Climatic Change (2014) 124:163–177
DOI 10.1007/s10584-014-1088-1

Has climate change driven spatio-temporal changes of cropland in northern China since the 1970s?

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Received: 9 July 2013 / Accepted: 7 February 2014 / Published online: 2 March 2014

Abstract Improving the understanding of cropland change and its driving factors is a current focus for policy decision-makers in China. The datasets of cropland and cropland changes from the 1970s to the 2000s were used to explore whether climate change has produced spatio-temporal changes to cropland in northern China since the 1970s. Two representative indicators of heat and water resources, which are important determinants of crop growth and productivity, were considered to track climate change, including active accumulated temperatures ≥10 °C (AAT10) and the standardized precipitation evapotranspiration index (SPEI). Our results showed that rapid cropland change has occurred in northern China since the 1970s, and the area of cropland reclamation (10.23 million ha) was much greater than that of abandoned cropland (2.94 million ha). In the 2000s, the area of cropland with AAT10 higher than 3,000 °C·d increased, while the area of cropland with an SPEI greater than 0.25 decreased compared to the 1970s, 1980s and 1990s. It appears that climate warming has provided thermal conditions that have aided rapid cropland reclamation in northern China since the 1970s, and drier climatic conditions did not become a limiting factor for cropland reclamation, especially from the 1990s to the 2000s. Approximately 70 % of cropland reclamation areas were located in warmer but drier regions from the 1990s to the 2000s, and approximately 40 % of cropland abandonment occurred in warmer and wetter conditions that were suitable for agriculture during the periods from the 1970s to the 1980s and the 1990s to the 2000s. Our results suggest that climate change can be considered a driving factor of cropland change in the past several decades in northern China, in addition to socioeconomic factors.

Electronic supplementary material The online version of this article (doi:10.1007/s10584-014-1088-1) contains supplementary material, which is available to authorized users.

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1 Introduction

Cropland is the largest man-made landscape type in China, and cropland changes have a complex linkage not only to climate change and other natural conditions but also to anthropogenic activites, especially government policies and socioeconomic factors. Climate change can substantially affect cropping systems, crop productivity and land use by influencing the temperature and water availability, subsequently causing considerable variability of cropland distribution and food production (Tao et al. 2003, 2009; Dong et al. 2009; Tsegaye et al. 2010; Verburg et al. 2011; Chen et al. 2012; Wang et al. 2012). For example, climate warming has benefited the agriculture of northern China in recent decades because heat is a limiting factor for agriculture (Tao et al. 2008a; Sun and Huang 2011; Chen et al. 2012). During the same period, cropland reclamation has increased rapidly in this region (Liu et al. 2005a, 2010).

Additionally, human activities, especially land use policies at the local scale, cumulatively affect the distributions of cropland at the regional level (Olson et al. 2008; Liu et al. 2011; Peng et al. 2011; Drummond et al. 2012). Therefore, socioeconomic factors are also driving factors of land use change, especially in Northern China. This view is confirmed by Ye et al. (2012) through a land use change analysis for Northeast China over the past 300 years. Liu et al. (2011) also indicated that a series of reforms and changes in land use policies have led to extensive changes in cropland. Our previous study showed that the greatest decline in cropland area in the Huang-Huai-Hai Plain occurred in economically developed metropolises or provinces because of the large areas of urbanization (Shi et al. 2013). China's cropland area has become a key issue because of the limited area of cropland per capita and the country's increasing population. Because of the policy requiring dynamic equilibrium of total cropland area, the climatic and land use change boundaries in the farming-pastoral ecotone of northern China exhibit opposing variations where fragile land has been reclaimed for cropland (Dong et al. 2013).

The farming-pastoral ecotone in northern China is a transitional zone between the arid and semi-arid pastoral grassland in the northwest and the traditional humid intensive cultivation region in the southeast, similar to the transitional climate between the continental and monsoon climate. The land use in this region is very sensitive to climate change, which can cause large variations of precipitation, and the ecological environment is extraordinarily fragile and sensitive to human activity (Tao et al. 2008b). Previous studies have given few descriptions of the contributions of climate change and human activity to cropland change patterns in different time periods.

In this study, we chose the farming-pastoral ecotone region to map and provide a further understanding of the response patterns of the responses of cropland changes to climate change in northern China since the 1970s. The objectives of our study were i) to describe the spatio-temporal distributions of cropland changes in northern China from the 1970s to the 2000s in relation to the distributions of annual active accumulated temperatures ≥10 °C (AAT10) and the standardized precipitation evapotranspiration index (SPEI) in the growing seasons; ii) to analyze the relationship between cropland change and climate change since the 1970s; and iii) to explore the effects of climate change and human influence on spatio-temporal changes to cropland.

2 Data and methods

2.1 Study area

The study area included the ten provinces (or autonomous regions, or metropolises) of Heilongjiang, Jilin, Liaoning, Inner Mongolia, Hebei, Beijing, Shanxi, Shaanxi, Ningxia and

Gansu (Fig. S1 in Supplementary Material). The study area lies between 92°20′–135°05′E and 31°43′–53°34′N. The annual average temperature (1970–2008) varied gradually from −5.4 °C in the northeast to 18.6 °C in the southwest. The average annual precipitation (1970–2008) varied from 34 mm in the northwest to 1,050 mm in the southeast. The elevation increases from lower than 200 m on the Northeast Plain and the North China Plain to higher than 3,000 m on the Qilian Mountain in west Gansu. The land use types of the study area are mainly cropland, grassland and woodland.

2.2 Data

2.2.1 Meteorological data

Daily temperature data from 197 national standard meteorological stations in northern China (1970–2008) were obtained from the homogenized national daily mean temperature series datasets for China using the Multiple Analysis of Series for Homogenization (MASH) software package (Li and Yan 2009) (Fig. S1 in Supplementary Material). The serial temperature data were adjusted to remove biases caused by changes in the observation time, instrument changes, and the movement of weather stations. Precipitation data from 197 national standard stations from 1970 to 2008 were obtained from the Data and Information Center of the China Meteorological Administration.

2.2.2 Cropland and cropland change data

Data for the spatial distributions of cropland across northern China in the 1970s (1972–1979), 1980s (1987–1990), 1990s (1999–2000) and 2000s (2004–2006) and cropland changes from the 1970s to 1980s, the 1980s to 1990s and the 1990s to 2000s are taken from the National Land-Use/Land-Cover datasets (NLCD) generated in the second nationwide land cover and land use classification project (Liu et al. 2003, 2005a, 2010). These datasets were produced using the visual interpretation primarily from Landsat TM/ETM/MSS images, with CBERS-1 and CBERS-2 images as a supplement for the areas not covered by Landsat. The details on the production of datasets and the protocol and quality assessment or the quality control for accuracy have been clearly described in previous literatures and the Supplementary Material (Liu et al. 2003, 2005a, b, c, 2010). Land use was classified into 6 main types (i.e., cropland, woodland, grassland, water body, built-up area, and unused land) and 25 sub-types. To evaluate the classification accuracy, a series of intensive field surveys were conducted (Table S1 in Supplementary Material). The survey for each period included more than 10 % of the counties in China, and the patches in 3 or 4 sample lines for each county were investigated. The accuracies for the cropland datasets were greater than 97 % for all time periods (Liu et al. 2005c; Zhang et al. 2012). A 1 km area-percentage data model developed by Liu et al. (2003, 2005a, 2010) was used to detect and represent cropland distribution and its change on a 1 km×1 km grid scale.

2.3 Methods

2.3.1 Calculations of the AAT10 and the SPEI

The AAT10 values of 197 national meteorological stations in northern China were calculated using a five-day moving average method to sum the daily mean temperatures and determine whether the average was greater than or equal to 10 °C based on the equation (1).

$$AAT10 = \sum_{i=1}^{n} \overline{T}_i \quad \overline{T} \geq 10 \tag{1}$$

where $\overline{T_i}$ is the average temperature on day i, and n is equal to the number of days in the given year. We calculated the average AAT10 at each station for four time periods: 1970 to 1979 (1970s), 1980 to 1989 (1980s), 1990 to 1999 (1990s) and 2000 to 2008 (2000s).

The SPEI for the main growing season (from May to October) over northern China was used as a climatic drought index. To calculate the SPEI, we used the precipitation and temperature data described in Section 2.2.1. The SPEI calculation is based on the monthly difference between the precipitation and the potential evapotranspiration (PET). The detailed calculation information for the SPEI can be found in Vicente-Serrano et al. (2010a, b). According to the calculation, the SPEI is a standardized variable, and an SPEI of 0 indicates a value corresponding to a 50 % cumulative probability of drought.

2.3.2 Trend analysis

An ordinary linear regression was used to detect the rates of change of both the AAT10 and the SPEI for each station. The trends that occurred on a pixel basis were calculated using the slope of the linear trends and were expressed on a decadal scale. All data analyses were carried out by Matlab version 7.1. The spatial distributions of the AAT10 and the SPEI and their linear trends were interpolated by ANUSPLINE version 4.2 and mapped by ArcGIS version 9.3.

2.3.3 Change analysis of the AAT10 and the SPEI in cropland change regions

The AAT10 (or SPEI) change characteristics for cropland change areas were quantitatively compared using a raster calculation and zonal statistics in ArcGIS 9.3. The changes of the AAT10 (or SPEI) for each grid from the 1970s to 1980s, the 1980s to 1990s and the 1990s to 2000s were calculated by subtracting the AAT10 (or SPEI) in the latter period from the prior period.

3 Results

3.1 Spatio-temporal distributions of cropland and cropland change in northern China

The distributions of cropland and cropland change in northern China are depicted in Fig. 1. It is clear that most of the cropland is distributed on the Northeast Plain, the North China Plain and the alluvial plain to the south and southeast of the Yellow River Basin. Cropland in northern China experienced a substantial increase from the 1970s to the 2000s (Table S2 in Supplementary Material), especially in Northeast China (Figs. 1b, d and f). In total, the increase of cropland area (10.23 million ha) was much greater than the decrease (2.94 million ha) in this period. A rapid cropland growth of 3.87 million ha occurred from the 1970s to the 1980s (Fig. 1b), and a further 5.46 million ha growth occurred from the 1980s to the 1990s (Fig. 1d). Cropland area decreases occurred from the 1980s to the 1990s (Fig. 1d) and the 1990s to the 2000s (Fig. 1f), with decreases of 1.39 million ha and 1.09 million ha, respectively. Increases of cropland mainly occurred in Northeast China and eastern Inner Mongolia, while cropland mainly decreased in North China and Northwest China (Figs. 1b, d and f). The largest area of cropland increases was converted from grassland in northern China

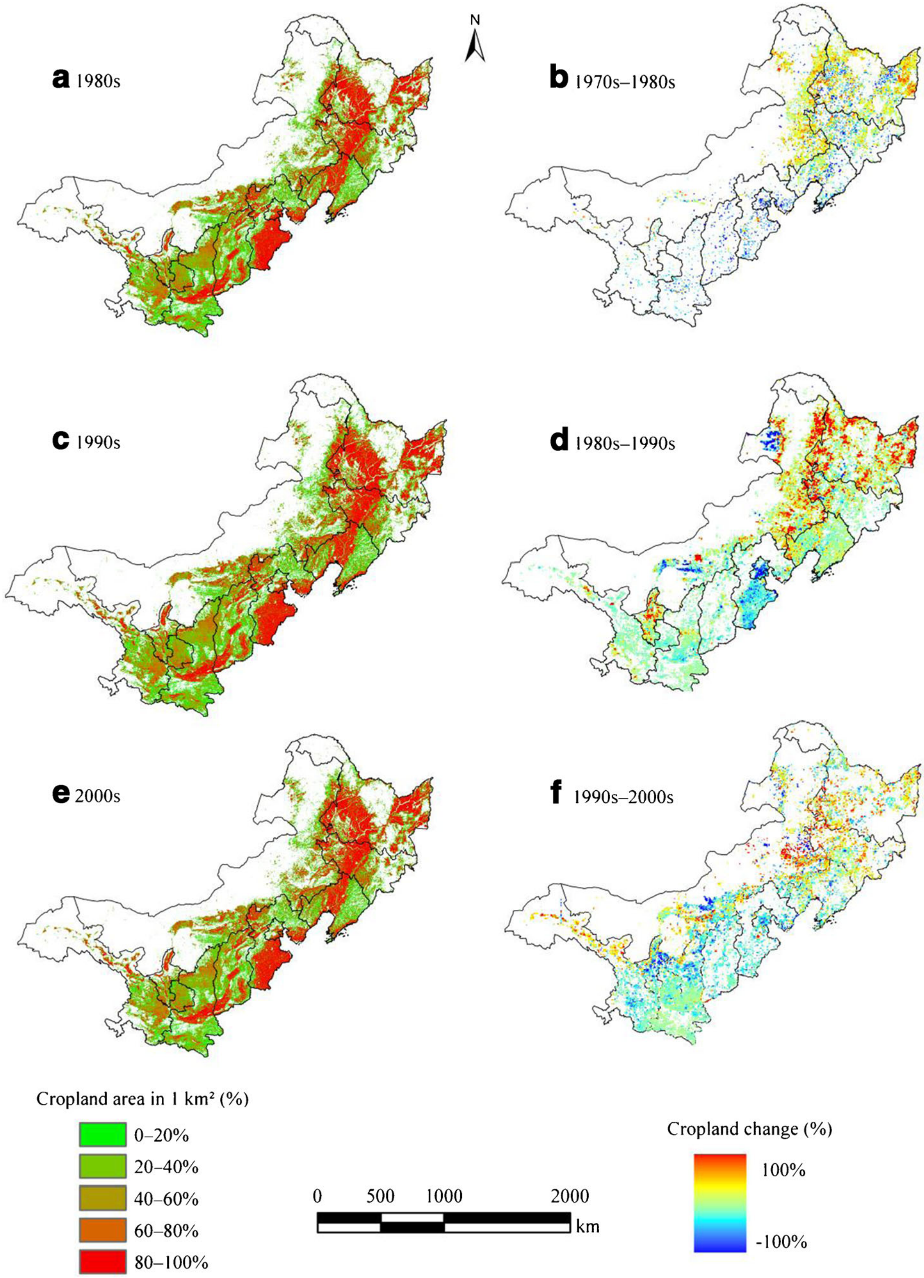

Fig. 1 Spatial distributions of cropland in the **a**) 1980s, **c**) 1990s and **e**) 2000s, and cropland changes from **b**) the 1970s to the 1980s, **d**) the 1980s to the 1990s and **f**) the 1990s to the 2000s in northern China

from the 1970s to the 2000s (Table S2 in Supplementary Material). The conversion from grassland to cropland involved 5.41 million ha in total over the three time periods, and was greater than the cropland reclaimed from other land use types. The areas of cropland converted from woodland constituted approximately one quarter of the increase in cropland area, mainly from the 1970s to the 1990s. However, the cropland decrease exhibited a different pattern. One third of the cropland decrease (1.04 million ha) was the result of the conversion to grassland mainly from the 1980s to the 2000s, and another third of the area of cropland decrease (1.06 million ha) was converted to built-up land mainly from the 1970s to the 1990s.

3.2 Spatio-temporal distributions of the AAT10, the SPEI and their changes in northern China

3.2.1 The AAT10

Overall, the regions with higher AAT10 were located in the North China Plain, southwestern Shanxi and southern Shaanxi (Figs. 2a and c). In contrast, the AAT10 showed clearly lower values in northern Heilongjiang, northern Inner Mongolia and western Gansu for both time periods. Decadal trends of the AAT10 from the 1970s to the 2000s increased across almost all of northern China (Fig. 2e). The average trend for the increase of AAT10 across all of northern China was approximately 106.2 °C·d/decade since 1970, and the range of this increase was from 21.4 to 155.2 °C·d/decade. The highest warming trends were in the southern Hebei Province, central and western Inner Mongolia, and the northwestern Gansu Province.

3.2.2 The SPEI

In the 1970s, most parts of northern China were wet, with SPEI values greater than zero, except in Heilongjiang, Jilin and a small part of Shaanxi Province (Fig. 2b). The wet conditions changed to dry conditions in the 2000s in most areas of Inner Mongolia, Northeast China, Hebei Province and northern Gansu Province (Fig. 2d). The decadal trends of the SPEI varied from −0.321 to 0.133 across all of northern China from the 1970s to the 2000s, and the average SPEI over the entire study area decreased by 0.029 per decade after 1970 (Fig. 2f). Decadal trends of the SPEI were less than zero in northeastern Inner Mongolia, northwestern Gansu Province and some parts of Liaoning and Hebei Provinces. These trends indicate that these areas became progressively drier from the 1970s to the 2000s.

3.3 The cropland distribution of different classes of the AAT10 and the SPEI

More than 90 % of croplands in northern China were located in regions with AAT10 greater than 2,000 °C·d (Fig. 3a). Nearly 60 % of the regions with AAT10 from 2,000 to 3,000 °C·d (Fig. 3a) were located in Northeast China (Figs. 2a and c), and more than 20 % with AAT10 from 3,000 to 4,000 °C·d (Fig. 3a) were located in central Liaoning, eastern Hebei and central and northern Shanxi (Figs. 2a and c). Approximately 10 % of the cropland areas that had AAT10 greater than 4,000 °C·d (Fig. 3a) were located in the North China Plain and the alluvial plain to the south and southeast of the Yellow River Basin (Figs. 2a and c). More croplands had AAT10 over 3,000 °C·d in the 2000s than in the other three time periods because the AAT10 increased from 1970 to 2008 (Fig. 2e).

The SPEI distributions in the cropland area were unimodal, varying from −0.75 to 0.75, with the most frequent occurrence from 0 to 0.25 (Fig. 3b). Approximately 60 % of the cropland area in northern China had SPEI values greater than zero (Fig. 3b). These areas were located mostly in regions above 40°N latitude (Figs. 2b and d). The other 40 % of cropland areas with SPEI values less than zero (Fig. 2b) were mostly located in regions below 40°N latitude (Figs. 2b and d). Cropland areas, located in central Heilongjiang, western Liaoning,

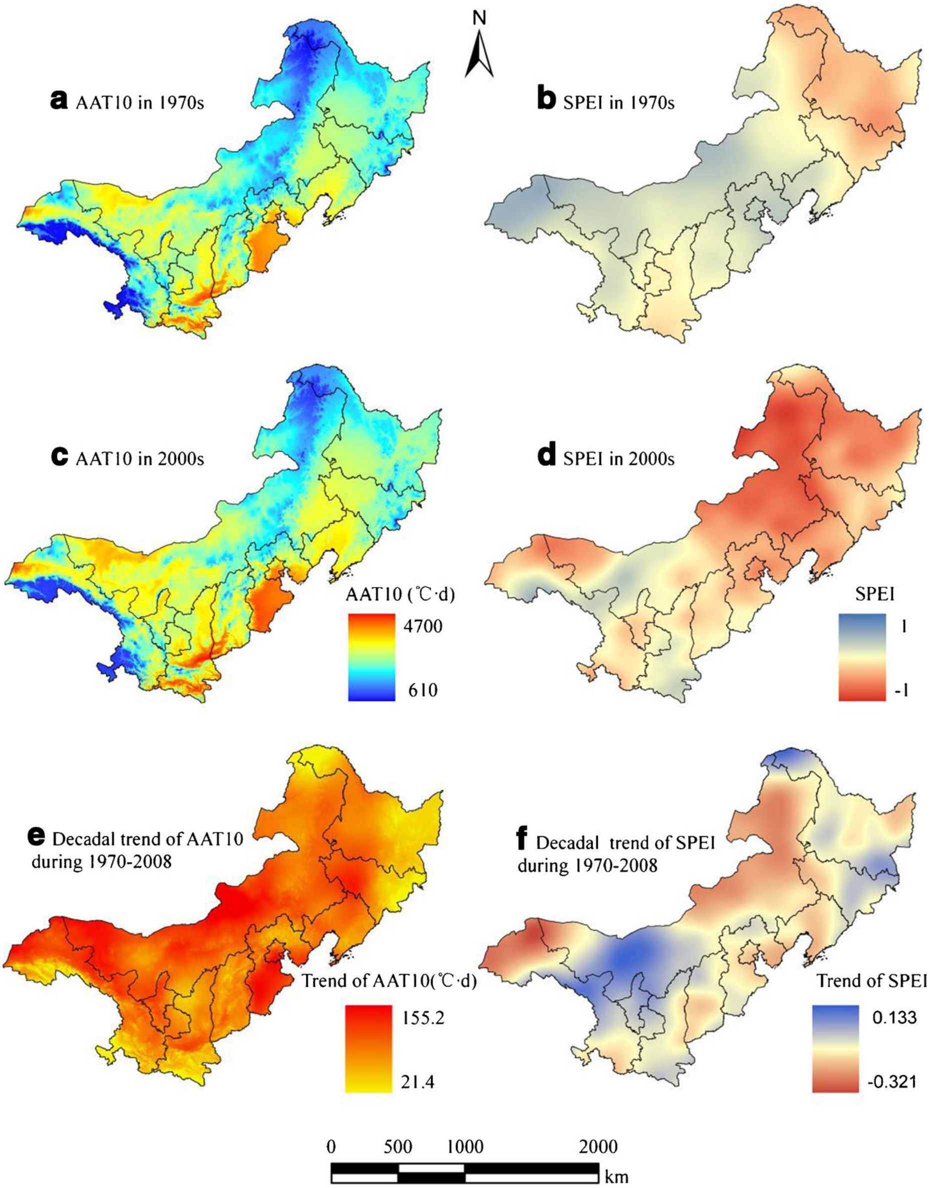

Fig. 2 Spatial distributions of the active accumulated temperatures ≥10 °C (AAT10) and the standardized precipitation evapotranspiration index (SPEI) in the 1970s and the 2000s, and the decadal trends from 1970 to 2008 in northern China

eastern Inner Mongolia and northern Hebei, which had SPEI values greater than 0.25 were wetter than the other cropland areas. In the 2000s, croplands located in regions with SPEI values greater than 0.25 decreased to the other three time periods because the decadal trends of the SPEI in northern China during 1970–2008 were less than zero as opposed to western Inner Mongolia and northern Gansu (Fig. 2e).

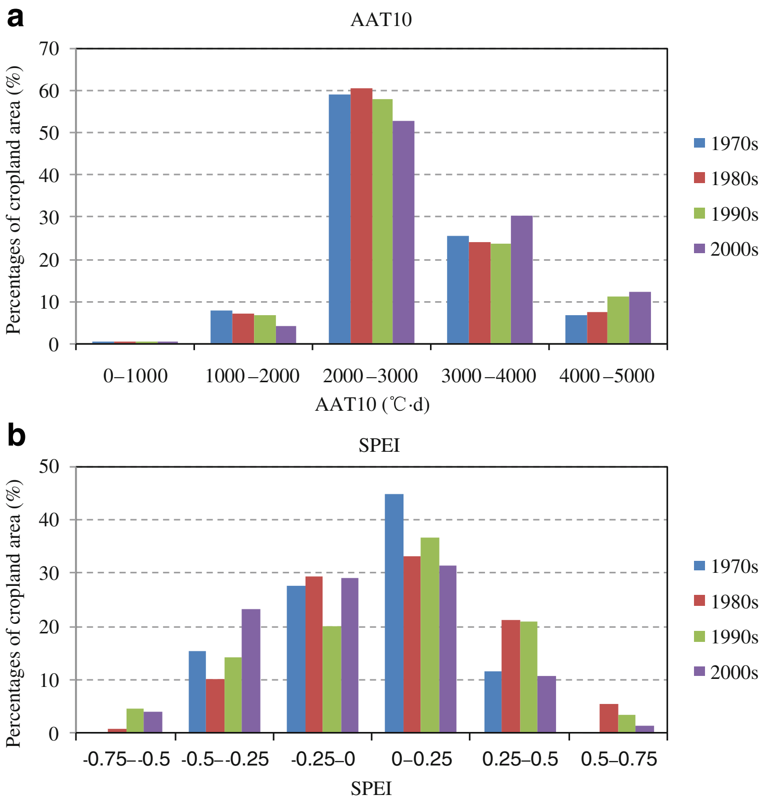

Fig. 3 Cropland area percentages in different classes of a) the AAT10 and b) the SPEI in the 1970s, 1980s, 1990s and 2000s

3.4 Spatio-temporal changes of the AAT10 and the SPEI in cropland change regions

3.4.1 Cropland reclamation

We found that increasing AAT10 values were associated with increased land reclamation from the 1970s to the 1980s, the 1980s to the 1990s and the 1990s to the 2000s (Figs. 4a, b and c), and decreasing SPEI values were not a limiting factor for cropland reclamation in those periods, especially in Northeast China from the 1990s to the 2000s (Figs. 4g, h and i).

From the 1970s to the 1980s, more than three quarters of reclamation lands occurred in regions where the AAT10 increased (2.94 million ha with an AAT10 increase of 0–100 °C·d and 0.01 million ha with an AAT10 increase of 100–200 °C·d), and less than one quarter of reclamation lands were in regions where the AAT10 decreased (0.91 million ha with an AAT 10 decrease of −100–0 °C·d) (Table S3 in Supplementary Material). The regions with an AAT10 decrease of −100–0 °C·d that were reclaimed for cropland from the 1970s to the 1980s were located mostly east of the Songhua River, where soils were suitable for cropping. From the 1980s to the 1990s and the 1990s to the 2000s, almost all cropland reclamation (99.2 % and 100.0 %, respectively) took place in the regions where the AAT10 increased. There were different patterns, however, between the two periods. Reclamation in the prior period mainly occurred in the regions where the AAT10 increased by 0–100 °C·d (4.52 million ha) and 100–

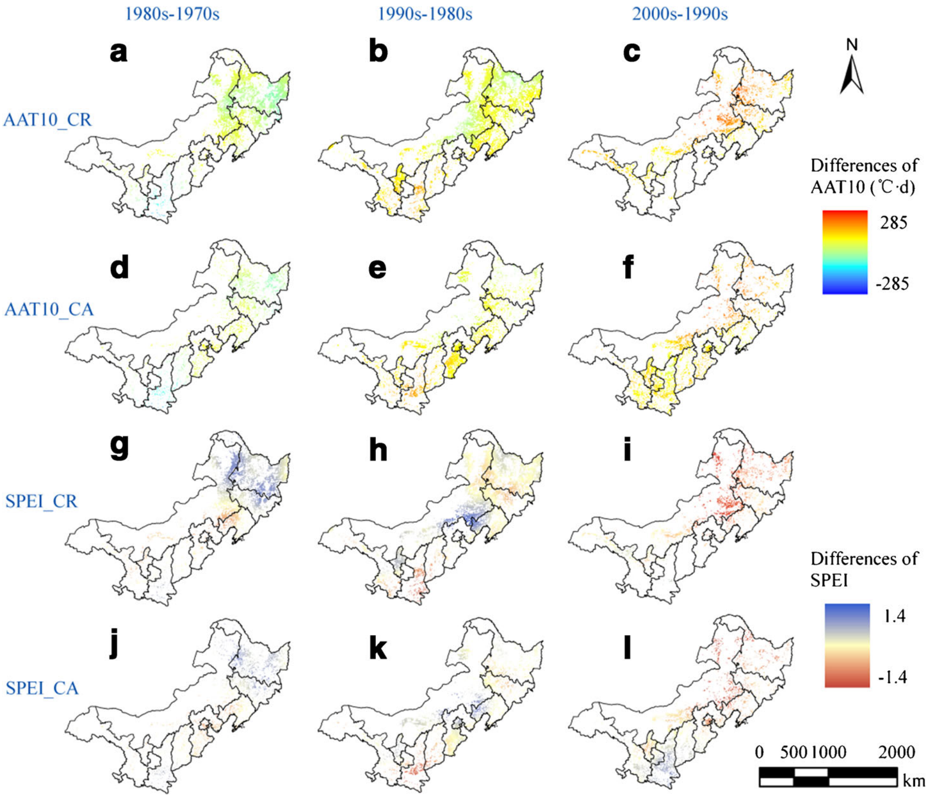

Fig. 4 Distributions of the changes of the AAT10 and the SPEI in cropland change regions in northern China from the 1970s to 1980s, the 1980s to the 1990s and the 1990s to the 2000s. CR and CA represent cropland reclamation regions and abandonment regions, respectively. **a**), **b**) and **c**) show the distributions of AAT10 changes in cropland reclamation regions; **d**), **e**) and **f**) show the distributions of AAT10 changes in cropland abandonment regions; **g**), **h**) and **i**) show the distributions of the SPEI changes in the cropland reclamation regions; **j**), **k**) and l) show the distributions of the SPEI changes in the cropland abandonment regions

200 °C·d (0.89 million ha) (Table S3 in Supplementary Material and Fig. 4b), but reclamation during the latter period mainly occurred in the regions with more warming, where the AAT10 increased by 100–200 °C·d (0.64 million ha) and 200–300 °C·d (0.19million ha) (Table S3 in Supplementary Material and Fig. 4c).

From the 1970s to the 1980s, 87.1 % (3.37 million ha) of cropland reclamation areas were located in areas where the SPEI increased by 0–0.5 and >0.5. Most of these areas were in Northeast China. However, a small proportion of land reclamation occurred in the Liao River drainage basin, where the SPEI decreased in this time period, but irrigation was intensely applied there (Table S3 in Supplementary Material and Fig. 4g). From the 1980s to the 1990s, 65.9 % of cropland reclamation occurred in areas where the SPEI increased by 0–0.5 (3112.85 thousand ha) and >0.5 (481.78 thousand ha), while 34.1 % of cropland reclamation (1856.46 thousand ha) occurred in areas where the SPEI decreased by −0.5–0 (1757.71 thousand ha), −1.0–−0.5 (76.56 thousand ha) and <−1.0 (22.19 thousand ha) (Table S3 in Supplementary Material and Fig. 4h). In this period, cropland reclamation with decreasing SPEI values was mainly located in Northwest and Northeast China (Fig. 4h). However, with the warming trend of the AAT10 (Fig. 2e), there were increasing percentages of cropland reclamation in drier areas (87.0 % of reclamation lands with a decreasing SPEI) than in wetter areas (13.0 % of reclamation lands with an increasing SPEI) from the 1990s to the 2000s (Table S3 in Supplementary Material and Fig. 4i).

3.4.2 Cropland abandonment

The increasing AAT10 occurred in most cropland abandonment areas from the 1980s to the 1990s and the 1990s to the 2000s (Figs. 4e and f), but not for the 1970s to the 1980s (Fig. 4d). This phenomenon occurred because the AAT10 trends were warming in northern China during the time of the study (Fig. 2e). Decreasing SPEI values occurred in areas where there was cropland abandonment in the three time periods (Figs. 4j, k and l), except in Northeast China from the 1970s to the 1980s (Fig. 4j), North China from the 1980s to the 1990s (Fig. 4k) and Northwest China from the 1990s to the 2000s (Fig. 4l).

Figures 4d, e and f show that, from the 1970s to the 1980s, cropland abandonment mainly occurred in areas where the AAT10 increased by 0–100 °C·d (0.34 million ha) and decreased by −100–0 °C·d (0.11 million ha) (Table S3 in Supplementary Material). There were 0.98 and 0.41 million ha of cropland abandonment that occurred in areas with AAT10 changes of 0–100 °C·d and 100–200 °C·d from the 1980s to the 1990s (Table S3 in Supplementary Material). Moreover, from the 1990s to the 2000s, most cropland abandonment occurred in areas with AAT10 increases by 100–200 °C·d (0.70 million ha) and 0–100 °C·d (0.32 million ha) (Table S3 in Supplementary Material).

From the 1970s to the 1980s, cropland abandonment occurred not only in the wetter areas where the SPEI increased, representing 298.44 thousand ha (accounting for 64.7 % of abandoned cropland area), but also in drier regions mostly located in Northeast China, where the SPEI decreased, representing 0.16 million ha (accounting for 35.3 % of abandoned cropland area) (Fig. 4j and Table S3 in Supplementary Material). From the 1980s to the 1990s, cropland abandonment mainly occurred in areas with SPEI changes of 0–0.5 (0.87 million ha) and in areas with SPEI changes of −0.5–0 (0.34 million ha). These areas were mostly located in North China (Fig. 4h and Table S3 in Supplementary Material). From the 1990s to the 2000s, the area of cropland abandonment with wetter conditions (0.41 million ha) was less than the area with drier conditions (0.68 million ha), and was mostly located in West China (Fig. 4l and Table S3 in Supplementary Material).

4 Discussion

4.1 Effects of climate change on cropland change

The results of this study showed that land reclamation mainly occurred in Northeast China and eastern Inner Mongolia, while cropland abandonment has mainly occurred in North China and Northwest China since the 1970s. Ye and Fang (2012) found similar patterns for the farming-pastoral ecotone in northern China. Their study showed that the farming-pastoral ecotone moved northwestward from 1980 to 2000, and they also found that climate change had been favorable for the forward movement of the northern boundary of farmland in Northeast China over the past 300 years (Ye et al. 2012). To investigate the effects of climate change on cropland change, we overlapped the distributions of AAT10 and SPEI changes with cropland changes since the 1970s and statistically examined the climate condition changes in areas of cropland reclamation and abandonment (Fig. 5). We defined warmer (or wetter) areas as those exhibiting AAT10 (or SPEI) differences between the latter period and the prior period greater

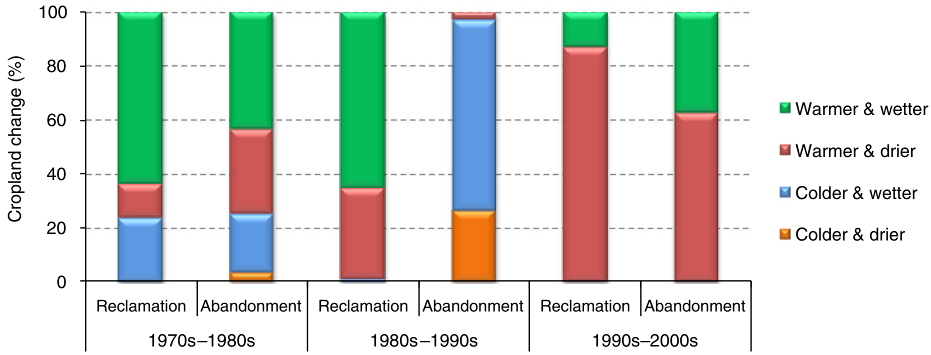

Fig. 5 Cropland change with different trends of the AAT10 (colder and warmer) and the SPEI (drier and wetter) from the 1970s to 1980s, the 1980s to the 1990s and the 1990s to the 2000s in northern China

than 0 °C·d (or 0). By these definitions, climate change was considered to be a driving factor of cropland reclamation and abandonment in northern China. For example, areas that became warmer and wetter from the 1970s to the 2000s were considered to be more suitable for cropland reclamation, whereas cropland in areas that became colder and drier were more likely to be abandoned. As a further consideration, areas in northern China were not considered for conversion to cropland from the 1970s to the 2000s because they were colder and drier than the areas analyzed in this study.

4.1.1 Cropland reclamation

The increasing AAT10 since the 1970s provided thermal conditions that supported cropland reclamation (warmer with green and red bars for reclamation in Fig. 5). From the 1970s to the 1980s and the 1980s to the 1990s, more than 60 % of cropland reclamation was located in warmer and wetter regions (green bars for reclamation in Fig. 5). From the 1990s to the 2000s, however, approximately 70 % of cropland reclamation occurred in warmer but drier regions (red bar for reclamation from the 1990s to the 2000s). These results indicate that most cropland reclamation from the 1970s to the 1990s occurred in improving climatic conditions with increased temperatures and more rainfall. Drier conditions did not become a limiting factor for cropland reclamation from the 1990s to the 2000s. Chen et al. (2012) predicted that the present cropping boundaries could be theoretically extended northward by approximately 80 km with the annual growing period extended by 10 days compared to the 1970s in Northeast China. Dong et al. (2009) also showed that changes in the AAT10 since the late 1980s had large influences on cultivated land area and cropping systems, especially in eastern Inner Mongolia and in western Liaoning and Jilin Provinces. In the western part of northern China, results similar to ours have also been observed. Wang et al. (2012) found an increase in cropland suitability in this region, with higher AAT10 and a lower aridity index.

4.1.2 Cropland abandonment

Our results indicated that 43.3 % of cropland abandonment occurred in areas with warmer and wetter conditions, which were suitable for cropping from the 1970s to the 1980s (green bar for abandonment from the 1970s to the 1980s in Fig. 5), but this phenomenon disappeared from the 1980s to the 1990s. From the 1980s to the 1990s, 26.3 % of the cropland abandonment area occurred in regions with worsening climate conditions that became colder and drier (orange bar for abandonment from the 1980s to the 1990s in Fig. 5). This result suggests that cropland abandonment in this area may have been influenced by climate conditions. From the 1990s to the 2000s, almost all areas of cropland abandonment were warmer and wetter (green bar for abandonment) or warmer and drier (red bar for abandonment in Fig. 5). This phenomenon may have been caused by the warming climate trends that occurred across northern China. However, we also noted that nearly 40 % of cropland abandonment areas were located in warmer and wetter regions from the 1990s to the 2000s (green bars for abandonment in Fig. 5).

4.2 Effects of policies on cropland changes

Government policy has been one of the key driving forces for cropland changes in northern China. In our study, some cropland abandonment occurred in warmer and wetter conditions from both the 1970s to the 1980s and the 1990s to the 2000s (green bars for abandonment), which suggests that there were other non-climate factors that influenced cropland conversions in northern China. We extracted the spatial distributions of cropland abandonment regions with warmer and drier climate conditions from the 1970s to the 1980s and the 1990s to the 2000s (green bars for abandonment from the 1970s to the 1980s and the 1990s to the 2000s, Fig. 5), and calculated the conversion area of cropland to other types of land, including woodland, grassland, water body, built-up land and unused land (Fig. 6). From the 1970s to the 1980s, nearly 90 % of the converted croplands changed to built-up land, showing that rapid urbanization was the most significant reason for cropland abandonment across northern China. In contrast, from the 1990s to the 2000s, the conversion of cropland was more diverse, e.g., to grassland (45.64 %), woodland (26.14 %) and built-up land (22.52 %). Deliberate human activity was the dominant factor that drove these conversions particularly to built-up land for urbanization. First, rapid economic development and population growth since the Reform and Opening-up policy began at the end of 1970s promoted economic development and urbanization. Policies such as the Development of Western China and Revitalization of Northeast China further accelerated urbanization after the year 2000 (Liu et al. 2010; Wang et al. 2012). These phenomena can reasonably explain the large areas of conversion from cropland to built-up land, even though the climatic conditions for crops had been improving since the 1970s.

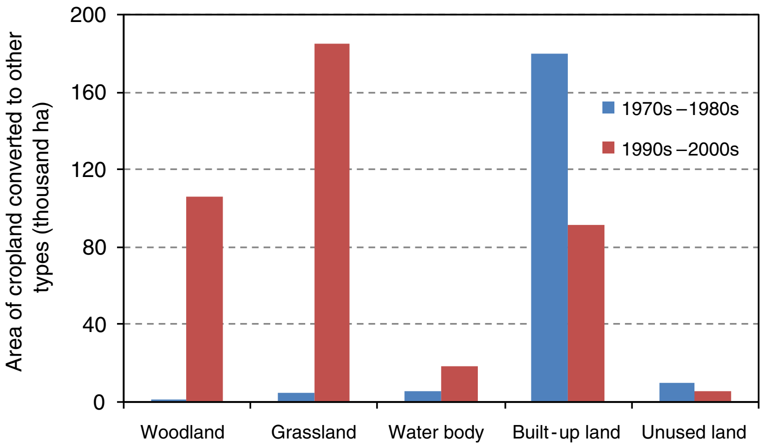

Fig. 6 Conversion area of cropland to other land types with warmer and wetter climatic conditions from the 1970s to the 1980s and the 1990s to the 2000s

Second, the Grain for Green project, implemented in 1999, encouraged cropland shrinkage by ecological restoration in hilly areas with a slope greater than 25°, especially in North China and the farming-grazing transitional zone of the Loess Plateau (Liu et al. 2010). This policy directed that terrain that is unsuitable for cropping should be converted to woodland or grassland for ecological restoration.

Local government policies and local human decisions also affect cropland patterns in some regions in northern China. Approximately 37 % of farmers in Shaanxi Province plan to recultivate converted land when the government subsidy payments end (Cao et al. 2009). Additionally, when the water demand of the large scale afforestation programs in northwest China increases the cost of irrigation, the cultivation of water demanding cash crops will increase (Sjögersten et al. 2013). In some villages of Shaanxi Province, the 'one village, one crop' policy has largely led to a monoculture approach to cropland use with the industrialized operation of agriculture (Sjögersten et al. 2013).

4.3 The response of cropland changes to the interaction of climate change and human activities

Complex driving forces, including climate change and human activities, influence the pattern of cropland change in northern China. We analyzed the overlapping conditions of the spatio-temporal cropland change and climate change data for three recent decades using spatial analysis, and we qualitatively showed the interactions of climate change and human activities. More quantitative research should be conducted for a further understanding of the driving forces of cropland change patterns. Northern China includes the largest farming-pastoral ecotone of China, and the spatial pattern of the farming-pastoral ecotone boundary always changes as a result of climate change and human activities (Dong et al. 2013). Competition over land between farmers and herders can be simulated by models such as the land transformation model (Olson et al. 2008). Further modeling work should be performed to investigate the response of cropland changes to the interaction of climate change and human activities. In addition, we have not considered the changes related to the inner structure of cropland in northern China. For example, climate warming and drying have changed crops from wheat to maize because maize is more drought tolerant than wheat in Northeast China. Moreover, human factors, such as changing food consumption patterns due to urbanization, can also alter the cropland distribution in northern China (Li et al. 2013).

5 Conclusions

Based on the NLCD data and observational data from meteorological stations, we analyzed whether cropland reclamation occurred in regions that had improved suitability because of climate change in northern China after the 1970s. Moreover, we explored whether cropland abandonment occurred in these increasingly suitable regions because of human activities. In general, climate warming has provided thermal conditions that aided rapid cropland reclamation in northern China since the 1970s, and drier climatic conditions did not become a limiting factor for cropland reclamation, especially from the 1990s to the 2000s. Even in areas with colder trends, cropland reclamation took place where the soil is especially fertile, for example, east of the Songhua River. Increasing SPEI values occurred in some cropland abandonment regions in Northeast China from the 1970s to the 1980s, North China from the 1980s to the 1990s and Northwest China from the 1990s to the 2000s and were largely driven by the conversion of cropland to urban and industrial land use caused by population growth and economic development policies.

Northern China, one of China's major agricultural regions, is an area of major concern for understanding the linkages between cropland use, climate change and government policies. Increasing cropland area combined with a drier climate places the agriculture system under increasing limitations and threats. Adaptation measures, such as irrigation, should be applied more extensively in northern China for the sustainable development of agriculture. The interactions among cropland change, climate change and policies are complicated and must be studied in a systemic and holistic view.

Acknowledgments This study was supported by the "Strategic Priority Research Program" of the Chinese Academy of Sciences, Climate Change: Carbon Budget and Relevant Issues, Grant No. XDA05090310, the National Natural Science Foundation of China (No. 41371002), the National Program on Key Basic Research Project (Project No. 2010CB950902 and 2014CB954302), and the State Key Laboratory of Resources and Environmental Information System. We gratefully acknowledge Prof. Warwick Harris (Landcare Research, New Zealand), the two anonymous reviewers and the editor for their insightful comments, suggestions and language revisions.

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