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LETTER

The 300 years cropland changes reflecting climate impacts and social resilience at the Yellow River–Huangshui River Valley, China

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Abstract
Changes of croplands often reflect the combined impacts of both natural environment changes and social agriculture activities. Such reflections manifested more significantly in agro-pastoral transition zones, e.g. in the North and West of China. In this study, cropland changes at the Yellow River–Huangshui River Valley, as a typical agro-pastoral transition zone in northwestern China, is analyzed in terms of the changes of the total amount and spatial pattern over the past 300 years (majorly in the Qing Dynasty). The reconstructed cropland data indicated a fluctuation of cropland areas in accordance with changes of regional climate conditions, natural hazards, agriculture activities and socio-economic development. A significant decrease of cropland in the middle of the 19th century was detected, which appeared a good consistency with the frequent natural disasters in the same period and the climate cooling trend across the whole 19th century. Though in the worsening conditions, three major coping strategies maintained and developed the local socio-agriculture system: (a) land reclamation policy encouraged immigrants and military farming; (b) construction of water conservancy facilities increased agricultural productivity; (c) increasing local Tibetans learned and transformed to implementing both agriculture and pastoral productions with flexibilities depending on climate conditions. The study demonstrates that the social-agriculture system held certain resilience, which can be maintained and enhanced with appropriate political, engineering, economic, and social-cultural measures.

1. Introduction
In recent years, researchers have carried out in-depth studies on the impact of climate change on human society. For instance, European scientists found that the food crisis, failed markets, empire demise, migration turmoil, etc, have a good performance with the fluctuation of temperature and precipitation variability over the past two millennia (Büntgen et al 2011, Chantal et al 2016). During the 4th–6th century, the poor harvest and famine of Northern Europe led to the great Germanic Migration, which was claimed as a result of colder and wetter climate (Hsu 1998). Further studies indicated that the cold climate in the 17th century triggered a serious of economic and social crises in Europe (Zhang et al 2011, Pei et al 2013). In addition, population collapse (Zhang et al 2007), war and turmoil (Zhang et al 2007, Tol and Wagner 2010) in Europe and the Northern Hemisphere over the past 1000 years were linked to climate deterioration as well.

Similar studies were also seen in Asia countries, where researchers argued special relationships between climate change and socio-economic fluctuations. A recent study indicated that intervals of prolonged summer monsoon weakening were correlated to a social crisis with declining agricultural productivity and economic development in the Indian subcontinent (Gupta et al 2019). Further studies also detected Holocene climate impacts and social responses at coastal East Asia (Park et al 2019), the Central Asia (Yang et al 2019), mountainous
Southwest China (Xu et al. 2019), and the Japanese islands (Kajita et al. 2020). More specifically, Wei et al. (2014) and Yin et al. (2015) found that economic prosperity often happened in warmer period and economic recession in cold periods. In warmer periods, it is often presented such as the expansion of croplands (Man et al. 1993, Zhang and Fang 1997), higher productivity per unit land (Fang et al. 2004), diverse agriculture development, economic prosperity, population migration, national prosperity and strength, etc (Yan et al. 2016). While, colder periods often presented cropland decreasing, productivity decline, agricultural shrinkage, resource shortages, and imbalances between food demand and land provision, economic recession, weak national power, population collapse (Rai et al. 2019, Zhang et al. 2007, Lee and Zhang 2013) and even social unrest.

However, social collapses did not always happen. Early farming communities were identified as certainly resilient to the abrupt, severe climate changes in the past (Flohr et al. 2016), and the social-culture systems were also resilient and persistent in marginal environments (Nicol and Zerboni 2020). Yang argued (Yang et al. 2019) that the cross-cutting theme has been to reach beyond simple explanations of environmental or human determinism, but social resilience under environmental impacts. Climate conditions could significantly influence human socio-cultural systems, while the socio-culture systems are able to make self-adjustments and take responding measures to maintain resilience to climate impacts and multiple hazards (Tian et al. 2019). These particular and various linkages between climatic impacts and social responses were often carried out in the context of historical ‘agricultural society’, while the most recent social development has significantly enhanced the social capabilities in coping with natural environmental stresses (Xu et al. 2020), especially after the Industry Revolutions in middle 18th century.

In particular, the links between natural environment changes and social development manifests more significantly in agro-pastoral transition zones where human livelihoods rely heavily on environmental conditions (Zhang et al. 2008). China has a large area of agro-pastoral transition zones that forms an agro-pastoral belt across its North and West. It is a transitional belt that divides not only agriculture areas and pastoral areas but also the humid climate areas and arid climate areas in China. Therefore, the agro-pastoral belt and zones are sensitive and of high significance on climate change impacts. In this study, a complex and specific area at the Yellow River–Huangshui River Valley (YHV) is chosen to analyze the interactions among climate change(Zhang et al. 2019), cropland changes and human activities over the last 300 years.

2. Data and methods

2.1. Study areas

The YHV locates at the northeast edge of the Qinghai–Tibet Plateau (Zhang et al. 2014) (figure 1), which is in the agro-pastoral belt of China. It is composed of a section of the upper reaches of the Yellow River and two secondary tributaries. The total area of the basin is approximately $3.3 \times 10^5$ km$^2$, and the altitude ranges from 1689 m to 5218 m above sea level. The region has a significant geographical feature of transitions between wet and dry zones and between low mountains and the high plateau. These two basic features further make this area a remarkable region for east–west transitions from the pacific monsoon climate to non-monsoon climate, from forest to grassland, from agriculture to animal husbandry, from outflow zone to inflow zone, from the Loess Plateau to the Qinghai–Tibet Plateau. Therefore, social–economic system experiences more diverse and complex impacts from the climate and environmental conditions.

High mountains (over 3500 m above sea level) account for 72.4% of the whole YHV area. The rest are mostly, hills, terraces and alluvial plains that are the main areas of croplands. The limited cultivable lands contribute to a cradle of the earliest human civilization in China, and the agricultural activities at the YHV can be traced back to the Majiayao Culture period around 5.9 ka BP (Liu et al. 2010). Approximately around the 4.2 ka BP, the agriculture changed significantly due to the ‘Meghalayan’ global cold event. Since then, the proportion of animal husbandry was kept increasing, and eventually, animal husbandry was separated from agriculture (Liu et al. 2010). As a typical agro-pastoral zone, the area with its cropland reclamations and changes are highly sensitive to and very pronounced of the combined climate impacts and human activities.

2.2. Data sources

Historic cropland data of Qing Dynasty are collected from various sources, which covers:

- ‘Xining Fu Zhi’ (西宁府新志) (Yang 1968), compiled in the 12th year of the Qianlong period in Qing Dynasty (AD 1747).
- ‘Xining Fu Zhi Continued’ (西宁续志) (Deng 1938), compiled in the 9th year of Guangxu period (光绪) (AD 1883).
- ‘Gansu Tongzhi’ (甘肃通志), recompiled in the 34th year of Guangxu period (AD 1908) and the 18th year of the Republic of China (AD 1929),
- ‘Gansu Tongzhi Manuscript’ (甘肃通志稿), pressed in 1936 (Liu 1964),
- ‘Xunhua Ting Zhi’ (循化厅志) (Gong 1970),
- ‘Dan ge er Ting zhi’ (丹噶尔厅志) (Yang 1989),
Figure 1. Location of the Yellow River–Huangshui River Valley on Qinghai–Tibet Plateau (upper left), with a detailed terrain map (right) showing major human settlements (cities and towns).

- ‘Compilation of local Chronicles of Qinghai’ (青海省地方志) (Wang 1987), and a few other local history materials.

Natural disasters and their impacts, social unrest, local conflicts, wars and other social data come from Yuan’s book ‘History of Disasters in Northwest China’ (Yuan 1994). The administrative boundary of the study area in the Qing Dynasty was different from the present. We adopted the ‘Historical Atlas of China’ (中国历史地图集) edited by Tan (1996) and the ‘Comprehensive Table of Administrative Districts Evolution in Qing Dynasty’ (Niu 1999) to keep consistency accuracy with the cropland reconstruction data.

2.3. Methods of cropland reconstruction

The agricultural system at the YHV area has been well developed by the early Qing Dynasty (in early 17th century), and data of croplands is relatively easy to access in various survey materials and statistical documents. Generally, the YHV area has six types of cropland: Tun cropland (屯垦), Ke cropland (科垦), Qiu cropland (秋垦), Zhan cropland (站垦), Ken cropland (垦田) and Fan cropland (番垦). The Tun type is a kind of state-owned land but was cultivated by either military or farmers. Some of the Tun croplands were converted to private farmlands since the late Ming Dynasty (1386–1644 AD). Ke cropland is a privately owned farmland that was registered and taxed by the government. Qiu cropland has relatively less fertile soil, where only one season crops can be planted (sow in summer and harvest in autumn). The Zhan type is the cultivated land that were originally owned by local relay/post stations but were then converted for civilian cultivations. Ken cropland is the officially reclaimed land, and the Fan cropland is the type of cropland owned by the ethnic minority groups in some marginal areas.

We obtained the cultivated land quantity of every county at the YHV in seven historical periods by consulting a variety of historical documents (Shao 1901, Deng 1938, Yang 1968, Gong 1970, Liang 1987). On account of the measurement unit of cropland area, ‘Qing Mu’, a unit of area in the Qing Dynasty, an area measurement transformation was needed. And a ‘Qing Mu’ is equal to 0.9216 mu or 0.0614 ha in modern times. Then, a grid with a size of 1 km × 1 km is masked over the research area. The factors, affecting the distribution of cultivated land, are spatially transformed into each grid. Meanwhile, the reclamation rate of each grid was obtained according to the reclamation rate model. Finally, the reclamation rate of the grid was optimized and adjusted under the restriction of cultivated land quantity, so as to realize the spatial reconstruction of cultivated land in the historical period.
2.4. Gridding model for reconstructing the cropland reclamation rate

Considering the complex natural environment of the Qinghai–Tibet Plateau and its various effects on farmland distribution, two types of constraint factors and suitability factors were divided. The former, expressed numerically, would control the spatial distribution range of cultivated land. For example, if the elevation is more than 3500 m it means no cultivated land could be distributed. In this method, constraint factors were used for excluding areas impossible for farmland. It only had two values of 0 and 1, with 0 means there was no cultivated land and 1 means there had. The suitability factors determined the possibility of the distribution of cultivated land according to its value. It was the important basis for the quantity allocation of farmland in this method. We selected seven factors to be used in model of cropland reconstruction. Among these, elevation, slope and soil type were constraint factors. Suitability factors included aspect, climatic production potential, organic matter and settlement distribution.

Cropland area data were collected from historical documents, which recorded only its amount. In order to reasonably allocate it into the spatial distribution, a composite cropland reconstruction model was constructed. Firstly, we divided the research area into 1 km × 1 km grid cell. It meant that all subsequent calculations were performed for each grid cell. Secondly, the constraint factors were entered into the model, including of soil type, altitude and slope, represented by 0 and 1. And only those cells whose results were equal to 1 were retained. It implied the identification of spatial distribution range of the possible cropland. The suitability factors were then input into the model, consist of aspect, soil organic matter, climate production potential and settlement distribution (figure 2). So far, the $G(i, v_n)$ in formula (1) could be obtained. Then, we continued to apply the formula (2), (3) and (4) to obtained the degree of reclamation, cultivated area ratio, and reclamation rate for each grid cell

\[
G(i, v_n) = \prod_{j=1}^{H} R_j \sum_{c=1}^{L} S_c A_c 
\]

where $G(i, v_n)$ is the degree of reclamation for $i$ grid in year $v_n$, $H$ is the number of constraint factors, $R_j$ is the value including of 0 and 1 which 0 is impossible for farmland while 1 is possible for farmland, $L$ is the number of suitability factors, $S_c$ is the value of suitability factor $c$, $A_c$ is the weight of factor $c$.

\[
B(i, v_n) = \frac{G(i, v_n)}{\sum_{i=1}^{H} G(i, v_n)} 
\]

\[
S(i, v_n) = B(i, v_n) D(w_m, v_n) 
\]

\[
KZ(i, v_n) = \frac{S(i, v_n)}{\text{area}(i)} 
\]

where $B(i, v_n)$, $S(i, v_n)$ and $KZ(i, v_n)$ are the cultivated area ratio, cultivated area and reclamation rate respectively for grid $i$ in year $v_n$. $D(w_m, v_n)$ is the total cropland area for county $w_m$ in year $v_n$, area($i$) is the area of grid $i$.

3. Reconstruction of cropland in the study areas

3.1. Total amount of cropland

According to the historical literature (Shao 1901, Deng 1938, Yang 1968, Gong 1970, Liang 1987), the reliable cropland statistic date of seven periods
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A large number of people died in the war and the farm-land were abandoned. A sharp decline in farmland occurred. The amount of cultivated land decreased rapidly from 1504.72 km² to 1106.19 km². Thus it can be seen that agriculture activity at the YHV, located in the transition area of agriculture and animal husbandry, was significantly influenced by social factors, such as population size, social institution, and stability.

Furthermore, we highly concerned about the intensive reclamation of farmland at the YHV since 1726. Fan cropland is the type of cropland owned by the ethnic minority groups on the fringes of agriculture. Through sorting out the historical documents, we further found that the Fan cropland reclaimed by ethnic minorities, were dominated by Tibetans which occupied an important part (figure 4). More than 80% of Fan cropland is dry land. The specific distribution were mainly on the upper slopes on both sides of the valley, shown in figure 5 of 2—Guide, 4—Jishi, 5—Datong, 6—Xunhua, 7—Bayanrongge, 8—Dangaer, 9—Menyuan, 11—Huangyuan, 13—Hualong.

3.2. Spatial pattern of reconstructed cropland

The spatial distribution of cultivated land in seven historical periods showed apparent aggregation on both sides of rivers (figure 5). The YHV has a large scope. However, less area is suitable for cultivated land. Farmland are mainly distributed near the Yellow River, Huangshui River, and their tributaries, including the Beichuan River, Datong River. Among them, the valley of Yellow River and Huangshui River have the highest density distribution of cropland. With the increase in altitude and slope, the distribution of cultivated land has decreased significantly. Thus, the spatial pattern of cultivated land distribution is limited by natural environment conditions.

We choose three periods of 1650, 1772 and 1934 to analyze the change of spatial distribution (figure 6). In 1650, the Huangshui Valley experienced war. There were a few people and less cultivated land which were concentrated in the valley with good water and soil resources. The government actively adopted the policy of immigration to develop agriculture, and the intensity of cultivated land increased. By 1772, the reclamation rate of cropland at the YHV had risen significantly. Later, to the end of Qing Dynasty, the society was in turmoil coupled with a cold climate. A large number of people fled to other places. As a result, a lot of cultivated land at the YHV was abandoned, which led to a remarkable decrease in the reclamation rate of cultivated land at the YHV.

4. Implications of cropland changes

In the Qing Dynasty, agriculture became a dominant mode of production from being next to animal husbandry at the YHV. It is just its unique geographical features that agricultural development has shown significant vulnerability and resilience to the combined effects of natural (e.g. climate change and disasters) and social factors (e.g. population and policy). The YHV, which is located in the northeast of the Qinghai–Tibet Plateau, is characterized by the arid
climate, high altitude and low accumulated temperature for agricultural activities. Agricultural production is very sensitive to climate change. And it got worse when encountering natural disasters. At the same time, the YHV has always been an important passage for the nomadic people of northwest China to enter Central China, and it was also an important outpost for Central government to control northwest China. Under the stable rule of Qing Dynasty, agriculture developed greatly and played a leading role in the economic structure. Therefore, we will further explore the impact of natural and social systems on agriculture and their responses.

4.1. The influence of the natural environment on the agriculture system
The natural disaster at the YHV had a great destructive effect on agriculture in the Qing dynasty. For example, drought, hail, flood and frost were the top four agricultural meteorological disasters in this region (Zhu 2012). The frequency of drought was high which led to a massive loss of crop and famine. Hail directly caused crop losses and failures. Floods washed away low-lying farmland. Frost prevent crops from growing properly and reduce production in this alpine zone (Deng 1938, Yang 1968). These extreme agro-meteorological events greatly increased the vulnerability of agricultural system at the YHV.

4.1.1. Climate change significantly affects agricultural distribution
Agricultural activity is primarily subject to precipitation and temperature conditions. Climate change has a more significant influence on agricultural production at the YHV due to its cold and drought climate. The warm and humid climate promotes expansion of agriculture, while cold and dry climate shrinks it. About 70 years after the beginning of Qing Dynasty, due to the cold climate, the progress of farmland reclamation was slow. After the 1720, there was a warm and humid period, and the cultivated land grew rapidly.

Since 1830, the climate began to enter the second cold period of Qing Dynasty (Li 1999). Especially after 1860, the climate became colder. At the same time, the amount of cropland experienced a short rise until 1845 and then began to decrease sharply (figure 8). Climate change is one of the critical reasons for agricultural expansion. Complex climate change and agricultural production conditions seldom match perfectly as we expected. And for the transition zone of agriculture and animal husbandry, climate change is an important factor affecting agricultural reclamation.
4.1.2. Natural disasters do more direct damage to croplands

To better understanding the relationship between the change of farmland area and the natural system in the Qing Dynasty, natural disaster records of the Yellow River–Huangshui River valley were extracted from the historical documents of this period (Gong 1970, Liang 1987, Wang 1987, Yuan 1994). Natural disasters, such as drought, flood, landslide, debris flow, frost and hail, always happen locally and have a certain causal relationship with...
the change of cropland. During the period of 1650–1900, 238 records of natural disasters were extracted at the YHV, and then drew a frequency histogram (figure 7) with every 10 years as a unit. As shown in figure 7, the frequencies of natural disasters that occurred between 1650–1720 and 1780–1800 were low. However, during 1720–1790 and 1800–1900, the high frequency of natural disasters, reached 101 (1.44 times/year) and 136 times (1.36 times/year) respectively. The results showed that the increase of this natural disaster was consistent with the expansion of farmland acreage. Although it was not completely certain that the expansion of cropland acreage was caused by the increase in natural disasters, this positive relationship should be concerned.

The further analyzed for nature disasters found that torrential flood was the main natural disasters during 1720–1780, accounting for about 40% of all disasters. To some extent, this information illustrates that more farmlands were reclaimed from plenty of native vegetation (forest or grassland). In another research work, the results proved that more farmland were reclaimed from shrub grassland (Wu et al 2016). Due to large-scale destruction of vegetation for the reclamation, water and soil conservation capacity was weaken and floods occurred frequency. This further led to that a large amount of land was washed by water and sand (Deng 1938, Yang 1968). High frequent natural disasters was a key factor for the reduction of cropland acreage in this region. While, human-land conflict was an indirect factor. For example in 1645, the population at the YHV was \( 3.6 \times 10^4 \) (Cui 1998), but in 1746, the population increased to \( 26.4 \times 10^4 \) (Cui 1998), with an increase of 733% in a short period of 100 years. The rapid increase in population led to environment deterioration and frequent disasters.

There is no doubt that the warm and humid climate promoted the development of agriculture. In the Qing Dynasty, the short warm and humid period make the saturation of cultivated land reclamation, while natural disasters destroyed the cultivated land. In face of an unfavorable natural environment for crop planting, management and policies from the social system were promising to enhance the resilience of agricultural system.

4.2. Social responses and resilience to cropland changes

4.2.1. Land reclamation policies

The government of the early Qing Dynasty attached great importance to the role of the YHV in consolidating Xinjiang and Tibet and thus some immigration and agricultural reclamation policies were developed sequentially. At the beginning of Qing Dynasty, the policy of ‘Reclamation farmland to support the frontier’ (屯垦开发, 以边养边) was implemented (Deng 1938). Garrisons troops and immigrants were engaged in farming. However, due to heavy taxation and low agricultural yields during a cold climate, the growers fled and the farmland was abandoned (Huang 2009). In order to attract more immigrants for agricultural reclamation, in 1648, the Qing government issued: ‘the garrisons will be transferred to farmers, and will never be changed.’ (卫军改屯丁，永不勾补) (ZhongHua Company 1986). In 1954, the government supervised the reclamation of wasteland throughout the country and promised that the cropland could be plowed for themselves for ‘forever’ after three years of farming. It also stressed that the purpose of reclamation land was to open up the wasteland and gather the people rather to supply troops (兴屯之意原以开荒，非以备饷；原以聚民，非以供兵，始初虽有屯名，其后永为民业) (Shao 1901). Since then, a large number of immigrants came to reclaim lands. In 1712, a preferential land tax policy of ‘Never raise taxes for the new born’ (滋生人丁，永不加赋) (ZhongHua Company 1986). In 1954, the government supervised the reclamation of wasteland throughout the country and promised that the cropland could be plowed for themselves for ‘forever’ after three years of farming. It also stressed that the purpose of reclamation land was to open up the wasteland and gather the people rather to supply troops (兴屯之意原以开荒，非以备饷；原以聚民，非以供兵，始初虽有屯名，其后永为民业) (Shao 1901). Since then, a large number of immigrants came to reclaim lands. In 1712, a preferential land tax policy of ‘Never raise taxes for the new born’ (滋生人丁，永不加赋) was issued. So that the peasants do not have to worry about adding tax increases. The population grew rapidly, which once again triggered a new round of development of farmland at the YHV.

With the implementation of a series of preferential land policies, significant effects were seen in the population. It increased from 22 000 in 1650 to 26400 in 1700, and then rapidly increased to 638 000 in 1752, with the highest population of 874000 appearing in 1853 (Deng 1938). With increase of agricultural labor
force, the final effect is shown in the rapid development of agriculture. In 1650, the cultivated land of the YHV was only 406.6 km², which soared to 1426.7 km² in 1726, and then entered a high period of nearly 100 years of cultivated land development, with the peak of 1504.2 km² appearing in 1845 (Deng 1938). However, the cultivated land area fluctuated during the period of 1700–1800 although the population was still increasing. The historical documents gave us some perspective that the exploitation of cultivated land maybe reach the upper limit. In 1728, for example, Local officials of the YHV, had reported to the central government that no suitable land could be cultivated. (地方官员向中央政府报告, 区域内循环厅内已无土地开垦。今保安、撤喇地方, 凡有成熟之地,久为番回恒产, 此外概无闲田可垦)(Gong 1970).

Some management policies had been also implemented to strengthen the organization of agricultural production. In 1724, the policy of transforming the Xining Wei government (equivalent to a county) into Xining Fu (equal to a provincial city) was carried out (Deng 1938). Then, the various types of farmland which were previously managed by the army or the monasteries were brought into the unified management of the Qing government. It greatly liberated the productive forces of the peasants and also aroused their enthusiasm for plant. Around 1850, the government continued to carry out agricultural development policies, such as the encouragement of try to reclaim arable land and duty-free policy. In 1908, the Bureau of Reclamation of Qinghai was set up in Xining Fu to make detailed plans for agricultural development (Yang 1968). But soon after the Qing Dynasty collapsed and the bureau did nothing.

We can obviously see that, under drought and cold climate condition, it was just the implementation of immigration, land tax and management policies to promoted the vigorous development of agriculture at the YHV. Especially, under the coupling effect of the first two policies, agricultural developed rapidly and steady. But with the demise of Qing Dynasty, the policy also lapsed.

4.2.2. The construction of water conservancy facilities

The YHV is located on the northeast margin of Qinghai-Tibet Plateau, with a relatively low altitude ranging from 1650 to 4400 m. A mild climate and fertile soil is suitable for agriculture production. However, this region is just in the transition zone between the monsoon region and the non-monsoon region. When the warm and wet southeast monsoon from Pacific Ocean arrives here in summer, it is already at the end of its tether, and it brings little precipitation. It belongs to the typical arid and semi-arid climate. Even in valley basins, precipitation meets only about 40% of the total water needs of crops. Irrigation accounted for the rest. Therefore, the construction of water conservancy has become an important guarantee and support for the development of agriculture in this region.

The government of Qing Dynasty paid high attention to the construction of water conservancy facilities. For example, in 1659, the administrator of Datong county put forward a way of intensified agricultural by irrigation. In 1746, the administrator of Xunhua County personally led local people to build ditches (about 40 km). According to historical records from 1661 to 1722, irrigation tools were used widely, such as water mill and hopper (Liang 1987). These efforts are, of course, confirmed. A total of 392 canals with a total length of 3.47 km were built, and the irrigated area of 32 400 ha were covered. By the middle of Qing Dynasty, in 1747, here had 212 private irrigation districts with 535 canals. The irrigated area reached more than 36 200 ha (Deng 1938, Yang 1968). 72% of the whole irrigation canal were concentrated in the area between 2100 and 2700 meters above sea level (up to 3000m). 97% of the irrigation canals were distributed within 5 km of both sides of the river. It reflected that the scale of agricultural development at the YHV greatly depended on the distance from river (Lou et al 2016).

The construction of water conservancy facilities greatly contributed to the increase of the cultivated land. It make the number increased from about 20 000 ha in the initial period to 50 000 ha in 1772. The traditional agriculture at the YHV reached the best level. The development of water conservancy facilities has improved the level of agricultural production, alleviated the adverse effects of climate change and drought in the region, and increased the stability of agricultural production and the growth of agricultural output.

4.2.3. Tibetans actively transferred into agriculture development

At the beginning of Qing Dynasty, ethnic groups (Fan), including Tibetan, Hui, Tu and salar, were subordinate to the center government. All ethnic groups were encouraged to be farmer and needed pay grain tax, just like the Han people (Gong 1970). The cultivated land area thus increased from 14 000 ha around 1600 to 43 000 ha around 1790. During the same period, 97 738 people switched from ranching to planting (Yang 1968). In 1726, the ethnic minority cultivated land of 193 365 blocks at the YHV, which took up 64.7% of the total cultivated land area (Luo et al 2014). It was mainly distributed in Datong, Xunhua and Hualong County (Yang 1968).

It is particularly worthy of attention to Tibetans. As an important component of the ethnic group, they took active participation in agricultural production. In 1791, for example, only the Tibetans in Xunhua County developed 18 698 blocks of cultivated land (Chen 1997). At the beginning of Qing Dynasty, the Tibetans at the YHV were ruled by the Mongolians who took animal husbandry as their
livelihood. The Tibetans were forced to concentrate on the mountain and hill areas on both sides of the YHV leaving Qinghai Lake. At that time, the grasslands available for them had been reduced greatly. However they enhanced communication with farming ethnic groups. The Tibetans thus began to transform pure animal husbandry into agricultural production. And they gradually changed dwell from the original ‘tent’ to ‘house’ or their coexisting. The Tibetans provided horses, cattle, sheep and grains to the Mongolian nobles. These historical facts proved that the Tibetans were changing from pure animal husbandry to mixed style of husbandry and farming (Deng 1938, Yang 1968). In 1723, the government of Qing Dynasty suppressed the Mongolian leader of Lobzang Danjin’s anti-Qing incident. Since then, the Tibetans have been under the management of the central government and actively accepted the agricultural reclamation policy. In 1791, local officials reported to the Qing government that the Tibetans at the YHV made a living from farming and animal husbandry and paid taxes. At the same time, the Tibetans lived in earthen houses and formed villages. (除西宁等属黄河以北，各番族抚绥日久，耕牧为生，与齐民无异。内循化所属熟番十八寨四屯，贵德所属熟番五十四寨族，俱耕种垧亩，完纳香粮，住居土房，已成村落…) (Deng 1938). It can be seen that Tibetans had been engaged in agricultural farming since the middle of Qing Dynasty, and which made positive contributions to the agricultural development of the Yellow-river and Huangshui-river Valley.

4.2.4. Special flexibilities of the agro-pastoral system

The YHV, is sensitive and vulnerable to climate and environmental changes, such as low cumulative temperature and dry climate. However, the transformation between agriculture and livestock activities were considered as being flexible and adaptive to external stresses. Farming, combination of cropping and husbandry, and animal husbandry were distributed from the middle valley to the surrounding mountains. The various production modes could well respond to the changes of natural environment. When climate become cool, agriculture shrinks and served animal husbandry by planting forage. On the contrary, animal husbandry extends due to the cold climate and the need for less labor. As the climate become warm, agriculture expands, and population increases. Ethnic minorities who engage in animal husbandry switch to farming. Therefore, it is just the complementarity of agriculture and animal husbandry to make the agricultural system at the YHV become flexible and adaptable suffering from a harsh natural environment.

Local households diversified their livelihoods in multiple production activities, for example, the developments of courtyard economy, large-scale farming, crop planting, cattle and sheep fattening. The ways of earning livelihood determine their capabilities to cope with unexpected disturbances. Generally, diverse livelihoods enable flexible transforms and thus somehow guaranteed survival and development though at a low level. The local farmers and pasturals were provided the opportunities to choose suitable livelihood according to climate and environmental conditions, which certainly enhanced their resilience in case of natural hazards.

The agriculture at the YHV has great uncertainty mainly due to the sensitive to natural environment and the interlaced culture of agriculture and pastoral. We also argue that its sustainable relationships between human and farmland required an emphasis on ecosystem resilience which was measured by the magnitude of disturbance that can be absorbed before the system changes its structure (Gunderson and Holling 2002). In the Qing dynasty, population here had a great increase driven by policy, and more cultivated land were need. Meanwhile, people gradually accumulated experience and skills in agricultural production which facilitate the cultivated land development. All these had made the tremendous increase in cultivated land quantity. Various agricultures were developed, such as irrigated agriculture in the valley, the improved agricultural on the terraces, and upland agriculture. The agricultural structure at the YHV became diversified and complicated. And thus the agricultural production function were improved. Therefore, we could conclude that the increase in the amount of farmland had effectively enhanced the resilience of the agricultural system at the YHV in the Qing dynasty.

5. Discussions and conclusions

5.1. Discussions

From the above analysis, we found that the change of cropland in this region was affected by natural factors (e.g. temperature rising and natural disaster etc) and human factors (such as policy and population growth etc). The YHV, where condenses the period from 1400 to 1900 the little ice age period of the Ming and Qing Dynasties. The frequent low-temperature disaster happened in China, and the temperature curves
of the three reconstructions we selected (figure 3) also conform to this trends. There was a period of lower temperature at the YHV before 1650, described ‘the land is cold and cannot grain,’ ‘the mountains are high and cold, the land is poor’ by historical materials. Because of the cold climate, the area of land reclamation was limited and grew slowly. However, the human system never passively accepts all. The agricultural technological innovation always had been promoted and active management systems had been implemented in face of the harsh natural environment. The agricultural production at the YHV had been struggling to develop in the interaction of the pressure of the natural system and the support of the social system.

The cropland reclamation at the YHV had obviously suffered from great pressure from natural conditions that are not conducive to agricultural production. When the temperature in the northern hemisphere increased from 1720 to 1770, the temperature in this region also risen. It significantly promotes the rapid development of cultivated land. The scope of cropland was rapidly expanded. Our investigation in this area for nearly 20 years’ works shows that the agricultural planting area here responds quickly to the temperature change, and it was also shown in other research work (Chen et al., Hou 2018, Li et al. 2019). During the period from 1770 to 1800, the temperature dropped again. The number of natural disasters caused by the increase of cultivated-land in the previous stage also increased, and the area of cultivated land decreased by about 320 km². During the period from 1800 to 1850, the temperature showed a gradual increase in the curve (figure 8). Driven by both policies and warm climate, the area of cultivated land had increased again. However, the cooling temperature in 1850 did not only lead to a reduction in cultivated land, but also caused ethnic conflicts within the region. Although the extent of the cooling was much lower than the event in 1750, the consequences were much more severe than 1750. The main reason might be that the population is much larger than the previous period of cooling, and the social contradictions are more profound.

The development of agriculture at the YHV in the Qing Dynasty was limited by the natural environment (temperature, precipitation and natural disasters), but benefited from social factors (population and agricultural measures). The animal husbandry economy of ‘living in pursuit of water and grass’ is characterized by strong mobility, a wide utilization of land resources, which has strong adaptability to the harsh natural environment. However, the animal husbandry economy is also greatly affected by the changes in the natural environment. Its disadvantages manifest in terms of food storage, vulnerability, instability and heavy dependence on water and grass. Though the cold, drought and high altitude are the main themes of the vast Qinghai–Tibet Plateau region, there are always some rivers, lakes and valleys with fertile soil, abundant water and convenient irrigation, which are suitable for the development of the agricultural economy. One such place is the YHV, which has been a nomadic region of the Qiang (an ancient minority) people for thousands of years. When the population, agricultural technology and agricultural reclamation policies arrived in this region in the Qing Dynasty, water conservancy facilities were improved, which greatly enhanced the ability of agricultural system to resist drought. The implementation of the immigration policy has resulted in a massive increase in population, which promoted agricultural productivity. The reduction and exemption of various agricultural taxes greatly stimulated farmers’ land reclamation activities. Ultimately, the production capacity of the agricultural social system is enhanced.

In summary, agriculture in the farming-pastoral zone is strongly limited by the natural conditions of temperature and precipitation. But it can also stimulate more feedback from the social system, which makes agriculture well developed at the YHV and thus enhance social resilience.

5.2. Conclusions

Limited to the map technology, the cultivated land in historical period cannot be expressed in an intuitive space. Fortunately, China has enough historical documents to provide a large amount of records and digital statistics that can be used to reconstruct historical farmland. Based on the information recorded in the literature, we reconstructed the cultivated land of a small area in the eastern edge of the Qinghai–Tibet Plateau. Around the cultivated land changes, the interaction among agriculture, the natural system and social support system were analyzed. Some conclusions are found.

(a) Cultivated land of the YHV, restricted by altitude, slope, soil, etc, was mainly distributed in the narrow river valley areas where population and settlements were concentrated. The cultivated land fluctuated under the influence of both natural and social factors at different stages. The changes in the reclaimed land between Tun, Ke, Ken, Qiu, Zhan and Fan cropland presented obviously the ebb and flow trend.

(b) Climate change has a significant impact on agriculture at the upper altitude. During the warm period, People living in high-altitude region had significantly expanded to a larger scape, which had promoted the increase of the cultivated land. On the contrary, in the cold period, cultivated land shrunk, high-altitude residents increased livestock supplementation to sustain livelihood.

(c) The cultivated land at the YHV appeared fragile and changeable. In order to adapted to this
change, various measures have been adopted by the local government, farmers and herdsmen to cope with it. The government encouraged land reclamation, built water conservancy facilities, improved farming techniques to increase food production. At the same time, the complementarity of agriculture and animal husbandry enhanced the flexibility and adaptability of the agricultural system, and greatly improved the resilience of agricultural production in the edge of the plateau.

Data availability statement

The data generated and/or analyzed during the current study are not publicly available for legal/ethical reasons but are available from the corresponding author on reasonable request.

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