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Boundary Shift of Potential Suitable Agricultural Area in Farming-grazing Transitional Zone in Northeastern China under Background of Climate Change During 20th Century

YE Yu[1, 2], FANG Xiuqi[1]

(1. *School of Geography*, *Beijing Normal University*, *Beijing* 100875, *China*; 2. *Key Laboratory of Environment Change and Natural Disaster*, *Ministry of Education*, *Beijing Normal University*, *Beijing* 100875, *China*)

Abstract: Climate change affected the agricultural expansion and the formation of farming-grazing transitional patterns during historical periods. This study analyzed the possible range of the boundary shift of the potential suitable agriculture area in the farming-grazing transitional zone in the northeastern China during the 20th century. Based on modern weather data, 1 km-resolution land cover data, historical climatic time series, and estimation by using similar historical climatic scenes, the following was concluded: 1) The climate conditions of suitable agriculture areas in the farming-grazing transitional zone in the northeastern China between 1971 and 2000 required an average annual temperature above 1℃ or ≥ 0℃ accumulated temperature above 2500℃–2700℃, and annual precipitation above 350 mm. 2) The northern boundary of the potential suitable agriculture area during the relatively warmer period of 1890–1910 was approximately located at the position of the 1961–2000 area. The northern boundary shifted back to the south by 75 km on average during the colder period of the earlier 20th century, whereas during the modern warm period of the 1990s, the area shifted north by 100 km on average. 3) The western and eastern boundaries of the suitable agriculture area during the heaviest drought periods between 1920s and 1930s had shifted northeast by 250 km and 125 km, respectively, contrasting to the boundaries of 1951–2008. For the wettest period, that is, the 1890s to the 1910s, the shift of western and eastern boundaries was to the southwest by 125 km and 200 km, respectively, compared with that in the 1951–2008 period. This study serves as a reference for identifying a climatically sensitive area and planning future land use and agricultural production in the study area.

Keywords: land cover changes; farming-grazing transitional zone; climate change; agricultural production

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1 Introduction

Land cover changes caused by land reclamation in ecologically fragile areas are influenced by climate change and human needs. The farming-grazing transitional zone in the northeastern China is located on the border of various types of natural areas. From the west to east, the Northeast China Plain in the humid and semi-humid monsoon region has a border line with eastern Inner Mongolia, a semi-arid plateau region that is located in the transition zone of the westerly inland area and the eastern monsoon area. From the north to south, the eastern Inner Mongolia and the Northeast China Plain which is located in the transition zone of the temperate continental climate and monsoon climate have a border with Shanxi Province, northern Hebei

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Corresponding author: YE Yu. E-mail: yeyuleaffish@bnu.edu.cn

Province and southern Liaoning Province in the warm temperate monsoon climate zone. In this natural environmental transition zone, the response to climate change is highly sensitive. Thus, small changes in the climate can result in swing of climate zone boundaries in this region, which leads to corresponding changes in the natural vegetation zone and the impact on the surface cover conditions. During the long term, the climate restricts agricultural reclamation and land use/cover change in this region. Climate changes alter the boundaries of the natural forest and grassland cover, for example, causing lake retreat or expansion, desert fixation or activation. With human influence, the changes also induce the expansion or abandonment of cultivated land.

Changes of land use or agricultural production types in various time scales in the farming-grazing transitional zone have a profound environmental change background. The results of studies showed that this region was in the primitive farm belt in 8–3.5 ka B P. Abrupt environment changes in 4–3.5 ka B P in the form of significantly less precipitation led to the formation of the farming-grazing transitional culture. Since 3.5 ka B P, the agricultural and pastoral culture has alternately advanced or retreated with the several climate oscillations between cold and warm, wet and dry. The expansion of the northern boundary for agriculture and relatively prosperous agricultural culture in the Spring and Autumn period along with the Han, Jin, Tang, Liao, Jin, and mid-Qing dynasties corresponded to a warm period or a relatively warm period. The expansion of the southern boundary of grazing land and relatively prosperous pastoral culture generally corresponded to a cold and dry period. The modern land-use pattern of farming-grazing transition corresponded to warmer in the 20th century (Fang, 1997; Zhang *et al*., 1997; Fang *et al*., 2002). Several studies have been conducted in similar areas in the world. Some of the studies were related to Holocene climate reconstructions in semi-arid Inner Mongolia, China (Yin *et al*., 2011). Some studies involved ancient agriculture and climate-zone boundary changes (Bruins, 2012). Some studies analyzed the role of climatic and human factors on the environment in semiarid areas, such as Central Asia (Lioubimtseva *et al*., 2005), the cultivated Sahelian area of south-west Niger (Cappelaere *et al*., 2009) and semiarid China (Wang *et al*., 2006). Other studies were focused on the potential impact of climate change on agriculture in semi-arid basins in Jordan (Jawad *et al*., 2011), East Africa (Philip and Peter, 2010) and Northwestern Turkey (Mutlu, 2011). In addition, several studies in China also analyzed human activities and the environment in farming-grazing transitional zones during historical period (Zou, 1995; Wang, 1996; Man *et al*., 2000; Yu, 2010), the characteristics and responses to climate change during the past 50 years (Li and Yan, 2013), the landscape pattern changes in the context of modern climate change (Wang *et al*., 1999; Chen *et al*., 2006; Liu *et al*., 2007; Liu and Gao, 2008), the impact of modern climate change and land use on boundary shift of farming pasture ecotone (Liu *et al*., 2011; Li and Pan, 2012), the agricultural climatic production and the population-carrying capacity of the farming pasture ecotone in the northern China (Zhao *et al*., 2009; Wang and Pan, 2010). However, few studies were conducted on the movement of boundaries of the farming-grazing transitional zone in the historical period, especially in the last 300 years. The contribution of climate change and human activities to the formation of the modern eastern section of the farming-grazing transitional zone in the northern China requires further researches.

This study estimated the possible range of potential suitable agricultural area influenced by climate change during the 20th century in the farming-grazing transitional zone in the northeastern China. The impacts of climate change on the agricultural expansion and the formation of the farming-grazing transitional pattern were analyzed, and the climatically sensitive area was identified. The results can help guide land use and agricultural practices, and preserve ecological security in this area.

2 Materials and Methods

2.1 Study area

Drawing on the widely adopted definitions of the farming-pastoral ecotone, which is determined by agricultural climate conditions and land uses according to several studies (Zhao, 1953; Zhang *et al*., 1997; Zhao *et al*., 2002; Liu and Gao, 2008). The region in the farming-grazing transitional zone in the northeastern China, including the eastern Inner Mongolia, western Liaoning Province, western Jilin Province, western Heilongjiang Province, and northern Hebei Province, was selected as the study area (Fig. 1). The study area includes 29 coun-

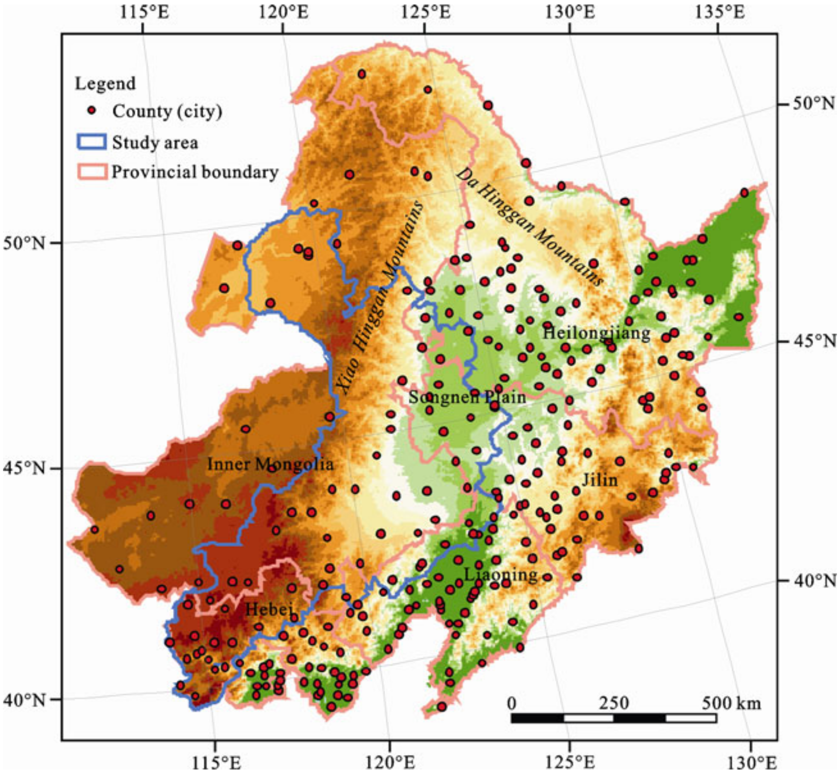

Fig. 1 Location of study area in northeastern China

ties (or cities) in the eastern Inner Mongolia, 22 counties (or cities) in the western parts of three provinces in the northeastern China and 17 counties (or cities) in the northern Hebei Province.

2.2 Data sources and methods

Data sources included annual precipitation, annual evaporation and average annual temperature from 129 meteorological stations during 1951–2008 and 1 km-resolution land cover data for the northeastern China from the Global Land Cover 2000 datasets (GLC2000/China dataset) (http://www.gvm.sai.jrc.it/glc2000/).

First, the range of the suitable agricultural area in the farming-grazing transitional zone in the northeastern China was divided and the climatic threshold was determined. The steps were conducted as described in the following. 1) The average annual temperature, precipitation and evaporation amounts for each meteorological station from 1971 to 2000 were calculated. 2) The reverse-distance powered method in the Spatial Analysis Tool of ARCGIS software was used to produce contour maps of average annual temperature, average annual precipitation and drought index (DI) in this area during 1971–2000. The DI was equal to the average annual precipitation divided by the average annual evaporation. 3) The point density analysis method in the Spatial Analysis Tool was applied to a cropland cover map for the northeastern China in 2000, and the percentage of cropland area in each round area was calculated sequentially with a 1-km grid as the unit, and a 100-cell as search radius. For each unit, the percentage of cropland area was obtained for the cropland density surface. Next, a cropland density contour map in 2000 was produced by using the reverse-distance powered method. 4) Contour maps of three climatic indices in 1971–2000 were produced and overlaid along with a land cover map of the study area in 2000 and the contour map of cropland density in 2000. The range of the modern farming-grazing transitional zone in the northeastern China was divided, and the boundary of its agriculturally appropriate area and climatic threshold were determined.

Second, the temperature and precipitation change and their variations in the farming-grazing transitional zone in the northeastern China during the 20th century were estimated by the study results of historical climate change in this area. The past temperature data were mainly sourced from temperature series of the northeastern China since the Little Ice Age by Wang *et al*. (1998) and tree ring-based temperature reconstructions for the Changbai Mountains in Northeast China by Shao and Wu (1997) and Zhu *et al*. (2009). The past precipitation data were sourced from tree-ring precipitation reconstruction in the Ortindag Sandy Land, the eastern Inner Mongolia as reported by Liang *et al*. (2007), in the Chifeng-Weichang region and Xilin Hot City in Inner Mongolia as reported by Liu *et al*. (2003; 2010), and the Xiaowutai Mountain in Hebei Province as reported by Wei *et al*. (2008).

Finally, based on the climatic threshold of the agricultural area and the extent of historical climate variation, the possible boundary range of the potential suitable agricultural area in the farming-grazing transitional zone in the northeastern China was analyzed under the background of climate change during the 20th century.

3 Results and Analyses

3.1 Suitable agricultural area and its climatic threshold

The suitable agricultural area was the concentrated agricultural area in the farming-grazing transition zone in the northeastern China and the boundary between forest land and agricultural land approximately coincided with the contour of the average annual temperature of 1℃. Overlaying the land cover map in 2000 with a contour map of average annual temperature in the study area from 1971 to 2000, it demonstrated that the northern boundary of suitable agricultural area corresponds to a contour of ≥ 0℃ accumulated temperature above 2500℃–2700℃ in Yichun City, Kedong County, Nehe County, Xilin Gol League, and East Ujimqin Banner from east to west (Fig. 2). The concentrated agricultural area to the south of this boundary involves single cropping, where the main crop is spring wheat, and other crops such as soybean, potato and miscellaneous cereal are grown to a lesser extent.

Overlaying land cover map in 2000 with contour map of average annual precipitation in the study area during 1971–2000, the results showed that the western and eastern boundaries of the cropland-meadow interwoven zone approximately coincided with the contours of average annual precipitation of 350 mm and 450 mm, respectively. The western boundary is along with New

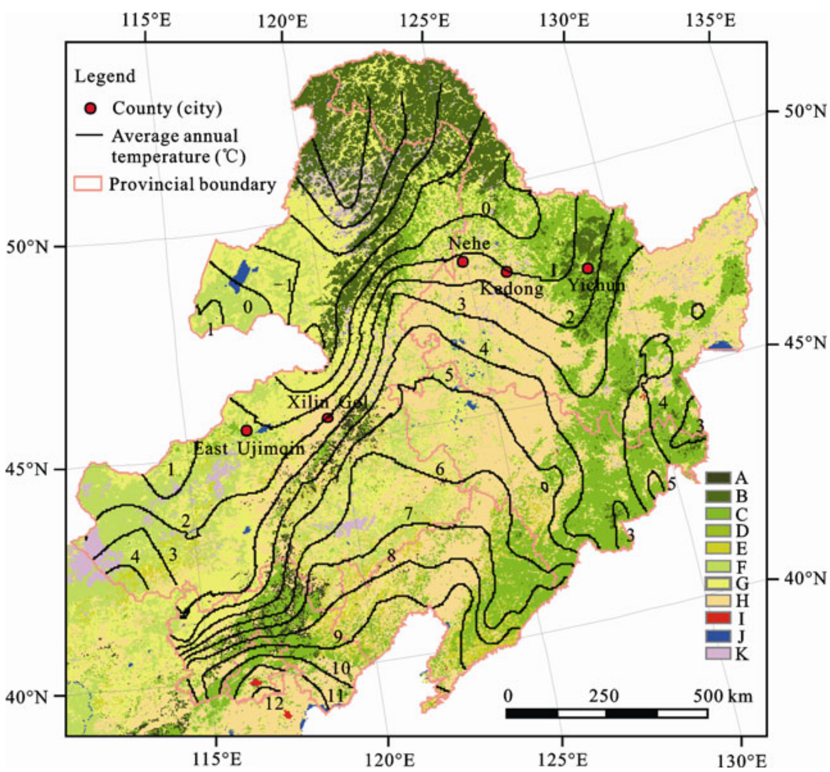

Fig. 2 Distribution of average annual temperature and land use in farming-grazing transition zone in northeastern China. Modern land-use types (China/GLC2000): A, evergreen needle-leaved forest; B, deciduous needle-leaved forest; C, deciduous broad-leaved forest; D, sparse wood; E, bush; F, grassland; G, meadow; H, farmland; I, city; J, water area; K, unutilized land

Barag Left Banner, West Ujimqin Banner, Taibus Banner and Shangyi County from the north to south, while the eastern boundary is along with Ergun Left Banner, Ulan Hot City, Longjiang County, Qiqihar City, Daqing City, Mongolian Autonomous County of Front Gorlos, Changling County, Kulun County, Ningcheng County, Chicheng County, Huailai County from the north to south (Fig. 3). This area belongs to a semi-arid and semi-humid region where the main vegetation type is forest steppe-steppe. The farming-grazing interlaced land uses appeared in this area. Average annual precipitation of 400 mm is the theoretic boundary of cropping and grazing.

Based on the contour map of farmland density in 2000, the range of contours of farmland density between 15% and 55% can also be observed to coincide with the range of the farming-grazing transition zone as defined by climatic indices and land-use types, within which the drought index is in the range of 0.2–0.3 (Fig. 4).

3.2 Range of climate change and variation in farming-grazing transitional zone

3.2.1 Temperature change and amplitude of fluctuation

A temperature series of the northeastern China by Wang *et al.* (1998) indicated that the period from the end of the 19th century to the beginning of 20th century was one of three coldest periods in the past 400 years. Reconstruction of temperature changes between February and April by using tree-ring data by Zhu *et al.* (2009) showed that there were two cold periods from the end of the 19th century to 20th century before the instrumental period. These periods were 1878–1889 and 1911–1945. In contrast, the climate in the period from 1890 to 1910 was relatively warmer.

The reconstruction results can indicate the change of the eastern Asia winter-monsoon amplitude (Fig. 5b). According to the reconstructed series, the average annual temperature during the period of 1990–2000 in the Changbai Mountains was –3.3℃, which is 1.2℃ higher than that of the previous 250 years. The average annual temperature during the period of 1890–1910 was 0.1℃ higher than average annual temperature of the past 250 years. The average annual temperature in 1878–1889 and 1911–1945 was 0.5℃ and 0.6℃, respectively, lower than the average annual temperature of the past 250 years. Thus, the highest amplitude of the average annual temperature during the various periods since the

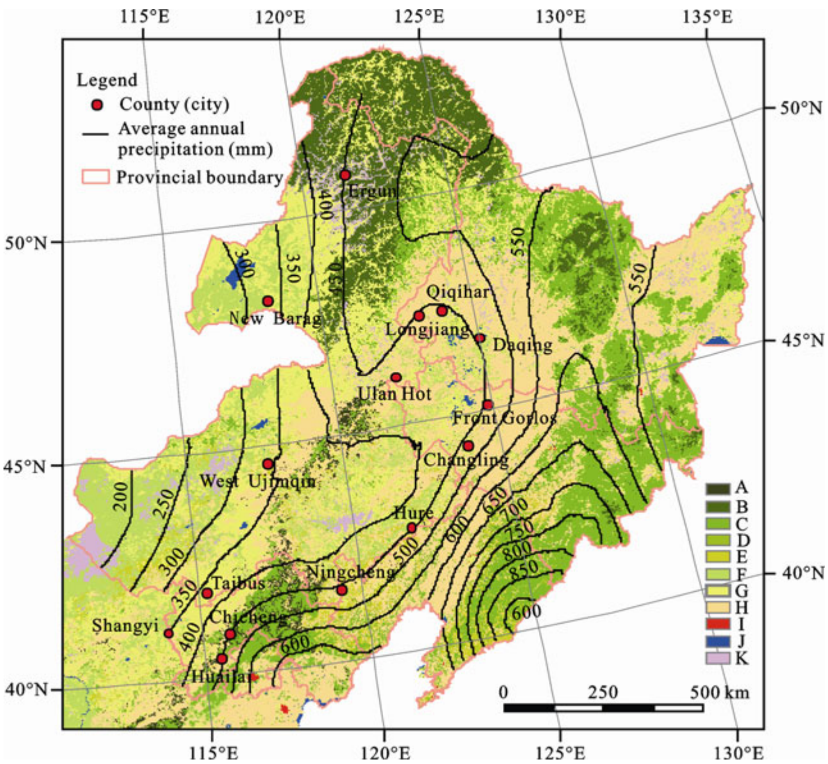

Fig. 3 Distribution of average annual precipitation and land use in farming-grazing transition zone in northeastern China. Modern land-use types (China/GLC2000): A, evergreen needle-leaved forest; B, deciduous needle-leaved forest; C, deciduous broad-leaved forest; D, sparse wood; E, bush; F, grassland; G, meadow; H, farmland; I, city; J, water area; K, unutilized land

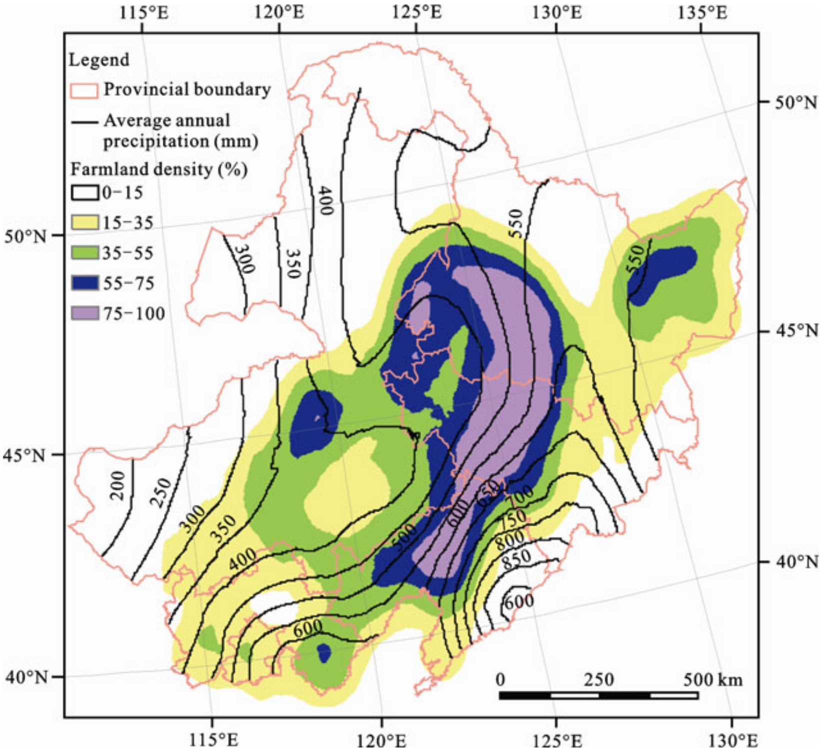

Fig. 4 Distribution of average annual precipitation and farmland density in northeastern China

start of the 20th century is approximately 1.8℃, and the average annual temperature in 1890–1910 and 1911–1945 was 1.1℃ and 1.8℃, respectively, lower than that in the modern periods.

3.2.2 Precipitation change and amplitude of fluctuation

Tree-ring precipitation reconstruction in the Ortindag Sand Land, East Inner Mongolia studied by Liang *et al.* (2007) indicated that there were two drought periods of 1903–1905 and 1924–1929 before 1966 (Fig. 5a). Reconstruction of precipitation from August last year to July in the Chifeng-Weichang region during the period of 1768–2003 showed that since the turn of the 20th century, it appeared two periods when average annual precipitation is low (1926–1972 and 1980–1989), and three periods with abundant average annual precipitation (1884–1925, 1973–1979 and 1990–1999) (Fig. 5d). Significant correlations were found between precipitation reconstructions and the series of drought/flood index of Datong and Beijing, and the reconstruction results in Bayan Obo, Helan Mountain and even in Mongolia. All of these data supported the amplitude change of the eastern Asia summer monsoon.

The reconstruction of precipitation in April–July in Bayan Obo, Xilin Hot of Inner Mongolia by using tree-ring width from Korean Spruce (*Picea Koraiensis*) indicated that there were two abundant-precipitation periods (1886–1921 and 1943–1968), and two scarce-precipitation periods (1922–1943 and 1969–1999) (Fig. 5c) (Liu *et al.*, 2003). Among these periods, the drought period of 1922–1943 and the wet period of 1943–1968 coincide with high temperature and low precipitation during the 1920s and low temperature and abundant precipitation in Northwest China, North China and the Changjiang (Yangze) River Basin since the 1940s. In addition, there is a significant negative correlation between temperature and precipitation in Weichang, which is in accordance with the fact that the main climate mechanism was cold-moist and warm-arid (Fig. 5e). The reconstruction results of precipitation in February–May since 1895 in the Xiaowutai Mountain by Wei *et al.* (2008) indicated that this area experienced four arid periods (1903–1911, 1927–1932, 1940–1943, and 1992–1996) and four relatively moist periods (1895–1898, 1912–1920, 1933–1936, and 1948–1950).

The average annual amplitude of precipitation fluctuation is within 70–100 mm in different regions. According to above reconstruction results, the average an-

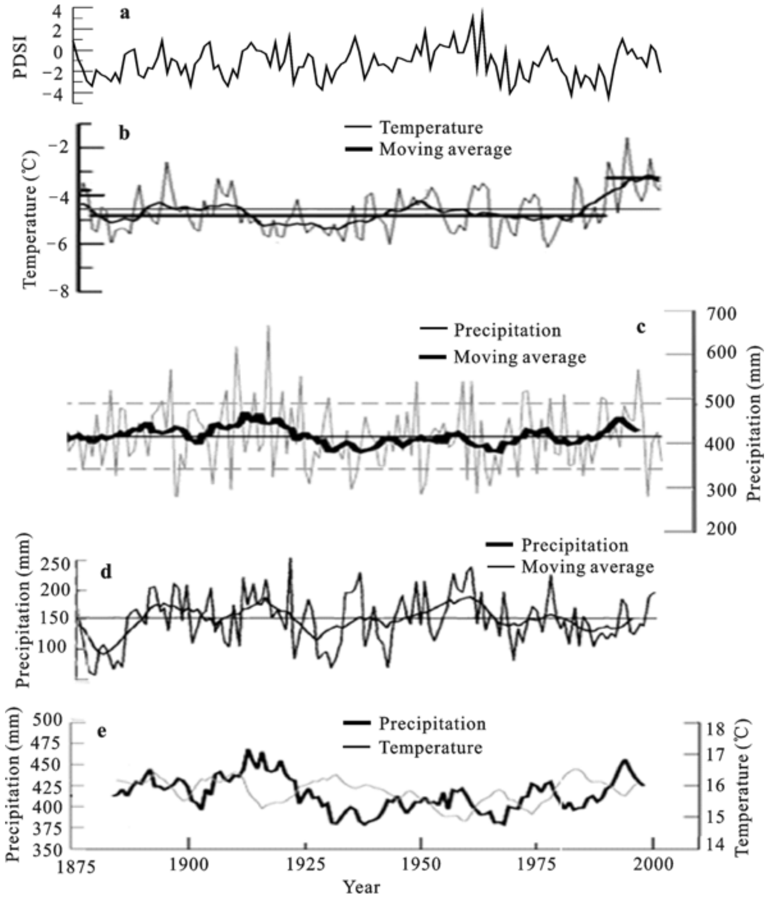

Fig. 5 Time series of temperature and precipitation series in study area since the end of the 19th century. a, palmer drought severity index (PDSI) of May–July in the Ortindag Sand Land, Liang *et al*. (2007); b, temperature of February–April in the Changbai Mountains, Zhu *et al*. (2009); c, precipitation of April–July in Bayan Obo, Xilin Hot, Liu *et al*. (2003); d, precipitation during August last year–July in Chifeng-Weichang, Liu *et al*. (2010); e, precipitation and temperature during August last year–July in Weichang region, Liu *et al*. (2010)

nual precipitation during 1952–2003 in the Chifeng-Weichang region was 410 mm, and the standard deviation for the past 125 years was approximately 78 mm. The average amplitude of precipitation fluctuation during April–July in the Bayan Obo region in Xilin Hot City was approximately 40 mm, and the average precipitation in April–July in this region was 152 mm, which was 43.4% of the average annual precipitation of 350 mm; thus, the average amplitude of the precipitation fluctuation over the past 125 years was approximately 92.1 mm. In the Xiaowutai Mountain in Hebei Province, during February–May the standard deviation of precipitation was 16.7 mm, and the average precipitation was 17.5% of the average annual precipitation. Therefore, the average amplitude of the precipitation fluctuation was approximately 95.4 mm.

4 Discussion

The development and formation of agricultural area requires more time to adjust and adapt to a relatively appropriate and stable climate. Therefore, the amplitude of the climate fluctuation was represented by the amplitude of the decadal change series fluctuation around the average value, and the average climatic conditions in a certain period was expressed by average annual values of the decadal change series. The above analysis of the amplitude of the climate fluctuation in the study area during the 20th century by using the 1℃ contour in 1990s as the standard, the northern boundaries of the potential suitable agricultural area in 1890–1910 and 1911–1945 were located where the contour of 2.1℃ and 2.8℃ in the 1990s were. Assuming the range of average annual precipitation of 350–450 mm as the standard, and the amplitude of the decadal precipitation fluctuation is approximately equal to half of the annual precipitation deviation of 70–100 mm (35–50 mm). In the study area the range of the eastern and western boundary of the potential agricultural area in the rainy and drought periods was located where the annual average precipitation levels of 300–400 mm to 315–415 mm and 385–485 mm to 400–500 mm in 1951–2008 were.

4.1 Range of northern boundary of potential suitable agricultural area

The northern boundary of the potential agricultural area swung south or north with temperature changes, and the range of the swing was approximately within 75–100 km (Fig. 6). The climatic northern boundary of the potential agricultural area in 1890–1910 was generally located where that of 1961–2000 was. Only along the East Ujimqin Banner in Inner Mongolia and Yichun City in Heilongjiang Province did the northern boundary moved slightly northward. The northern boundary of the potential agricultural area during the earlier half of 20th century moved southward 75 km on average. It reached the line of Yichun City, Qing′an County, Yi′an City, Arun Banner, Xilin Gol City, and Sonid Left Banner during 1911–1945. The northern boundary in the Xilin Gol Plateau to the west of the Da Hinggan Mountains and the northern Songnen Plain to the south of the Xiao Hinggan Mountains moved distinctively southward. The northern boundary of 1990s shifted northward 100 km compared with the boundary in the period of 1961–2000, which was along the line of Sunwu County, Nenjiang County, Arxan Mountain and East Ujimqin Banner. These results indicated that the region, west of the Da Hinggan Mountains and the south of the Xiao Hinggan Mountains, was more sensitive to temperature change.

4.2 Range of eastern and western boundary of potential suitable agricultural area

The eastern and western boundary of the potential agricultural area swung east or west with precipitation. The range of boundary swing caused by precipitation was larger than that caused by temperature. The range of boundary was approximately 125–250 km (Fig. 7). During the 20th century, the period of 1920s–1930s were the driest, and the period of 1970s–1990s were relatively drier. During this driest period, the range of potential suitable agricultural area shifted eastward to where the contour of 385–485 mm or 400–500 mm in 1951–2008 were. The range of suitable agricultural area is between two contours of light blue or two contours of dark blue. The western boundary was along the line of Ergun Left Banner, Yakeshi City, Xilin Gol League, Ja-

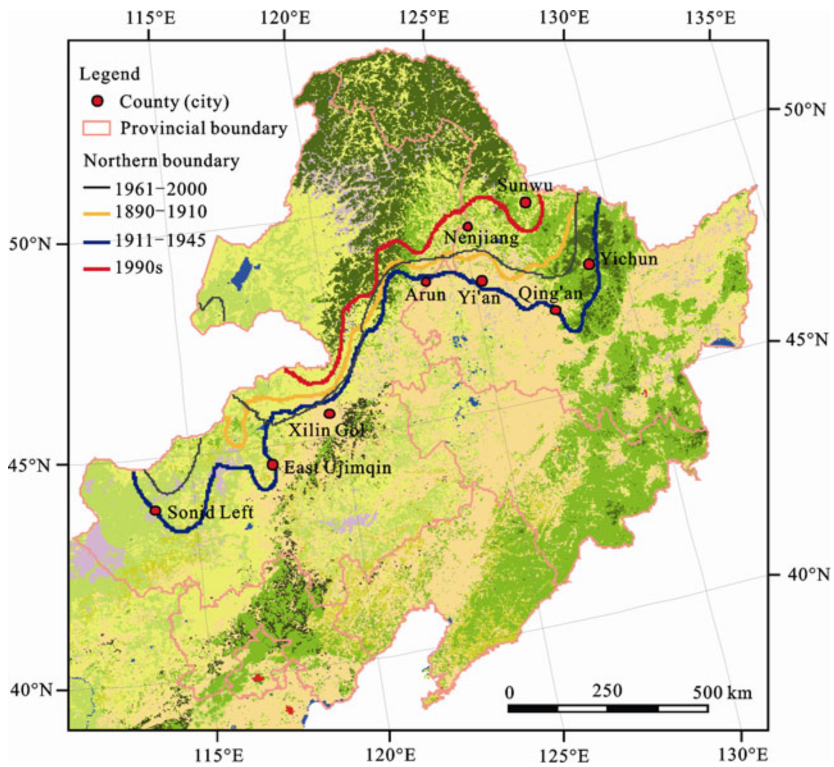

Fig. 6 Temperature change and movement of northern boundary of potential suitable agricultural area in farming-grazing transitional zone in northeastern China

rud Banner, Kailu County, Chifeng City, Duolun County, and Zhangbei County. The eastern boundary was along the line of Nenjiang County, Yi′an County, Zhaodong County, Nong′an County, Shuangliao County, Beipiao City, Longhua County, Fengning County, and Yanqing County (Fig. 7). Compared with the range of the potential suitable agricultural area in the modern farming-grazing transitional zone in the northeastern China, the western and eastern boundaries during the driest period of 1920s–1930s moved northeastward by 250 km and 125 km, respectively. During the extreme drought period, the regions to the southwest of the line of Xilin Gol League, Jarud Banner, Kailu County, Kulun Banner changed into potential agriculturally non-suitable area due to scarcity of precipitation.

In 1890s–1910s and 1940s–1960s, there was abundant rainfall, especially in 1890s–1910s. The range of potential suitable agricultural area moved westward to where the precipitation contour of 315–415 mm or 300–400 mm in 1951–2008 was. It was between two contours of light brown or two contours of dark brown contours. The western boundary was along the line of Manzhouli City, New Barag Left Banner, East Ujimqin Banner, and Xianghuang Banner. The eastern boundary was along the line of Ergun Left Banner, Yakeshi City, Xilin Gol League, Tuquan County, Taonan City, Tongyu County, Tongliao City, Naiman Banner, Harqin Banner, Taibus Banner, and Wanquan County (Fig. 7). Compared with the range of potential suitable agricultural area in the farming-grazing transitional zone in the northeastern China in 1951–2008, the western and eastern boundary moved southwestward by 125 km and 200 km, respectively during the 20th century. During the extreme rainy period, the region to the southwest of the line of Xilin Gol League, Jarud Banner, Kailu County and Kulun Banner changed into potential suitable agricultural area due to abundant rainfall, whereas the region to the northeast of Xilin Gol League, Tuquan County, Tailai County, Tongyu County, Tongliao City changed to agricultural area outside the farming-grazing transitional zone. The southwestern Songnen Plain in the farming-grazing transitional zone in the northeastern China, including Jarud Banner, Tuquan County, Jalaid Banner, Tailai County, Tongyu City and Tongliao City, was the region most sensitive to precipitation.

5 Conclusions

The suitable agricultural area in the farming-grazing transition zone in the northeastern China actually had

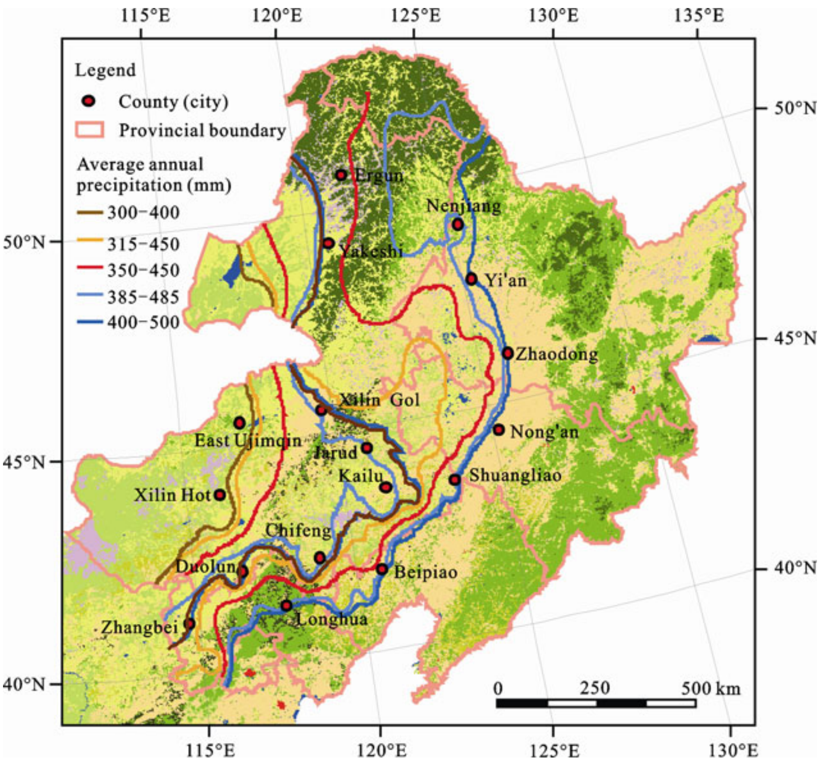

Fig. 7 Precipitation change and movement of western and eastern boundaries of potential suitable agricultural area in eastern farming-grazing transitional zone in northeastern China

climatic thresholds during 1971–2000, which is an average annual temperature above 1℃ or ≥ 0℃ annual accumulated temperature above 2500–2700℃ and an annual precipitation above 350 mm. These results are reasonable and reflect the limited climatic conditions required for agriculture. It also demonstrates the northern boundary of the forest-cropland interwoven zone and the western boundary of the grass-cropland interwoven zone. The highest amplitude of the average annual temperature in the study area during various periods since the start of the 20th century was approximately 1.8℃, and the amplitude of the decadal precipitation fluctuation was approximately within 35–50 mm. It indicates the shift of the boundary of the potential suitable agricultural area based on the limited effect of agricultural climate.

The estimated northern boundary of the potential suitable agricultural area swung south or north with temperature changes, and the range of the swings are approximately 75–100 km. The eastern and western boundaries of the potential suitable agricultural area swung east or west with precipitation changes, and the range of boundary swinging in the rainy and arid periods was approximately 125–250 km. Regions sensitive to temperature change are the Xilin Gol Plateau and the northern Songnen Plain, and the regions sensitive to precipitation change are the southwest of the line of Xilin Gol City, Jarud Banner, Kailu County, and Kulun County.

The above results have practical significance in guiding land use planning, agricultural production and ecological preservation in the study area. The strategy of agricultural land planning and pasture management needs to respect natural rule and consider whether climatic conditions are appropriative. Emphasis should be placed on defending climatically sensitive regions. For example, it is not suitable to extensively exploit the farming-grazing transitional zone in the northeastern China, especially in the Xilin Gol Plateau, in the northern Hebei Province and other such areas. Returning cultivated land to grassland and replacing cropland with pasture should be the main and necessary measure used to restore the environment in these areas.

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