RECONSTRUCTION OF PREHISTORIC CROPLAND SPATIAL PATTERNS IN HEHUANG VALLEY

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Abstract. Hehuang Valley is a historically significant agricultural region on the Tibetan Plateau in China. Based on archaeological data, historical literature, GIS technology, this paper reconstructs the spatial pattern of cropland in the prehistoric period in Hehuang Valley, focus on three stages of Majiayao culture, Qijia culture and Cayo culture. The results show that: (1) In the Majiayao culture period (5290 a BP-4055 a BP), the total population reached 27,340 and the estimated cropland area was 55228 hm². The warm and humid climate promoted the development of agriculture. (2) During the Qijia Culture period (4300 a BP-4000 a BP), the climate became cold and dry, the cropland area decreased significantly to 9792 hm²and the population decreased to 4848. (3) During the Cayo Culture period (3600 a BP-2066 a BP), the climate tended to be dry and cold, the total population reached 46,145, and the cropland area increased significantly to 67556 hm². Cropland expanded to high-altitude areas. The study reveals that changes in prehistoric cropland area in Hehuang Valley of China were closely linked to population, climate, cultural succession, and livelihood strategies, providing important historical insights into prehistoric human responses to environmental change.
Keywords: *cultivated land distribution, grid model, Majiayao culture, Qijia culture, Cayo culture, livelihood strategies*

Introduction

LUCC (Land use and land cover changes) influence global environmental transformations and are therefore crucial in studying environmental change and sustainable development (Wang and Bao, 1999). The change of land cover has a more profound impact on the regional water cycle, environmental quality, biodiversity, and the productivity and adaptability of terrestrial ecosystems. The accumulation of various land use practices alters land cover on a global scale, resulting in significant impacts on local, regional, and global environments (Cai, 2001). The implementation of the “LUCC Study” strategy, jointly launched by the International Geosphere and Biosphere Program (IGBP) and the Humanities Program for Global Environmental Change (IHDP), highlights the significance of studying land cover change and its interaction with global change in different historical periods (Li et al., 2001). Land cover change in historical periods helps humans better understand the human-land relationship and improves the prediction of future changes (Nan and Chen, 2023). Major achievements have been made in historical LUCC research. At present, six sets of global historical land use datasets exist: HH (Daniels et al., 1995; Houghtonetal et al., 2008), SAGE (Quaas and Boucher, 2005), HYDE (Goldewi and Klein, 2001; Goldewi et al., 2017, 2015), LSCAN (Ge et al., 2008), LUH (Cheng et al., 2011; Wang et al., 2003) and KK10 (Fang et al., 2019; Ge et al., 2003). On this basis, small-scale cropland reconstruction is conducted to improve the reliability of global land use datasets.

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As a large agricultural country with a long history of reclamation, drawing on abundant historical materials, Chinese scholars have carried out many historical reconstructions of cropland. For example, based on the time scales, the reconstruction time period is mainly concentrated in the last 300 years (Li, 2020; Liu, 2020; Yang et al., 2021; Li et al., 2019). Some cropland reconstruction research has been extended to the past thousands of years (Zhao et al., 2022; Fang et al., 2021; Wang et al., 2024; He et al., 2023). From the spatial scope, it is mainly concentrated in China's farming-pastoral transitional zone (Wu et al., 2023), Northeast China (Ye et al., 2009), North China (Chen et al., 2019), Yangtze River delta area (Tong et al., 2024), Pearl River Delta region (Qiu et al., 2023). The valley area of Tibet Plateau (Luo et al., 2014; Tian et al., 2023) and reconstruction of settlements and cropland in a certain drainage basin (He et al., 2023; Zhang et al., 2020; Gu et al., 2021; Xiong et al., 2022; Lian et al., 2020). These all reflect the condition of cropland at the local and regional scale in prehistoric and historical periods. This paper can be based on this basis to enrich the results of prehistoric cropland reconstruction in this area and provide a basis for subsequent researchers.

The Tibetan Plateau is a fragile and start-up area for global climate change (Yao et al., 2000). As an important valley area of the Tibetan Plateau, Hehuang Valley has always been an important agricultural farming area on the Tibetan Plateau, so it was chosen to reconstruct the cropland distribution pattern in this area. This area has a long history and is one of the cradles of ancient civilization. From the Paleolithic Age to the Ming and Qing Dynasties, there are rich cultural relics. The Majiayao culture, the Qijia culture and the Cayo culture belong to the Neolithic Age and the Bronze Age (Xiao, 2013a; Jia, 2012). Based on the archaeological survey and ^{14}C dating results, this paper confirms that there were three prehistoric cultural periods and the specific age in this area.Respectively, and the three cultures have the development of continuity in time and region, but archaeologically, it is also the result of cultural transformation, which also means the change of human activities. It is of great significance to study cropland distribution of the area to reveal the evolution of the natural environment and the history of human activities in the upper area of the Yellow River. There are many archaeological sites in this area. From the unearthed carbonized crops, it reflects that the ancient ancestors had some reclamation activities in this area. Therefore, this paper can be studied on this basis. The study reveals that changes in prehistoric cropland area in Hehuang Valley were closely linked to population, climate, cultural succession, and livelihood strategies, providing important historical insights into prehistoric human responses to environmental change.

Materials and methods

Overview of the study area

Regional geographical overview

Hehuang Valley of China is taken as the research area (from *Fig. 1*), which is located in the Yellow River basin and its tributary Huangshui River basin in the east of Qinghai Province, and is mainly composed of Huangshui Valley and Yellow River valley, covering an area of about 3.3×10^4 km^2. This area is the key zone for the transition from the Loess Plateau to the Tibetan Plateau, the agricultural areas and pastoral areas and the eastern monsoon area to the northwest arid area. The Hehuang Valley includes 14 administrative districts. These administrative districts include Xining, Huangzhong, Huangyuan, Datong,

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Menyuan, Huzhu, Ledu, Minhe, Ping An, Hualong, Xunhua, Tongren, Jianzha and Guide County. Compared with other areas of Qinghai Province, Hehuang Valley is lower, with an average elevation between 2000 and 3000 m. The climate type is arid and semi-arid climate in the plateau temperate zone, with the annual average temperature between 5℃ and 9℃, and the sunshine hours between 2600 and 3000 h. The precipitation changes greatly, and the annual precipitation in most areas is below 400 mm.

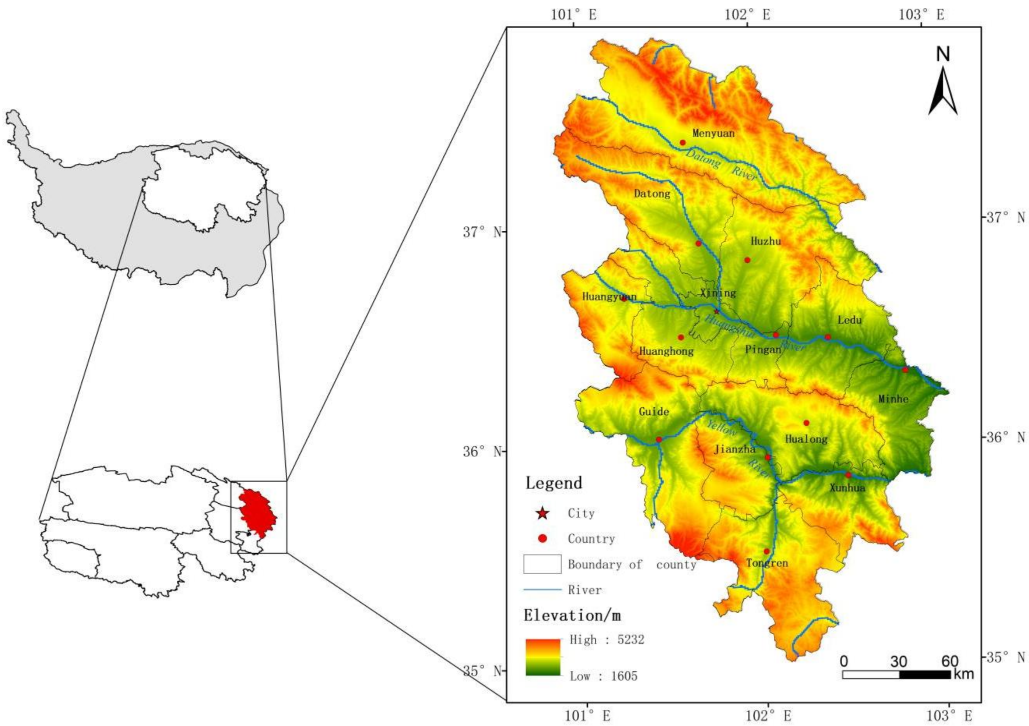

Figure 1. *Overview of the study area*

Overview of regional agricultural development

The ancient human relics in Hehuang Valley can be traced back to 30,000 years ago. In the age of Yangshao Culture (about 5500 years ago), the relics of Hu Li family in Hehuang Valley were found (Ye et al., 2001). The unearthed carbonized millet relics can show the emergence of prehistoric dry agriculture in this area. Majiayao culture, about 5.3 ~ 3.9 kaBP, is a local culture mainly distributed in the upper area of the Yellow River. It originated from the Yangshao Culture in the Central Plains (Xie, 1981; Gao, 1997; An, 2020), From the Majiayao cultural remain relics found as an agricultural production tools of the axe, adze, chisel, knife, ring (Xiao, 2013b), The excavation of these cultural relics shows that people lived a settled agricultural life, and began reclamation activities. In the Qijia culture period of 4.3~3.6 kaBP, the climate of this area tended to be dry and cold (Hou, 2004) which made the agricultural production conditions more unfavorable (Wang et al., 2015). The change of environment made the ancestors of the Qijia culture change their original means of livelihood, and the scope of activities suitable for agricultural production was smaller than before. From the Qijia culture period Lajia site millet for agricultural phytolith and (Wang et al., 2023, 2022) the relics of crop seeds can prove the cultivation of millet at that time.

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3.6~2.1 kaBP Cayo culture replaces Qijia culture, to adapt to climate change, the means of livelihood of this period also changed significantly. In addition to agricultural activities, animal husbandry also became an important means of livelihood, which also means that the area of cultural activities should be significantly adjusted (Hou and Liu, 2004). In the upper reaches of the Yellow River and the Huangshui River basin, barley is mainly planted (Jia, 2012; Zhang, 2012), millet as a supplement to wheat crop. And also distributed in a small amount of wheat, very few unearthed oats. In order to adapt to the significant change of the cooling climate before 3900a (Liu et al., 2005) the cultural residents had to increase the cultivation of the more drought-tolerant millet (Zhao, 2004). Although the yield is low, it can be used as a crop, and the stalk of millet seedlings can be used as livestock feed. In addition, the unearthed seeds include a certain amount of quinoa seeds, which can be judged as herbage crops and become animal feed when the drought is low (Ye, 2015; Liu et al., 2013).

Overview of regional animal husbandry development

In the late period in Majiayao, the most commonly raised animals were probably pigs. At that time, there was the custom of burying pig bones in tombs (Liu et al., 2013, 2005). Pigs are not suitable for frequent migration, so it also shows the life characteristics of the residents who did not move often at that time. In the period of Qijia culture, sheep raising in Hehuang area of Qinghai Province was more important than pig raising. Although it is still dominated by agriculture, the proportion of animal husbandry mainly by sheep has increased. Take the relics of animal bones unearthed from shenna Site in Xining City as an example (Zhou, 2020). Judging from the animal bone isotope, the animals unearthed from the four types of sites of Cayo culture were classified (Zeng, 2013; Xie, 2002). Among them, Ahatla Mountain type in Xunhua County (3565-3377 bp.) is distributed in the upper reaches of the Yellow River in Qinghai Province (Xu, 1983). Taking Xunhua County as the distribution center, the animal bones of sheep, cattle, horses, deer and dogs were unearthed in the cemetery. The type of Shangsunjiazhai in Datong County (3161-2865 bp.) is distributed in the Datong River Basin. With Datong County as the distribution center, sheep, cattle, horses, pigs, dogs and deer were unearthed in the cemetery (Gao et al., 1993). In general, like the Ahatla Mountain type, the means of livelihood is semi-farming and semi-animal husbandry, and the accumulation of sites is generally thin, indicating that residents will not live in one site for a long time. Panjialiang type (2918-2740 bp.) is distributed in the middle area of Huangshui River, with Xining, Huangzhong and other places as the distribution center. Dogs, cattle and sheep unearthed in the cemetery are the most common animals unearthed in the cemetery, which is also the biggest difference between this area and other areas (Gao and He, 1994a; Zeng, 2013; Gao et al., 1994b). In addition, there are horses in other cemeteries in the Huangshui River Basin, but there are no horses in the tombs of Panjialiang. The horses appear in other cemeteries later than Panjialiang. This phenomenon may be due to the horses have not been domesticated in large numbers during the tombs of Panjialiang (Gao and He , 1994a). The type of Dahu Village (2327-2080 bp) in Huangyuan County is widely distributed in the upper reaches of Hehuang Valley. Sheep, horses, cattle and dogs were unearthed in the cemetery. Sheep and horses were the most common animals unearthed in the cemetery, followed by cattle and occasional dogs (Zeng, 2013; Gao, 1986). From the early days of the cemetery, horses were the most abundant, followed by sheep, and by the later years the number of horses decreased and the number of cattle increased. In the early period of Cayo culture, the types of unearthed animals were dogs, cattle and sheep, and

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the number of dogs was large, followed by cattle and sheep. In the middle period, and the number of horses increased rapidly, and the number of cattle was also higher than before. the most unearthed animals in this period are horses and sheep, and dogs are rare. In the late Cayo culture, the number of horses decreased and the number of cattle increased, but most common were sheep and few dogs. At the time of Cayo culture, the valley and hilly area were semi-agricultural and semi-pastoral, while the high mountains were based on animal husbandry.

Data sources and research methods

Data source

(1) The archaeological data source: according to *the atlas of Chinese cultural relics, Qinghai*, and through screening, determination Majiayao culture can rebuild the settlement sites of information points 367 (from *Fig. 2*), Qijia culture settlement sites information point 202 (from *Fig. 2*), Cayo culture settlement sites information point 1022 (from *Fig. 2*), add new sites according to the newly excavated sites information.

(2) Map data source: Altitude data is derived from the 12.5 m × 12.5 m DEM data in NASA (https://search.asf.alaska.edu/). Slope data were extracted from DEM data, soil type data from the National Earth System Science Data Center (www.geodata.cn), and river data from National geographic information resource directory service system, Organic matter data are obtained from the website of the National Tibetan Plateau Scientific Data Center.

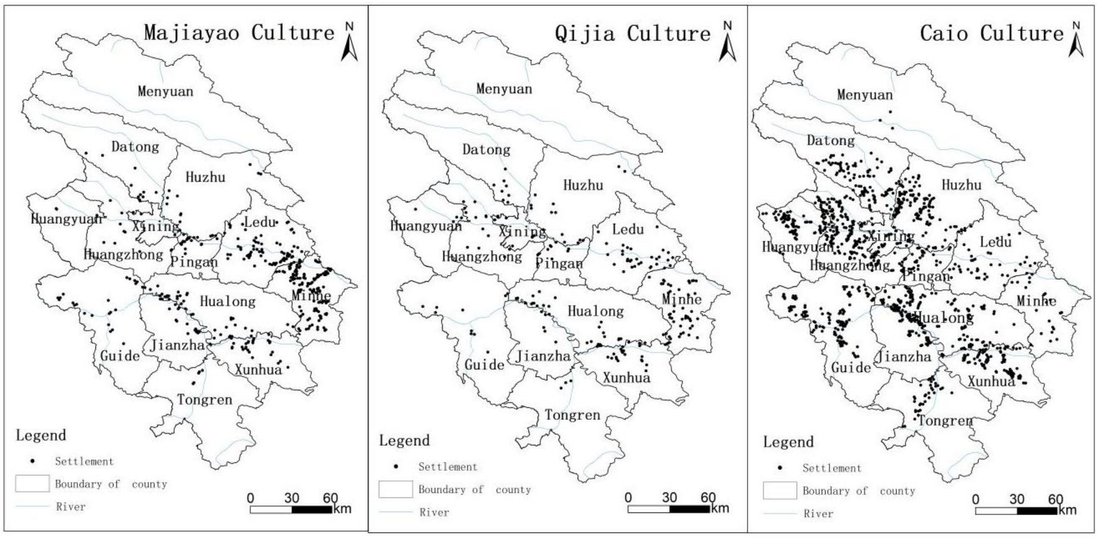

Figure 2. *The spatial distribution pattern of the settlement*

Study methods

Tomb analysis method

This paper studies the reconstruction of prehistoric cropland, and uses the tomb analysis method to calculate the population, which is a common method in China (Qiao, 2010), Mainly used in settlement archaeology, etc. This method estimates the population size of the Neolithic period and the Bronze Age based on the human bone data of the tombs in the archaeological excavation report.

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Assuming that the annual number of births and deaths are equal per year, the annual number of deaths of the tomb and the average age of death of the tomb can obtain the average annual population of the site, that is the stationary population model was adopted in the domestic population analysis (Wang, 1991).

$$Pm = \frac{A \times D}{T} \quad \text{(Eq.1)}$$

Pm is the average annual population size of A typical site, and A is the average age of death in the tomb, recorded from human bone data. D is the total death toll at a typical site, derived from the number of human bones excavated. The T is the duration of the burial period (Zhu, 1994).

$$Sp = \frac{Sm}{Pm} \quad \text{(Eq.2)}$$

The per capita floor area of the typical sites is calculated based on the excavated area of the typical sites and the population size of the typical sites (Zhu, 1994). Sp is the per capita area of the site, and Sm is the excavation area of the site, according to the site excavation report. Pm is the site population size.

$$P = \frac{S}{Sp} \quad \text{(Eq.3)}$$

The population size of the total site in the study area was calculated by the total site area in the study area and the per capita floor area of the site (Qiao, 2010). P is the total population size within the settlement site. S is the total area of the sites in the study area, which is derived from the information database of the sites. Sp covers the per capita area of the site (*Table 1*).

Table 1. *Number of tombs in typical sites of various cultural periods in Hehuang Valley*

Culture type	Typical site	Activity time (cal kaBP)	Human bone count (man)	Life expectancy (years)	Estimated permanent resident population (man)	Literature reference
Majiayao culture (Banshan-machang type)	Minhe yangshan	4.5~4.3	344	30	35	Peng and Ma (1984)
Qi jia culture	Ledu Liuwan	4.3~4	395	36.5	24	Liang (1986)
Cayo culture	Xunhua Ahatra Mountain	3.5~ 2.7	278	33	15	Han (2000)

Estimation method of cropland area

The area of cropland is related to the number of population and means of livelihood. The more population engaged in agriculture, the larger the area of cropland is. Majiayao culture and Qijia culture respectively used per unit area output of the Xia Dynasty and Shang Dynasty, which were close to the period. The per capita consumption of millet and the yield per unit area of millet to calculate area of required cropland per capita at that time. Historical literature record that the output of millet in China during the Warring States period was about 890 kg/hm^2, the estimated Xia dynasty grain yield is

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300 kg/hm^2 (Wang , 2003a), Excluding 15% of the seed yield an actual millet yield is 255 kg/hm^2. The per-area yield of Shang dynasty millet is assumed to be 457.5 kg/hm^2 (Yang, 1988), Excluding 15% of the seed amount to obtain the actual 388.875 kg/hm^2. In addition, 258 kg/person was set as the per capita annual consumption of millet among prehistoric residents (Peng and Ma, 1984).

In Cayo cultural period, due to the dry and cold climate (Xie, 2002), the livelihood means was measured by the barley planting and animal husbandry development, so the calculation of the cropland area used the yield per unit area of wheat farming in the pre-Qin period, namely “the average yield per mu (one mu = 0.0667 hectares) was one dan (an ancient Chinese unit of measurement) of wheat” (Yu, 1980). Equivalent to the present system calculation, one mu of wheat yield 0.732 dan, this paper uses the research of the cropland area conversion relationship:

Now1 dan (an ancient Chinese unit of measurement) = 50 kg

0.732 dan/mu (one mu = 0.0667 ha) = 549 kg/hm^2

According to the records of wheat grain in “Shuowen”, “The Book of Rites”, “Zhou Xiang·Siwen”, “Poetry·Feng·July” and the records of Japanese authors, the previous wheat farming refers to barley (Zheng, 2000). The difference between barley and millet is that there is no need to shell to calculated yield, so it is higher than the yield per unit area of millet, so the yield of grain is 549 kg/hm^2 (Yu, 1980), The per capita annual consumption of barley is 450 kg per person (Zheng and Wang, 2000) (*Grain Consumption and Grain Production in the Pre-Qin Period*). Hou et al. (2013) believe that according to the relics of unearthed animal and plant, the proportion of agriculture and animal husbandry at that time was 6:4. The estimated population of the Cayo cultural period is divided into agricultural population and animal husbandry population, so the cropland accounts for 60% of the production activities. In the late Neolithic Age, the agricultural area has generally adopted a relatively short-term and relatively regular rotation farming system, that is, three or five years of continuous crop abandonment, three or five years of ripe crop farming, setting a three-year rotation farming policy is the basic farming system of this era (Shen, 2000).

$$\text{Sa} = \frac{258\text{kg/Man}}{255\text{kg/hm}^2} = 1.01\text{hm}^2/\text{Man} \quad \text{(Eq.4)}$$

$$\text{S} = \text{Sa} \times \text{P} \times \text{R} \quad \text{(Eq.5)}$$

$$R = \frac{T_f + T_c}{T_c} = 2 \quad \text{(Eq.6)}$$

S is the cropland area of the settlement sites in the study area, Sa is the cropland area needed per capita during the period, P is the population size of the study area, R is a cultivation period, T_f is fallow period, T_c is tillage period (*Table 2*).

Grid method of cropland data

This paper mainly selects the cropland reconstruction method of Luo (2015), selects the restrictive factors (altitude, slope, river, soil) and suitable factors (altitude, accumulated temperature, river, organic matter, slope, settlement), and uses ArcGis for cropland grid treatment. According to the plant flotation results of site in Huzhu county

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during Cayo culture, barley of carbonized grain accounted for 92% of the total number of unearthed grain. And barley is a kind of hardly crops. It can still grow normally at about –10℃. Even during the flowering period, it can withstand low temperatures of about zero degrees. The strong cold tolerance is incomparable to other food crops (Li et al., 2010) Therefore, the altitude of cropland distribution in this area is limited to 4000 m. The altitude from 0 to 1600 m and from 1600 to 4000 m is assigned a value of 1. Above 4000 m is assigned a value of 0. Most of the reclaimed areas of Hehuang Valley are mainly loess landform, and soil erosion in areas with slope > 25°is serious, which is not suitable for reclamation. In this paper, the grid with slope > 25°is used as the upper slope of cropland allocation (Sun and Shi, 2003; Wu et al., 2017；Wang, 2003b). The river adopts surface data, with a value of 1 in the area outside the river and 0 within the river. The type of reclaimable cropland in the soil data was assigned as 1, and the value of non-cropland as 0, The soil types that do not have soil fertility, such as frigid calcic soils and frigid frozen soils, are eliminated. So that each restriction factor was binarized. Therefore, the limiting factors are binarized and the undistributed cultivated land is eliminated by using the limiting factors. Assuming that the elevation, slope, soil type, river and so on of Hehuang Valley in prehistoric times are the same as now, we select the elevation, slope, river, soil type, accumulated temperature, organic matter and distance from settlement site to rebuild the prehistoric cultivated land in Hehuang Valley.

Table 2. *Results of prehistoric population-cropland data reconstruction in Hehuang Valley*

Culture type	Annual average population size of typical sites (man)	Area per capita of typical site (m^2/man)	Total site population size (man)	Per capita arable area (hm^2/man)	Total cropland area of the site (hm^2)	Literature reference
Majiayao culture Banshan-Machang type	35	193.41	27340	1.01	55228	Peng and Ma (1984)
Qijia culture	24	4681.64	4848	0.66	9792	Xiao (2001)
Caro culture	15	327	46145	1.22	67556	Xu (1983)

The suitability factors are weighted according to different elevations, gradients, rivers, soil types, organic matter and the distance from settlements, so as to obtain the most suitable area of cultivated land distribution. The possibility of cultivated land distribution can be increased according to soil type and organic matter distribution. Since the units of each factor are different and the values vary greatly, the suitable factors such as elevation, soil, river, organic matter, slope and settlement are standardized according to *Equation 7*, so that the contribution rate of each factor can be judged more accurately.

$$NXi = \frac{\max\ Xi - Xi}{\max\ Xi} \tag{Eq.7}$$

In the formula: X represents the influence factor; NXi represents the standardized factor of grid i of Wj county, the value range is [0, 1]; Xi represents the value of grid i of Wj county; max Xi represents the maximum value of grid i of Wj county After standardized processing, all factors are added to the grid model for space allocation. The formula of the grid model is as follows:

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$$M(i,v_n)=\prod_{k=1}^{Q}R_k\sum_{y=1}^{p}\beta_y\times A_y\times\phi \quad \text{(Eq.8)}$$

$$Z(i,v_n)=\frac{M(i,v_n)}{\sum_{i=1}^{n}M(i,v_n)} \quad \text{(Eq.9)}$$

$$C(i,v_n)=Z(i,v_n)\times E(W_j,v_n) \quad \text{(Eq.10)}$$

$$FR(i,v_n)=\frac{C(i,v_n)}{area_i} \quad \text{(Eq.11)}$$

In the formula, Z (i, vn) and C (i, vn) respectively represent the proportion (%) of the cropland area (km^2) of grid i in vn years in Wj county. E (Wj, vn) is the total cropland area (km^2) in vn years in Wj county; $area_i$ is the area (km_2) of grid i.

Analysis of the reconstruction results

This paper takes Minhe Yangshan, Liuwan and Xunhua Ahatla Mountain sites as examples to estimate the per capita area of the three cultural periods. Calculate the average annual population of Majiayao culture, Qijia culture and Cayo culture sites is 35, 24 and 15 Man respectively (*Eq. 1*; from *Table 2*). Typical sites cover an area of 193.41 m^2/Man, 4681.64 m^2/Man, 327 m^2/Man respectively (*Eq. 2*; from *Table 2*), according to the total research area (*Eq. 5*). To sum up, the population of Majiayao culture, Qijia culture and Cayo culture in Hehuang Valley is 27340, 4848 and 46145 Man respectively (*Eq. 3*), the total area of cropland is 55228, 9792 and 67556 hm^2 respectively, and the reclamation rate of the whole area is 0.764%, 0.146% and 0.816% respectively (from *Fig. 3*).

Change of cropland area of Majiayao, Qijia and Cayo culture

From Majiayao culture to Cayo culture, the number of cropland area first decreased and then increased. Among them, during the period of Majiayao culture, the climate was warm and humid, and more people were engaged in agricultural activities. During the period of Qijia culture, the cropland area was the least. This is partly due to the increased climate instability that caused by the 4 kaBP climate mutation (Liu et al., 2002), the increase of meteorological disasters and geological disasters. The instability of social conditions led to the large reduction of population, and the large decrease of cropland reclamation. During the period of the Cayo culture, the cropland area was the largest and the population was the largest. The main reason was that the dry and cold climate was basically stable at 3.6 kaBP (Fang et al., 2004). The prehistoric residents adapted to this change and found a way to deal with the climate change. With the rise of animal husbandry, the number of sites increased rapidly, the surviving population increased, and the active area expanded.

Distribution of cropland in Majiayao, Qijia and Cayo culture

In the period of Majiayao culture, the cropland was obviously distributed along the banks of the Huangshui River and the Yellow River, mainly distributed in Ledu County

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and Minhe County in the upper and middle area of the Huangshui River. The average reclamation rate of the above two counties reached more than 15%. From the perspective of restrictive factor elevation, 63.4% of the cropland distribution grid is distributed in the area below 1600 m, and 36.6% of the cropland is distributed in the Sichuan water area between 1600 and 2600 m (Luo, 2015), The highest altitude of the cropland distribution reached 2263 m.

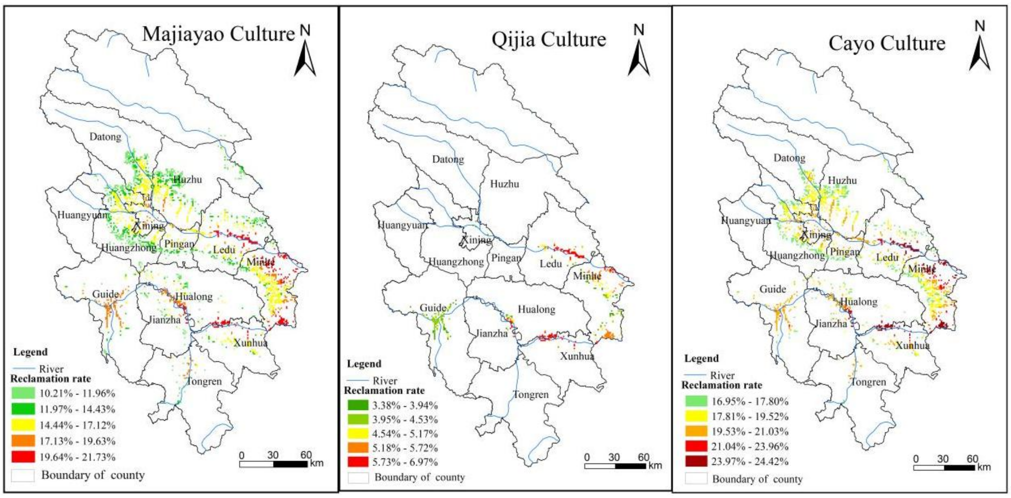

***Figure 3.** Spatial distribution pattern of cropland*

In the period of Qijia culture, a small amount of cropland was still distributed in river valleys, tableland and some small basins, and scattered in local mountainous areas, but on the whole, it was still distributed in the areas with superior cropland conditions. However, the distribution area has decreased sharply, which also paved the way for the expansion and prosperity of animal husbandry during the Cayo period, and brings about the transformation and development of culture.

In the period of Cayo cultural, 71.9% of the cropland distribution grid is distributed in the area below 2600 m, which has relatively low terrain and favorable thermal conditions; 28.1% of the cropland is distributed in the lower mountain area between 2600 and 3200 m, and the highest altitude of cropland distribution reached 2897 m. Most of them are alpine crops such as barley. Due to the rarefied air at high altitude and harsh climate environment, the cropland reclamation is relatively limited, but the cropland has expanded to the mountainous areas.49.6% of the cropland distribution grid is distributed below the slope 15°, and 50.4% of the cropland distribution grid is distributed below the slope 15°~25°. The Yellow River valley is located in the slope, alluvial and floodplain, more gravel in the material composition, the soil organic matter content is not high, the salinity is high, the serious soil and water erosion leads to obvious differences in the distribution of cropland with different slopes.

Analysis of reclamation intensity of cropland in Majiayao, Qijia and Cayo

According to the above grid model, the spatial distribution pattern of 1 km × 1 km resolution in Majiayao, Qijia, Cayo culture. Although the area is large, it is less farmland due to the limitation of natural environmental conditions and productivity level.

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In the period of Majiayao culture, the cropland had a certain scale in space. The cropland grid accounted for 4.94% of the total number of grids in the study area. The average grid reclamation rate was 16.9%, and the highest reclamation rate was 21.73%. The reclamation rate of less than 10% accounts for 95.06%, and the reclamation rate of all the grids is between 10% and 22%. The grid with high reclamation rate is concentrated in Ledu County, Minhe County obviously along the upper and middle area of the Huangshui River, and Guide and Hualong counties in the Yellow River basin below Longyang Gorge. Due to the low altitude along the Huangshui River and the Yellow River, the warm and humid climate is suitable for the development of farming agriculture. Human beings choose to develop agriculture in areas with good farming conditions.

In the period of Qijia culture, the cropland grid accounted for 1.13% of the total number of grids in the study area, the average grid reclamation rate was 3.94%, the highest reclamation rate was 6.97%, and the reclamation rate of the whole area was below 15%. The cropland is only sporadically distributed in the middle and lower area of the Huangshui River and the Yellow River, including Ledu County, Minhe County, Xunhua County, Hualong County, Guide County and other counties. This is mainly due to the mutation of 4 kaBP climate, the climate tends to be cold and dry. And the ecological environment is fragile, which directly affects the light, heat and precipitation conditions, and then affects the growth of crops (Gao, 1993). When agricultural production became more and more difficult to meet peoples living needs, the residents of Hehuang area had to give up agriculture and develop animal husbandry.

In the period of Cayo culture, the cropland grid accounted for 6.28% of the total number of grids in the study area, and the average reclamation rate of the grid was 19.4%. The reclamation rate is more than 15%, and the reclamation rate is more than 21% accounts for 18.98%, and the highest reclamation rate is 24.42%, which is distributed in the Huangshui River and the Yellow River basin. The cropland began to spread westward, gradually throughout the main valleys of Hehuang area, even in the mountainous areas. With the spread of settlement distribution, the scale of cropland shows an expanding trend, at the same time, the land arability showed a fluctuation downward trend. The dry cold climate was basically stable in 3.6 kaBP. In the face of the dry cold climate mutation, Cayo culture rather than narrow. The number of sites increased rapidly, expend to higher elevations and westward. Prehistoric residents not only engaged in animal husbandry, but agricultural production structure also made adjustment. No longer or very few millet, instead of barley. Economic nature changed, so that the cropland expend to high altitude and increased rapidly, reclamation rate reached the largest in prehistoric culture.

Discussion and conclusion

Discussion

Reasons for changes of prehistory cultivated land pattern in Hehuang Valley

The reconstruction results reflect the distribution pattern of cropland and population in each cultural period of the area. However, it should be pointed out that, due to the particularity of the geographical location of the Hehuang Valley and the different characteristics of the prehistoric culture, the actual situation of the prehistoric period may be different from the reconstruction results. The reasons for the change of cropland

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distribution and population in each cultural period in the area include but are not limited to the following aspects:

(1) The change of prehistoric climate led to changes in the natural environment, thus the area of cropland changed. The warm and wet climate during the Majiayao culture period (5290-4055 BP) promoted the development of agriculture and the rapid growth of population, which was mainly reflected in the rapid increase of the number of sites and the expansion of the distribution range of cropland 4 kaBP during the Qijia culture period, the population and cropland were decreased, the trees of the area rapidly reduced, vegetation to grassland significantly, is obviously driven by dry climate change, Qijia culture in 3.9 kaBP suddenly weakened and a large number of barley was planted (Fang, 2004), at the same time animal husbandry not as advanced production activities, no longer use a large number of climate resources. During the period of Cayo culture, it was continuously dry and cold (Fang et al., 2004), after adapting to the sudden change of climate, the original production mode was changed. And a new livelihood strategy—animal husbandry was produced, and it expanded to the west and higher elevations in the middle and high mountains, reaching the largest geographical scope of prehistoric culture. Therefore, with the sudden change of climate, prehistoric inhabitants adopted different coping strategies and formed different cultures (Gao, 1993). Animal husbandry developed in great numbers, and agriculture was no longer used as an advantageous means of livelihood, so the livelihood means changed (Liu et al., 2002).

(2) Natural disasters such as floods and earthquakes led to a large decrease of population and cropland (Qi, 2022). The discovery of prehistoric disasters during the Qijia period revealed prehistoric disasters in the upper reaches of the Yellow River around 4000 years this year, including major floods and earthquakes (Wang et al., 2021; Huang et al., 2019; Zhen et al., 2024). This caused the destruction of the Lajia site, the disaster scene retained the original life of many ancestors, and the disaster event reflected the extreme relationship between people and cropland. The settlement form of Lajia site had a certain process of change, which may mean the change of civilization factors. Natural disasters may also promote the transformation of civilization process or explore and reveal the relevant civilization factors and the cause of transformation and development.

(3) With the continuous development and evolution of human civilization, the continuous improvement of productivity and the continuous progress of production tools, promoting the increase of population and the expansion of cropland (Chen et al., 2022). The tools used for food processing were more advanced and can feed more people (Gao et al., 2008). The emergence of bronze ware also provided favorable conditions for the development of animal husbandry. Every new technology or the development of new productivity over a prolonged period, new productivity can give people the means of production is always limited. It was difficult to adapt to the growing population and the needs of human life, the solution to this problem was often to expand the living area. Constantly immigrate to the new area and solve the contradiction between the limited living materials and a large growth of population. The continuous development of productivity and the continuous improvement of production tools made the prehistoric civilization not disappear even in the face of the harsh conditions of dry and cold climate and limited means of production during the Cayo culture period. On the contrary, after a lag of some time, prehistoric people adapted to this change and continued to cope with the sudden change of climate, increasing their

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productivity, so that the number of cultural sites increased rapidly and the area of activity expanded.

(4) The exchange, dissemination and migration of prehistoric eastern and western cultures in Eurasia, introduced to animal husbandry from Europe and and the migration of nomads (Zhen et al., 2024). The exchange of Eastern and Western cultures during the Cayo period had a certain influence on the introduction of animal husbandry production. The introduction of animal husbandry brought new ways of living and new productivity to the Cayo culture residents, which led to a large increase in population and a large expansion of living areas. Bronze Age herders migrated long distances for a long time and had an important influence on European and Central Asian civilizations (Gao et al., 2008). Different herdsman groups of the Bronze Age kept migrating in the heart of Asia. The research showing that herders began their seasonal migration through the mountains from 4000 years ago, creating key Silk Road routes over the next two thousand years. Archaeological findings suggest that the Bronze Age herders were good at intercontinental communications.

Verification of prehistoric cultivated land area change in Hehuang Valley

The cited temperature records in AINC and the TP are shown in: c, Hurleg Lake; d, Xiangride loess section; e, Hongyuan peatland; f, Aweng Co; g, Lugu Lake; h, Tengchongqinghai Lake; i, Tingming Lake; j, Chongce ice cap. A comparison of the temperature records is shown in the lower column: (c) Hurleg Lake alkenone-based summer temperature record (Zhao et al.., 2013); (d) Xiangride loess section brGDGTs-based temperature record (Sun et al., 2019); (e) HY brGDGTs-based temperature record (Zheng et al., 2015); (f) Aweng Co lacustrine brGDGTs-based temperature record (Li et al., 2017); (g) Lugu Lake lacustrine brGDGTs-based temperature record (Zhao et al., 2021); (h) Tengchongqinghai Lake lacustrine brGDGTs-based temperature record (Zhao et al., 2021); (i) Tingming Lake lacustrine brGDGTs-based temperature record (Sun et al., 2020); (j) Chongce ice core $\delta^{18}O$ record (Pang et al., 2020). The absolute age control points for each record are represented by dots with error bars.

This paper reconstructs the Majiayao culture period, Qijia Culture period and Cayo Culture period, which are about 5 kaBP, 4 kaBP and 3 kaBP. According to the above climate reconstruction curve (from *Fig. 4*), it can be seen that the temperature in the warm period at 5 kaBP was at a high value in the three prehistoric periods in this paper, and the climate was relatively warm and humid, and there were climatic conditions suitable for farming. This is consistent with the characteristics that the reconstructed cultivated land area in this period is larger than 55228 hm^2. During the cold period of Qijia Culture, the environment was harsh, and the area suitable for cultivation in theory was small. In this paper, the distribution of cultivated land was sparse and the minimum amount was 9792 hm^2. The temperature in the Cayo culture period was higher than that in the Qijia culture period. At the same time, climate factors such as low temperature and human factors such as productivity at this time were more suitable for the development of animal husbandry, which could feed a large number of people, thus expanding the scope of cultivated land. This is consistent with the fact that the area of cultivated land reconstructed in this paper is 67556 hm^2 and the area of cultivated land is the largest among the three cultural periods, which is significantly increased compared with the Qijia culture period. Therefore, using the reconstructed climate curve of predecessors to verify the reconstructed cultivated land area of Hehuang Valley in this paper, the rationality is obtained.

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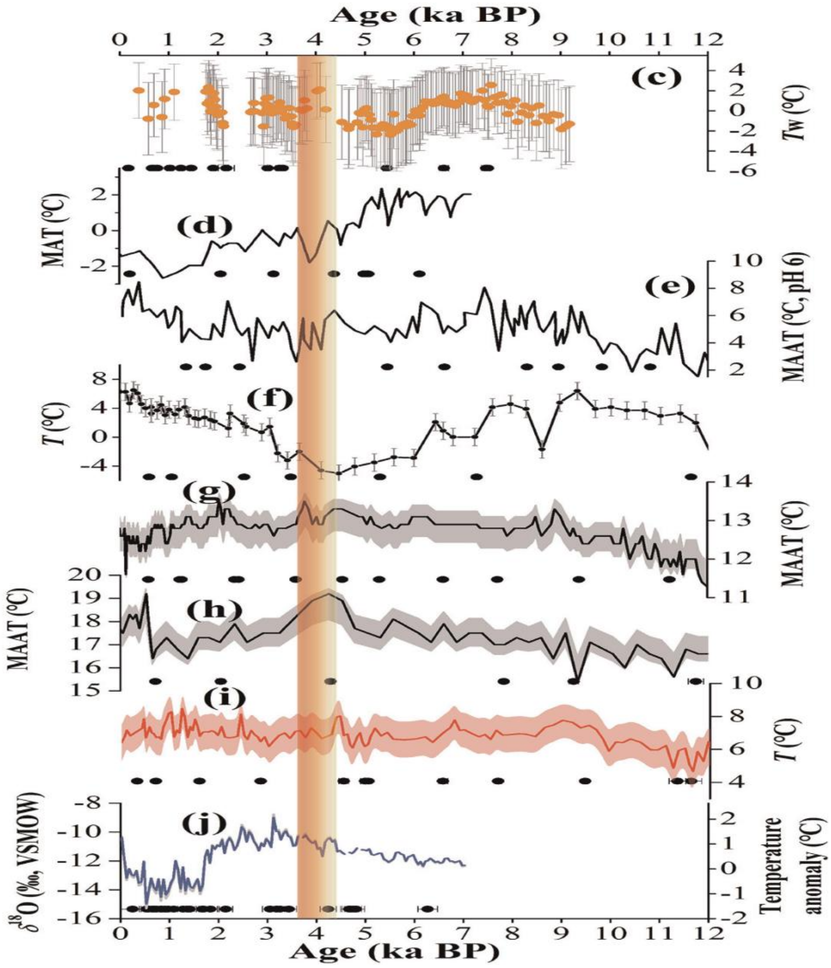

Figure 4. *Reconstruction of the climate curve (cited from Rao, 2021)*

Conclusion

To estimate and reconstruct the prehistoric period of the spatial and temporal pattern of population and cropland area are as follows.

(1) Analyzing the archaeological data of the study area, constructing the population calculation method of tomb analysis, and estimating the population and its changes. The results show that the total population in the middle and late period (4655-4055 kaBP) reached 27,340 Man, and the average annual population size of the site was 35 Man. During the Qijia culture period of 4 kaBP, the total population decreased to 4848 Man, and the average population size of the site also dropped to 24 Man. During the Cayo cultural period (3600-2066 kaBP), the total population rebounded significantly to 46,145 Man, the average annual population size of the site decreased to 15 Man, and the number of sites reached 1025 sites.

(2) According to the population, site distribution and elevation, river and other data, GIS was used to analyze the cropland area and its spatial pattern in the prehistoric period. In the middle and late period, the cropland area was 55228 hm², the cropland was mainly distributed in Huangshui River and Yellow River valley; the Qijia culture area decreased significantly to 9792 hm², and the distribution pattern was generally consistent with the previous period; the Cayo culture period not only occupied the

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valley, but also extended to the high mountains, and the cropland area increased to 67,556 hm².

(3) The reconstruction results show that the population size of the three cultural periods from Majiayao culture to Cayo culture is closely related to the continuation and fault of culture. Majiayao culture has been divided into three types by many scholars: Majiayao type, Banshan type and Machang type, but this paper only reconstructed the population and cropland of Banshan-Machang type. In addition, the continuous development from Majiayao culture and directly transformed to the Qijia culture, which once appeared cultural disruption. At the end of the culture, it developed to the east of Qinghai to the Cayo culture and part of the development to Gansu led to the cultural split, so the Qijia culture turned to decline at the end of the period. Majiayao culture has prospered, and Qijia culture is facing a trend of decline, which is positively correlated with the change of population and cropland. Therefore, there is a certain relationship between the surge of population and cropland and the succession of prehistoric culture.

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