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Asynchronous Transformation of Cropping Patterns from 5800–2200 cal BP on the Southern Loess Plateau, China

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Abstract: Archaeobotanical studies have largely illuminated spatiotemporal differences in agricultural development across the Loess Plateau. However, the particularities of local agricultural development have not been adequately studied for complex geographical, environmental, and prehistoric contexts. Here, new archaeobotanical data and radiocarbon dating results from 27 Neolithic and Bronze Age sites in Baoji are reported. Combining these data with published archaeobotanical datasets, this study explores shifts (and underlying driving factors) in cropping patterns from the late Neolithic to Bronze Age on the southern Loess Plateau (SLP). Regional geographic, environmental, and climatic factors produced mixed millet-rice agricultural systems in the Guanzhong Plain (GZP) and western Henan Province (WHN) and foxtail and broomcorn millet dry-farming systems in the Upper Weihe River (UWR) from 5800–4500 cal BP. Wheat and barley were added to the agricultural systems of the UWR as auxiliary crops after ~4000 cal BP, while cropping patterns remained largely unchanged in GZP and WHN from 4500–3500 cal BP. Cultural exchanges and technological innovations may have influenced the formation of different agricultural patterns across the three regions (i.e., GZP, WHN, and UWR) from 4500–3500 cal BP. From 3500–2200 cal BP, wheat and barley became increasingly important crops on the SLP, although their importance varied spatially, and rice was rarely cultivated. Spatiotemporal variation in cropping patterns was driven by altered survival pressures associated with climate deterioration and population growth from 3500–2200 cal BP. This process was reinforced by internal social developments, as well as interactions with close northern neighbors, in the Shang-Zhou period.

Keywords: archaeobotany; cropping patterns; climate change; trans-continental cultural exchange; southern Loess Plateau

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1. Introduction

The origins and spread of agriculture in Eurasia substantially impacted prehistoric subsistence strategies, as intensively discussed in recent decades [1–7]. Crops served as an important basis for trans-Eurasian cultural exchanges, and the establishment of agricultural economies enhanced societal capacity for coping with climate change [2,8,9], promoted the growth and expansion of human populations [10,11], and laid the foundation for the formation of contemporary world patterns. The cultivation of millet originated in the Yellow River Valley [12,13], and the development and diffusion of millet crops economically supported the birth and evolution of Chinese civilization. Thus, characterizing the history of prehistoric crop cultivation is essential to understanding ancient agricultural economies and societal dynamics. By analyzing plant remains excavated at archaeological sites, ancient cropping patterns can be reconstructed for different spatiotemporal conditions, and societal responses to environmental stressors are evaluated [14,15]. The late Neolithic to the Bronze Age (4500–3500 cal BP) was a period of intense climatic fluctuations in northern China [16–18], as well as a critical period for the emergence and intensification of trans-Eurasian cultural exchanges [19,20]. To understand the evolution of historical human–land relations, temporal agricultural patterns can be analyzed to characterize adaptations to diverse natural and socioenvironmental factors.

On the Loess Plateau, millet has been continuously cultivated since the early Neolithic [21–23]. Additionally, the abundance of Neolithic-Bronze Age archaeological sites on the Loess Plateau makes the area ideal for investigations of prehistoric adaptations to climatic and environmental changes [24,25]. Archaeobotanical analyses of plant remains have shown dry farming dominated on the Loess Plateau during the Neolithic-Bronze Age, with foxtail millet and broomcorn millet representing the two main crops [15,26,27]. The importance of foxtail millet for human subsistence exceeded that of broomcorn millet around 5500 BP [28]. About 4000 BP, trans-Eurasian exchanges introduced wheat from West Asia to the Loess Plateau, where it became an important crop [19,29]. By the Shang-Zhou period (3500–2200 cal BP), diverse (i.e., multi-species) cropping systems had been established [30,31]. However, previous archaeobotanical research has mostly focused on the western Loess Plateau and Hexi corridor (to the west) [32–34]. On the southern Loess Plateau, spatiotemporal variation in agricultural development and cultivation practices remains poorly characterized for the Neolithic period to present.

The southern Loess Plateau (SLP), located at the easternmost point of the ancient Silk Road, represents a key region for ancient Chinese civilizations, also serving as a link between Northwest China and the Central Plains. The cultural evolution of the Neolithic and Bronze Ages was closely related to shifts in agricultural systems [25]. The SLP spans a vast east–west expanse across which environmental factors affecting crop growth, such as climate, geomorphology, hydrology, and soil type, vary substantially. This variation has resulted in diverse cropping strategies and agricultural systems. In addition, the SLP spanned from the peripheral (the Arc) to the core area of the Neolithic civilization in northern China. Exchanges and conflicts between the Arc and Central Plains (triggered by resource differences) resulted in the adoption of wheat and barley crops, as well as herded animals (horse, cattle, sheep/goat, etc), promoting the rise of the Shang Dynasty. Thus, characterizing historical cropping patterns on the SLP will foster a better understanding of agricultural strategies in the subhumid to semi-arid transition region in the context of transcontinental exchanges. Carbonized plant remains have been used to describe patterns of agricultural development during the late prehistoric period on the SLP [27,35,36]. However, spatial environmental variation is much more extensive on the SLP versus the central or northern Loess Plateau. Therefore, it is necessary to study historical relationships between ancient agricultural systems and geography specifically for the SLP.

In this study, a systematic archaeobotanical analysis and radiocarbon dating was performed for samples from 27 Neolithic and Bronze Age sites in Baoji. These data were combined with published archaeobotanical datasets for the SLP from 5800–2200 cal BP to: (1) reconstruct historical cropping patterns in the vicinity of Baoji; (2) more broadly elucidate the trajectory of agricultural development from a temporal and regional perspective on the SLP; and (3) explore transformations in crop cultivation patterns, as well as the influence of trans-Eurasian cultural exchanges, climate change, and the local regional environment.

2. Study Area

The study area encompassed the southern Loess Plateau (33°45′~35°52′ N, 104°35′~112°15′ E; SLP) in west-central China (Figure 1). The SLP represents a transition zone between the Loess Plateau and Guanzhong Plain. The Weihe River, which is the main tributary of the Yellow River, flows through the region and finally feeds into the Yellow River in Tongguan County, Weinan, Shaanxi. The study area lies within the monsoon margin, a transitional zone between semi-arid and subhumid climates. The climate is strongly controlled by the East Asian monsoon and sensitive to climate change [37]. Annual precipitation decreases gradually from the southeast to northwest, with annual precipitation averaging 500–900 mm and evaporation 1500–2000 mm [38]. The SLP is topographically complex, with the mean elevation ranging from 1600 m a.s.l. in the northwest to 500 m a.s.l. in the southeast; moving towards the southeast, mountains gradually give way to hills and eventually valley plains. The archaeobotanical sites included in this study (both surveyed sites and those with published data) were located on an east–west transect of the SLP, encompassing Tianshui on the upper Weihe River (UWR); Baoji, Xianyang, Xi'an, and Weinan on the Guanzhong Plain (GZP); and Sanmenxia in western Henan Province (WHN). The UWR contains a diverse array of landforms; the average elevation is 1100 m above sea level. The climate on the UWR is classified as continental winter dry (Dwb) [39], with an annual average temperature of 8–10 °C and an annual precipitation of 500–650 mm. Guanzhong Plain contains extensive loess accumulations, with loess tablelands, alluvial plains, and other landform types. The plain experiences a warm temperate, semi-humid continental monsoon climate, and modern dry farming is well developed in the region. The annual average temperature is 12–13.6 °C, and annual precipitation is 590–900 mm. In Henan Province, the terrain includes high hilly regions in the west and low alluvial plains in the east. Western Henan also contains mountains, hills, and loess tablelands, among other landforms. The climate of western Henan is classified as continental monsoon semi-arid, with a mean annual temperature of 14.2 °C and mean annual precipitation ranging from 400–700 mm [40]. The varied environmental conditions on the SLP have influenced historical agricultural economies, thus moderating the development of different socioeconomic formations.

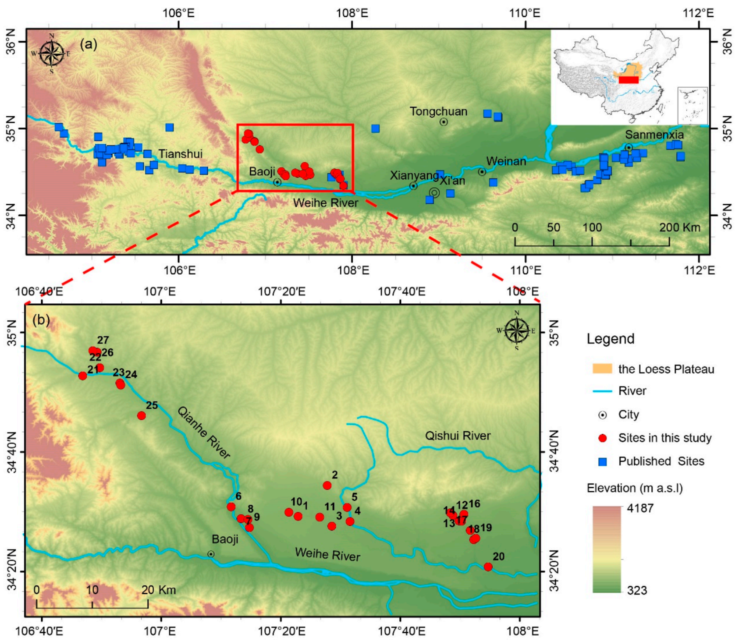

Figure 1. (**a**): Location of the study area within China, and distribution of study sites with published archaeobotanical datasets and study sites sampled near Baoji. (**b**): Location of study sites within the area surrounding Baoji. 1. Gaojiahe; 2. Shuigou; 3. Guanmaotou; 4. Hengshui; 5. Yuxiang; 6. Xiaoyuan; 7. Lijiagou; 8. Chaojiagou; 9. Madaokou; 10. Daxin; 11. Yaoziao; 12. Lujiacun; 13. Qiyang; 14. Shuang'an; 15. Wangjiazui; 16. Zhouyuan (Fengchu); 17. Yaobai; 18. Dingtong; 19. Tiezhang; 20. Anban; 21. Maizaoyu; 22. Yuanzitou; 23. Bianjiazhuang; 24. Shenjiazui; 25. Mogouyuan; 26. Baguankou; 27. Xinpingsi.

Baoji is located in present-day Shaanxi Province (33°35′~35°06′ N, 106°18′~108°03′ E), in the western Weihe Valley, 150 km west of Xi'an; Baoji encompasses two important south-flowing tributaries of the Weihe River, Qian River, and Jing River (Figure 1b). The sites investigated in this study were located on the terraces of these tributaries and the alluvial plain. According to the Second National Archaeological Survey, many Neolithic and Bronze Age sites have been found on the SLP [24]. The prehistoric cultural sequence involved Laoguantai, Yangshao, and Longshan cultures in the Neolithic Age and Shang, Proto-Zhou, Zhou, and Qin cultures in the Bronze Age [24,41]. Modern agriculture in the area includes wheat, corn, millet, beans, and potato crops; the main livestock are sheep, chickens, pigs, and cattle.

3. Materials and Methods

3.1. Archaeobotanical Methods

A total of 27 Neolithic and Bronze Age sites were investigated in the city of Baoji during field surveys in 2016. We performed profile analyses of several archaeological deposits at each site to expose cultural layers and features (ash pits and room relics, etc). Based on ceramics recovered from the section of the investigated sites, all of them belong to Yangshao culture, Longshan culture, Zhou-Qin Period. Despite natural erosion of the surface sediments of the section, the contours of the remains are clearly visible (Figure 2). After cleaning off the surface of the ash pit and culture layer, we collected soil samples from each relic unit at each site. The average volume of 166 sample soils was not less than 15 L. Samples were floated using manual bucket flotation, sieved through an 80-mesh sifter (aperture size of 0.2 mm) to gather any carbonized remains, and then dried naturally. Charred plant seeds were identified in the MOE Key Laboratory of Western China's Environmental Systems at Lanzhou University.

Figure 2. Archaeological remains from some investigated sites in Baoji. (**a1**): Mogouyuan; (**a2**): Gaojiahe; (**a3**): Qiyang; (**b1**): Daxin; (**b2**): Yaoziao; (**b3**): Shenjiazui; (**c1**): Yuanzitou; (**c2**): Bianjiazhuang; (**c3**): Maizaoyu.

3.2. Radiocarbon Dating

Twenty-eight carbonized plant remains from Baoji were selected for AMS radiocarbon dating, including sixteen charred millet seeds, eight charred rice seeds, and four charred wheat seeds. The seeds were treated with an acid–base–acid method [42]; processed samples were then graphitized using the AGE III system and tested using MICADAS [43]. Dating was performed by the Radiocarbon Laboratory of Lanzhou University in China. Dating results were calibrated using OxCal v.4.4.0 [44] and an IntCal20 calibration curve [45]. All ages reported are relative to AD 1950 (referred to as "cal BP").

3.3. Data Analysis

A total of 153 published archaeobotanical datasets were collected from 83 Late Neolithic and Bronze Age sites within the SLP. Site locations are shown in Figure 1a, and site information is detailed in Supplementary Table S1. Due to differences in the geographical distribution of the sites and the proportion of different types of archaeological remains (e.g., cultural layers, ash pits, and room relics) [46], the number of plant remains per city was averaged and weights calculated using the Weight Ratio Function proposed by Zhou [33]. The quantitative methods used to estimate the yield percentage (weight) of major crops were adapted from Zhou et al. [33] and Sheng et al. [14].

4. Results

4.1. Radiocarbon Dating Results

In our radiocarbon dating analysis, 26 radiocarbon dates were obtained from Neolithic and Bronze Age sites in Baoji, Shanxi Province. The ^{14}C dating results for the 26 charred seed samples are provided in Table 1 and shown in Figure 3; the seed samples were dated from 5716 to 2493 cal BP. Comparing these results to dated samples of pottery and other excavated materials, three much older radiocarbon dates obtained from seeds are excluded from our analysis because they are inconsistent with the chronological range of the Longshan culture, which is generally accepted by archaeology. The other 23 ^{14}C dates accord well with the characteristics of cultural relics unearthed from prehistoric sites in the Guanzhong Plain and are used for the chronological reconstruction. Fifteen samples were dated between 5716 and 4832 cal BP, corresponding to the Mid–Late Yangshao period. Four samples were dated to between 4352 and 3889 cal BP, corresponding to the Longshan period. The other three charred seeds were dated to between 2997 and 2493 cal BP, corresponding to the Zhou-Qin period.

Table 1. Radiocarbon dates from sites investigated in Baoji. Calibrated ranges are given at 68.2 and 95.4% probabilities using OxCal 4.4 and the IntCal20 curve.

Lab Code	Sample Number	Dating Material	Dating Method	Radiocarbon Age (yr BP)	Calibrated Age (cal. yr BP) 1σ	2σ	Period
LZU16170	Baguankou H5	Rice	AMS	4925 ± 25	5657–5598	5716–5592	Middle Yangshao
LZU16168	Maizaoyu H1	Foxtail millet	AMS	4885 ± 25	5650–5588	5659–5582	Middle Yangshao
LZU16171	Yuanzitou H2	Broomcorn millet	AMS	4815 ± 50	5594–5478	5653–5331	Middle Yangshao
LZU17050	Shuigou Layer ⑨	Foxtail millet	AMS	4805 ± 40	5589–5479	5600–5335	Middle Yangshao
LZU17051	Wangjiazui	Broomcorn millet	AMS	4780 ± 25	5582–5479	5585–5474	Middle Yangshao
LZU20526	Gaojiahe1 H2	Foxtail millet	AMS	4590 ± 20	5432–5300	5442–5144	Middle Yangshao
LZU20524	Qiyang1 H4	Broomcorn millet	AMS	4570 ± 20	5318–5289	5435–5070	Middle Yangshao
LZU20533	Yuanzitou H2	Foxtail millet	AMS	4550 ± 20	5313–5090	5318–5056	Middle Yangshao
LZU20528	Madaokou H4	Broomcorn millet	AMS	4540 ± 20	5309–5075	5315–5053	Middle Yangshao

Table 1. *Cont.*

Lab Code	Sample Number	Dating Material	Dating Method	Radiocarbon	Calibrated Age (cal. yr BP)		Period
				Age (yr BP)	1σ	2σ	
LZU20536	Xinpingsi H4	Foxtail millet	AMS	4530 ± 20	5305–5065	5312–5052	Middle Yangshao
LZU20527	Guanmaotou H2	Foxtail millet	AMS	4480 ± 20	5277–5048	5287–4986	Middle Yangshao
LZU20521	Anban layer3	Foxtail millet	AMS	4490 ± 20	5280–5052	5289–5045	Late Yangshao
LZU20529	Xiaoyuan H3	Foxtail millet	AMS	4370 ± 20	4960–4872	5025–4861	Late Yangshao
LZU16165	Bianjiazhuang H2	Rice	AMS	4335 ± 30	4959–4850	4973–4841	Late Yangshao
LZU16164	Yuanzitou layer ②	Rice	AMS	4310 ± 35	4956–4836	4965–4832	Late Yangshao
LZU16167	Maizaoyu H2	Rice	AMS	4160 ± 30	4821–4624	4828–4580	Longshan
LZU16169	Mogouyuan H4	Rice	AMS	4130 ± 50	4815–4573	4828–4523	Longshan
LZU16166	Xinpingsi layer ②	Rice	AMS	4125 ± 25	4800–4578	4817–4529	Longshan
LZU20530	Yaozi'ao H4	Foxtail millet	AMS	3830 ± 20	4284–4155	4352–4148	Longshan
LZU20532	Yuxiang H3	Rice	AMS	3710 ± 20	4090–3988	4146–3981	Longshan
LZU20534	Mogouyuan H1	Foxtail millet	AMS	3700 ± 20	4085–3987	4144–3976	Longshan
LZU20522	Tiezhang H3	Foxtail millet	AMS	3640 ± 20	3981–3909	4078–3889	Longshan
LZU20531	Yaozi'ao H6	Wheat	AMS	2830 ± 20	2961–2881	2997–2869	Zhouqin
LZU20519	Wangjiazui H1	Wheat	AMS	2650 ± 20	2766–2748	2840–2740	Zhouqin
LZU20525	Daxin H5	Wheat	AMS	2540 ± 20	2737–2543	2742–2516	Zhouqin
LZU20535	Baguankou H4	Wheat	AMS	2500 ± 20	2710–2515	2722–2493	Zhouqin

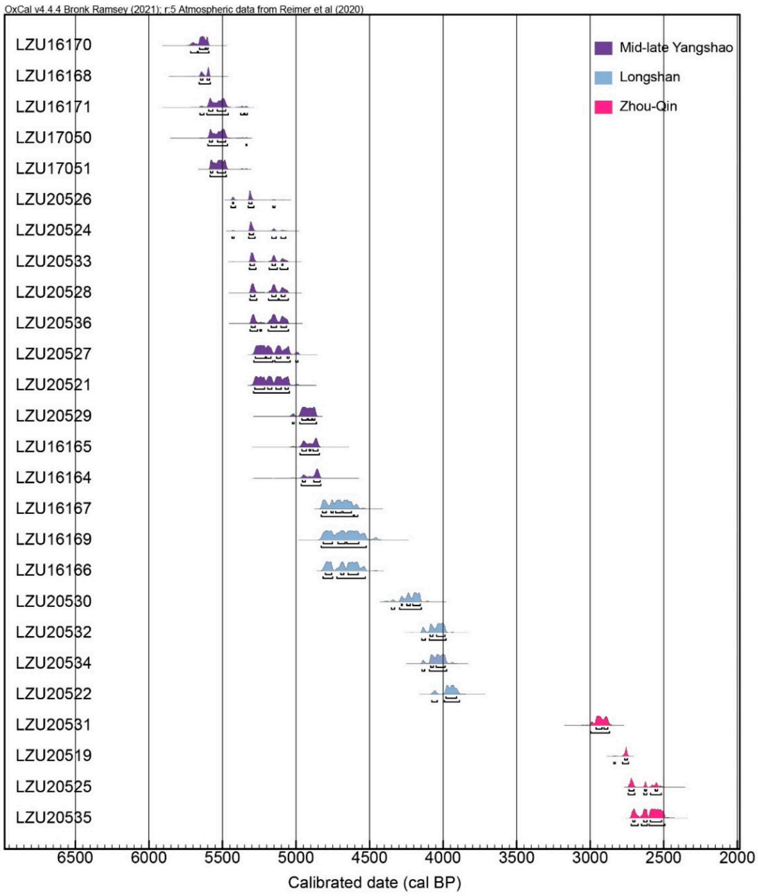

Figure 3. Calibrated dates of investigate sites in Baoji. using OxCal 4.4 software.

4.2. Archaeobotanical Analysis Results

In this study, a total of 40,594 charred seeds were identified from 27 late-Neolithic-to-Bronze Age sites (Table S2), including 29,075 foxtail millet (*Setaria italica*) seeds (Figure 4a), 8584 broomcorn millet seeds (*Panicum miliaceum*) (Figure 4b), 95 rice (*Oryza sativa*) seeds (Figure 4c), 857 wheat (*Triticum aestivum*) seeds (Figure 4d), and 2 barley (*Hordeum vulgare*) seeds. The remaining 1979 seeds belonged to weedy or uncultivated species (such as *Astragalus membranaceus*, *Chenopodium album*, *Eleusine indica*, *Lespedeza bicolor*, *Melilotus suaveolens*, *Perilla frutescens*, *Rumex acetosa*, *Setaria viridis*, and *Xanthium sibiricum*).

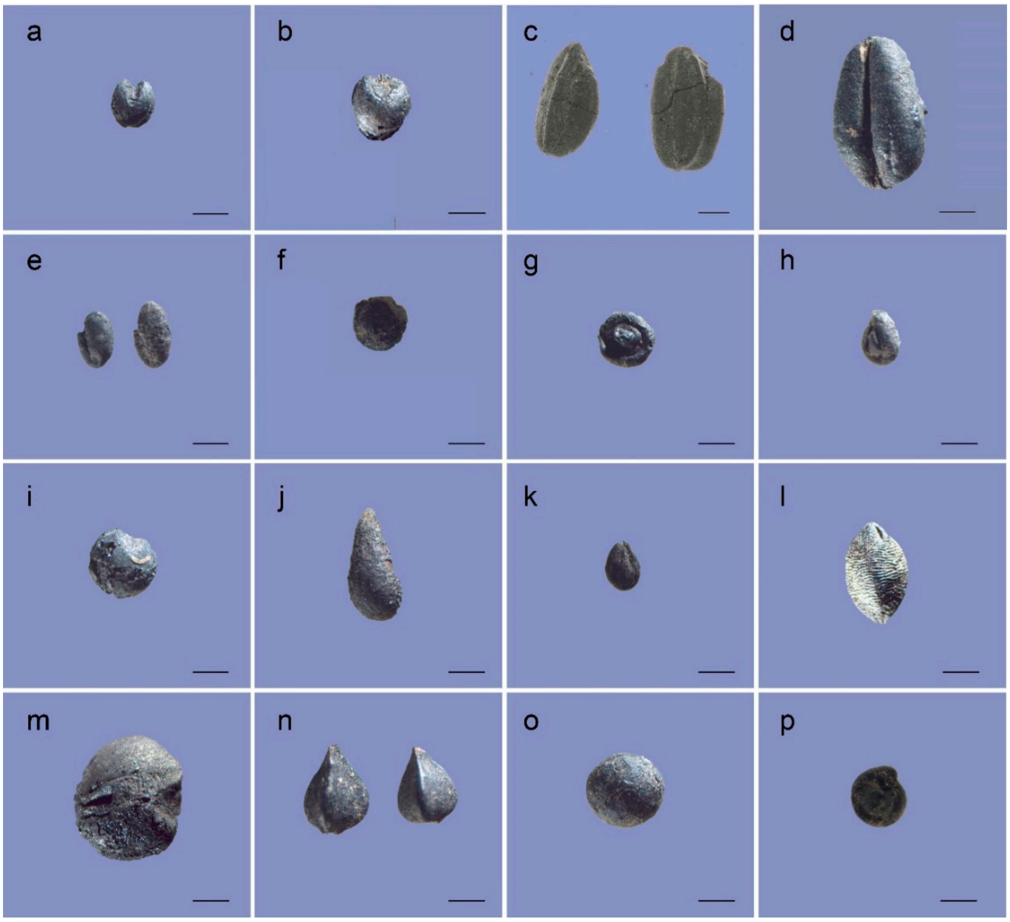

Figure 4. Charred crop seeds identified from archaeological sites in Baoji (Scale bar: 1 mm). (**a**) *Setaria italica*; (**b**) *Panicum miliaceum*; (**c**) *Oryza sativa*; (**d**)*Triticum aestivum*; (**e**) *Melilotus officinalis*; (**f**) *Atriplex patens*; (**g**) *Salsola collina*; (**h**) *Kochia scoparia*; (**i**) *Glycyrrhiza uralensis* Fisch.; (**j**) *Erodium stephanianum*; (**k**) *Lespedeza bicolor*; (**l**) *Setaria pumila*; (**m**) *Iris lactea*; (**n**) *Rumex acetosa*; (**o**) *Perilla frutescens*; (**p**) *Chenopodium album.*

4.3. Quantitative Reconstruction of the Ancient Cropping Patterns in Baoji

Based on the new radiocarbon dating and archaeobotanical data, prehistoric patterns of plant utilization were summarized for Baoji. The percentage, weight (as a proportion), and ubiquity of different crops varied across chronological phases (Table S2, Figure 5). During Phase 1 (5716–4832 cal BP), the presence of 11,920 sampled foxtail millet seeds (66.86% weight, 80.65% ubiquity) and 6231 broomcorn millet seeds (28.23% weight, 52.69% ubiquity) identified from 93 samples (744 L of soil in total) suggest a millet-based agriculture (Figure 5a). Rice was integrated into this millet-based farming strategy no later than 5690 cal BP in the Guanzhong Plain [47,48]. A total of 38 rice remains were identified from six sites; these were much less common (4.91% of weight (9.68% ubiquity) in Baoji than millet crop remains, suggesting that rice production was unimportant to the agricultural economy of this period. No wheat crop remains were identified from this period. Wheat may not have been introduced to Baoji by the late Yangshao period, or may have only played a small role in agricultural systems of this time [49,50]. During Phase 2 (4828–3889 cal BP), a mixed farming practice gradually emerged: 1382 foxtail millet seeds (70.95% weight, 93.75% ubiquity), 247 broomcorn millet seeds (20.57% weight, 58.33% ubiquity), 56 rice seeds (7.08% weight, 18.75% ubiquity), 1 wheat seed (0.61% weight, 2.08% ubiquity), and 1 barley seed (0.79% weight, 2.08% ubiquity) were identified from 48 samples (384 L of soil in total). This again suggests a largely millet-based agriculture that was supplemented with rice (Figure 5b). However, agriculture was more diverse as compared to the Mid–Late Yangshao, given the introduction of wheat into crop assemblages [49,50]. In Phase 3 (2840–2493 cal BP), cropping patterns underwent substantial changes, as reflected in the abundance of auxiliary crops such as rice and wheat. A total of 15,772 foxtail millet seeds (47.66% weight, 96% ubiquity), 2106 broomcorn millet seeds (8.46% weight, 56% ubiquity), 856 wheat seeds (41.94% weight, 64% ubiquity), 1 barley seed (1.94% weight, 4% ubiquity), and 1 rice seed (0.01% weight, 4% ubiquity) were identified from 25 samples (200 L of soil in total) (Figure 5c). Compared to the Longshan period, the proportion of wheat remains rose sharply, with the estimated yield percentage only slightly inferior to foxtail millet, especially at the Daxin site (2742–2516 cal BP). The estimated yield percentage for wheat was 98.32%, indicating wide cultivation in Baoji during this period. In contrast, the weight ratios and ubiquity of rice and broomcorn millet decreased significantly, suggesting possible limitation by hydrothermal conditions [51,52]. Collectively, these results reveal advanced, mixed farming practices, utilizing foxtail millet and wheat as the primary and secondary cultivated crops, respectively; broomcorn millet and rice were supplementary, minor crops.

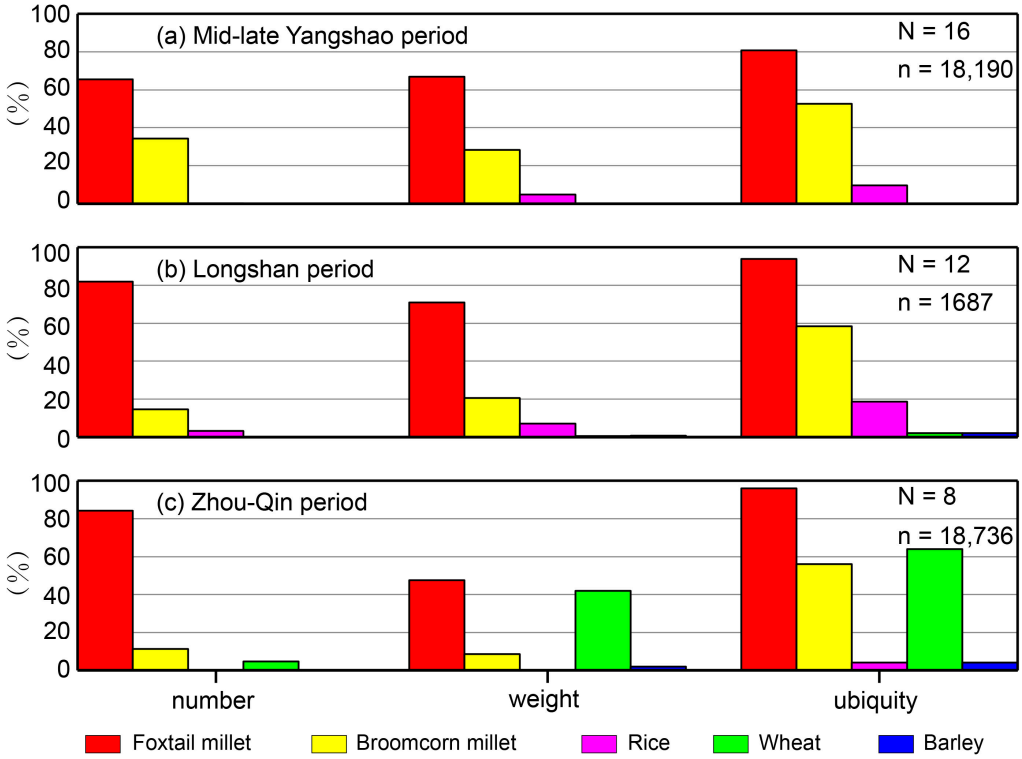

Figure 5. (**a**–**c**) Comparison of the proportion, weighted proportion, and ubiquity of study crops between the Mid–Late Yangshao and Zhou-Qin periods in Baoji. "N = XX" means the total number of sites at this stage; "n = XX" means the total number of carbonized seeds counted at this stage.

5. Discussion

5.1. Geographical Shifts in Cropping Patterns from 5800 to 2200 cal BP on the SLP

The earliest finding of combined wheat/barley and millet crop remains (from ~4500 cal BP) (crops originating from West and East Asia, respectively) was located in the Altai-West Tianshan Mountains, south of the Central Eurasian Steppes [53], In other words, the trans-Eurasian exchange reached northern China no later than ~4500 cal BP. From 4500–3500 cal BP, the trans-Eurasian exchange intensified, and archaeological finds linked to steppe cultures were most commonly found at Arc sites [54,55]. During the Shang and Zhou Dynasties (~3500–2200 cal BP), pastures and settlements were abandoned, as populations moved further south. These movements fostered the rise of the Shang Dynasty and promoted the formation of a new Bronze Age civilization in the Central Plains. Therefore, the three historical periods from 5800 to 4500 cal BP (Mid–Late Yangshao), 4500 to 3500 cal BP (Longshan-Xia), and 3500 to 2200 cal BP (Shang-Zhou period) are used here to define an overall chronological framework, facilitating the following discussion of temporal agricultural patterns.

Agricultural patterns across the SLP varied temporally and spatially, partly due to local geographic and environmental variation. Archaeobotanical data and ^{14}C dating can be used to reconstruct spatial patterns in the development of prehistoric agriculture [56,57]. Based on the new archaeobotanical data collected here from Baoji, foxtail millet, supplemented with broomcorn millet, was the primary crop grown on the SLP from 5800–4500 cal BP. Rice was also an important crop in GZP and WHN during this period. However, the proportion of each crop varied significantly among geographical areas in some cases, such as the Xinglefang site (alluvial plain) and the Xiahe site (transitional loess gully). Both of these mid-Yangshao sites were located in Weinan, in Shaanxi Province, and were not far apart. Millet agriculture dominated in both sites. In addition, rice remains (21.52% by weight) were unearthed in the Xinlefang site, indicating mixed millet-rice cropping. During the Yangshao period, rain-fed agriculture was first developed in the Henan and Shaanxi provinces [19,25,58], and then spread widely westward across the Loess Plateau to appear for the first time in the eastern Gansu Province [32,34,59]. For the period from 5500–4500 cal BP, in UWR, foxtail millet seeds (59.71% by weight) and broomcorn millet seeds (39.09% by weight) were the most important cultivated crop. This illustrates the rapid development of millet agriculture in UWR during the Majiayao period from 5500–4500 cal BP. These patterns are consistent with previously published archaeobotanical evidence from the adjacent Zhuanglang county [15]. During the Majiayao period, rice cultivation also spread northwards to the middle Yellow River Valley [11,48], extending as far northwest as Xishanping, which is located on the western Loess Plateau [60]. Rice was integrated into millet farming strategies no later than 5690 cal BP [47,48]. Carbon isotopes of human bones unearthed from late Yangshao sites (5800–4500 cal BP) display relatively high C_4 values, indicating a heavy reliance on millets and/or millet-fed animals within the SLP [61–64].

From 4500–3500 cal BP, millets were still the most important crops on the SLP, while exotic crops (e.g., barley and wheat) were cultivated in UWR only after ~4000 cal BP; rice was a minor crop in GZP and WHN. Cultural exchanges between the East and the West increased during this period, especially in Northwest China. Wheat and barley were initially domesticated in West Asia [65,66] and first identified in northern Xinjiang at the Tongtian cave site [53]. After ~4000 cal BP, wheat remains became more common, and have been frequently identified from sites in Northwest China, such as Fengtai [67], Jinchankou [68], Lijiaping [68], Shipocun [69]. Wheat/barley replaced millet as the dominant crop in the Hexi Corridor around ~3700 cal BP [33]. Wheat and barley remains from the Qijia culture (4300–3600 cal BP) have been found in UWR [69], suggesting that wheat/barley may have reached this region after 4000 cal BP, although neither crop was widely cultivated (Figures 5 and 6). However, no direct radiocarbon dating of wheat remains has been performed. Carbon isotope data from human bones collected from Huoshaogou (3870–3634 cal BP) and Mogou (3684–3076 cal BP) sites [5] in the Gansu-Qinghai region reveal mixed C4 and C3 signals, suggesting a reliance on both C4 and C3 plants at this time [19]. In GZP, a mixed agriculture based on foxtail/broomcorn millet and supplemented by rice persisted from 4500 to 3500 cal BP, as shown by previous archaeobotanical studies of the Weihe river valley (Figures 5 and 6) [27,47]. Wheat was first discovered in the Weihe river valley in the late Yangshao period, as described by Anban [70] and Xinjiekou [50]. In this study, wheat and barley remains were found at Shuang'an from the Longshan period, indicating that wheat crops had been introduced into the Weihe river valley by 4500–3500 cal BP. Millet-based agriculture was still an important subsistence strategy in WHN, but the proportion of different crop species grown had shifted. Rice yields accounted for 23.36% of the total yield, greater than the broomcorn millet yield (9.81% by weight) (Figure 6), suggesting that rice was a secondary crop after foxtail millet [51].

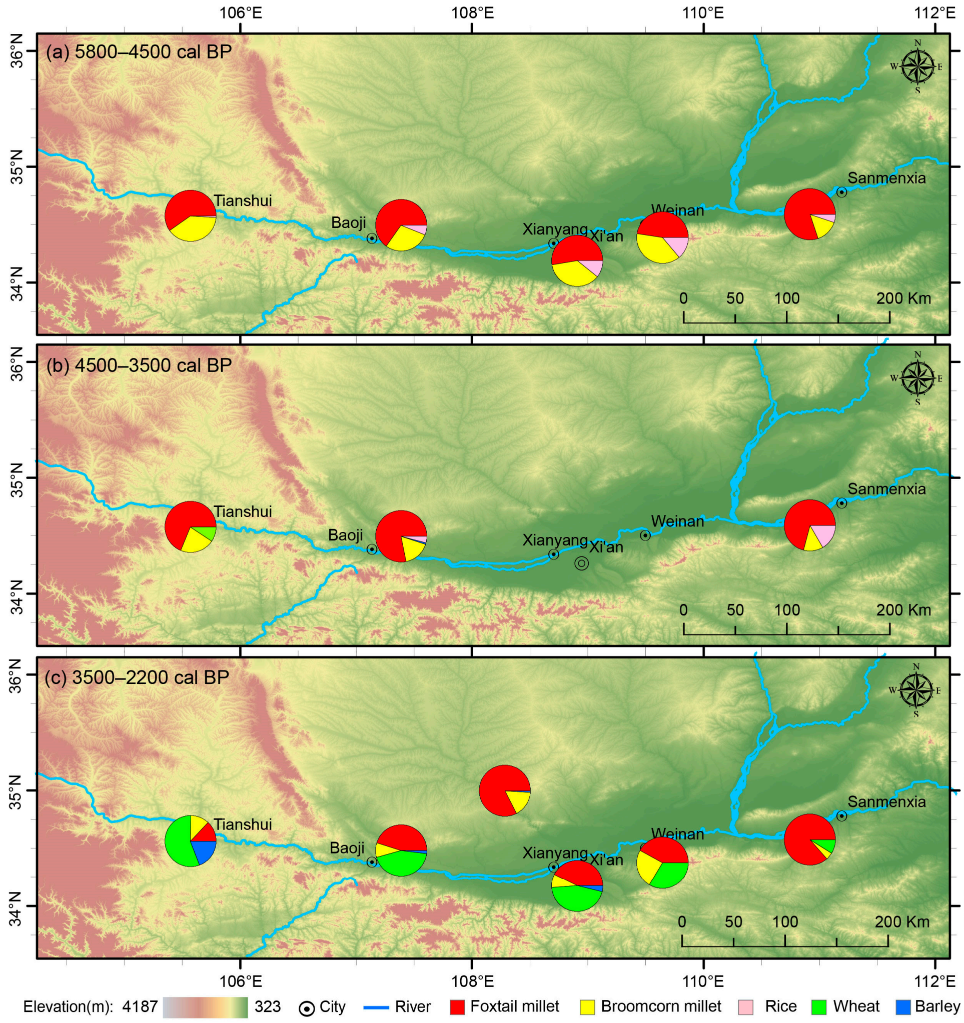

Figure 6. Spatial and temporal distribution of sites with crop remains dated between 5800 and 2200 cal BP on the SLP (proportions were calculated by city).

From 3500–2200 cal BP, cropping patterns showed significant geographical variation across the SLP, as reflected in the results for minor crops such as wheat and rice (Figures 5 and 6). A large number of charred wheat remains were recovered from UWR, and the proportion of wheat and barley remains in the crop assemblage far exceeded that of millets (Figure 6). This suggests that wheat was the most important crop in this area, underlying the agricultural economy at the time [69]. According to archaeobotanical evidence, wheat first appeared in the Central Plains and on the Guanzhong Plain during the Longshan period. Wheat remains were found at Wadian [71], Xijincheng [72], and Zhaojialai [73] sites, and wheat was widely cultivated between 3500 and 2200 cal BP [26,74]. Foxtail millet remained the most important crop in Baoji, while wheat surpassed broomcorn millet as a secondary crop; meanwhile, the proportion of rice decreased significantly (Figures 5 and 6). In GZP, cropping patterns shifted from a relatively millet-based agriculture to a multi-variety, mixed millet-wheat-barley-rice agriculture from 3500–2500 cal BP. In contrast to GZP, in WHN, wheat appeared for the first time, while rice disappeared (Figures 5 and 6). Overall, agricultural patterns diversified spatially, showing unique regional characteristics, from 3500–2200 cal BP.

In summary, from 5800–4500 cal BP, human populations primarily cultivated foxtail millet, with a secondary reliance on cultivated broomcorn millet; rice was also an important crop in GZP and WHN. From 4500–3500 cal BP, foxtail millet and broomcorn millet were still the most important crops within the SLP. Meanwhile, wheat and barley ("exotic" crops) were present in UWR, and mixed millet-rice agriculture emerged in GZP and WHN. From 3500–2200 cal BP, more diversified cropping patterns emerged in different areas of the SLP; these were based on the mixed cultivation of wheat/barley and millet crops. The importance of barley and wheat crops exceeded that of millets in UWR. The proportion of wheat increased significantly over time in GZP, gradually surpassing broomcorn millet as a secondary crop. Millet-based agriculture still represented an important subsistence strategy, supplemented by rice and wheat in WHN.

5.2. Factors influencing Spatiotemporal Variation in Cropping Patterns from 5800–2200 cal BP on the SLP

In recent years, archaeobotanical studies have demonstrated that spatiotemporal variation in agricultural patterns in northern China has been shaped by multiple factors, such as climate change [34,75,76], agricultural development [32], long-distance cultural exchanges [51,53], and geomorphological aspects [15,77,78]. However, the major factors driving shifts (since the Neolithic Age) in agricultural strategies on the SLP remain unclear, due to limitations in study scope (e.g., the time period and geographical area examined), as discussed previously.

The SLP has high environmental heterogeneity, and the local environment around human settlements may be an important factor driving spatiotemporal variation in agricultural patterns [76,79,80]. In general, China's annual precipitation decreases from the southeast coast to the inland northwest, and the higher the altitude, the lower the temperature and precipitation; these patterns have important impacts on agricultural systems. Foxtail and broomcorn millet, in addition to rice, were domesticated in the Yellow River and Yangtze River valleys in China during the early Holocene and then spread to surrounding areas. During the Yangshao period, the geographical distributions of millet and rice expanded significantly [25,81]. Millet cultivation became the main agricultural activity on the Loess Plateau [21,31], and the boundary of rice cultivation also shifted northwards; mixed rice-millet cultivation became common around 33–36° N in central-eastern China [82], while also extending further northwestwards to the western Loess Plateau [60]. Spatially, the percentage of foxtail millet and rice crop remains in the eastern part of the study area was significantly higher than that in the western part (Figures 5 and 6a). According to the thermal niche model proposed by D'Alpoim Guedes (2015) [83], the baseline temperature at which millet grows is above 8 °C, while rice needs temperatures above 10 °C. Drought-tolerant millets, particularly broomcorn millet, grow well with an average annual rainfall of 350–550 mm [22,84], whereas rice requires two or three times more rainfall [85]. The hydrothermal conditions in GZP and WHN are more favorable for crop cultivation than those in UWR, potentially explaining the observed increase in foxtail millet yields and rice cultivation. In terms of landforms, millets were widely distributed across all landforms (Figure 6), but were most abundant within hilly areas on loess terraces close to rivers and less abundant on the plains [15,25,86]; this may be due to the relatively low water needs of millet crops and their rapid maturation. The life cycles and niches of rice and wheat crops are very different compared to millet, requiring more water resources and field management during growth. The alluvial plains and loess tableland gullies were rich in water and had fertile soils, making these ideal places for growing rice and wheat [11,87]. Here, most SLP archaeological sites were located in alluvial plains and loess plateau valleys, where rivers are recharged (Figure 6). Therefore, on the SLP, the agricultural model of the late prehistoric period can be summarized as: millet agriculture on hilly terraces combined with mixed agriculture on the plain and in low-lying tableland ravines.

Trans-cultural interactions and associated agricultural technology exchanges shaped the formation of different agricultural systems [88,89]. The diffusion of Eurasian culture and agricultural practices intensified from 4500–3500 cal BP [90,91], facilitating the transformation of cropping patterns across the SLP. Millet-based agriculture remained an important subsistence strategy on the SLP (Figure 6b). More cold-tolerant and high-yielding wheat and barley crops (originating in western Asia) were also introduced into UWR at this time (Figure 6b), diversifying cropping patterns as the climate deteriorated around 4000 cal BP (Figure 7). However, millet-based cultivation (supplemented with rice) continued to dominate in GZP and WHN from 4500–3500 cal BP (Figure 6b) [92]. The annual cumulative temperature was higher in GZP and WHN versus UWR, and the colder climate may have limited the crops that could be successfully cultivated [93]. Furthermore, the improvement of millet and rice farming technology (e.g., weed control and tool modifications), as well as the exchange of agricultural technology between northern and southern China, likely also promoted the development of mixed millet-rice agriculture in GZP and WHN.

Climate change may be another factor underlying shifts in cropping patterns, as the climate on the SLP has changed significantly since the Early Bronze Age [17,94] (Figure 6). According to high-resolution paleoclimatic records, global temperatures rapidly declined after 3500 cal BP [94], as did precipitation [95], resulting in colder and drier climatic conditions. Changes in temperature and/or precipitation can disrupt agricultural patterns, leading to fluctuations in crop yields and planting scales [14,33,96]. Rice growth requires a warm and wet environment, and its cultivation is strongly restricted by hydrothermal conditions [97]; this made rice yields unpredictable in GZP and WHN from 3500–2200 cal BP (Figure 6c). Agriculture provides human populations with a steady supply of food and nutrients; as such, agriculture fostered the rapid population growth observed after 4000 cal BP (Figure 6f), which led to greater demands for food. At the time, millet monoculture yields were fragile and sensitive to environmental change. Exotic crops, such as barley and wheat, were more cold-tolerant and high-yielding, making them ideal for higher elevations and colder locales [2]. From 3500–2200 cal BP, human populations on the SLP had to shift their subsistence strategies (e.g., to extensive wheat and barley cultivation) to cope with resource shortages caused by climate deterioration and population pressure (Figures 6c and 7). Nevertheless, according to the archaeobotanical data collected here, spatial variation in the cultivation intensity of wheat crops persisted across the SLP (Figure 6c). More wheat and barley was grown in UWR versus GZP and WHN, and especially barley with better cold tolerance; this was probably due to greater environmental sensitivity to climate change in UWR. In GZP and WHN, the local environments showed much stronger resilience to climate-mediated deterioration, providing local inhabitants with more freedom and options regarding crop cultivation. In terms of social culture, wheat and barley were likely adopted in UWR and GZP under the influence of neighboring pastoralists to the north; these crops began a southwards descent as the climate continued to deteriorate during the Shang-Zhou period [54]. Located in the central government core, WHN had a long history of rain-fed farming and a longstanding tradition of wholegrain steaming and boiling [98]; this may have led local people to resist any changes to their agricultural traditions. Isotopic evidence suggests that there was a considerable 2500-year-lag between the introduction of wheat to the Central Plains and human acceptance of wheat crops as an agriculture staple [99].

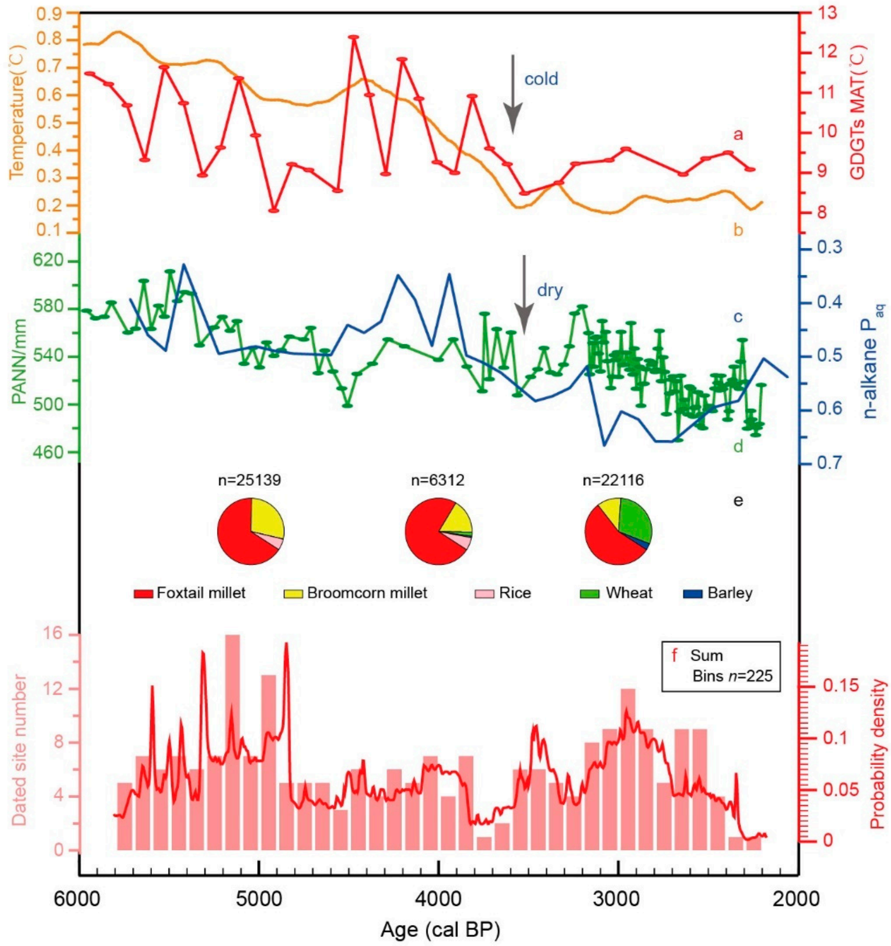

Figure 7. Comparison of human-activity intensity, climate change, and weight percentage of crops in the SLP from 5800–2200 cal BP: (**a**) GDGTs-inferred MAT for Liupan Tianchi Lake [100]; (**b**) Northern Hemisphere (30° to 90° N) temperature records [94]; (**c**) Paq-values based on n-alkane measurements in Liupan Tianchi Lake [101]; (**d**) pollen-based annual precipitation reconstructed for Gonghai Lake [17]; (**e**) the prevalence of SLP crops (by weight) between 5800–2200 BP for three time periods; and (**f**) the summed probability distribution (SPD) of average bin dates (the line chart) and the number of sites (column chart) on the SLP. GDGTs: Glycerol Dialkyl Glycerol Tetraethers; MAT: Mean Annual Temperature; Paq: the proportion of aquatic macrophytes to the total plant community.

In summary, the asynchronous transformation of cropping patterns across the SLP was most likely related to a number of geographical factors, climate change, cultural exchanges, and sociocultural developments. Trans-continental cultural exchanges and associated technological innovations, such as cold-tolerant wheat and barley varieties, provided the material basis for the transformation of cropping patterns within the SLP. Climate change may have influenced the hydrothermal conditions supporting crop growth, indirectly affecting human choices regarding which crops to cultivate. Population growth probably drove preferences for high-yielding foxtail millet crops from 5800–2200 cal BP and wheat crops after 4000 cal BP.

6. Summary

In this study, new archaeobotanical and ^{14}C radiocarbon results are reported for the area surrounding Baoji; these are combined with previously published archaeobotanical results (from the late Neolithic and Bronze Ages) to demonstrate the long and complex history of indigenous agricultural development across the SLP. From 5800–4500 cal BP, human populations primarily cultivated foxtail millet, supplemented with broomcorn millet, although rice was also an important crop in GZP and WHN. From 4500–3500 cal BP, foxtail and broomcorn millet remained the most important crops on the SLP, but wheat and barley were added to cropping systems in UWR as minor crops; rice acted as a secondary crop in GZP and WHN. From 3500–2200 cal BP, cropping patterns on the SLP underwent dramatic shifts, with wheat and barley replacing millet as the primary subsistence crops in UWR. Foxtail millet remained the main crop in GZP, but wheat replaced broomcorn millet as a secondary crop. In WHN, foxtail millet cultivation dominated, supplemented by broomcorn millet, rice, and wheat.

The geography and environmental conditions of UWR, GZP, and WHN guided agricultural choices made by local communities. Climate change moderated patterns of plant growth and the evolution of human societies, thereby influencing variation in planting scale and yield for rice and millet crops from 5800–2200 cal BP, as well as promoting the extensive adoption of exotic wheat and barley crops from 3500–2200 cal BP. Population growth likely triggered a reliance on high-yield foxtail millet crops from 5800–2200 cal BP and wheat after 4000 cal BP. The diversification of available crop species and technological innovations, driven by trans-continental cultural exchanges, were the key factors driving spatial variation in cropping patterns across the SLP during the Bronze Age. This study investigated historical transformations in agricultural patterns in key regions of the trans-continental exchange, as well as their reliance on changes to natural and social environments; it provides insight into the development of ancient Chinese civilizations within the SLP.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land12020343/s1. References [102–108] have been cited in the Supplementary Materials.

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References

1. Jones, M.K.; Liu, X.Y. Origins of agriculture in East Asia. *Science* **2009**, *324*, 730–731. [CrossRef] [PubMed]
2. Chen, F.H.; Dong, G.H.; Zhang, D.J.; Liu, X.Y.; Jia, X.; An, C.B.; Ma, M.M.; Xie, Y.W.; Barton, L.; Ren, X.Y.; et al. Agriculture facilitated permanent human occupation of the Tibetan Plateau after 3600 B.P. *Science* **2015**, *347*, 248–250. [CrossRef] [PubMed]
3. Frachetti, M.D.; Smith, C.E.; Traub, C.M.; Williams, T. Nomadic ecology shaped the highland geography of Asia's silk roads. *Nature* **2017**, *543*, 193–198. [CrossRef] [PubMed]
4. Bao, Y.G.; Zhou, X.Y.; Liu, H.B.; Hu, S.M.; Zhao, K.L.; Atahan, P.; Dodson, J.; Li, X.Q. Evolution of prehistoric dryland agriculture in the arid and semi-arid transition zone in northern China. *PLoS ONE* **2018**, *13*, e0198750. [CrossRef]

5. Liu, X.Y.; Jones, P.J.; Matuzeviciute, G.M.; Hunt, H.V.; Lister, D.L.; An, T.; Przelomska, N.; Kneale, C.J.; Zhao, Z.J.; Jones, M.K. From ecological opportunism to multi-cropping: Mapping food globalisation in prehistory. *Quat. Sci. Rev.* **2019**, *206*, 21–28. [CrossRef]
6. Chang, C.; Ivanov, S.S.; Tourtellotte, P.A.; Spengler, R.N., III; Mir-Makhamad, B.; Kramar, D. Ancient Agricultural and Pastoral Landscapes on the South Side of Lake Issyk-Kul: Long-Term Diachronic Analysis of Changing Patterns of Land Use, Climate Change, and Ritual Use in the Juuku and Kizil Suu Valleys. *Land* **2022**, *11*, 902. [CrossRef]
7. Dong, G.H.; Du, L.Y.; Yang, L.; Lu, M.X.; Qiu, M.H.; Li, H.M.; Ma, M.M.; Chen, F.H. Dispersal of crop-livestock and geographical-temporal variation of subsistence along the Steppe and Silk Roads across Eurasia in prehistory. *Sci. China Earth Sci.* **2022**, *65*, 1187–1210. [CrossRef]
8. Dong, G.H.; Li, R.; Lu, M.X.; Zhang, D.J.; James, N. Evolution of human-environmental interactions in China from the Late Paleolithic to the Bronze Age. *Prog. Phys. Geogr. Earth Environ.* **2020**, *44*, 233–250. [CrossRef]
9. Dong, G.H.; Lu, Y.X.; Zhang, S.J.; Huang, X.Z.; Ma, M.M. Spatiotemporal variation in human settlements and their interaction with living environments in Neolithic and Bronze Age China. *Prog. Phys. Geogr. Earth Environ.* **2022**, *46*, 949–967. [CrossRef]
10. Gignoux, C.R.; Henn, B.M.; Mountain, J.L. Rapid, global demographic expansions after the origins of agriculture. *Proc. Natl. Acad. Sci. USA* **2011**, *108*, 6044–6049. [CrossRef]
11. Zhang, J.P.; Lu, H.Y.; Gu, W.F.; Wu, N.Q.; Zhou, K.S.; Hu, Y.Y.; Xin, Y.J.; Wang, C. Early Mixed Farming of Millet and Rice 7800 Years Ago in the Middle Yellow River Region, China. *PLoS ONE* **2012**, *7*, e52146. [CrossRef]
12. Yan, W.M. *The Origin of Agriculture and Civilization*; Science Press: Beijing, China, 2000; pp. 50–89. (In Chinese)
13. Li, Y.C.; Tian, J.Y.; Liu, F.W.; Yang, B.Y.; Gu, K.S.Y.; Rahman, Z.U.; Yang, L.Q.; Chen, F.H.; Dong, G.H.; Kong, Q.P. Neolithic millet farmers contributed to the permanent settlement of the Tibetan Plateau by adopting barley agriculture. *Natl. Sci. Rev.* **2019**, *6*, 1005–1013. [CrossRef]
14. Sheng, P.F.; Shang, X.; Sun, Z.Y.; Yang, L.P.; Guo, X.N.; Jones, M.K. North-south patterning of millet agriculture on the Loess Plateau: Late Neolithic adaptations to water stress, NW China. *Holocene* **2018**, *28*, 1554–1563. [CrossRef]
15. Li, H.M.; Cui, Y.F.; James, N.; Ritchey, M.; Liu, F.W.; Zhang, J.N.; Ma, M.M.; Dong, G.H. Spatiotemporal variation of agricultural patterns in different geomorphologic and climatic environments in the eastern Loess Plateau, north-central China during the late Neolithic and Bronze Ages. *Sci. China Earth Sci.* **2022**, *65*, 934–948. [CrossRef]
16. Cai, Y.J.; Tan, L.C.; Cheng, H.; An, Z.S.; Edwards, R.L.; Kelly, M.J.; Kong, X.G.; Wang, X.F. The variation of summer monsoon precipitation in central China since the last deglaciation. *Earth Planet Sci. Lett.* **2010**, *291*, 21–31. [CrossRef]
17. Chen, F.H.; Xu, Q.H.; Chen, J.H.; Birks, H.J.B.; Liu, J.B.; Zhang, S.R.; Jin, L.Y.; An, C.B.; Telford, R.J.; Cao, X.Y.; et al. East Asian summer monsoon precipitation variability since the Last Deglaciation. *Sci. Rep.* **2015**, *5*, 11186. [CrossRef] [PubMed]
18. Tan, Z.H.; Han, Y.M.; Cao, J.J.; Huang, C.C.; An, Z.S. Holocene wildfire history and human activity from high-resolution charcoal and elemental black carbon records in the Guanzhong Basin of the Loess Plateau, China. *Quat. Sci. Rev.* **2015**, *109*, 76–87. [CrossRef]
19. Dong, G.H.; Yang, Y.S.; Han, J.Y.; Wang, H.; Chen, F.H. Exploring the history of cultural exchange in prehistoric Eurasia from the perspectives of crop diffusion and consumption. *Sci. China Earth Sci.* **2017**, *60*, 1110–1123. [CrossRef]
20. Zhang, C.; Pollard, A.M.; Rawson, J.; Huan, L.M.; Liu, R.L.; Tang, X.J. China's major Late Neolithic centres and the rise of Erlitou. *Antiquity* **2019**, *93*, 588–603. [CrossRef]
21. Barton, L.; Newsome, S.D.; Chen, F.H.; Wang, H.; Guilderson, T.P.; Bettinger, R.L. Agricultural origins and the isotopic identity of domestication in northern China. *Proc. Natl. Acad. Sci. USA* **2009**, *106*, 5523–5528. [CrossRef]
22. Lu, H.Y.; Zhang, J.P.; Liu, K.B.; Wu, N.Q.; Li, Y.M.; Zhou, K.S.; Ye, M.L.; Zhang, T.Y.; Zhang, H.J.; Yang, X.Y.; et al. Earliest domestication of common millet (Panicum miliaceum) in East Asia extended to 10,000 years ago. *Proc. Natl. Acad. Sci. USA* **2009**, *106*, 7367–7372. [CrossRef] [PubMed]
23. Zhao, Z.J. New archaeobotanic data for the study of the origins of agriculture in China. *Curr. Anthr.* **2011**, *52*, 295–306. [CrossRef]
24. Bureau of National Cultural Relics. *Atlas of Chinese Cultural Relics-Fascicule*; Surveying and Mapping Press: Beijing, China, 2010. (In Chinese)
25. Dong, G.H.; Liu, F.W.; Yang, Y.S.; Wang, L.; Chen, F.H. Cultural expansion and its influencing factors during Neolithic period in the Yellow River valley, northern China. *China J. Nat.* **2016**, *38*, 248–252. (In Chinese)
26. Lee, G.A.; Crawford, G.W.; Liu, L.; Chen, X.C. Plants and people from the early Neolithic to Shang periods in North China. *Proc. Natl. Acad. Sci. USA* **2007**, *104*, 1087–1092. [CrossRef]
27. Qu, Y.T.; Hu, K.; Yang, M.M.; Cui, J.X. Biological evidence for human subsistence strategy in the Guanzhong area during the Neolithic Period. *Acta Anthr. Sin* **2018**, *37*, 96–109. (In Chinese)
28. Yang, Y.S.; Wang, J.; Li, G.; Dong, J.J.; Cao, H.H.; Ma, M.M.; Chen, G.K.; Dong, G.H. Shift in subsistence crop dominance from broomcorn millet to foxtail millet around 5500 BP in the western Loess Plateau. *Front. Plant Sci.* **2022**, *13*, 939340. [CrossRef]
29. Liu, X.Y.; Lister, D.L.; Zhao, Z.J.; Petrie, C.A.; Zeng, X.S.; Jones, P.J.; Staff, R.A.; Pokharia, A.K.; Bates, J.; Singh, R.N.; et al. Journey to the east: Diverse routes and variable flowering times for wheat and barley en route to prehistoric China. *PLoS ONE* **2017**, *12*, e0187405. [CrossRef]
30. Zhao, Z.J. Characteristics of agricultural economy during the formation of ancient Chinese Civilization. *J. Natl. Mus. China* **2011**, *1*, 19–31. (In Chinese)

31. Zhao, Z.J. The process of origin of agriculture in China: Archaeological evidence from flotation results. *Quat. Sci.* **2014**, *34*, 73–84. (In Chinese)
32. Jia, X.; Dong, G.H.; Li, H.; Brunson, K.; Chen, F.H.; Ma, M.M.; Wang, H.; An, C.B.; Zhang, K. The development of agriculture and its impact on cultural expansion during the late Neolithic in the western Loess Plateau, China. *Holocene* **2013**, *23*, 85–92. [CrossRef]
33. Zhou, X.Y.; Li, X.Q.; Dodson, J.; Zhao, K.L. Rapid agricultural transformation in the prehistoric Hexi corridor, China. *Quat. Int.* **2016**, *426*, 33–41.
34. Dong, G.H.; Yang, Y.S.; Liu, X.Y.; Li, H.M.; Cui, Y.F.; Wang, H.; Chen, G.K.; Dodson, J.; Chen, F.H. Prehistoric trans-continental cultural exchange in the Hexi corridor, northwest China. *Holocene* **2018**, *28*, 621–628. [CrossRef]
35. Wang, X.; Shang, X.; Jiang, H.E.; Wang, C.P.; Wang, W.L.; Wang, C.S. The analysis of flotation result of carbonized seeds recovered from two sites in Baishui River valley, Shaanxi Province. *Archaeol. Cult. Relics* **2015**, *2*, 100–104. (In Chinese)
36. He, K.Y.; Lu, H.Y.; Zhang, J.P.; Wang, C.; Huan, X.J. Prehistoric evolution of the dualistic structure mixed rice and millet farming in China. *Holocene* **2017**, *27*, 1885–1898. [CrossRef]
37. Gong, J.F.; Wang, Y.R. Response of climate in Loess Plateau in China to global change. *Agricul. Res. Arid Areas* **2015**, *23*, 6–11.
38. Qian, L.Q. *Climate of Chinese Loess Plateau*; China Meteorological Press: Beijing, China, 1991. (In Chinese)
39. Chan, D.; Wu, Q.; Jiang, G.X.; Dai, X.L. Projected shifts in Köppen climate zones over China and their temporal evolution in CMIP5 multi-model simulations. *Adv. Atmos. Sci.* **2016**, *33*, 283–293. [CrossRef]
40. Shi, Z.M. *Natural Conditions and Natural Resources in Henan*; Henan Science and Technology Press: Zhengzhou, China, 1983; pp. 5–202. (In Chinese)
41. Dai, X.M. Evolution of the Neolithic cultural Pattern in the Yellow River Valley. *Acta Archaeol. Sin.* **1998**, *4*, 389–418.
42. Brock, F.; Higham, T.; Ditchfield, P.; Ramsey, C.B. Current pretreatment methods for AMS radiocarbon dating at the Oxford Ra-diocarbon Accelerator Unit (ORAU). *Radiocarbon* **2010**, *52*, 103–112. [CrossRef]
43. Cao, H.H.; Wang, Z.L.; He, J.H.; Guo, J.L.; Jull, A.J.T.; Zhou, A.F.; Dong, G.H.; Chen, F.H. Performance and inter-comparison tests of the MICADAS at the radiocarbon laboratory of Lanzhou University, China. *Radiocarbon* **2022**. [CrossRef]
44. Bronk, R. OxCal. v4. 4. 4. 2021. Available online: https://c14.arch.ox.ac.uk/oxcal/OxCal.html (accessed on 20 November 2020).
45. Reimer, P.J.; Austin, W.E.N.; Bard, E.; Bayliss, A.; Black, W.; Ramsey, C.B.; Butzin, M.; Cheng, H.; Edwards, R.L.; Friedrich, M.; et al. The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP). *Radiocarbon* **2020**, *62*, 725–757. [CrossRef]
46. Zhao, Z.J. *Paleoethnobotany: Theories, Methods and Practice*; Science Press: Beijing, China, 2010. (In Chinese)
47. Liu, H.; Hu, S.M.; Zhang, P.C.; Yang, Q.H.; Jiang, H.E.; Wang, W.L.; Wang, C.S. Results of soil samples flotation from two Yangshao sites in Shaanxi and a comparative study. *Archaeol. Cult. Relics* **2013**, *4*, 106–112. (In Chinese)
48. Zhang, J.P.; Lu, H.Y.; Wu, N.Q.; Li, F.J.; Yang, X.Y.; Wang, W.L.; Ma, M.Z.; Zhang, X.H. Phytolith evidence for rice cultivation and spread in Mid-Late Neolithic archaeological sites in central North China. *Boreas* **2010**, *39*, 592–602. [CrossRef]
49. Zhouyuan Archaeological Working Team. The excavation of the bronze casting remains in locus west of Zhuangli village at Zhouyuan site in the springs of 2003 and 2004. *Acta Archaeol. Sin.* **2011**, *2*, 245–316. (In Chinese)
50. Zhong, H.; Yang, Y.C.; Shao, J.; Zhao, Z.J. The Research on the Remains of the Carbonized Plant in the New Street Site, Lantian County, Shaanxi Province. *Cult. Relics South China* **2015**, *8*. (In Chinese) [CrossRef]
51. Yang, L.; Ma, M.M.; Chen, T.T.; Cui, Y.F.; Chen, P.P.; Zheng, L.C.; Lu, P. How did trans-Eurasian exchanges affect spatial-temporal variation in agricultural patterns during the late prehistoric period in the Yellow River valley (China)? *Holocene* **2021**, *31*, 247–257. [CrossRef]
52. Wang, X.G. The climatic change and the early rice cultivation in the middle and lower reaches of the Yellow River. *Agric. Hist. China* **2011**, *30*, 3–12. (In Chinese)
53. Zhou., X.Y.; Yu, J.J.; Spengler, R.N.; Shen, H.; Li, X.Q. 5200-year-old cereal grains from the eastern Altai Mountains redate the trans-Eurasian crop exchange. *Nat. Plants* **2020**, *6*, 78–87. [CrossRef]
54. Rawson, J.; Huan, L.M.; Taylor, W.T.T. Seeking Horses: Allies, Clients and Exchanges in the Zhou Period (1045–221 BC). *J. World Prehist.* **2021**, *34*, 489–530. [CrossRef]
55. Ma, M.; Lu, M.X.; Zhang, S.J.; Min, R.; Dong, G.H. Asynchronous transformation of human livelihoods in key regions of the trans-Eurasia exchange in China during 4000–2200 BP. *Quat. Sci. Rev.* **2022**, *291*, 107665. [CrossRef]
56. Hageman, J.B.; Goldstein, D.J. An integrated assessment of archaeobotanical recovery methods in the Neotropical rainforest of northern Belize: Flotation and dry screening. *J. Archaeol. Sci.* **2009**, *36*, 2841–2852. [CrossRef]
57. Gaudzinski-Windheuser, S.; Kindler, L. Research perspectives for the study of Neandertal subsistence strategies based on the analysis of archaeozoological assemblages. *Quat. Int.* **2012**, *247*, 59–68. [CrossRef]
58. Lu, H.Y. New methods and progress in research on the origins and evolution of prehistoric agriculture in China. *Sci. China Earth Sci.* **2017**, *60*, 2141–2159. [CrossRef]
59. Zhou., X.Y.; Li, X.Q.; Zhao, K.L.; Dodson, J.; Sun, N.; Yang, Q. Early agricultural development and environmental effects in the Neolithic Longdong Basin (eastern Gansu). *China Sci. Bull.* **2011**, *56*, 762–771. [CrossRef]
60. Li, X.Q.; Zhou, X.Y.; Zhou, J.; Dodson, J.; Zhang, H.; Shang, X. The earliest archaeobiological evidence of the broadening agriculture in China recorded at Xishanping site in Gansu Province. *Sci. China Earth Sci.* **2007**, *50*, 1707–1714. [CrossRef]
61. Dong, Y.; Morgan, C.; Chinenov, Y.; Zhou, L.G.; Fan, W.Q.; Ma, X.L.; Pechenkina, K. Shifting diets and the rise of male-biased inequality on the Central Plains of China during Eastern Zhou. *Proc. Natl. Acad. Sci. USA* **2017**, *114*, 932–937. [CrossRef]

62. Chen, X.L.; Wu, Y.H.; Li, Z.P. Subsistence around 3rd millennium B.C. in Luoyang basin evidenced by human diets at Zhonggou and Wanggedang sites. *Quat. Sci.* **2019**, *39*, 197–208.
63. Guo, Y.; Xia, Y.; Dong, Y.F.; Yu, B.Y.; Fan, Y.L.; Wen, F.Y.; Gao, Q. Stable Isotopic Analysis of Human Remains from the Beiliu Site. *Archaeol. Cult Relics* **2016**, *1*, 115–120.
64. Zhang, X.J.; Qiu, S.H.; Zhong, J.; Zhao, X.P.; Sun, F.X.; Chen, L.Q.; Guo, Y.Q.; Li, X.W.; Ma, X.L. Studies on Diet of the Ancient People of the Yangshao Cultural Sites in the Central Plains. *Acta Anat. Sin.* **2010**, *29*, 197–207.
65. Zeder, M.A. Domestication and early agriculture in the Mediterranean Basin: Origins, diffusion, and impact. *Proc. Natl. Acad. Sci. USA* **2018**, *105*, 11597–11604. [CrossRef]
66. Riehl, S.; Zeidi, M.; Conard, N.J. Emergence of agriculture in the foothills of the Zagros Mountains of Iran. *Science* **2013**, *341*, 65–67. [CrossRef]
67. Zhao, Z.J.; Wang, W.; Xu, X.G.; Niu, S.S.; Cai, L.H.; Song, J.N.; Xiao, Y.M.; Zhang, C.S.; Yang, J.G. Analysis of flotation results of the Cayue Cultural Site at Fengtai in Qinghai Province. *Archaeol. Cult Relics* **2004**, *2*, 85–91. (In Chinese)
68. Yang, Y. The Analysis of Charred Plant Seeds at Jinchankou Site and Lijiaping Site during Qijia Culture Period in the Hehuang Region, China. Master's Thesis, Lanzhou University, Lanzhou, China, 2014. (In Chinese).
69. Chen, T.T.; Qiu, M.H.; Liu, R.L.; Li, H.M.; Zhou, A.F. Human responses to climate change in the late prehistoric western loess plateau, northwest China. *Radiocarbon* **2020**, *62*, 1193–1207. [CrossRef]
70. Liu, X.Y. Study on the Plant Remains EXCAVATED in Anban site in 2012. Master's Thesis, Northwest University, Xi'an, China, 2014. (In Chinese).
71. Zhao, Z.J. Agricultural Economics Research of 2500 BCE–1500 BCE in Central Plains. In *Keji Kaogu (Science for Archaeology)*; Science Press: Beijing, China, 2007; Volume 2, pp. 1–11. (In Chinese)
72. Wang, Q.; Wang, L.Z. The Discovery of a Longshan Period City Site in Henan. *Zhongguo Wenwubao (China Cultural Relics News)* **2008**, *28*, 1.
73. Huang, S.L. Wheat (culms) unearthed from Longshan Cultural Site, Shaanxi Province. *Agricul Archaeol* **1991**, *1*, 118–120. (In Chinese)
74. Dodson, J.R.; Li, X.Q.; Zhou, X.Y.; Zhao, K.L.; Sun, N.; Atahan, P. Origin and spread of wheat in China. *Quat. Sci. Rev.* **2013**, *72*, 108–111. [CrossRef]
75. Jia, X.; Sun, Y.G.; Wang, L.; Sun, W.F.; Zhao, Z.J.; Lee, H.F.; Huang, W.B.; Wu, S.Y.; Lu, H.Y. The transition of human subsistence strategies in relation to climate change during the Bronze Age in the West Liao River Basin, Northeast China. *Holocene* **2016**, *26*, 781–789. [CrossRef]
76. Roffet-Salque, M.; Marciniak, A.; Valdes, P.J.; Pawlowska, K.; Pyzel, J.; Czerniak, L.; Krüger, M.; Roberts, C.N.; Pitter, S.; Evershed, R.P. Evidence for the impact of the 8.2-kyBP climate event on Near Eastern early farmers. *Proc. Natl. Acad. Sci. USA* **2018**, *115*, 8705–8709. [CrossRef]
77. Wang, Z.K.; Ding, Y.; Liu, J.S. Brief report of M4 excavation at Shigushan Shang-Zhou Cemetery in Baoji, Shaanxi Province. *Cult. Relics* **2016**, *1*, 49.
78. Festa, M.; Monteith, F. Between Plain and Plateau: Micro-Transitions in Zooarchaeological Landscapes in the Guanzhong Region of Northwest China. *Land* **2022**, *11*, 1269. [CrossRef]
79. Cramp, L.J.E.; Ethier, J.; Urem-Kotsou, D.; Bonsall, C.; Borić, D.; Boroneanţ, A.; Evershed, R.P.; Perić, S.; Roffet-Salque, M.; Whelton, H.L.; et al. Regional diversity in subsistence among early farmers in Southeast Europe revealed by archaeological organic residues. *Proc. R Soc. B* **2019**, *286*, 20182347. [CrossRef]
80. Tan, L.C.; Dong, G.H.; An, Z.S.; Edwards, R.L.; Li, H.M.; Li, D.; Spengler, R.; Cai, Y.J.; Cheng, H.; Lan, J.H.; et al. Megadrought and cultural exchange along the proto-silk road. *Sci. Bull.* **2021**, *66*, 603–611. [CrossRef]
81. Li, R.; Lu, F.Y.; Yang, L.; Liu, F.W.; Liu, R.L.; Dong, G.H. Spatial–Temporal Variation of Cropping Patterns in Relation to Climate Change in Neolithic China. *Atmosphere* **2020**, *11*, 677. [CrossRef]
82. Liu, G.E.; Xiang, A.Q. Discussion on the prehistorical south rice-north millet blended zone and its genesis. *Agric. Archaeol.* **2005**, *1*, 115–122.
83. D'Alpoim, G.J. Rethinking the spread of agriculture to the Tibetan Plateau. *Holocene* **2015**, *25*, 1498–1510. [CrossRef]
84. Weber, S.; Lehman, H.; Barela, T.; Hawks, S.; Harriman, D. Rice or millets: Early farming strategies in prehistoric central Thailand. *Archaeol. Anthr. Sci.* **2010**, *2*, 79–88. [CrossRef]
85. Shrestha, S.; Chapagain, R.; Babel, M.S. Quantifying the impact of climate change on crop yield and water footprint of rice in the Nam Oon Irrigation Project, Thailand. *Sci. Total. Environ.* **2017**, *599–600*, 689–699. [CrossRef]
86. Liao, Y.N.; Lu, P.; Mo, D.W.; Wang, H.; Storozum, M.J.; Chen, P.P.; Xu, J.J. Landforms influence the development of ancient agriculture in the Songshan area, central China. *Quat. Int.* **2019**, *512*, 85–89. [CrossRef]
87. Li, Y.P.; Zhang, J.N. The influence of landscape evolution on rice planting in the middle-late Neolithic period to Xia-Shang dynasties in Luoyang Basin. *Quat. Sci. Rev.* **2020**, *40*, 499–511.
88. van der Veen, M. Agricultural innovation: Invention and adoption or change and adaptation? *World Archaeol.* **2010**, *42*, 1–12. [CrossRef]
89. Boivin, N.; Fuller, D.Q.; Crowther, A. Old World globalization and the Columbian exchange: Comparison and contrast. *World Archaeol.* **2012**, *44*, 452–469. [CrossRef]

90. Anthony, D.W. *The Horse, the Wheel, and Language: How Bronze-Age Riders from the Eurasian Steppes Shaped the Modern World*; Princeton University Press: Princeton, NJ, USA, 2010; pp. 121–456.
91. Kuz'mina, E.E. *The Prehistory of the Silk Road*; University of Pennsylvania Press: Philadelphia, PA, USA, 2008; pp. 39–108.
92. Hou, L.L.; Hu, Y.W.; Zhao, X.P.; Li, S.T.; Wei, D.; Hou, Y.F.; Hu, B.H.; Lu, P.; Li, T.; Song, G.D.; et al. Human subsistence strategy at Liuzhuang site, Henan, China during the proto-Shang culture (~2000–1600 BC) by stable isotopic analysis. *J. Archaeol. Sci.* **2013**, *40*, 2344–2351. [CrossRef]
93. Hou, L.L.; Zhao, J.; Deng, H.; Chen, X.; Chen, T.; Tao, D.; Guo, Y. The subsistence patterns of Xinding Basin, Shanxi, China during ~4000 yr BP by stable isotopes and plant microfossils analysis. *Sci. China Ser D-Earth Sci.* **2020**, *50*, 369–379. (In Chinese)
94. Marcott, S.A.; Shakun, J.D.; Clark, P.U.; Mix, A.C. A reconstruction of regional and global temperature for the past 11,300 years. *Science* **2013**, *339*, 1198–1201. [CrossRef] [PubMed]
95. Zhao, Y.; Yu, Z.C. Vegetation response to Holocene climate change in East Asian monsoon-margin region. *Earth Sci. Rev.* **2012**, *113*, 1–10. [CrossRef]
96. Li, X.Q.; Shang, X.; Dodson, J.; Zhou, X.Y. Holocene agriculture in the Guanzhong Basin in NW China indicated by pollen and charcoal evidence. *Holocene* **2009**, *19*, 1213–1220. [CrossRef]
97. Liu, Z.H.; Yang, P.; Tang, H.J.; Wu, W.B.; Zhang, L.; Yu, Q.Y.; Li, Z.G. Shifts in the extent and location of rice cropping areas match the climate change pattern in China during 1980–2010. *Reg. Env. Change* **2015**, *15*, 919–929. [CrossRef]
98. Zeng, X.S. On the spread of wheat in ancient China. *J. Chin. Dietary Cul.* **2005**, *1*, 99–133. (In Chinese)
99. Zhou, L.G.; Garvie-Lok, S.J. Isotopic evidence for the expansion of wheat consumption in northern China. *Archaeol. Res. Asia* **2015**, *4*, 25–35. [CrossRef]
100. Sun, H.L. Palaeoenvironment Reconstruction of the Middle to Late Holocene in a High-Resolution Sediment Core from Tianchi Lake on Liupan Mountain. Ph.D. Thesis, Lanzhou University, Lanzhou, China, 2011; pp. 77–89. (In Chinese).
101. Sun, H.L.; Bendle, J.; Seki, O.; Zhou, A.F. Mid-tolate Holocene hydroclimatic changes on the Chinese Loess Plateau: Evidence from n-alkanes from the sediments of Tianchi Lake. *J. Paleolimnol.* **2018**, *60*, 511–523. [CrossRef]
102. Liu, C.J.; Kong, Z.C.; Lang, S.D. Relics of crops and discussion on the environment of primitive people living in Dadiwan site. *Cul Rel Cent. China* **2004**, *4*, 26–30. (In Chinese)
103. Zhouyuan Archaeological Working Team. The excavation of Zhuangli village at Zhutong site of western Zhou in the springs of 2003 and 2004. *Acta Archaeol. Sin* **2011**, *2*, 245–316. (In Chinese)
104. Chen., S.Y.; Fu, W.B.; Liu, J.Q.; Tang, L.Y.; Zhai, L.L.; Zhao, Z.J.; Wen, R. Study on Remains of Carbonized Plant in Zaolin River Beach Site in Xunyi, Shaanxi Province. *Cult Relics South China* **2019**, *1*, 103–112. (In Chinese)
105. Tang, L.Y.; Yang, J.H.; Guo, X.; Tian, J.; Han, K.; Zhang, X.Y. Consistency and imbalance of agricultural production in the Guanzhong region in the pre-Qin period: Evidence from the Gongbeiya site in Xi'an. *Cult Relics South China* **2020**, *4*, 163–172. (In Chinese)
106. Zhong, H.; Li, X.W.; Wang, W.L.; Yang, L.P.; Zhao, Z.J. Preliminary research of the farming production pattern in the Central Plain area during the Miaodigou Period. *Quat Sci* **2020**, *40*, 472–485. (In Chinese)
107. Zhao, Z.J. Changes and Development of Ancient Agriculture on Weihe Plain——An Analysis of Plant Remnants Excavated from Dongyang Site in Huaxian District. *Huaxia Archaeol.* **2019**, *15*, 70–84. (In Chinese)
108. *Henan Provincial Institute of Cultural Relics and Archaeology*; Sanmenxia Nanjiaokou Science Press: Beijing, China, 2009; pp. 316–320. (In Chinese)