



The Impact of Climate Change on Yield Potential of Maize across China

X. Xu^a, L. Wang^{a,b}, D. Sun^{c,*}, L. Liu^a, K.E. Banson^{c,d}

^aState Key Laboratory of Resources and Environmental Information Systems, Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China.

^bUniversity of Chinese Academy of Sciences, Beijing 100049, China.

^cThe University of Adelaide Business School, Adelaide, Australia.

^dThe Socio-economic and Commercialisation Unit, Biotechnology and Nuclear Agriculture Research Institute, Ghana Atomic Energy Commission, Box LG80, Legon, Accra-Ghana.

*Corresponding author. E-mail: daowei.sun@adelaide.edu.au

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Abstract

Maize is one of the major crops in China and its yield potential has been changed significantly by climate change induction during last five decades. The national policy of maize production sufficiency emphasizes the necessity for a more accurate estimation of yield potential of maize at a national level. In this paper yield potential of maize was calculated using the Global Agro-Ecological Zones (GAEZ) model and key meteorological factors impact on yield potential across China was also analyzed. The results shows that, total yield potential of maize increased by 0.15 million tons/year during the past five decades due to an increase in cultivated area as a result of climate change impact. The partial correlation analysis between main meteorological factors and yield potential of maize at a county level showed that 47% of the counties of China were predominately influenced by changes in solar radiation while 16% of counties were predominately affected by temperature changes. In addition, each agricultural zone showed clear spatial difference in the distribution of key impact factors. These research findings will not only provide scientific basis for making good use of meteorological resources under climate change, but also play a vital role for the management of national maize production for food security.

Keywords: Climate change; Maize; Yield potential; GAEZ model; Maize production; Cropping Pattern.

Introduction

Global warming has been a major trend of climate change (Roshan and Grab, 2012). At the global scale, the air temperature on earth has been rising at an average 0.13 °C per decade since 1950 (IPOC, 2007). It is believed that in the next two or three decades the temperature on earth will increase to an average rising rate of 0.2 °C per decade (Mi et al., 2012; Solomon, 2007). Climate change influences the agricultural environment, which affects both cropping patterns and crop yield potential (Gustafson et al., 2014a; Muhire et al., 2015; Urban et al., 2012; Zhong et al., 2012). Changing cropping patterns and associated yield potentials pose threats to both regional and world food securities (Gustafson et al., 2014b; Meza et al., 2008; Sarker et al., 2012; Wang et al., 2015). Climate change impacts add to the already severe plight of food production in China considering that more than 1.3 billion people are living on an arable land that

is less than half of the world's average (Godfray et al., 2010; Jiang et al., 2015). Meeting challenges of climate change on food security necessitate the need for more adaptive agricultural management. This involves a more accurate calculation of yield potential of different crops at the national level (Magrin et al., 2005).

As one of the major grain crops in China and the world, maize is not only an important staple for many people but also a major source of livestock feed and bio-fuel (Azizian et al., 2015; Gustafson et al., 2014b). China is the second largest maize producer after the United States of America (Meng, 2006). With the rapid improvement in the quality of life of the Chinese people, the demand for maize consumption has been increasing (Tao et al., 2015). The Chinese government has implemented a self-sufficiency national policy on maize production as a pathway to achieve national food security (Zhang, 2013). As a result of this, the last three decades have seen rapid increases in maize production through seed improvements, changed cultivation regimes, expanding planting areas and improved crop management practices (Ge et al., 2015; He and Zhou, 2012; Zhao et al., 2015b; Zhong et al., 2012).

During the last two decades, researchers have conducted various studies on how climate change is affecting crop production in China and around the world (Blanc and Sultan, 2015; Daccache et al., 2015; Kumar et al., 2015). For instance, a research conducted by Zhang et al. (1995) in the Loess Plateau area showed that yield capacity of maize production declined from 1960 to 1980 due to decreased temperatures. Other studies found that the climate change affected not only the cropping patterns, but also the climatic suitability of spring maize in Northeast China (Lv et al., 2015; Wreford and Adger, 2010; Zhao et al., 2015a; Zhao et al., 2015b). From 1978 to 2010, the northern cropping boundaries expanded northward and eastward and the yield of spring maize increased significantly. The key meteorological factors limiting the climate-induced yield were temperature, precipitation and sunshine, which vary in the different regions. Another research study conducted in the Heilongjiang province revealed that maize yield potential was increasing, however fluctuating in yield potential due to the impact of other climate factors in the region (Wang et al., 2012). In contrast, research on maize yield potential in both Northeast and Southwest China, projected that impacts of climate change on maize production by 2030 would decrease (Li et al., 2014). However, maize yield potential in Southwest China is more likely to increase and the increase in Southwest China can offset that of the decrease in Northeast China (Li et al., 2014). Also, there was research conducted on China's maize yield potential taking into consideration the fertilization effect of CO₂ (Xiong et al., 2007). It was concluded that, when the CO₂ fertilization effect is taken into account, production was predicted to increase for rain-fed maize but decrease for irrigated maize (Xiong et al., 2007). When the CO₂ fertilization effect is not taken into consideration, China's maize productivity was predicted to decrease (Xiong et al., 2007).

Despite significant research on how climate change affects maize production in China, the common weaknesses of previous research are a regional focus and conclusions drawn on the basis of limited climatic factors. In some cases, conflicting research results were obtained as a result of using calculations based on different models. To overcome weaknesses of previous research, this research applied a GAEZ model to examine the maize yield potential at a national level. This is because compared to other models, especially "light-temperature based models", the GAEZ model is designed to predict crop yield potential at a national or global scale. The ultimate advantage for using the GAEZ model to calculate maize yield potential is that, it is also agricultural resources

based which can accommodate large numbers of agricultural resource factors (Alcamo et al., 2007). In addition to the common light-temperature factors, the GAEZ model takes into consideration factors which are closely related to maize growth such as terrain elevation, soil, the spatial distribution of cultivated land and other meteorological data for tabulating maize yield potential.

The aim of this research paper is to examine the change of maize yield potential under the influence of climate change in China using the GAEZ model based on soil data, the spatial distribution of cultivated land and major meteorological factors including temperature, precipitation and solar radiation for the periods of 1960-2010. It also reveals the primary meteorological factors affecting the maize yield potential in different agro-ecological zones in China. The research results will not only address the issue of regionalized research on maize yield potential across China, but also the research will provide a holistic view to policy makers on how to adapt climate change for maize production at the national level.

Materials and Methods

The calculation of yield potential of maize in this research was based on data obtained from terrain elevation, soil, the spatial distribution of cultivated land and meteorological factors. The research approach used the GAEZ model to estimate the yield potential of maize.

Data Sources

The terrain elevation data set was derived from the Shuttle Radar Topography Mission (SRTM) C-band. This was the first publicly available near-global, high-resolution data raster Digital Elevation Model (DEM). Globally, SRTM data has been used for environmental analysis in numerous applied studies (Shortridge and Messina, 2011).

Soil data were used to calculate the soil-water balance to determine the potential and actual evapotranspiration for a reference crop and the length of its growing period (LGP, days). Soil data extracted included soil types, effective soil depth and soil water-holding capacities. A nation-wide soil dataset at the scale of 1:1,000,000 was provided by the Data Center for Resources and Environmental Sciences at the Chinese Academy of Sciences (RESDC).

The spatial distribution of cultivated land data, with a mapping scale of 1:1,000,000, was derived from the 2010 land-use database, which was developed by the Chinese Academy of Sciences (CAS). The primary data source for the land-use database was Landsat TM images. The China-Brazil Earth Resources Satellite (CBERS) was used as a data source supplement for the land areas not covered by the Landsat images. The land-use data were classified into 25 categories and then grouped into six classes: cropland, woodland, grassland, water body, built-up area and unused land. These databases have also been previously used in various research (Liu et al., 2005a; Liu et al., 2003; Liu et al., 2005b; Liu et al., 2012; Liu et al., 2010). The cultivated land data used to estimate the yield potential of maize for this study were extracted from the land-use database.

Meteorological data covers the period from 1960 to 2010, including the monthly maximum air temperature, minimum air temperature, precipitation, relative humidity, wind speed at 10 m height and hours of sunshine which were obtained from over 760

nationwide weather stations. These stations are operated by the Chinese Meteorological Administration. The impact of topography on the interpolation of the meteorological data was also considered because of the diverse terrains across China. The ANUSPLIN software was used in this study to interpolate the meteorological data based on the terrain elevation dataset. This software is designed for spatial interpolation of climatic data (Hutchinson, 1995; Hutchinson, 1998a, b). The monthly data for the above six key plant growth factors were interpolated to 10km resolution maps using the ANUSPLIN software based on the digital terrain model of China.

Methods

The technical flowchart used in analyzing the influence of climate change on maize yield potential in China is presented in Figure 1.

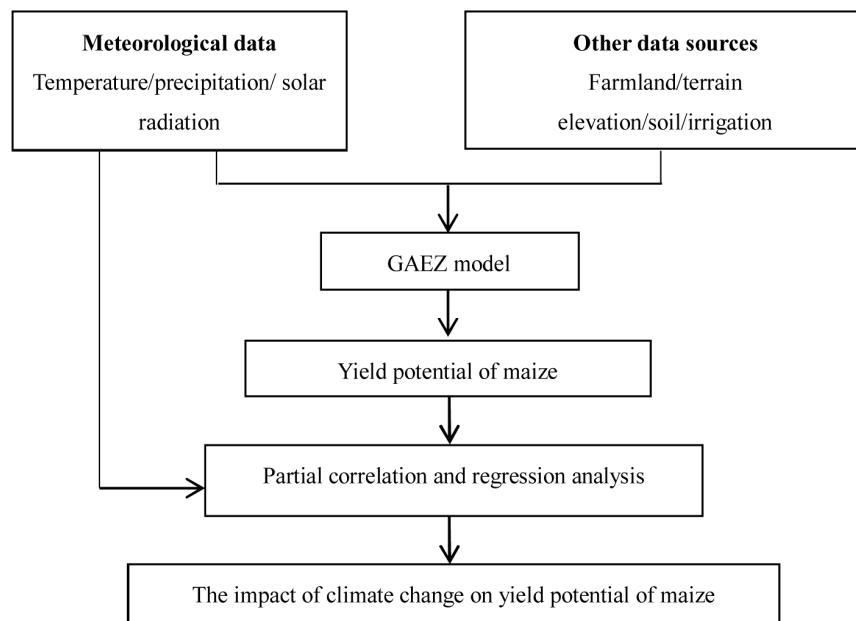


Figure 1. Flowchart for analyzing the influence of climate change on maize yield potential in China.

The GAEZ model was used to estimate the yield potential of maize in this study, which was developed by FAO and IIASA (Masutomi et al., 2009). Currently, the GAEZ model is one of the best models to estimate the yield potential for crop production. The GAEZ model is based on principles of land evaluation and it utilizes meteorological, terrain elevation, soil and farmland distribution data to calculate the yield potential, which is dependent upon the supply of water, energy, nutrients and physical support to plants. The GAEZ model extrapolates the appropriate climate conditions for maize by taking into consideration temperature (daily mean temperature, maximum and minimum daily temperature, accumulated temperature) and precipitation (rainfall amount, relative humidity, precipitation variability). The yield potential of maize based on climatic factors is then calculated using the limit step-by-step method based on suitability of area for maize production. Finally, the estimation of the yield potential of maize is achieved by taking the restrictive factors into account such as soil, terrain and temperature (Liu et al., 2014a; Liu et al., 2014b; Liu et al., 2015).

In order to estimate the long-term climate change trend, a simple linear regression analysis, namely the least square method or linear regression was used (Mamtimin et al., 2011). The slope of the regression line, which is calculated using the least squares method, was used to generate the spatial distribution maps of temperature, precipitation and solar radiation change trends by ArcGIS© 10.1 software.

The primary meteorological factors influencing the yield potential of maize were obtained by comparing the partial correlation coefficients between yield potential and the meteorological factors (De La Fuente et al., 2004). The partial correlation coefficient calculated in this study quantified the correlation between yield potential and each meteorological factor. By means of partial correlation analysis, the effects of temperature, precipitation, solar radiation were analyzed on total yield potential of maize in each county, respectively. A positive correlation coefficient indicates that the change of one meteorological factor exerts a beneficial effect on the yield potential of maize. The larger the positive correlation coefficient, the more it benefits maize production. However, a negative correlation coefficient indicates that the change of the meteorological factor has adverse influence on the total yield potential of maize. Furthermore, the larger the absolute value of correlation coefficient, the more disadvantages it has for maize production.

To estimate the influence of climate factors on yield potential of maize, a linear regression model was established using the following equation:

$$Y=ax+by+cz+d \quad (\text{Eq. 1})$$

where, the dependent variable Y stands for total yield potential of maize in each county. The independent variables of x , y and z are temperature, precipitation and solar radiation respectively. The regression coefficient a , b and c indicates the impact rate of temperature, precipitation and solar radiation on total yield potential of maize. On the other hand, the following equations are used to estimate the influence of each climate factor on yield potential of maize.

$$I_i = \frac{A_i \times B_i}{\sum A_j \times B_j} \quad (\text{Eq. 2})$$

$$H_i = \frac{|A_i \times B_i|}{\sum |A_j \times B_j|} \quad (\text{Eq. 2})$$

where, i stands for the each climate factor; I_i is influence percentage of each climate factor on yield potential of maize; H_i is the contribution rate of each climate factor on yield potential of maize; A_i means impact rate of each climate factor on yield potential of maize, which is a , b or c in equation 1; B_i means the average trends of each climate factor during five decades. The equation 2 was used to reveal the influence percentage of each climate factor on yield potential of maize across China, while the equation 3 was used to seek the chief climate factor affecting the change of yield potential of maize in each county during the past five decades.

Results

Verification

To verify the accuracy of the calculated results, the estimated yield potential of maize in 2005 and 2010 in each county was compared with the actual production reported in official statistics for same years (Figure 2). The results showed that, the average yield potential per hectare in 2005 was 7361.80kg/ha and in 2010 was 6853.46kg/ha, which were 1.53 and 1.42 times as much as the actual production respectively. And the standard deviations were 113.41kg/ha and 101.93kg/ha respectively. As a result, the estimated yields potential reflected the trend of actual production changes.

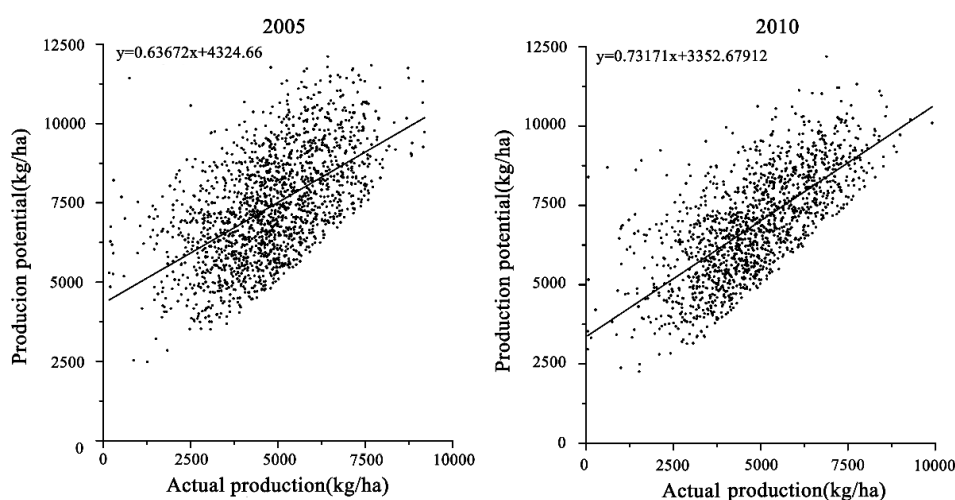


Figure 2. Potential and actual production of maize in 2005 and 2010.

The spatiotemporal changes of maize yield potential

The distribution of yield potential of maize in China in 2010 was uneven, with increasing yield potential both from west to east and from south to north (Figure 3). Among the nine agro-ecological zones, the Northeast China Plain (A) has the highest yield potential of maize per hectare, with 8481kg/ha. The yield potential of the Huang-Huai-Hai Plain (C) and the Middle-lower Yangtze Plain (F) were also relative higher per hectare, with 7993kg/ha and 7167kg/ha, respectively. These regions are the major agricultural regions in China characterized by a flat terrain, suitable climate conditions, fertile soil and enough water resources (Gong and Lin, 2000; Pan et al., 2011). In contrast, the area with lowest per hectare yield potential of maize was the Qinghai Tibet Plateau (E), with only 4180kg/ha which has a high elevation. Furthermore, the average yield potential per hectare in the Sichuan Basin (G), the Loess Plateau (D) and the Yunnan-Guizhou Plateau (I) were 5113 kg/ha, 5496kg/ha and 5827kg/ha, respectively.

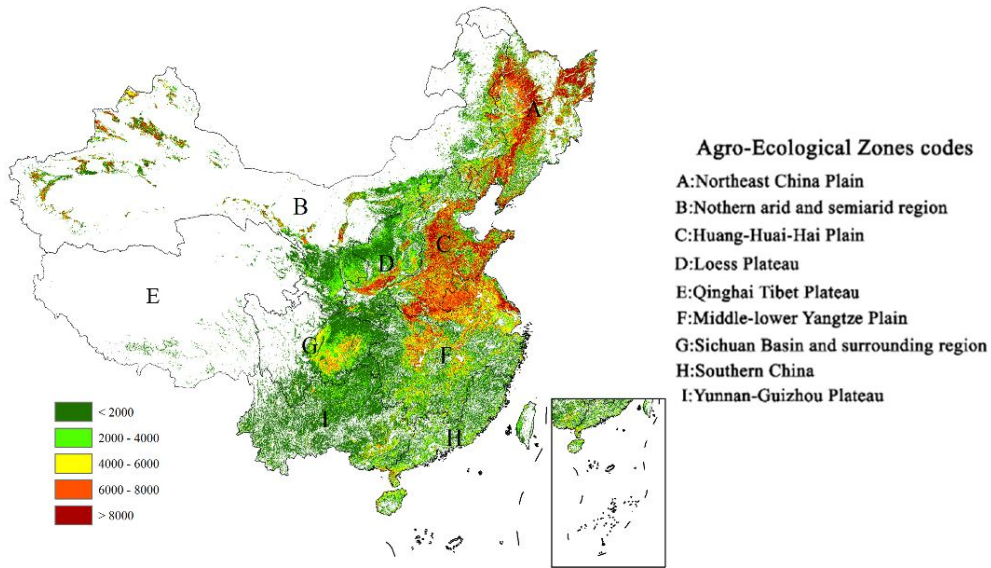


Figure 3. Yield potential of maize in China in 2010 (kg/ha).

The change of yield potential of maize per hectare displays a downward trend with the average rate of 3.67kg/ha/year during the past five decades ($t = -1.83$, $|P| > 0.05$) as shown in Figure 4. And the highest per hectare yield potential of maize was 7475kg/ha in 1998 while the lowest per hectare yield potential was 6531kg/ha in 1999, the difference was 944kg/ha. On the contrary, the total yield potential of maize increased by 0.15 million tons/year from 1960 to 2010, due to the expansion of suitable area for maize production ($t = 0.539$, $|P| > 0.05$). The maximum of total yield potential of maize was 882 million tons in 1990, while the minimum of total yield potential of maize was 760 million tons in 1982; the difference was 122 million tons.

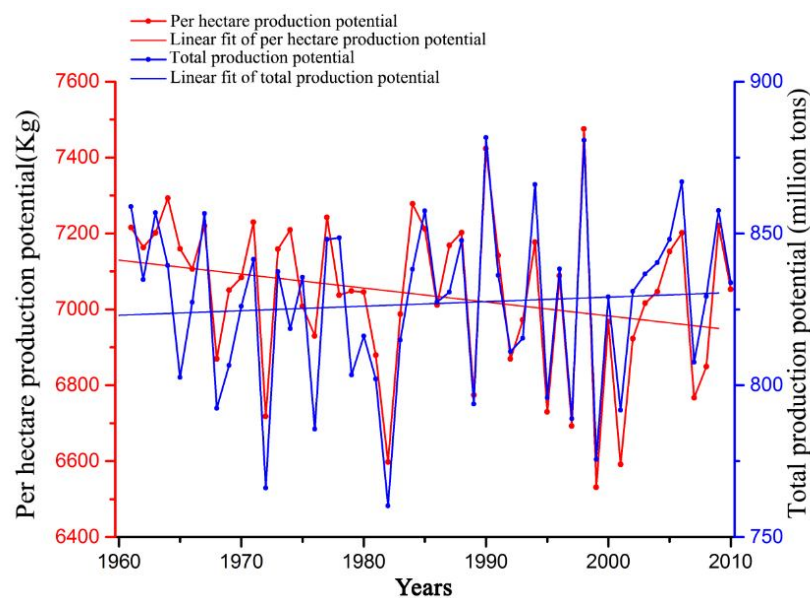


Figure 4. Annual changes of yield potential of maize from 1960 to 2010.

The trend of the total yield potential of maize showed characteristics of spatial differentiation during the past five decades (Figure 5). A positive growth trend was exhibited in 31% of the counties. The highest increase was over 2000 tons/year and this was found in the north of the Northeast China Plain (A), the east of the Northern arid and semiarid region (B) and in some counties in other regions. While the other 69% of counties mainly located in southeast China indicated a decreasing trend. The maximum decrease was more than 1000 tons/year and this was found in the south of the Huang-Huai-Hai Plain (C), the north of the Middle-lower Yangtze Plain (F), the east of the Sichuan Basin and surrounding regions (G) and the center of the Yunnan-Guizhou Plateau (I).

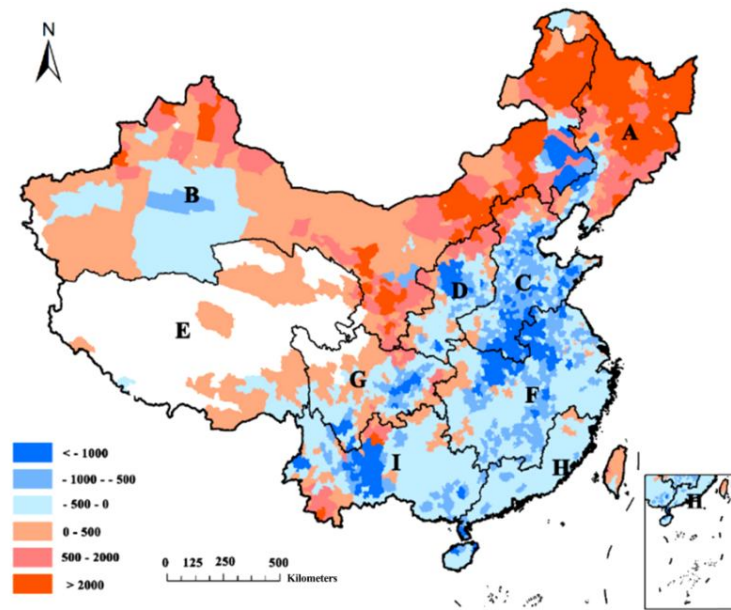


Figure 5. The trend of the total yield potential of maize in different counties during 1960-2010 (tons/year).

Impact of Climate Change on Maize Yield potential from 1960 to 2010

Characteristics of Climate Change from 1960 to 2010

The changes of main climate factors of temperature, precipitation and solar radiation during the past five decades also showed a significant spatial heterogeneity in China as illustrated in Figures 6 and 7. The annual mean temperature showed an increasing trend in 95% of counties (Figure 6). Furthermore, the rising of temperature in 63% of the counties exceeded 0.2 °C/decade. And the temperature increased by over 0.3 °C/decade during the past five decades in the Northeast China Plain (A), the Loess Plateau (D) and Northern arid and semi-arid region of China. In addition, the Sichuan Basin and the surrounding regions (G) had the lowest mean temperature increase by 0.1 °C/decade.

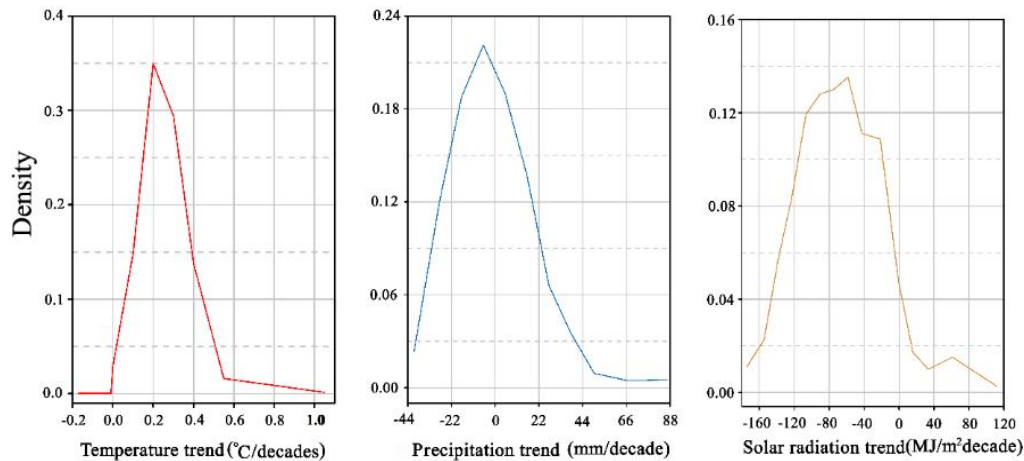


Figure 6. Frequency distribution of main climate factors 1960-2010.

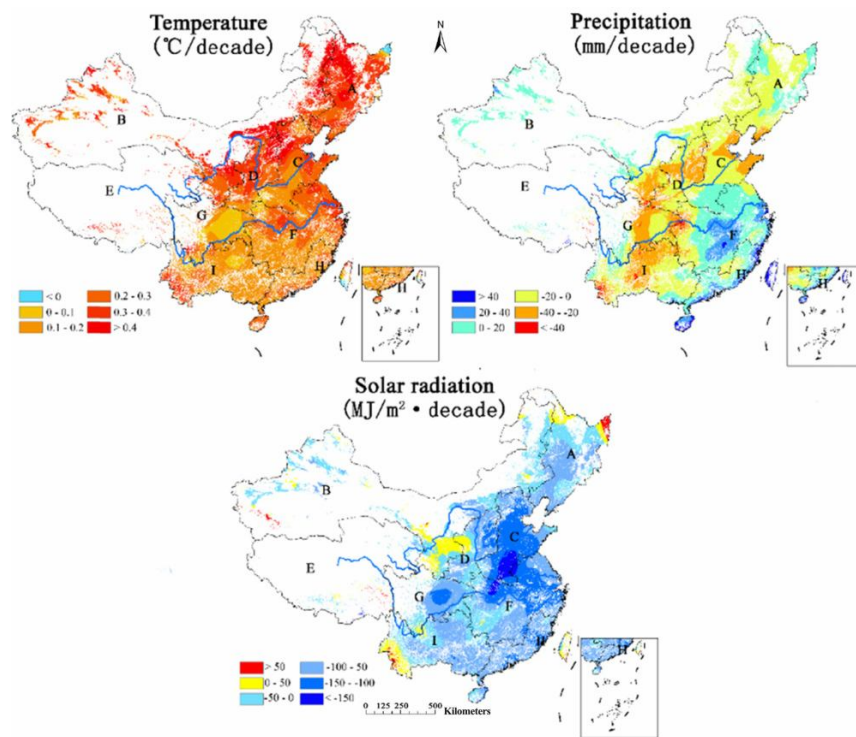


Figure 7. The changed trend of temperature, precipitation and solar radiation during 1960-2010.

In contrast, the changed trend of precipitation displayed a spatial heterogeneity pattern. Annual precipitation showed an increasing trend in about 55% of the counties. Among them, 12% of the counties experienced an over 20 mm/decade increase in precipitation, which mainly occurred in the Southern China (H) and the Middle-lower Yangtze Plain (F), in which the precipitation increased by 21.7 mm/decade and 9.7 mm/decade, respectively. While the precipitation in central China showed a significant decreased trend, with 19% of the counties experiencing more than 20 mm/decade decrease of precipitation. In particular, the precipitation in the Loess Plateau (D) displayed the maximum decrease of 20.5 mm/decade.

Contrary to the commonly increased trend of temperature across China, the solar radiation in almost 95% of counties showed a decreased trend. Decreased solar radiation was experienced by 77% of the counties, at a rate of more than 40 MJ/m²·decade. The Huang-Huai-Hai Plain (C) experienced the highest decrease, up to 111.5 MJ/m²·decade. In the Middle-lower Yangtze Plain (F), the Southern China region (H) and the Sichuan Basin and surrounding regions (G), solar radiation also showed a decreased trend. However, solar radiation presented an incremental trend in limited sections of the Northern Heilongjiang Province and Southwestern Yunnan Province.

Correlation analysis of climate change and yield potential of maize

The correlation coefficient between the main climate factors and total yield potential of maize in each county showed a distinct spatial pattern as shown in Figure 8. Strong correlations ($|P| < 0.05$) between the temperature and the yield potential of maize were found in 41% of the counties. The warming trend in temperature exerted a positive impact on yield potential of maize in 20% of the counties which were mainly located in the Northeast China Plain (A), Qinghai-Tibet Plateau (E) and Northern arid and semi-arid region (B). The temperature was low in the northern China areas in winter and spring. As a result, the warming trend prolongs the growing season of maize and raises the yield potential in those areas. In contrast, increased temperature exerted negative impacts on yield potential of maize in 21% of counties which was mainly found in the Southern China (H) and Middle-lower Yangtze Plain (F). The temperature in the Southern China region (H) is relatively high, therefore, further warming trends exert an adverse impact on the yield potential of maize.

The correlation between precipitation and yield potential of maize was significant in 70% of counties ($|P| < 0.05$). The correlation coefficient displayed a positive correlation in most northern regions (34% of counties), thus the increased precipitation is of advantage to the growth of maize in these areas. On the contrary, it displayed a negative correlation in most Southern regions (36% of counties). Southern China has a humid climate, thus the reducing precipitation is beneficial to increasing the yield potential of maize.

The correlation coefficient between the change of solar radiation and the yield potential of maize is significantly positive in 54% of Chinese counties. The decreasing trend of solar radiation exerts negative effects on yield potential of maize in the Southern China region (H), the Middle-lower Yangtze Plain (F) and the Sichuan Basin and surrounding regions (G), with average correlation coefficients of 0.45, 0.44 and 0.43, respectively. Reduced solar radiation is a disadvantage for the accumulation of the biomass. Therefore, the decreased trend of solar radiation in these areas is an adverse factor for the growth of maize.

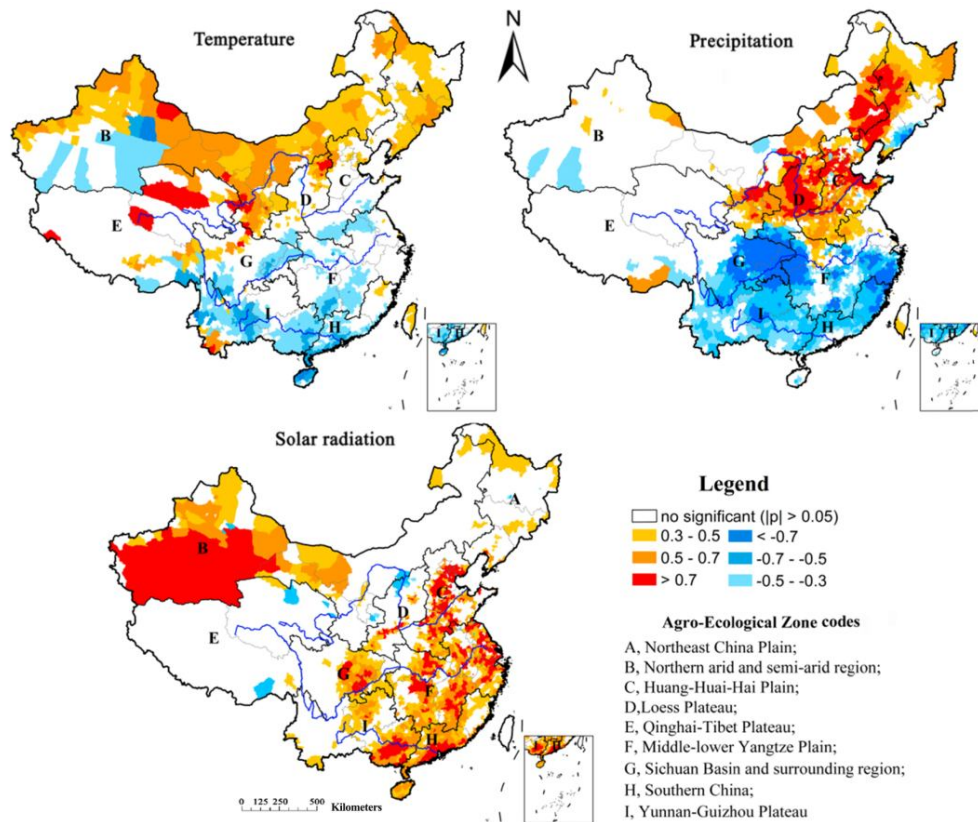


Figure 8. The correlation coefficient between main climate factors and total yield potential.

Based on the correlation analysis, the influence percentages of temperature, precipitation and solar radiation on yield potential of maize were estimated during the past five decades as shown in Figure 9. The influence percentage of temperature change on yield potential of maize showed an increasing trend from Southeast to Northwest. The regions which experienced 50% influence percentage change of temperature, were mainly located in the Northeast China Plain (A), Qinghai-Tibet Plateau (E) and Northern arid and semiarid region (B). And the influence percentage is 160.24%, 95.73% and 59.83% respectively in the above three regions. On the other hand, the positive influence percentages in the west parts of Yunnan-Guizhou Plateau (I) were also relatively high, which could reach 49.50%. While in the Southern China (H) and the Middle-lower Yangtze Plain (F), the negative influence percentage of temperature change is -57.16% and -14.67%, respectively.

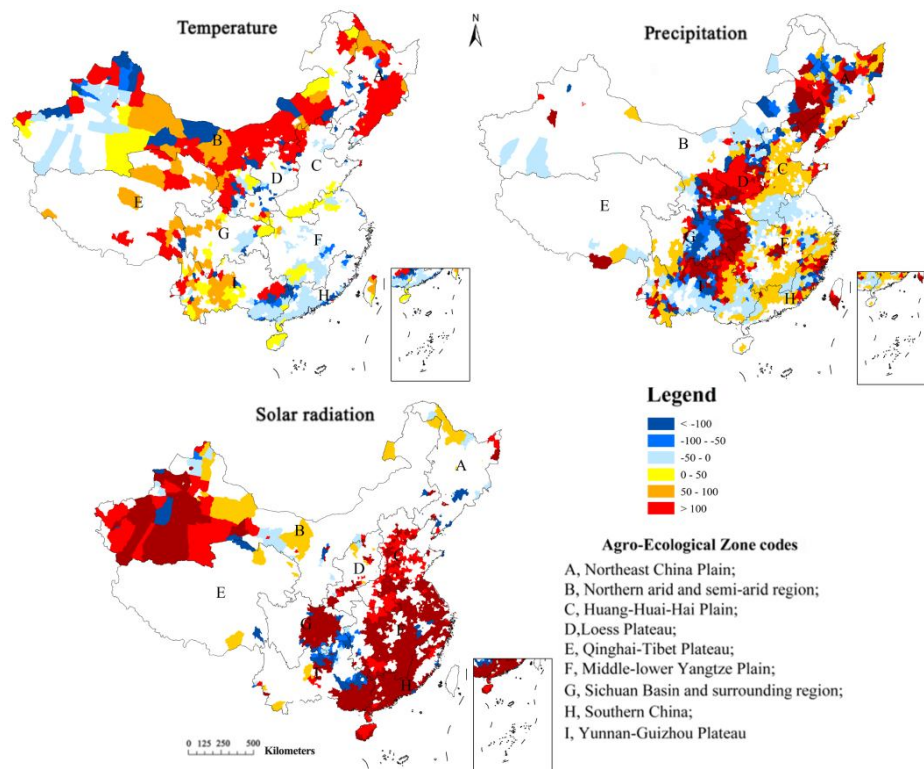


Figure 9. The influence percentage of each climate factor on yield potential of maize in each county.

With regard to the precipitation change, apart from the Sichuan Basin and surrounding regions (G), all other agriculture zones experienced positive influence on yield potential of maize. Among the Loess Plateau (D), Northeast China Plain (A) and Northern arid and semiarid region (B) positive influence percentages of 71.68%, 47.54% and 47.45% were respectively recorded. However, the Sichuan Basin and surrounding regions (G) recorded a negative influence percentage of -44.17%. So it can be concluded that the highest influence percentage of precipitation change on yield potential of maize mainly occurred in the central parts of China.

Most counties in China experienced a positive influence percentage of solar radiation. The highest positive influence percentage of solar radiation was recorded in the Loess Plateau (D), which was up to 204%. In addition, the positive influence percentages of solar radiation change recorded were 160%, 152% and 129%, in the Sichuan Basin and surrounding regions (G), Southern China (H) and the Middle-lower Yangtze Plain (F), respectively.

During the past five decades, the key impact factors in each county and agricultural zone are illustrated in Figure 10. The spatial heterogeneity of key impact factors in the whole country and each agricultural zone are significant. At the national level, solar radiation (R) is the key meteorological impact factor influencing the yield potential of maize during the past five decades. Solar radiation as the key factor influenced 47% of counties, which were mainly located in the Huang-Huai-Hai Plain (C), Middle-lower Yangtze Plain (F), Sichuan Basin and surrounding regions (G), Southern China (H) and Yunnan-Guizhou Plateau (I), which accounted for 76%, 79%, 56%, 62% and 27% impacts respectively. Thus the solar radiation plays a dominant role in the cultivation of maize in China.

In summary, the key meteorological impact factor for the change of yield potential of maize was temperature (T) which occurred in 16% of counties. The regions affected by the key meteorological impact factor of temperature were mainly located in the Northeast China Plain (A), Northern arid and semiarid region (B) and Qinghai Tibet Plateau (E). In these regions, the counties with temperature as a key impact factor accounted for 40%, 38% and 93% respectively. And it showed that temperature was the most crucial impact factor influencing the yield potential of maize in the Qinghai Tibet Plateau (E). Therefore the planning of maize production in these regions should primarily focus on temperature changes.

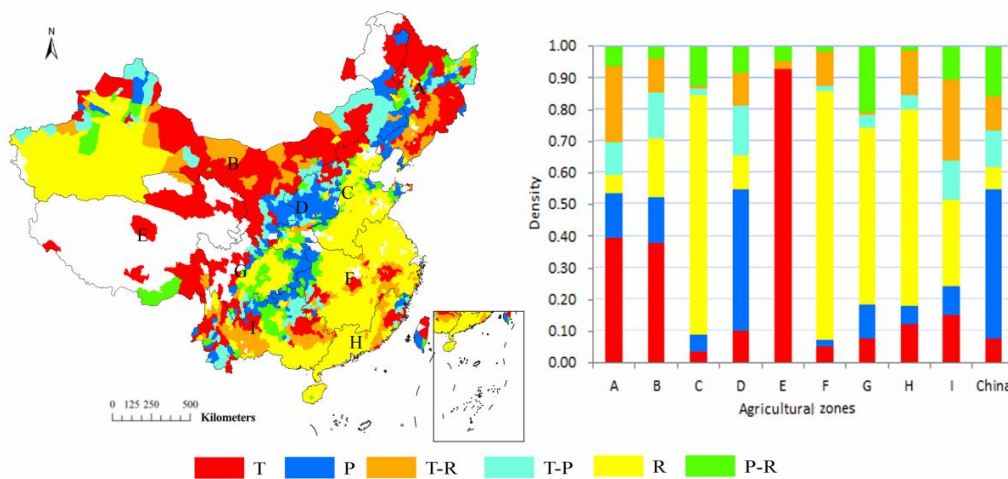


Figure 10. The distribution of key impact factors in each county and agricultural zone. (Where T, P, R indicates temperature, precipitation and solar radiation respectively. T-P indicates the influence induced by both temperature and precipitation together. T-R indicates the influence induced by both temperature and solar radiation together. And P-R indicates the influence induced by both precipitation and solar radiation together).

In each agricultural zone, the distribution of key impact factors still showed significant spatial difference. In the Northeast China Plain (A), Middle-lower Yangtze Plain (F), Southern China (H) and Yunnan-Guizhou Plateau (I), both temperature and solar radiation (T-R) was the second key impact factor accounting for 24%, 10%, 14% and 26% yield potential of maize respectively. T-R's influence mainly occurred in the southern part of zone 'A', in the southern and middle parts of zone 'F', in the eastern parts of zone 'H' and in the eastern and western parts of zone 'I'. In the Northern arid and semiarid region (B), solar radiation was the second key impact factor and occurred in 18% of all counties, mainly located in the west of the Xinjiang Uygur autonomous region. In the Huang-Huai-Hai Plain (C) and Sichuan Basin and surrounding regions (G), both precipitation and solar radiation (P-R) accounted for 12% and 21% of yield potential of maize respectively. This mainly occurred in the northern and middle parts of 'C' zone and in the eastern parts of 'G' zone. Also in the region of Loess Plateau (D), precipitation (P) was the key impact factor influencing 45% of yield potential of maize in the region.

Conclusion and Discussion

Maize yield potential across China has changed significantly as a result of climate change during last five decades. The spatial distribution pattern of the yield potential of maize in 2010 exhibited an increased trend both from west to east and from south to north. The areas with the highest yield potential of maize per hectare were mainly located in the Northeast China Plain (A). The total yield potential of maize during the past five decades increased by 0.15 million tons/year due to the expansion of suitable area for maize production as a result of climate change. A positive growth trend of yield potential of maize was exhibited in 31% of the counties within China. The production potential increased most in the Northern Northeast China Plain (A) and Eastern Northern arid and semiarid region (B). On the contrary, the greatest decreases in production potential were found in the south of the Huang-Huai-Hai Plain (C), the north of the Middle-lower Yangtze Plain (F), the east of the Sichuan Basin and surrounding regions (G) and the center of the Yunnan-Guizhou Plateau (I).

The changes of the main climate factors of temperature, precipitation and solar radiation during the past five decades have had a significant impact on the yield potential of maize in China. The annual mean temperature showed an increasing trend in almost all counties. The increased temperature exerted a positive impact on yield potential of maize in 20% of the counties which were mainly located in the Northeast China Plain (A), Qinghai-Tibet Plateau (E) and Northern arid and semi-arid region (B). While 21% of counties experienced negative impacts which were mainly found in the Southern China (H) and Middle-lower Yangtze Plain (F). The increased trend of precipitation mainly occurred in the Southern China (H) and the Middle-lower Yangtze Plain (F). While precipitation in central China decreased significantly. In most parts of the northern regions the increased precipitation is of advantage to the growth of maize, while in the southern areas of China, the decreased precipitation is beneficial to increasing the yield potential of maize. Contrary to the generally increased trend of temperature, the solar radiation in almost 95% of counties showed a decreasing trend. Apart from the Sichuan Basin and surrounding regions (G), the solar radiation changes positively influenced the yield potential of maize in all other agricultural zones. During the past five decades, the key impact factors in each county and agricultural zone vary. At a national level, solar radiation is the foremost meteorological impact factor influencing the yield potential of maize. The temperature is also a key meteorological impact factor for the change of yield potential of maize. The regions predominately affected by temperature were mainly located in Northeast China Plain (A), Northern arid and semiarid region (B) and Qinghai Tibet Plateau (E).

There are many more meteorological factors affecting the yield potential of maize in China. The combined meteorological factors in some of the agricultural zones also significantly affected the production potential of maize. For example, in the Northeast China Plain (A), Middle-lower Yangtze Plain (F), Southern China (H) and Yunnan-Guizhou Plateau (I), both temperature and solar radiation (T-R) were also key impact factors influencing the yield potential of maize. And in the Huang-Huai-Hai Plain (C) and Sichuan Basin and surrounding regions (G), precipitation and solar radiation (P-R) were important impact factors as well.

Across China, 81% of arable land is distributed in the northern regions where natural rainfall does not meet the water demands for the production of maize both in terms of volume and frequency. Therefore, the influence of annual precipitation changes on yield potential of maize is more severe than other meteorological factors.

This research not only provides scientific basis for making good use of meteorological resources to design cropping pattern in China under the background of climate change, but also plays a vital role for the management of national maize production and assuring national food security.

The limitation of this study is that, extreme weather conditions were not taken into consideration in the study. It is understandable that the extreme weather conditions (i.e., freezing, high temperatures, or heavy snow) may have a significant impact on maize yield in some regions in certain seasons within the period studied. However, the study did not take these extreme weather conditions into account due to the lack of data at a national level. In addition, spring maize and summer maize were not differentiated in this research. Finally, the data used to populate the GAEZ model was primarily from natural elements drawn from unevenly distributed 752 meteorological stations instead of socio-economic factors (i.e. farming technics, cultivar shift, human interest and policies) which inevitably affect the maize yield to a certain degree. However, further studies is planed that will take into account the extreme weather and social factors listed above.

Acknowledgments

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