Institute of Earth Environment, Chinese Academy of Sciences, China. They were oven dried (60 °C) to constant weight, then ground and sieved. In order to extract humic acids and date the humin fraction only, samples are commonly treated with acid and alkali (Mook and Streurman 1983). All pre-treated samples were combusted by sealing the sample with CuO wire in an evacuated quartz tube, then placing the tube in a 950 °C oven for 2 h. The resulting CO_2 was purified and reduced to graphite targets for AMS using the apparatus and methods described in Vogel et al. (1987). The calibration of the ^{14}C age used the methods of Ramsey (2001) and Reimer et al. (2004).

Meteorological data

The data of annual average temperature and rainfall in Luochuan County, Yanchang County, and Hengshan County were from China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/).

Hurst exponent, R/S analysis and fractal dimension

Hurst exponent is used to measure the strength of the trend and the noise level changes over time to judge whether or not the time series has long-range dependence. The rescaled range analysis method (R/S analysis) is one of most widely used method to estimate the Hurst exponent (Weron 2002; Cajueiro and Tabak 2004). Its purpose is to provide assessment of how the apparent variability of a series changes with the length of the time-period being considered. The rescaled range is calculated from dividing the range of the values exhibited in a portion of the time series by the standard deviation of the values over the same portion of the time series. As a result, the law of statistical change in small range of time scale could be applied in large range of time scale, vice versa.

The rescaled range is calculated for a time series $\xi(t)$, $t = 1, 2, 3, \ldots$ For any integer $\tau \geq 1$, the mean of time series is defined as:

$$\langle \xi \rangle_\tau = \frac{1}{\tau}\sum_{i=1}^{\tau} \xi(t), \quad \tau = 1, 2, 3 \cdots \tag{1}$$

Thus obtain the cumulative deviation:

$$X(t,\tau) = \sum_{\mu=1}^{\tau} \left[\xi(t) - \langle \xi \rangle_\tau\right], \quad 1 \leq t \leq \tau \tag{2}$$

Range defined as:

$$R(\tau) = \max_{1 \leq t \leq \tau} X(t,\tau) - \min_{1 \leq t \leq \tau} X(t,\tau) \tag{3}$$

Standard deviation is defined as:

$$S(\tau) = \sqrt{\frac{1}{\tau}\sum_{t=1}^{\tau} \left(\xi(t) - \langle \xi \rangle_\tau\right)^2} \tag{4}$$

R/S analysis can be used to calculate any given sequence whose length equals to τ, and its value increased with the growth of the sequence. Mandelbrot and Wallis (1969) found that:

$$R/S \propto \left(\frac{\tau}{2}\right)^H \tag{5}$$

where H is Hurst exponent which can be expressed by the slope of the linear regression in bi-logarithm coordinates, one plot log (R/S) against log (τ/2). H has three value areas with different physical significance: (a) a value in the range $0 < H < 0.5$ indicates the direction of overall trend in the future is opposite to the trend before; (b) a value of $H = 0.5$ can indicate a completely uncorrelated series. For climatic proxies, the results of each time range is absolutely independent, so the change of climatic environment is completely random; (c) a value H in the range $0.5 < H < 1$ indicates a time series with long-term positive autocorrelation. The change of overall direction in climatic environment will inherit the trend past.

The exponential law in R/S analysis method is consistent with the scale invariance in fractal theory (Mandelbrot 1985). A fractal is a mathematical set that has a fractal dimension (D) that usually exceeds its topological dimension and may fall between the integers. Fractals are typically self-similar patterns, where self-similar means they are “the same from near as from far”. A fractal dimension is a ratio providing a statistical index of complexity comparing how detail in a fractal pattern changes with the scale at which it is measured. The structure of climatic system is multilayered and self-similar. Therefore, the fractal dimension can be used to analyze the changing trend of disorderly climatic sequence in different time scale. The relationship between the fractal dimension of the time series curve and the Hurst exponent H can be expressed as $D = 2–H$ (Mandelbrot 1985).

Results and discussion

Changes in the substitutive climatic proxies

Figure 2 shows the magnetic susceptibility of the soil (χ_{lf}), calcium carbonate ($CaCO_3$) content, total organic carbon (TOC), total ferrum content (TFe), pH, and particle size composition (clay fraction <0.005 mm and coarse silt 0.01–0.05 mm) in the LC, YC, and HS profiles in the research area. All seven substitutive climatic proxies fluctuated with time, and their changing patterns greatly varied. These proxies have been utilized in previous paleoclimate research. For example, χ_{lf} has been used to indicate the changes in temperature and rainfall (Huang et al. 2003). However, establishing the accurate linear relationship between the substitutive climatic proxies and the climatic indices is difficult. Therefore, a nonlinear analysis is an alternative method to establish the relationship between them.

R/S analysis of the substitutive climatic proxies

R/S analysis was applied to the following substitutive climatic proxies in the LC, YC, and HS profiles in the research area: magnetic χ_{lf}, $CaCO_3$, TOC, TFe, pH, clay fraction <0.005 mm, and coarse silt 0.01–0.05 mm. The H values of these proxies were derived from the slope of the linear equation fitted between the log of R/S and the log of $\tau/2$. In the same way, the H values of the annual average temperature (T), annual rainfall (P), East Asian summer monsoon index (S), and East Asian winter monsoon index (W) of the LC, YC, and HS areas in the recent five decades were calculated (Table 1). Finally, the D values of the substitutive climatic proxies and the climatic indices were computed (Table 1).

The D values of the substitutive climatic proxies were close to that the D values of the climatic indices in the LC, YC, and HS profiles (Table 1); therefore, these proxies indicated climate change very well. Furthermore, the H values of the substitutive climatic proxies and the climatic index were larger than 0.5; thus, the climosequence in the research area was persistent or increasing. The overall trend of the climate change in the future adopted the past trend, and the closer the H values were to 1, the stronger the persistence was. Moreover, the H values of the substitutive climatic proxies had slight differences (Table 1), thereby reflecting the diverse trends of the climate indices in terms of temperature, rainfall, and monsoon.

Significance of the substitutive climatic proxies

Although linear correlation analysis has been shown to have shortcomings in determining the relationship between the substitutive climatic proxies and the climatic indices, it can still be referenced to determine the correlations among the different substitutive climatic proxies. The Pearson correlation coefficient was used to describe the relationship among the different proxies (Table 2). Observations listed in Tables 1 and 2 are explained below:

1. The D values of the χ_{lf} in the LC, YC, and HS profiles were 1.24, 1.25, and 1.26, respectively, and were between the D values of the local T and P. Furthermore, the χ_{lf} in the three profiles were significantly or highly significantly correlated with the $CaCO_3$ content, TOC, TFe and pH. Therefore, the χ_{lf} can reflect both temperature and rainfall. This result is in accordance with those presented in previous works. For example, the palaeorainfall has been reconstructed using the positive relationships between the P and the χ_{lf} (Maher et al. 1994). In addition, Lu et al. (1994) determined that both temperature and rainfall are significantly correlated with the χ_{lf} on the Chinese Loess Plateau. Furthermore, these relationships can be described through the quartic polynomial.
2. The D values of the $CaCO_3$ content in the LC, YC, and HS profiles were 1.18, 1.20, and 1.19, respectively, and were closer to the D values of the local P (1.17, 1.19, and 1.20) than those of T (1.32, 1.30, and

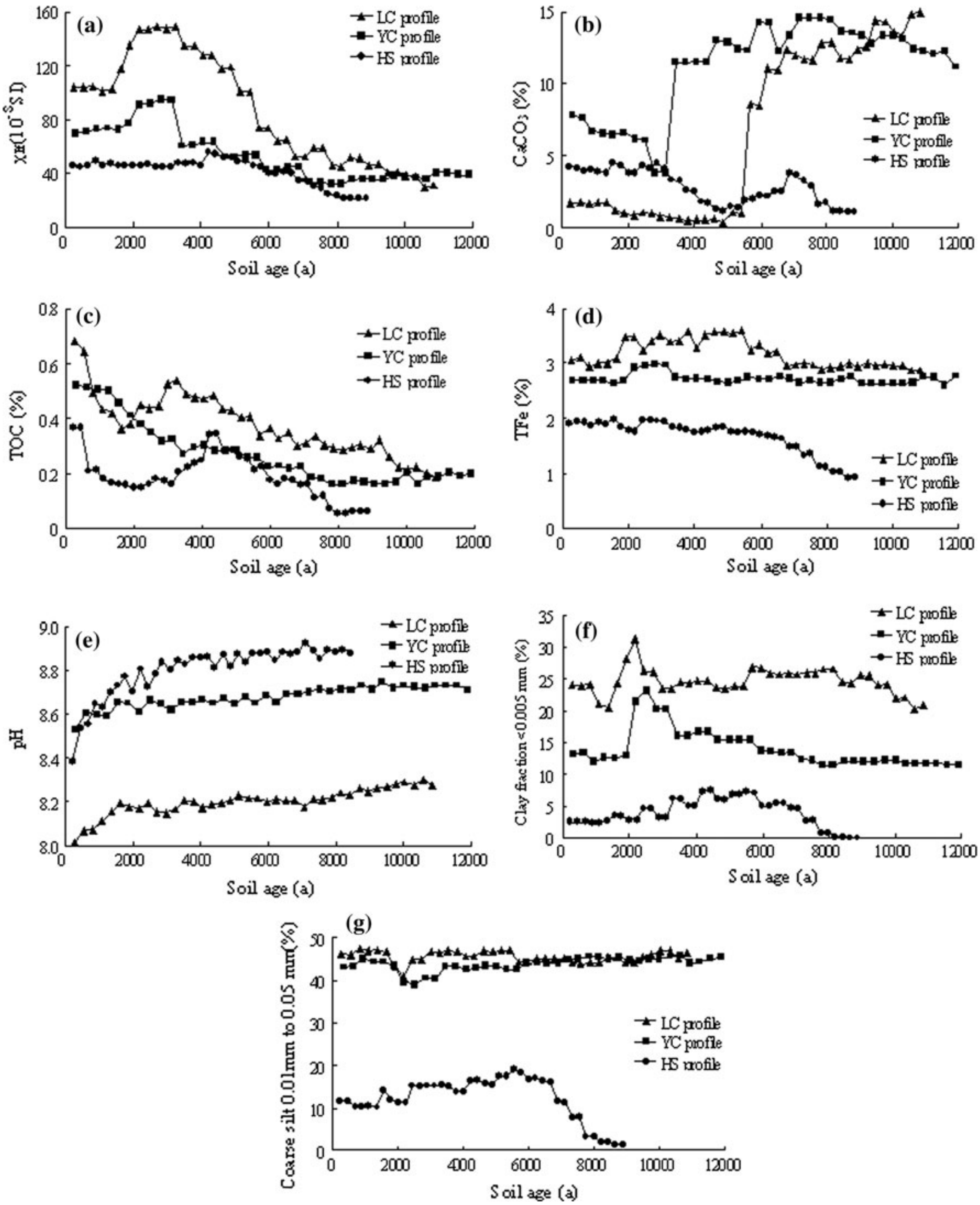

Fig. 2 The substitutive climatic proxies change with time in LC, YC, and HS profiles. **a** Magnetic susceptibility of soil (χ_{lf}); **b** calcium carbonate content ($CaCO_3$); **c** total organic carbon (TOC); **d** total ferrum content (TFe); **e** pH; **f** clay fraction <0.005 mm; **g** coarse silt 0.01–0.05 mm

1.29), *S* (1.37), and *W* (1.27). Thus, the $CaCO_3$ content in the profiles accurately indicates changes in the rainfall. This result is in accordance with the assumption that the most important factor in $CaCO_3$ formation is rainfall (Zhao 2000). Zhao (2000) determined that the annual rainfall has a linear relationship with the depth of the $CaCO_3$ illuvial horizon in an investigation of the paleosol and weathered eluvial zone in the Loess Plateau. This assumption is also true in the alkali gray desert soil (Zhu et al. 2007), although the parameters of the formula employed varied because of the different

Table 1 The Hurst exponent and fractal dimension of substitutive climatic proxies and climatic indices in LC, YC, and HS profiles

Profiles	Substitutive climatic proxies and climatic indexes	Time range	Hurst exponent *H*	Fractal dimension *D*
LC	Annual average temperature in Luochuan County (*T*)	47 a(1955 ~ 2001)	0.68	1.32
	Annual rainfall in Luochuan County (*P*)	47 a(1955 ~ 2001)	0.83	1.17
	Magnetic susceptibility (χ_{lf})	11000 a	0.76	1.24
	Calcium carbonate content ($CaCO_3$)	11000 a	0.82	1.18
	Total organic carbon (TOC)	11000 a	0.70	1.30
	Total ferrum content (TFe)	11000 a	0.75	1.25
	Potential of hydrogen (pH)	11000 a	0.77	1.23
	<0.005mm clay fraction	11000 a	0.72	1.28
	0.01–0.05 mm coarse silt	11000 a	0.72	1.28
YC	Annual average temperature in Yanchang County (*T*)	47 a(1955 ~ 2001)	0.70	1.30
	Annual rainfall in Yanchang County (*P*)	47 a(1955 ~ 2001)	0.81	1.19
	Magnetic susceptibility (χ_{lf})	12000 a	0.75	1.25
	Calcium carbonate content ($CaCO_3$)	12000 a	0.80	1.20
	Total organic carbon (TOC)	12000 a	0.71	1.29
	Total ferrum content (TFe)	12000 a	0.76	1.24
	Potential of hydrogen (pH)	12000 a	0.77	1.23
	<0.005 mm clay fraction	12000 a	0.72	1.28
	0.01–0.05 mm coarse silt	12000 a	0.73	1.27
HS	Annual average temperature in Hengshan County (*T*)	48 a(1954 ~ 2001)	0.71	1.29
	Annual rainfall in Hengshan County (*P*)	48 a(1954 ~ 2001)	0.80	1.20
	Magnetic susceptibility (χ_{lf})	9000 a	0.74	1.26
	Calcium carbonate content ($CaCO_3$)	9000 a	0.81	1.19
	Total organic carbon (TOC)	9000 a	0.71	1.29
	Total ferrum content (TFe)	9000 a	0.76	1.24
	Potential of hydrogen (pH)	9000 a	0.76	1.24
	<0.005 mm clay fraction	9000 a	0.74	1.26
	0.01–0.05 mm coarse silt	9000 a	0.73	1.27
	East Asian summer monsoon index (*S*)	50 a(1951 ~ 2000)	0.63	1.37
	East Asian winter monsoon index (*W*)	50 a(1951 ~ 2000)	0.73	1.27

soil-forming conditions. Furthermore, a similar linear relationship between the $CaCO_3$ lamina thickness and rainfall has been reported after the investigation of the laminated sediment from a karstic lake (Romero-Viana et al. 2008). Therefore, the indicative significance of the $CaCO_3$ for the rainfall could be applied in a wider area except for the Loess Plateau.

3. The *D* values of the TOC in the LC, YC, and HS profiles were 1.30, 1.29, and 1.29, respectively, and were very close to the *D* values of the local *T* (1.32, 1.30, and 1.29). Therefore, TOC reflected the change in temperature very well. However, rainfall also has an effect on the soil processes apart from temperature (Burke et al. 1989; Alvarez and Lavado 1998). Furthermore, both of these parameters are associated with the TOC, and can be fitted with diverse curves in different areas (Alvarez and Lavado 1998; Jobbágy 2000). However, the relationship between rainfall and TOC is not always significant. For example, a less significant relationship between organic carbon and precipitation has been discovered in a research on the Southern Great Plains in the US (Nichols 1984).
4. The *D* values of both the TFe (1.25, 1.24, and 1.24) and pH (1.23, 1.23, and 1.24) in the LC, YC, and HS profiles, respectively, were between the *D* values of the local *T* (1.32, 1.30, and 1.29) and *P* (1.17, 1.19, and 1.20). Furthermore, TFe and pH were significantly or highly significantly correlated with χ_{lf} and $CaCO_3$, and χ_{lf}, $CaCO_3$, and TOC, respectively, in all three profiles. Thus, both TFe and pH indicated the changes in rainfall and temperature synthetically. This result is in accordance with those of previous studies. For instance, Huang et al. (2002) determined that the higher TFe value in the profile in the Chinese Loess Plateau can indicate the soil formation under warmer and wetter climates. In addition, Jia et al.

Table 2 Correlation analysis for substitutive climatic proxies

Profiles	Variable	χ_{lf}	$CaCO_3$	TOC	TFe	pH	<0.005 mm	0.01–0.05 mm
LC	χ_{lf}	1	−0.953**	0.805**	0.777**	−0.613**	0.187	0.117
	$CaCO_3$	−0.953**	1	−0.845**	−0.750**	0.675**	−0.043	−0.277
	TOC	0.805**	−0.845**	1	0.540**	−0.873**	0.083	0.214
	TFe	0.777**	−0.750**	0.540**	1	−0.230	0.237	0.081
	pH	−0.613**	0.675**	−0.873**	−0.230	1	−0.106	−0.142
	<0.005 mm	0.187	−0.043	0.083	0.237	−0.106	1	−0.814**
	0.01–0.05 mm	0.117	−0.277	0.214	0.081	−0.142	−0.814**	1
YC	χ_{lf}	1	−0.924**	0.798**	0.628**	−0.777**	0.781**	−0.838**
	$CaCO_3$	−0.924**	1	−0.792**	−0.606**	0.676**	−0.559**	0.652**
	TOC	0.798**	−0.792**	1	0.189	−0.893**	0.334*	−0.451**
	TFe	0.628**	−0.606**	0.189	1	−0.258	0.727**	−0.747**
	pH	−0.777**	0.676**	−0.893**	−0.258	1	−0.469**	0.550**
	<0.005 mm	0.781**	−0.559**	0.334*	0.727**	−0.469**	1	−0.960**
	0.01–0.05 mm	−0.838**	0.652**	−0.451**	−0.747**	0.550**	−0.960**	1
HS	χ_{lf}	1	0.338*	0.814**	0.921**	−0.363*	0.736**	0.839**
	$CaCO_3$	0.338*	1	0.116	0.616**	−0.600**	−0.089	0.196
	TOC	0.814**	0.116	1	0.690**	−0.443**	0.654**	0.675**
	TFe	0.921**	0.616**	0.690**	1	−0.519**	0.571**	0.798**
	pH	−0.363*	−0.600**	−0.443**	−0.519**	1	0.207	−0.034
	<0.005 mm	0.736**	−0.089	0.654**	0.571**	0.207	1	0.906**
	0.01–0.05 mm	0.839**	0.196	0.675**	0.798**	−0.034	0.906**	1

* level of significance is 0.05, ** level of significance is 0.01

(2004) reported that the pH values of 190 samples from the Laoguantai profile at the middle of the Loess Plateau also indicate the climate change; Moreover, the pH value is lower when the climate is warmer and more moist, and vice versa.

5. The D values of both the clay fraction <0.005 mm (1.28, 1.28, and 1.26) and coarse silt 0.01–0.05 mm (1.28, 1.27, and 1.27) in the LC, YC, and HS profiles, respectively, were also between the D values of the local T (1.32, 1.30, and 1.29) and P (1.17, 1.19, and 1.20). However, such D values were not totally significantly correlated with the other five proxies in the three profiles at the same time. This discrepancy can be attributed to the effects of the monsoon factor. The values were much closer to the D values of W (1.27); thus, the particle size composition could be used as the substitutive proxies for the winter monsoon. Despite the difference in grain size system, this result is accordance with that reported by Lu and An (1998). In our study, no proxy can describe the changes in S, which is due to the effects of the intense weathering and pedogenesis during the dust deposition on the Chinese Loess Plateau (Lu and An 1998).

Conclusions

Several conclusions can be drawn in this study. These are listed below.

1. The soil samples from the three soil profiles in the Holocene in the northern Shaanxi were studied to analyze changes in seven substitutive climatic proxies. The R/S analysis method and Pearson correlation coefficient were used to determine the relationships among these proxies and their significance.
2. The χ_{lf}, Fe, and pH are significantly or highly significantly close with one another. They can demonstrate changes in both temperature and rainfall during soil formation.
3. The $CaCO_3$ content is mainly affected by rainfall and can reflect this climate information very well.
4. The TOC is affected by both temperature and rainfall. However, TOC is proven to indicate only the changes in temperature in this study area.
5. The particle size composition (clay fraction <0.005 mm and coarse silt 0.01–0.05 mm) can be used to describe changes in the East Asian winter monsoon, however, further research is required to

determine the suitable indicator that reflects the changes in the East Asian winter monsoon.

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References

Alvarez R, Lavado RS (1998) Climate, organic matter and clay content relationships in the Pampa and Chaco soils, Argentina. Geoderma 83:127–141

Bascomb CL (1961) A calcimeter for routine use on soil samples. Chem Ind 45:1826–1827

Burke IC, Yonker CM, Parton WJ, Cole CV, Schimel DS, Flach K (1989) Texture, climate, and cultivation effects on soil organic matter content in U.S. grassland soils. Soil Sci Soc Am J 53: 800–805

Cajueiro DO, Tabak BM (2004) Ranking efficiency for emerging markets. Chaos Solitons Fractals 22:349–352

Heller F, Liu TS (1982) Magnetostratigraphical dating of loess deposits in China. Nature 300:431–433

Huang CC, Pang JL, Huang P, Hou CH, Han YP (2002) High-resolution studies of the oldest cultivated soils in the southern Loess Plateau of China. Catena 47:29–42

Huang CC, Zhao SC, Pang JL, Zhou QY, Chen S, Li PH, Mao LJ, Ding M (2003) Climatic aridity and the relocations of the Zhou culture in the southern Loess Plateau of China. Clim Change 61:361–378

Jia YF, Pang JL, Huang CC (2004) pH value's measurement and research of its palaeoclimatic meaning in the Holocene loess section. J Shaanxi Norm Univ (Natural Science Edition) 32:102–105 (in Chinese with English abstract)

Jobbágy EG, Jackson R (2000) The vertical distribution of soil organic carbon and its relation to climate and vegetation. Ecol Appl 10:423–436

Knorr W, Schnitzler KG (2006) Enhanced albedo feedback in North Africa from possible combined vegetation and soil-formation processes. Clim Dyn 26:55–63

Kukla G, An ZS, Melice JL, Gavin J, Xiao JL (1990) Magnetic susceptibility record of Chinese Loess. Trans Royal Soc Edinb Earth Sci 81:263–288

Liu TS (1985) Loess and environment. Science Press, Beijing, pp 341–343 (in Chinese)

Lu HY, An ZS (1998) Paleoclimatic significance of grain size of loess-palaeosol deposit in Chinese Loess Plateau. Sci China (Series D) 41:626–631

Lu HY, Han JM, Wu NQ, Guo ZT (1994) Magnetic susceptibility of modern soils in China and their paleoclimatic implications. Sci China (Series B) 24:1290–1297 (in Chinese)

Maher BA, Thompson R, Zhou LP (1994) Spatial and temporal reconstructions of changes in the Asian palaeomonsoon: a new mineral magnetic approach. Earth Planet Sci Lett 125:461–471

Mandelbrot BB (1985) Self-affine fractals and fractal dimension. Phys Scr 32:257–260

Mandelbrot BB, Wallis JR (1969) Robustness of the rescaled range R/S in the measurement of noncyclic long run statistical dependence. Water Resour Res 5:967–988

Mook WG, Streurman HJ (1983) Physical and chemical aspects of radiocarbon dating. In: Mook WG, Waterbolk HT (eds) ^{14}C and Archaeology. Proceedings of the First International Symposium (=PACT 8), Strasbourg, pp 31–55

Nichols JD (1984) Relation of organic carbon to soil properties and climate in the Southern Great Plains. Soil Sci Soc Am J 48: 1382–1384

Ramsey CB (2001) Development of the radiocarbon calibration program. Radiocarbon 43:355–363

Reimer PJ, Baillie MGL, Bard E, Bayliss A, Beck JW, Bertrand CJH, Blackwell PG, Buck CE, Burr GS, Cutler KB, Damon PE, Edwards RL, Fairbanks RG, Friedrich M, Guilderson TP, Hogg AG, Hughen KA, Kromer B, McCormac G, Manning S, Ramsey BC, Reimer RW, Remmele S, Southon JR, Stuiver M, Talamo S, Taylor FW, Van der Plicht J, Weyhenmeyer CE (2004) IntCal04 terrestrial radiocarbon age calibration, 0–26 cal kyr BP. Radiocarbon 46:1029–1058

Romero-Viana L, Julià R, Camacho A, Vicente E, Miracle MR (2008) Climate signal in varve thickness: lake La Cruz (Spain), a case study. J Paleolimnol 40:703–714

Schlichting E, Blume HP, Stahr K (1995) Bodenkundliches Praktikum. Blackwell Wissenschafts-Verlag, Berlin, p 295

Tang KL, He XB (2004) Re-discussion on loess-paleosol evolution and climatic change on the Loess Plateau during the Holocene. Quat Sci 24:129–139 (in Chinese with English abstract)

Vogel JS, Southon JR, Nelson DE (1987) Catalyst and binder effects in the use of filamentous graphite for AMS. Nucl Instrum Methods Phys Res Sect B 29:50–56

Weron R (2002) Estimating long-range dependence: finite sample properties and confidence intervals. Physica A 312:285–299

Wu TN, Lu GY (2012) Climatic sub-cycles recorded by the forth paleosol layer at Luochuan on the Loess Plateau. Environ Earth Sci 66:1329–1335

Zhao JB (2000) A new geological theory about eluvial zone – Theory illuvial on depth of $CaCO_3$. Acta Sedimentol Sin 18:29–35 (in Chinese with English abstract)

Zhu H, Zhao CY, Li J, Li YJ, Wang F (2007) Indication of soil $CaCO_3$ sedimentation to rainfall and environmental change. Chin J Soil Sci 38:810–812 (in Chinese)