Human responses to climate change in the late prehistoric Western Loess Plateau, northwest China

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Abstract Human responses to the rapid climate change in antiquity has been extensively discussed and debated. This paper reports 91 new archaeobotanical results including 13567 charred plant seeds and 19 radiocarbon dates from 41 late prehistoric sites in the upper Wei River valley of Western Loess Plateau (WLP). Based on the new dating results as well as the culture attributes, the 41 sites can be divided into four chronological phases (Phase 1: Late Yangshao and Majiayao culture; Phase 2: Qijia culture; Phase 4: Siwa culture). A significant gap has been identified around 3600-3000 cal yr BP in this region. A further comparison with the high-resolution paleoclimate records (Tianchi) suggests that this gap could be attributed to the dramatic drop in the temperature around 3600 cal yr BP. But archaeobotanical evidence with refined chronology shows that adoption of cold-tolerant subsistence such as barley in NETP. Drawing from various lines of information (chronology, palaeoclimate, archaeobotany and archaeology), it is reasonable to conclude that even confronting the similar magnitude of climate change, the local human responses could vary tremendously. It was essentially result of the asynchronous adoption of the new subsistence strategies brought by the prehistoric trans-Eurasia culture exchange.

Keywords: archaeobotanical analysis, radiocarbon dating, subsistence strategy, late Neolithic and Bronze periods, climate change

INTRODUCTION

Climate change matters in the human history (e.g. Weiss et al., 1993; D'Andrea et al., 2011; Wu et al., 2018). Large-scale migration or social expansions, technological innovations, and the rise and fall of ancient civilisations were often triggered by important climate events, such as significant cold periods, droughts (Marshall et al., 2011; Timmermann and Friedrich, 2016; Staubwasser et al., 2018). Climate events declined the ancient civilizations (Staubwasser et al., 2003; Dong et al., 2017a) in the Late Pleistocene and the Early to Mid-Holocene. From Late Paleolithic to Neolithic, when the climate became favorable for human survival, human activity was markedly increased and culture flourished (Hu et al., 2016). However, when climate became deteriorated, we can see a series of cultural collapse and migration to lower elevations or latitudes (Bhattacharya et al., 2015; Bai et al., 2017; Cui et al., 2018). The relationship between climate change and human activity during the transition period from Late Neolithic to Bronze Age, which was characterized by global cooling but marked expansion of human living space. Such as Central Asia (Spengler and Willcox, 2013; Spengler, 2015) and the Tibetan plateau (Chen et al., 2015). Different trajectories of human response to climate change in the prehistoric period in the world is various. During 8450-5650 cal yr BP, as a result of major changes in temperature and humidity, the Apulia region of southeast Italy saw considerable fluctuations of the population density. Local farmers therefore had to adjust the sorts of crops that were available to them and the cultivation time (Fiorentino et al., 2013). Likewise, although radical changes happened in Greece in 6500-500 cal yr BP with the three continuous droughts (5800-5700, 5450 and 5000-4900 cal yr BP), they appeared to have very little impact on the human activities. Local people became well adapted to the climate changes by adjusting the agricultural and pastural practice (Lespez et al., 2016). The Canaan region in the western side of Eurasia, controlled by the Egyptian empire in the late Bronze Age had experienced a dry climate around 3200-3050 cal yr BP. The governors chose to develop new technologies such as dry farming and ploughing in order to cope with the increasingly drier conditions reflected in increasing cattle frequencies and animals that were kept to colder age (Finkelstein et al., 2017). In the Indus valley during the post-urban period (3950-3150 cal yr BP), the Late Harappan civilization increased the cultivation of drought-resistant crops (e.g. millet) in the peripheral areas, which was also an echo to the decline of SW monsoon during the late Holocene, to which millets are better suited (Pokharia et al., 2014). Except them, the same gap around 3.5 ka BP between the Lower Xiajiadian Culture and Upper Xiajiadian Culture in the West Liao River Basin (Jia et al., 2016), the birth of civilization in the Central Plains, and the cultural transformation from Baodun Culture to Sanxingdui Culture in Chengdu Plain (Zhang et al., 2019).

In the northeast Tibetan Plateau (NETP), people migrated toward the high-altitude areas from the upper Yellow River valleys and became permanently settled above 3000 m.a.s.l (meter above sea level) after 3600 cal yr BP (the calibrated year before present, before AD 1950) (Chen et al., 2015; Dong et al., 2016) when climate became cooler (Marcott et al., 2013). Archaeobotanical and zooarchaeological evidence suggests that adoption of barley growing, sheep and yak herding, greatly facilitated the year-round activities in the high-cold environment of the Tibetan Plateau in the

Bronze Age. The results of archaeological survey and radiocarbon dating (Bureau of National Cultural Relics, 1996; Dong et al., 2013; Chen et al., 2015) suggest a clear continuation in settlement between Neolithic and Bronze Age in NETP (Fig 1a) and the number of Bronze Age sites dated to 4000-2300 cal yr BP in that area is much more abundant than in the Neolithic (5200-4000 cal yr BP).

However, the trajectory of the culture evolution in the adjacent Longxi Loess Plateau (WLP) appears rather different. The Yangshao and Majiayao Neolithic cultures (~6000-4000 cal yr BP) and the Qijia Chalcolithic culture (~4300-3600 cal yr BP) were prosperous but the Bronze Age cultures, including Siwa (~3600-2600 cal yr BP), show a downward trend (Bureau of National Cultural Relics, 2011). The spatial pattern for the culture evolution in WLP and NETP during the Bronze Age was abnormal. In theory, the lower altitude environment in WLP to be more suitable for human survival and cultural development than NETP, which is located on higher altitudes. Therefore, it is necessary to further understand the different patterns for the evolution of prehistoric human-environment interaction in these two areas and the underlying mechanism of development.

The Tibetan Plateau has been the focus of a large number of research projects (Chen et al., 2015; Dong et al., 2016). Given its remarkable geographical feature such as low-high elevation, changing temperature and humidity or the different vegetation, human inhabitation to the Tibetan Plateau in prehistory must have required a variety of strategies and adaptations that were dramatically different from those in the lower flat plains. This paper focused on the two adjacent areas (NETP and WLP) to attempt to illustrate different human responses to the same climatic change. The Western

Loess Plateau is really important. It is the link between the Central Plains and the northeast Tibetan Plateau and the prehistoric culture in the Western Loess Plateau is also a key node for the spread westward from Central Plains culture to the Northeast Tibetan Plateau. But the history of human settlement and subsistence strategy in WLP during the late prehistoric period remains rather ambiguous, owing to a lack of archaeobotanical and chronological data. While NETP has been comprehensively studied (Chen et al. 2015; Dong et al. 2016). This paper has investigated a substantial number of Neolithic and Bronze Age sites in the upper Wei River valley of WLP (Bureau of National Cultural Relics, 2011). With the aid of 13567 charred plant seeds and 19 AMS ^{14}C dates, we have reconstructed the chronology of local settlements and associated crop subsistence. A further comparative study between the charred plant seeds of WLP/NETP and the high-resolution paleoclimate record illustrates the rather different patterns of social evolution affected by the climate change and cultural exchanges around the northeastern area of Tibetan Plateau during the late prehistoric period.

STUDY AREA

The upper Wei River valley (104°41′-106°18′ E, 34°24′-35°8′ N) is located in the Gansu Province (Fig 1b). The study area is approximately 200 km long from west to east. The trunk stream flows from 1600-900 m.a.s.l and forms a gentle slope and a broad river valley. The climate of this area was classified as continental winter dry (Dwb) according to Köppen classes classification (Chan et al., 2016). The mean annual temperature is about 8-10°C and the mean annual precipitation is around 500-650 mm. Modern agriculture in this area includes millets, wheat, corn, potato etc.

The Second National Archaeological Survey in China have found more than two hundred archaeological sites in this area, ranging from the Late Neolithic to the Bronze Age (Bureau of National Cultural Relics, 2011). A majority of them are distributed in the valley of the upper Wei River and its main tributaries. The late Neolithic and Chalcolithic sites can be further divided into three cultures, among which 125 have been attributed to the Late Yangshao Culture (~5500-5000 cal yr BP), 42 to the Majiayao Culture (~5300-4000 cal yr BP) and 371 to the Qijia Culture (~4300-3600 cal yr BP). Merely 14 belong to the Siwa Culture (~3600-2600 cal yr BP) and one site belongs to the Xindian Culture (~3600-2600 cal yr BP).

MATERIALS AND METHODS

In 2016, 41 Late Neolithic and Bronze Age sites in WLP were investigated by the Gansu Institute of Cultural Relics and Archaeology (Fig 1b). At each site, one can identify archaeological deposits such as single or multiple cultural layers and ash pits that have been exposed on the profile. These deposits in different archaeological units were sampled for floatation. The units were avoided in case of any latter natural or anthropogenic disturbances. The average volume of the 91 sampled soils was 19.78 L. Over the process of flotation, lighter remains such as charcoal and charred plant seeds were floated upward and gathered by 80-mesh sifter (with 0.2 mm aperture). These were subsequently wrapped by gauze and hung in shady and cool area for desiccation. The species of the charred plant seeds were identified in the Paleoethnobotany Laboratory, Institute of Archaeology, Chinese Academy of Social Sciences and the MOE Key Laboratory of Western China’s Environmental Systems, College of Earth & Environmental Sciences, Lanzhou University.

The number of different plant species were recorded to analyze the structure of the past agricultural activities in the targeted area. However, different crops have different weight and behave rather differently in the process of harvesting, utilizing and carbonizing (Yang et al., 2011). As a result, the proportions revealed by the unearthed charred seeds may not precisely reflect the true proportion of crops utilized in past agriculture. Therefore, a modified method of using the Weight Ratio Function for different crops proposed by Zhou (Zhou et al., 2016). The statistical analysis of the Weight Ratio Function of charred plant seeds can better reflect the actual proportion of different sorts of crops.

Where N1=number of common millet grains, F1=7.5, N2= number of foxtail millet grains, F2=2.6, N3=number of wheat grains, F3=35, N4=number of barley grains, F4=45, and P(S)=actual yield percentage of that particular crop.

19 of plant remains were selected for radiocarbon dating, including foxtail millet, wheat and barley (Table 1). The samples were pretreated at the MOE Key Laboratory of Western China's Environmental Systems, College of Earth & Environmental Sciences, Lanzhou University using standard pre-treatment (acid-alkali-acid) and were subsequently measured by accelerator mass spectrometry (AMS) at Peking University. All dates were calibrated using Calib 7.0.2 calibration software (Reimer et al., 2009) with the IntCal13 calibration curve (Reimer et al., 2013). The cumulative probability distribution (CPD) curve of radiocarbon dates has been applied to estimate the intensity of human activities in the following discussion (Michczyńska and

Pazdur., 2004).

RESULTS

The 19 AMS ^{14}C dates are listed at Table 1, ranging between 5500 and 2300 cal yr BP. Based on the new dating results as well as the culture attributes (Phase 1: Late Yangshao and Majiayao culture; Phase 2: Qijia culture; Phase 4: Siwa culture), the 41 sites can be divided into four chronological phases. Phases 1, 2, 4 are contemporary with the Late Yangshao-Majiayao cultures, the Qijia culture and the Siwa culture, respectively.

A total number of 13567 charred plant seeds have been recovered from the 91 flotations (Table 2), including 9809 foxtail millet (*Setaria italica*) (Fig 2a), 1649 broomcorn millet (*Panicum miliaceum*) (Fig 2b), 1016 wheat (*Triticum aestivum*) (Fig 2c) and 259 barley (*Hordeum vulgare*). The rest 834 seeds are weed remains (such as *Chenopodium album, Setaria viridis, Melilotus suaveolens, Xanthium sibiricum, Sphaerophysa salsula, Atriplex patens, Galium tricorne, Glycyrrhiza uralensis, Kochia scoparia, Salsolacollina pall, Polygonum nepalense, Rumex acetosa* and et al) (Fig 2d).

Based on the new radiocarbon dates and the results of archaeobotanical analysis, one can quickly draw an agriculture development for WLP during the late prehistoric period (Table 1, 2; Fig 3e). During the Phase 1 (5500-4300 cal yr BP), the 4934 foxtail millets (72.46% of weight) and 650 broomcorn millets (27.54% of weight) identified from 42 samples (855 L soil in total) indicate a millet-based agriculture. Only one charred barley grain has been identified from the Shizhaocun, which is very likely due to the later disturbance of the site or context. Similar issues were also encountered in previous research (Dodson et al., 2013; Jia et al., 2013). During Phase 2 (4300-3600 cal yr BP), a mixed farming practice gradually emerged: 3783 foxtail millets (75.44% of weight), 239 broomcorn millets (13.75% of weight), 39 wheats (10.47% of weight) and 1 barley were collected from 21 samples of 387 L soil. Phase 3, spanning from 3600 to 3000 cal yr BP, reveals a significant gap in human activities in WLP. No traces of agriculture within the study area are found during this phase. During Phase 4 (3000-2300 cal yr BP), A more mixed agricultural tradition is in evidence when compared to Phase 2, as the addition of wheat and barley to the dominant crops occurs. 977 wheat (62.98% of weight), 257 barley (21.30% of weight), 760 broomcorn millet (10.50% of weight) and 1092 foxtail millet (5.22% of weight) were identified from 28 samples (560 L soil).

DISCUSSION

Different temporospatial patterns for the human activities and subsistence strategies in WLP and NETP during the late prehistoric periods

Archaeobotanical studies and radiocarbon dating have greatly contributed to the study of the density of human activities and subsistence strategies in the prehistoric societies (Hageman and Goldstein, 2009; Gaudzinski-Windheuser and Kindler, 2012; Dong et al., 2016, 2018). New chronological framework can be established for the occupation sequence in WLP by the new results of radiocarbon dating together with the published crop grain dates (Fig 3f). Relative to Phase 2 (4300-3600 cal yr BP), the probability density of radiocarbon dating appears more gentle of Phase 1 (5500-4300 cal yr BP). This is probably representative of an early stage of settlement by the farming group in

WLP. Phase 2 (4300-3600 cal yr BP) witnessed a sharp increase in the probability density, which reaches the maximum between 3900-3800 cal yr BP, suggestive of rapid intensification of human activities in the Qijia period in WLP. This theory is reinforced by the results of national archaeological survey (Bureau of National Cultural Relics, 2011). Based on the updated radiocarbon data, the lack of radiocarbon dates between ~3600-3000 cal yr BP suggests a gap in human activities in WLP (Table 1).

Comparing with WLP, the history of human activities during the late prehistoric periods in NETP depicts the same trajectory during Phase 1 and 2, but radically differ in Phase 3 and 4 (Fig 3h). During Phase 1 and Phase 2, the intensity of human activity also fluctuated at a relatively low profile, then increased and reached a peak at ~4100-3800 cal yr BP before dropping again. However, during next two phases of NETP, the intensity of human practice maintained a relatively high level from ~3500-3100 cal yr BP which continued to ~2300 cal yr BP (Fig 3h, Chen et al., 2015).

Archaeobotanical and zooarchaeological evidence can also make vital contributions to the understanding of subsistence strategy in these two areas during the late prehistoric period (Lee et al., 2007; Yuan et al., 2008; Zhao et al., 2010). In Phase 1, people in WLP only cultivated foxtail millet and broomcorn millet, which was initially domesticated in north China (Zhao, 2011). As seen in Fig 3e, the importance of foxtail millet appears far greater than the other. These millet farmers also raised domestic animals (pig and dog) and hunted wild animals (Caprinae and deer) as auxiliary animal resource (Zhou, 1999). In Phase 2 sheep, wheat and barley that were initially domesticated in west Asia (Zeder, 2008; Riehl et al., 2013) were introduced into northwest China (Flad et al., 2007; Dodson et al., 2013; Dong et al., 2018). While wheat became the most important cultivated crop in the Hexi Corridor from ~3700 cal yr BP (Zhou et al., 2016) and was utilized in WLP during Phase 2, the most dominant local crop was still millet (Fig 3e). Phase 2 also saw an increasing variety of domestic animals, including sheep, cattle, pig and dog in WLP (Zhou, 1999; Jia et al., 2013). There was no sites to excavating crops in WLP of Phase 3, but wheat was the most important crops in Phase 4 (Fig 3e).

The history for the transition of subsistence strategies in NETP was different in comparison to that of WLP. Local NETP people relied mainly on broomcorn millet instead of foxtail millet in Phase 1 (Chen et al., 2015; Fig 3g). Hunting was another important subsistence strategy in NETP during the same period, Millet continued to be the major local crop in Phase 2 and pigs and dogs domesticated (Ren, 2017; Wang, 2017). And a supplementary proportion of barley being used simultaneously (Fig 3g). This is also verified by the stable isotopic analysis of human bones unearthed from sites dated to the same period (Ma et al., 2014; 2016). Zooarchaeological analysis from the Lajia site of NETP also suggests an interesting change in the meat supply, shifting from pig to sheep (Ye, 2015). Phase 3 in NETP, in contrast to Phase 3 in WLP, witnessed not only the radical expansion of humans' living space, the increasing dependence on barley (Fig 3g), but also different subsistence strategies taken by different groups of people along different altitudes (Zhang and Dong, 2017). This spatial differentiation of the human subsistence was retained in Phase 4 in NETP and the most characteristic pattern was the increasing ratio of barley in NETP (Chen et al., 2015; Zhang and Dong, 2017).

In summary, the temporospatial difference of human subsistence strategy in NETP and WLP was mainly reflected by the variation in cultivated crop types. During Phase 1, the most important crops were foxtail and broomcorn millet in WLP and NETP. Stepping into the next phase, the primary crop in both regions was foxtail millet, broomcorn millet, and wheat began to increase in WLP and barley began to increase in NETP (Figs 3e and 3g). In Phases 3 and 4, barley became the dominant plant subsistence in NETP, while WLP shifted to wheat, followed by barley, broomcorn and foxtail millet (Figs 3e and 3g).

Contrasting different human responses to the same climate change between WLP and NETP

The late Neolithic and Bronze Age were unique periods to studying the evolution of the human-land relation, because this period has the rise and fall of the earliest civilizations, trans-Eurasia culture exchange (Spengler et al., 2014; Dong et al., 2017b; Liu et al., 2019). According to high-resolution paleoclimate records in WLP, including bio-markers from the sediment of the Liupan Tianchi lake (Sun, 2011; Sun et al., 2018) and oxygen isotopes of stalagmite in the Jiuxian cave (Cai et al., 2010), the temperature remained relatively high during 5500-3600 cal yr BP as a whole, but followed by several cold periods between ~4900-4500 cal yr BP and 3600-2000 cal yr BP (Fig 3d). Meanwhile, four droughts can be detected in the periods of ~4900-4700 cal yr BP, ~3800-3600 cal yr BP, ~3000-2800 cal yr BP and ~2700-2500 cal yr BP, respectively (Figs 3a and 3b).

The correlation between paleoclimate records and CPD curves of radiocarbon dates suggests that human settlement in WLP and NETP during the late prehistoric period was mainly affected by the variation in temperature rather than precipitation. Compared with precipitation, the decline in temperature appears more dramatic. The shortage of water supply caused by decreased precipitation (with fluctuations) can also be eased by the abundant local river system, such as the Wei River and its branches. The most notable decline in the CPD distribution of the two areas occurred around 3600 cal yr BP, when the temperature reached its lowest (Figs 3c and 3d). In NETP settlement was soon re-established but WLP experienced a period of nearly six hundred years with virtually no human activities. The next inhabitation of WLP can been seen during 3000-2300 cal yr BP (Phase 4). It was an interesting period as there were two droughts identified by the record obviously (Figs 3a and 3b). This phenomenon might be related to the physiological characteristics of foxtail and broomcorn millets, both of which are drought-tolerant but sensitive to low temperature (Baltensperger, 1996).

The difference of life-styles in NETP and WLP during the Late Neolithic period was also affected by the climate. The temperature becomes much lower in NETP than in WLP due to the higher elevation. Therefore, human mainly cultivated foxtail millet in WLP, compared to broomcorn millet in NETP during 5500-4300 cal yr BP (Phase 1) as broomcorn millet is much more resistant to a cold environment (Baltensperger, 1996). Temperature between 4300-4000 cal yr BP was higher than Phase 1 (Fig 3d), foxtail millet became the primary crop in NETP during that period (Chen et al., 2015). Wheat and barley were subsequently introduced into northwest China around 4000 cal yr BP (Dodson et al., 2013; Dong, 2018). When the temperature declined again between 4000-3600 cal yr BP (Figs 3c and 3d), human in NETP and WLP might have added barley and wheat into their cultivated crops (Figs 3e and 3g), sheep was also frequently utilized in NETP during that period (Ye, 2015; Ren, 2017).

The temperature remained persistently low in Phases 3 and 4 (Figs 3c and 3d), which might have significantly affected the yield of millet and therefore resulted in the absence of human activities in WLP (Table1; Fig 3f). However, people survived in NETP and even successfully expanded to high-cold areas during this period. This could be explained by the development of new strategies such as the cultivation of barley and adopting sheep and yak (Chen et al., 2015; Dong et al., 2016). In Phase 4, WLP decided to have wheat that has the higher production than barley as the primary plant subsistence, along with the emergence of the Siwa culture in the area. Undoubtedly, the choice made by WLP was completely different from NETP. Compared to wheat, barley requires a much shorter growth period and appears more adapted to high-cold areas of the Tibetan Plateau (Páldi et al., 2001; D'Alpoim Guedes et al., 2014, 2015).

CONCLUSION

The new archaeobotanical and radiocarbon results in the upper Wei River valley, combined with previously published data, have demonstrated that people in WLP were mainly dependent on foxtail millet and to a lesser extent, broomcorn millet during 5500-4300 cal yr BP. Wheat was subsequently added to the local choice during 4300-3600 cal yr BP. The current data shows a serious gap of human activity in WLP during 3600-3000 cal yr BP. The area/region was repopulated between 3000-2300 cal yr BP, during which phase wheat became the most important subsistence, followed by barley, broomcorn and foxtail millet. Further comparisons to high-resolution paleoclimate records suggest that human activity in the late prehistoric WLP was not affected by variation in precipitation levels but variation in temperature.

Despite the rapid decline of the local temperature, by adopting new crop species with different physiological characteristics, people successfully adapted to the new climatic conditions in NETP and WLP during 5500-3600 cal yr BP. One of the ultimate reasons that allowed people to survive (and even migrate to higher elevations in NETP) was the quick adoption of new cold-tolerant barley and sheep, which were brought into northwest China by trans-Eurasia culture exchange during early Bronze Age.

ACKNOWLEDGEMENTS

This research was supported by the National Key R&D Program of China (2018YFA0606402), Strategic Priority Research Program of the Chinese Academy of Sciences, Pan-Third Pole Environment Study for a Green Silk Road (Pan-TPE) (Grant No. XDA2004010101), the National Natural Science Foundation of China (Grant Nos. 41671077 and 41620104007), the International Partnership Program of Chinese Academy of Sciences (grant no. 131C11KYSB20160061).

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Zhou XY, Li XQ, Dodson J, Zhao KL. 2016. Rapid agricultural transformation in the prehistoric Hexi corridor China. *Quaternary International* 426: 33-41.**Table 1. Calibrated radiocarbon dates and associated information of samples from the sites in WLP.**

Site	Lab number	Dated material	^{14}C age	Calibrated age (cal yr BP)		Culture	References
				1 sigma	2 sigma		
Bupo	**LZU17206**	**Foxtail millet**	**4495±25**	**5167±113**	**5168±122**	**Majiayao**	**This study**
Xishanping	**TKa13889**	**Foxtail millet**	**4490±35**	**5166±117**	**5140±158**	**Majiayao**	**Li et al., 2007**

Yujiawa	LZU17196	Foxtail millet	4465±25	5131±143	5129±154	Late Yangshao	This study
Yangwa	LZU17195	Foxtail millet	4450±25	5119±144	5123±157	Majiayao	This study
Xishanping	TKa13890	Rice	4430±100	5075±199	5077±236	Majiayao	Li et al., 2007
Huidier	LZU17208	Foxtail millet	4425±35	5049±162	5073±202	Late Yangshao	This study
Buziping	BA110882	Foxtail millet	4300±25	4854±10	4894±64	Majiayao	Jia et al., 2013
Lixinzhen	LZU17210	Foxtail millet	4185±35	4738±91	4712±126	Majiayao	This study
Shizhaocun	LZU17191	Foxtail millet	4000±25	4471±43	4470±50	Majiayao	This study
Laohuzui	BA110866	Charred millets	3870±30	4323±81	4287±126	Qijia	Dong et al., 2014
Shangmiangua	LZU14230	Foxtail millet	3845±30	4253±95	4279±125	Qijia	Chen et al., 2019
Jiangjiazui	BA110871	Broomcorn millet	3835±25	4222±65	4277±127	Qijia	Chen et al., 2019
Zhengjiashanliang	LZU17212	Foxtail millet	3725±25	4069±75	4067±82	Qijia	This study
Qiaocun	BA110870	Foxtail millet	3635±25	3943±35	3972±100	Qijia	Chen et al., 2019

Guanziziui	BA120217	Charred millets	3630±30	3939±40	3965±111	Qijia	Dong et al., 2014
Buzipin g	BA110883	Foxtail millet	3610±20	3927±39	3919±59	Qijia	Jia et al., 2013
Yuanggudui	LZU17207	Foxtail millet	3600±30	3914±49	3908±70	Qijia	This study
Sumiao yuantou	BA110879	Charred millets	3600±25	3916±47	3908±64	Qijia	Dong et al., 2014
Wujiaping	LZU17193	Foxtail millet	3585±25	3877±33	3902±68	Qijia	This study
Shipocun	LZU17201	Foxtail millet	3570±35	3875±44	3850±124	Qijia	This study
Shuiquangou	LZU17211	Foxtail millet	3570±25	3866±28	3849±116	Qijia	This study
Yierjidianguandi	LZU17203	Foxtail millet	3520±35	3784±62	3792±94	Qijia	This study
Yaoshang	LZU17189	Wheat	2865±25	3001±54	2976±89	Siwa	This study
Longxixihetan	LZU17188	Wheat	2765±30	2856±62	2863±80	Siwa	This study
Qinjiaping	LZU17197	Wheat	2545±25	2644±100	2625±122	Siwa	This study
Dongjiaping	LZU17198	Wheat	2510±25	2613±106	2614±123	Siwa	This study
Ruji	LZU17190	Wheat	2445±25	2532±152	2529±170	Siwa	This study

Laoyeshan	**LZU17202**	**Wheat**	**2420±20**	**2412±48**	**2517±161**	**Siwa**	**This study**
Sanjiaodi	**LZU17200**	**Barley**	**2320±25**	**2343±8**	**2335±22**	**Siwa**	**This study**

Table 2. Charred plant seeds identified from the 41 archaeological sites during 5500-2300 cal yr BP in WLP.

Site	**Sample number**	**Soil floatation quantity (L)**	**Crop**				**Weed**	**Total**
			Setaria italica	***Panicum miliaceum***	***Triticum aestivum***	***Hordeum vulgare***		
Nuanquanshan	**1**	**20**		**29**			**5**	**34**
Zhoujiawan	**2**	**30**	**46**	**50**				**96**
Chaijiaping	**2**	**30**	**35**	**16**				**51**
Xishanping	**3**	**53**	**71**	**37**			**1**	**109**
Shanpingli	**2**	**45**	**139**	**72**			**6**	**217**
Caikeding	**1**	**17**	**5**					**5**
Shizidao	**2**	**38**	**1634**	**37**				**1671**
Yangwa	**3**	**60**	**1591**	**32**			**1**	**1624**
Xiewanding	**1**	**28**	**231**	**12**			**2**	**245**
Chunshuwan	**2**	**46**	**32**				**3**	**35**

Yujiawa	4	106	497	183			3	683
Wayaoding	1	16		1				1
Shangrenwan	2	40	21				1	22
Yangjiaping	1	16	39				2	41
Douwashan	2	42	77	26			13	116
Bupo	2	52	28					28
Huidier	3	56	48	5			7	60
Lixinzhen	4	80	209	50			3	262
Yingwuwa	2	44	180	79			1	260
Shizhaocun	2	36	51	21		1	2	75
zhengjiashanliang	4	93	270	30			7	307
Wujiaping	2	40	855	13			7	875
Yierjidianguandi	1	13	38	9				47
Shuiquangou	2	50	267	45			5	317
Fanjiacheng	2	36	26	4	1		11	42
Siping	2	24	137	56		1	18	212
Sishilipu	2	33	1350	64	33		40	1487
Shipocun	1	16	257	4	3		5	269
Weishuiyu	2	27	21	4	1			26
Yuanguduii	3	55	562	10	1			573

Laoyeshan	**1**	**18**	**191**	**500**	**31**	**9**	**1**	**732**
Yaoshang	**2**	**30**	**184**	**21**	**17**	**1**	**56**	**279**
Qinjiaping	**4**	**88**	**180**	**27**	**69**	**32**	**6**	**314**
Xihetan	**5**	**96**	**83**	**75**	**38**	**29**	**98**	**323**
Sanjiaodi	**3**	**56**	**88**	**14**	**62**	**26**	**3**	**193**
Ruji	**3**	**51**	**57**	**35**	**127**	**41**	**25**	**285**
Wapenyao	**2**	**47**	**112**	**11**	**163**	**19**	**28**	**333**
Diantiandi	**3**	**74**	**34**	**1**	**197**	**28**	**15**	**275**
Dongjiaping	**3**	**56**	**37**	**71**	**86**	**1**	**2**	**197**
Majiayao	**1**	**24**	**119**	**1**	**127**	**51**	**449**	**747**
Beiposi	**1**	**20**	**7**	**4**	**60**	**20**	**8**	**99**
Total	**91**	**1802**	**9809**	**1649**	**1016**	**259**	**834**	**13567**

Figure captions

Fig 1. (a) Distribution of prehistoric sites with radiocarbon dates in NETP (Dong et al., 2014; Yang, 2014; Chen et al., 2015). (b) Location of the 41 sampled sites in the study area in the paper. Sample sites: 1. Nuanquanshan, 2. Longxixihetan, 3. Lixinzhen, 4. Yingwuwa 5. Wujiaping, 6. Laoyeshan, 7. Yujiawa, 8. Bupo, 9. Majiayao, 10. Dongjiaping, 11. Diantiandi, 12. Qinjiaping, 13. Sishilipu, 14. Wapenyao, 15. Chunshuwan, 16. Beiposi 17. Shuiquangou, 18. Yuangudui, 19. Yierjidianguandi, 20. Huidier, 21. Wayaoding, 22. Shangrenwan, 23. Yangwa, 24. Shizidao, 25. Sanjiaodi, 26. Yangjiaping, 27. Siping, 28. Shipocun, 29.

Xiewanding, 30. Zhengjiashanliang, 31. Douwashan, 32. Weishuiyu, 33. Yaoshang, 34. Shanpingli, 35. Fanjiacheng, 36. Shizhaocun, 37. Xishanping, 38. Ruji, 39. Chaijiaping, 40. Caikeding 41. Zhoujiawan.

Fig 2. Charred plant seeds collected from WLP (scale bar: 1mm).

a. *Setaria italica*, b. *Panicum miliaceum*, c. *Triticum aestivum*, d. *Hordeum vulgare*, e. *Chenopodium album,* f. *Setaria viridis,* g. *Melilotus suaveolens,* h. *Galium tricorne,* i. *Sphaerophysa salsula,* j. *Atriplex patens,* k. *Galium tricornutum,* l. *Glycyrrhiza uralensis,* m. *Kochia scoparia,* n. *Salsola pestifer,* o. *Polygonum nepalense,* p. *Rumex acetosa*.

Fig 3. Human-environment interaction in WLP and NETP.

a. The $\delta^{18}O$ record of the Jiuxian Cave stalagmites (Cai et al., 2010), b. Paq values based-on n-alkanes in Liupan Tianchi Lake (Sun et al., 2018), c. Northern Hemisphere (30° to 90°N) temperature record compared to 1961–1990 instrumental mean temperature (Marcott et al., 2013), d. MBT/CBT-derived MAT in Liupan Tianchi Lake (Sun, 2011), e. The weight percentage of crops in WLP, f. CPD curve formed by the probability density of radiocarbon dates from charred plant seeds in WLP (Li et al., 2007; Jia et al., 2013; Dong et al., 2014; Chen et al., 2019), g. The weight percentage of crops in NETP (Chen et al., 2015), h. CPD curve formed by the probability density of radiocarbon dates from charred plant seeds in NETP (Dong et al., 2014; Chen et al., 2015).