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Variety distribution pattern and climatic potential productivity of spring maize in Northeast China under climate change

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This study was based on the daily meteorological data of 101 meteorological stations from 1971 to 2000 and the 0.25°×0.25° grid data from 1951 to 2100 simulated by RegCM3 under the future A1B climatic scenario published by National Climate Center, in combination with the demand of climatic condition for maize growth in Northeast China. The trajectory of agricultural climatic resources and the effects of climate change on variety distribution and climatic potential productivity of spring maize in Northeast China under future climate change were analyzed. The main agro-climatic resource factors include: the initial date daily average temperature stably passing 10°C (⩾10°C), the first frost date, the days of growing period, the ⩾10°C accumulated temperature, and the total radiation and precipitation in the growing period. The results showed that: (1) in the coming 100 years, the first date of ⩾10°C would be significantly advanced, and the first frost date would be delayed. The days of growing period would be extended, the ⩾10°C accumulated temperature and the total radiation would be significantly increased. However, no significant change was found in precipitation. (2) Due to the climate change, the early-maturing varieties will be gradually replaced by late-maturing varieties in Northeast China, and the planting boundaries of several maize varieties would be extended northward and eastward. (3) There would be a significant change in the climatic potential productivity of maize in Northeast China with the high-value gradually moving towards northeast. (4) It was an effective way to increase the climatic potential productivity of maize by appropriate adjustment of sowing date.

climate change, agricultural climate resource, variety distribution, climatic potential productivity, adjustment of sowing date

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In recent yeas, global climate change has become a hot issue. The fourth assessment report of IPCC showed that the average global temperature had increased 0.74±0.18°C in the recent 100 years [1], and the linear trend of recent 50 years would be almost twice as much as that of recent 100 years [2]. Researches showed that due to future climate change, the agricultural production pattern and crop planting system would be changed, and the agriculture production cost and investment cost would be increased [3,4], which would have an important influence on food security production [5]. The climate warming led to an obvious increase in the temperature and aridity, and a decrease in the precipitation due to the high latitude of Northeast China, which had a great influence on agriculture production [6,7]. From the 1980s, there was an obvious and sustaining increase in the temperature in northeast plain under global warming. The average temperature of 1980s–1990s in northeast plain was increased by 1.0–2.5°C [8] compared with that of 1960s–1970s, and the warming amplitudes was the largest among all the agriculture areas in the country. As a result, how to adapt to climate change of the food production in northeast plain had become a universal concern. At present, there were a lot of research results on the temperature, precipitation and the variation of agricultural climate resource in the three provinces of Northeast China [9–13], and the effects of climate change on crops were mainly fo-

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*Corresponding author (email: gjp@cams.cma.gov.cn) cused on simulated crop yield [14]. However, there is little research on the change of maize agricultural climate resources in Northeast China in the future and the corresponding change of maize varieties distribution and climatic potential productivity. The planting area of maize in Northeast China accounts for 26.6% of the whole country, which plays an important role in the food production of our country [15]. Therefore, this paper was based on the daily meteorological data of 101 meteorological stations from 1971 to 2000 and the 0.25°×0.25°grid data from 1951 to 2100 simulated by RegCM3 under the future A1B climatic scenario published by National Climate Center, and combined with the demand of climatic condition for maize growth in Northeast China. The change of agricultural climate resources and the effects of climate change on variety distribution and climatic potential productivity of spring maize in Northeast China were analyzed and predicted. At the same time, an effective way to increase the climatic potential productivity of maize by appropriate adjustment of sowing date was proposed for reasonably utilizing agriculture climate resource for maize variety layout and obtaining the maximum yield in Northeast China.

1 Data and methods

1.1 Data resources

The daily meteorological data of 101 meteorological stations from 1971 to 2000 in Northeast China included daily average temperature, daily highest and lowest temperature, daily precipitation, daily average wind speed, and daily average relative humidity, which were provided by National Meteorological Information Center. The 0.25° × 0.25° grid data of Northeast China from 1951 to 2100 simulated by RegCM3 under the future A1B climatic scenario included daily average temperature, daily highest and lowest temperature, daily precipitation, daily average wind speed, daily average relative humidity, daily total radiation, and daily net radiation, which were obtained from National Climate Center.

1.2 Methods

(i) Correction of data for climate model simulation. As there were some differences between the data simulated by climate model and the data observed, error correction should be made to the simulated data (1971–2000) before the climate model was used. As the limitation of practical meteorological stations, error corrections were only made to daily average temperature, daily highest and lowest temperature, precipitation of ten days, daily average relative humidity, and daily average wind speed, among which data of 70 meteorological stations were uniformly selected from the three northeast provinces for the interpolation correction, and the data of the rest 31 meteorological stations were used for the validation of the correction simulate.

The bilinear interpolation method was utilized for the interpolation, where the grid data are firstly interpolated to the known stations, and the results were then corrected by the observation data. The principle of bilinear interpolation method is as follows [16]: Designating the longitude latitude coordinate of a station as $\left(x, y\right)$, the coordinates of its peripheral forecast grids as $\left(x_1, y_1\right)$, $\left(x_2, y_1\right)$, $\left(x_1, y_2\right)$, and $\left(x_2, y_2\right)$, the grid forecast data as F_1, F_2, F_3 , and F_4, and the forecast data F of the station is:

$$\begin{aligned} F = {} & \frac{x_2 - x}{x_2 - x_1} \times \frac{y_2 - y}{y_2 - y_1} \times F_1 + \frac{x - x_1}{x_2 - x_1} \times \frac{y_2 - y}{y_2 - y_1} \times F_2 + \frac{x_2 - x}{x_2 - x_1} \\ & \times \frac{y - y_1}{y_2 - y_1} \times F_3 + \frac{x - x_1}{x_2 - x_1} \times \frac{y - y_1}{y_2 - y_1} \times F_4, \end{aligned} \tag{1}$$

where x_1, x_2 refer to latitude, and y_1, y_2 refer to longitude.

The root mean square error (s) and the average relative error (re) are selected as the index to verify the correction precision. Both s and re are reflections of the numerical deviation of the interpolation, but s is tend to describe the discrete degree of the interpolation and re is tend to describe the value difference. The smaller the value of s and re, the better of the interpolation results [17].

(ii) Stabilization of the beginning and ending date of boundary temperature. The beginning and ending date of boundary temperature are determined by"5-day-sliding-average"approach [18]. As the planting and growing date of thermophilic crops are regarded as the initial date daily average temperature stably passing 10°C (⩾10°C), the proper sowing date of maize is regarded as the first day when air temperature ⩾10°C. As frost is an important weather disaster that restrict maize growth and the day of the first frost is generally the same as the day when maize stops growing, the termination stage of maize is regarded as the first day of frost (the first day when lowest air temperature ⩽2°C). The probable growth period days of maize can be regarded as the number of days between the first day when air temperature ⩾10°C and the first day of frost, and the accumulated temperature ⩾10°C can reflect the requirement of heat to accomplish the development of maize [19]. The beginning and ending date of many years can be determined by experienced frequency method [18], where the guarantee rate is 80%.

(iii) Thermal index for different mature variety. The mature variety of maize can be expressed by the number of lamina of each variety, and the larger the number of lamina the later mature of the variety. The planting boundary of each variety is determined by the thermal index required for different development periods, and the maize variety layout is carried out based on the planting boundary demarcated according to the criterion of maturity in 80% of years, the detailed index are shown in Table 1.

Table 1 Thermal index of maize during the development period [20]

Development period	Thermal index	Remark
Seeds bourgeon	10.0°C	Planting can be made before the temperature increasing steadily to 10.0°C
Germination-emergence	effective accumulated temperature ≥10.0°C adds up to 100°C d	Applicable to different mature varieties
Emergence-heading	y=30.2x+31.8	y: effective accumulated temperature ≥10.0°C required from germination to emergence x: number of lamina (invalid accumulated temperature is deducted for calculation)
Heading-mature	1100°C d (14 laminas) 1150°C d (15 laminas) 1200°C d (16 laminas) 1250°C d (17 laminas) 1300°C d (18 laminas) 1350°C d (19 laminas) 1400°C d (20 laminas) 1450°C d (21 laminas) 1500°C d (22 laminas)	Active accumulated temperature ≥10.0°C. Designating the standard date of heading as 16th, June, if the heading date is advanced or delayed one day, the corresponding accumulated temperature should be increased or decreased by 13°C d

(iv) Climatic potential productivity. The estimation of crop climatic potential productivity is a foundation for the research of comprehensive grain production capacity, which can provide an important theoretical guidance for agricultural productive distribution, agricultural structure adjustment, and reasonable use of climate resource [21,22]. The crop climatic potential productivity was calculated according to the "Crop growth dynamics statistical method", which wass generally used 3 levels correction (photosynthesis potentiality, photosynthesis and temperature potentiality, and climate potentiality). The calculation was firstly made according to the growth period of maize, then the crop production potential during the whole period was accumulated. When calculating the development period, the beginning and ending date of each development period derived from the thermal index in variety layout were adopted in this paper, and the growth period of maize could be divided into 3 stages as germination-emergence, emergence-heading, and heading-mature. The potential climate productivities of maize of different varieties under various periods were calculated using the following equations:

(1) Temperature modification function $f(T)$ [23,24]. The three basis points temperatures for maize growth and yield are selected as the benchmark to determine $f(T)$:

$$f(T)=\left[(T-T_1)(T_2-T)^B\right]\Big/\left[(T_0-T_1)(T_2-T_0)^B\right], \quad (2)$$

$$B=(T_2-T_0)/(T_0-T_1), \quad (3)$$

where T is the average temperature of the growth period, T_1, T_2, and T_0 are the lower limit temperature, upper limit temperature, and the optimum temperature for crop development of the same growth period. $f(T)=0$ when $T\leqslant T_1$. The lower limit temperature, upper limit temperature, and the optimum temperature for different growth periods are illustrated in Table 2.

Table 2 Three basis points temperatures of each growth period for spring maize in Northeast China [23]

	T_0 (°C)	T_1 (°C)	T_2 (°C)
Germination-emergence	25.0	10.0	35.0
Emergence-heading	26.0	12.0	35.0
Heading-mature	24.0	15.0	30.0

(2) Water correction function $f(R)$ [25]. $f(R)$ is the water correction function for crop growth, development and yield:

$$f(R)=\begin{cases}1 & \text{when } R_j\geqslant E_{0j},\\ R_j/E_{0j} & \text{when } R_j<E_{0j},\end{cases} \quad (4)$$

where $E_{0j}=\alpha_j\times E_j$, R_j is the rainfall of the jth period, E_{0j} is the total evaporation, E_j is the probable evaporation obtained by the FAO Penman-Monteith method [26], and α_j is the crop coefficient [27].

(3) Climatic potential productivity [24,25]. The photosynthesis potential productivity Y_1 can be calculated as

$$\begin{aligned}Y_1&=C\cdot f(Q)\\&=C\Omega\varepsilon\varphi(1-\alpha)(1-\beta)(1-\rho)(1-\gamma)\\&\quad(1-\omega)(1-\eta)^{-1}(1-\xi)^{-1}\cdot s\cdot q^{-1}f(L)\sum Q_j,\end{aligned} \quad (5)$$

where C is the unit conversion coefficient, Q_j is the total radiation of sun (MJ m^{-2}), and the explanation of other parameters can be found in Table 3.

The modifications of temperature and growth period are carried out on the basis of photosynthesis potential productivity to obtain the photosynthesis and temperature potential productivity Y_2:

$$Y_2=f(T)\cdot f(N)\cdot Y_1, \quad (6)$$

where $f(T)$ is temperature modification function, and $f(N)$ is

Table 3 The meaning and value of parameters for the calculation of photosynthesis potential productivity

Parameter	Physical meaning	Value	Parameter	Physical meaning	Value
ε	The ratio of photosynthetic radiation to total radiation	0.49	η	Water content of mature corn	0.15
φ	Quantum efficiency of photosynthesis	0.224	ξ	Ratio of plant abio-ash contents	0.08
α	Plant population reflectivity	0.68	s	Crop economic coefficient	0.40
β	Plant rankness population transmittance	0.06	q	Heat content of dry matter (MJ kg^{-1})	17.2
ρ	Ratio of radiation intercepted by non-photosynthetic organs	0.10	Ω	Ratio of CO_2 photosyntheticly fixated by crop	1.00
γ	Ratio of light over the saturation point	0.01	$f(L)$	Modification value for the dynamic change of leaf area	0.58
ω	Ratio of respiration consumption to photosynthetic product	0.30			

the growth period modification function, which can be calculated according to the practical situation of Northeast China as

$$f(N)=1+(N-N_0)/(1.7N_0), \tag{7}$$

where N is the number of effective growth day (number of days when daily average temperature ⩾10°C), N_0 is the number of days from May to September (165 d). As the period from May to September can completely satisfy the growth period requirement of the latest-mature variety, $f(N>165)=f(165)$.

The climate potential productivity Y_3 can be obtained by the modification of moisture based on the calculation of photosynthesis and temperature potential productivity:

$$Y_3=f(R)\cdot Y_2, \tag{8}$$

where $f(R)$ is the moisture modification function.

2 Results and analysis

2.1 Results of the modification of model simulated data

The comparison of daily average temperature and precipitation of 10 d (the average value for 30 years) were compared in Figure 1. There were some differences between the observed data and model simulated data before modification, and larger errors could be found in the comparison of precipitation. However, the errors were significantly reduced after the modification, and the model simulated data agreed well with the observed data. The average error of daily average temperature and precipitation of 10 d after modification were compared in Figure 2. There was a significant reduction of errors after modification as well as the root mean square error. As a result, it could be regarded that the model simulated data after modification could well reflect the climate condition in Northeast China from 1971 to 2000. Similar results could be found for the modification of other essential factors. Supposing the errors from the simulation of climate model were systemic, then all the data simulated by the climate model would have the same errors that did not change with time, therefore the same modification could be used for all the data simulated by climate model to obtain the new data from 1951 to 2100, which could be used to analyze the trend of climate change and its impact on agriculture.

2.2 Change of agriculture climate resource

The whole time sequence was divided into 5 periods: 1951–1980, 1981–2010, 2011–2040, 2041–2070, and 2071–2100, in which the period of 1981–2010 was selected as the benchmark period to analyze the change of agriculture climate resource in Northeast China.

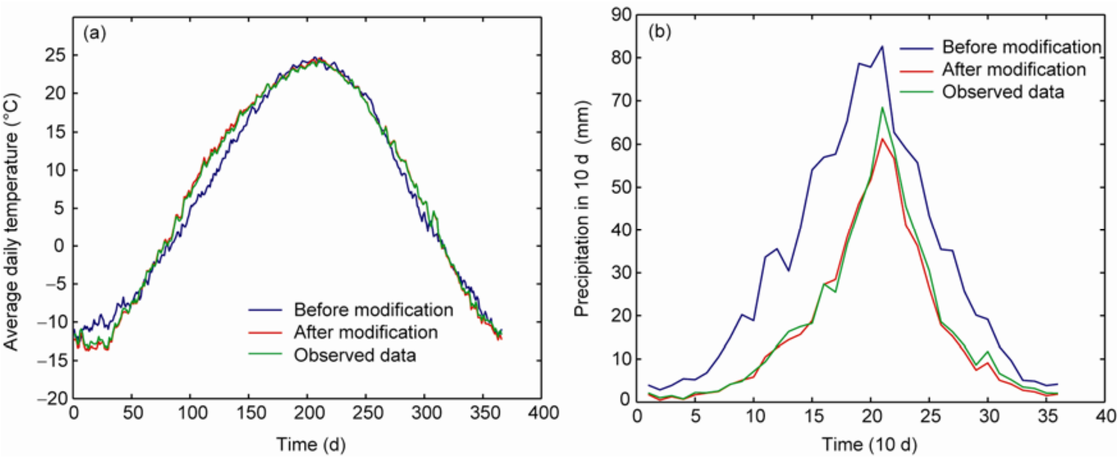

Figure 1 Comparison between observed and simulated data before and after modification. (a) Average daily temperature; (b) precipitation in 10 days.

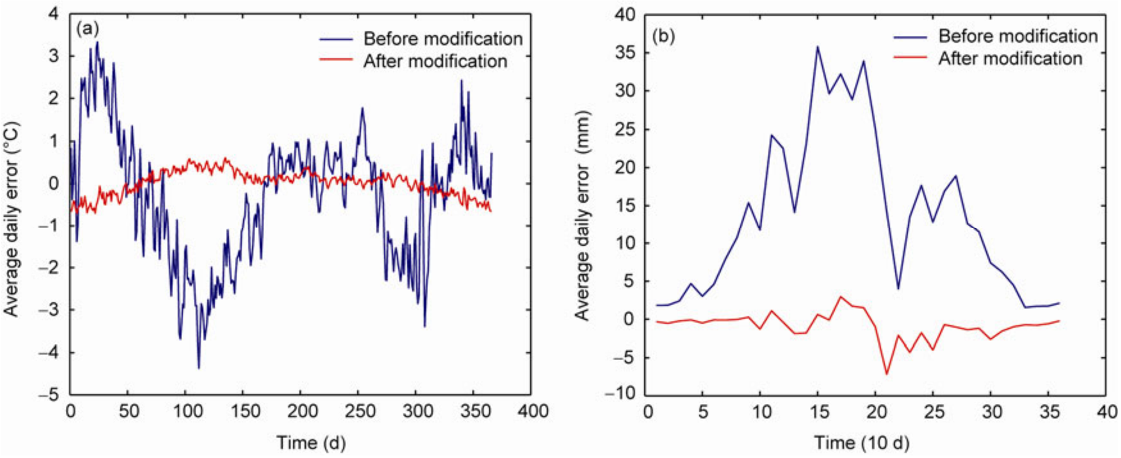

Figure 2 Comparison of average errors before and after modification. (a) Average daily temperature; (b) precipitation in 10 d.

The results showed that from 1951 to 2100 the initial date daily average temperature stably passing 10°C will be advanced, the first frost day would be delayed, the days of growing period would be extended, the total radiation and the ⩾10°C active accumulated temperature under the guarantee rate of 80% would be increased in Northeast China, and the above mentioned changes would be more obvious after the year 2011 especially for the change of the ⩾10°C active accumulated temperature (Figure 3). For the benchmark period, the ⩾10°C active accumulated temperature was gradually decreased from the south to the north, and from the west to the east. The area with the highest value located in the west Liaoxi corridor and Liaodong peninsula with the active accumulated temperature above 3400°C d. The area with the lowest value located in the Xiao Hinggan Mountains and Changbai Mountains area with the active accumulated temperature under 2100°C d. Compared to the benchmark period, the ⩾10°C active accumulated temperature would be increased from the east to the west after 2011, and more increase would appear in the northeast plain and Liaoning Province. It was estimated that during 2071–2100, the ⩾10°C active accumulated temperature would come to 4000–5000°C d in Liaoning Province, the middle-west part of Jilin Province, and the southwest part of Heilongjiang Province, and the value would also be increased during 2200–2500°C d to 3400°C d in the Changbai Mountains, which would meet the requirement of heat for the grow and development of spring maize. As for the precipitation, there was only small fluctuation from 1951 to 2100, and the overall change was not significant.

2.3 Variety distribution pattern of maize

The variety distribution pattern of maize in Northeast China for different periods under the guarantee rate of 80% were analyzed according to the ⩾10°C active accumulate temperature at different areas and the heat source requirement of different maize varieties (shown in Figure 4). For the benchmark period, the late variety (with 21 or 22 laminas) could be planted in the whole area of Liaoning Province. From the southwest part of Jilin Province to the northeast part of Jilin Province (near Heilongjiang Province), the maize variety could be planted varies from 22 laminas to 14 laminas. For the Sanjiang Plain region, the variety with 17–18 laminas could be planted.

The planting boundary of maize from 1951 to 1980 was further south compared to that of the benchmark period. And only the varieties with 16–17 laminas could be planted in the Three-River Plain from 1951 to 1980. The planting boundary of all the varieties from 2011 to 2040 would move northward significantly, the latest variety with 22 laminas could be planted in Liaoning Province and the northeast plain, and the variety with 19 laminas could be planted in the Changbai Mountains area. It was also estimated that the planting boundary of maize with different varieties would move northward and eastward significantly from 2041 to 2070, and the latest variety (with 22 laminas) could be planted all over Northeast China except the Xiao Hinggan Mountains and small parts of the Changbai Mountains. As the accumulated temperature got higher, the latest variety could be planted all over Northeast China except the Xiao Hinggan Mountains from 2071 to 2100. The above results obtained in this paper about the variety planting boundary's significant movement northward and eastward basically agreed with other research results [28,29].

2.4 Climatic potential productivity

Designated 1981–2010 as the benchmark period, the yearly climatic potential productivity changed significantly in both time (Figure 5) and space (Figure 6) compared to that of the benchmark period.

The maize climatic potential productivity from 1951 to 2010 was basically on a stable state, with small fluctuation in different years, but the 2010 witnessed the significant

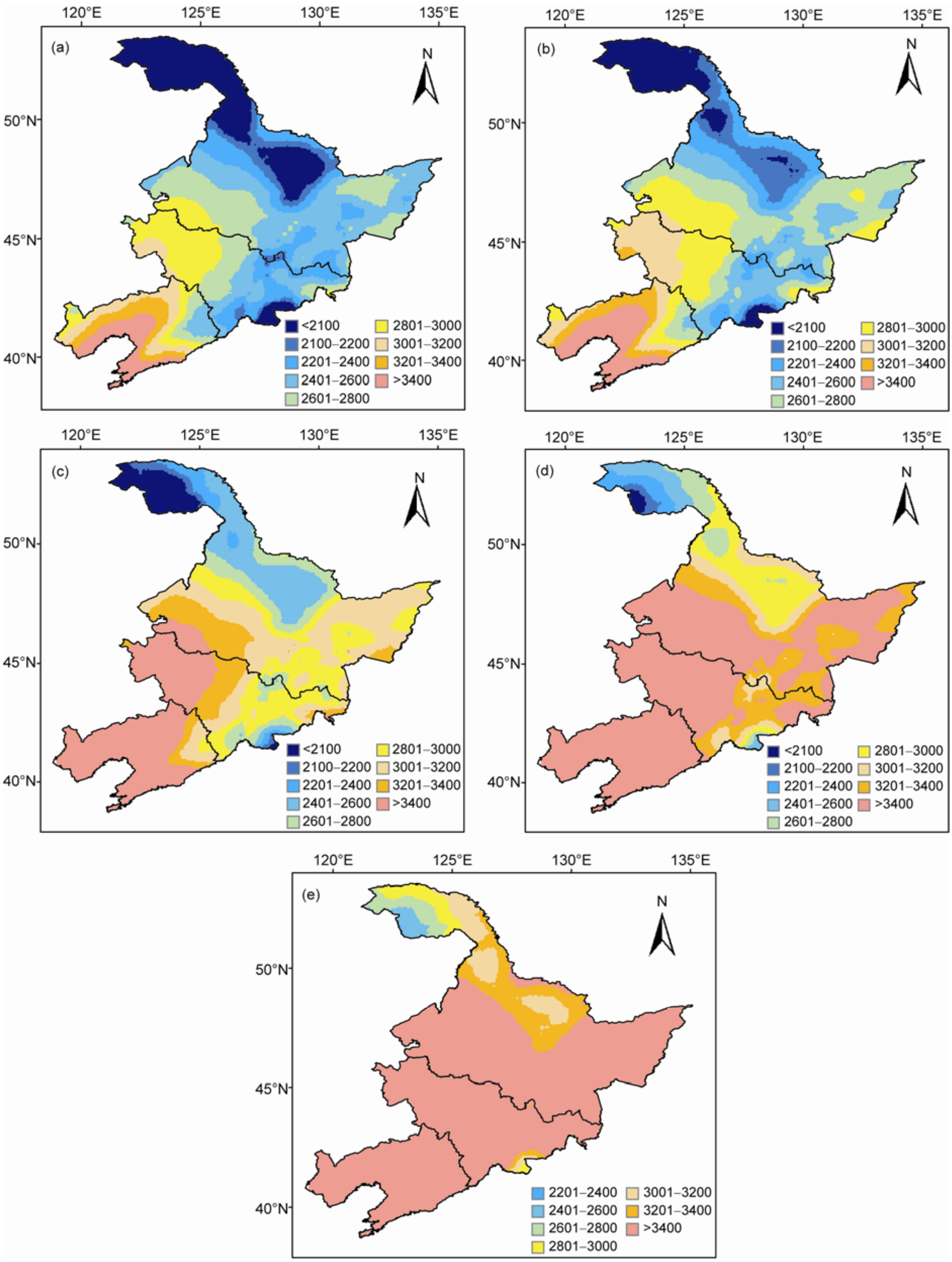

Figure 3 Accumulated temperature ⩾10°C under the guarantee rate of 80% for Northeast China (°C d). (a) 1951–1980; (b) 1981–2010; (c) 2011–2040; (d) 2041–2070; (e) 2071–2100.

decrease of climatic potential productivity in Liaoning Province. The main reason was the heat resources in Liaoning Province had been able to fully meet the growth and development of late variety, which resulted in a higher yield. As the temperature gradually increased, although the heat resource continued to increase, the temperature in some areas exceeded the upper limit of temperature for maize growth. Especially after 2051, in the maize's heading to the maturation stage, the daily average temperature had been higher than the highest temperature allowed for the growth of the maize in this stage, which had greatly reduced the maize climatic potential productivity. Obviously, although

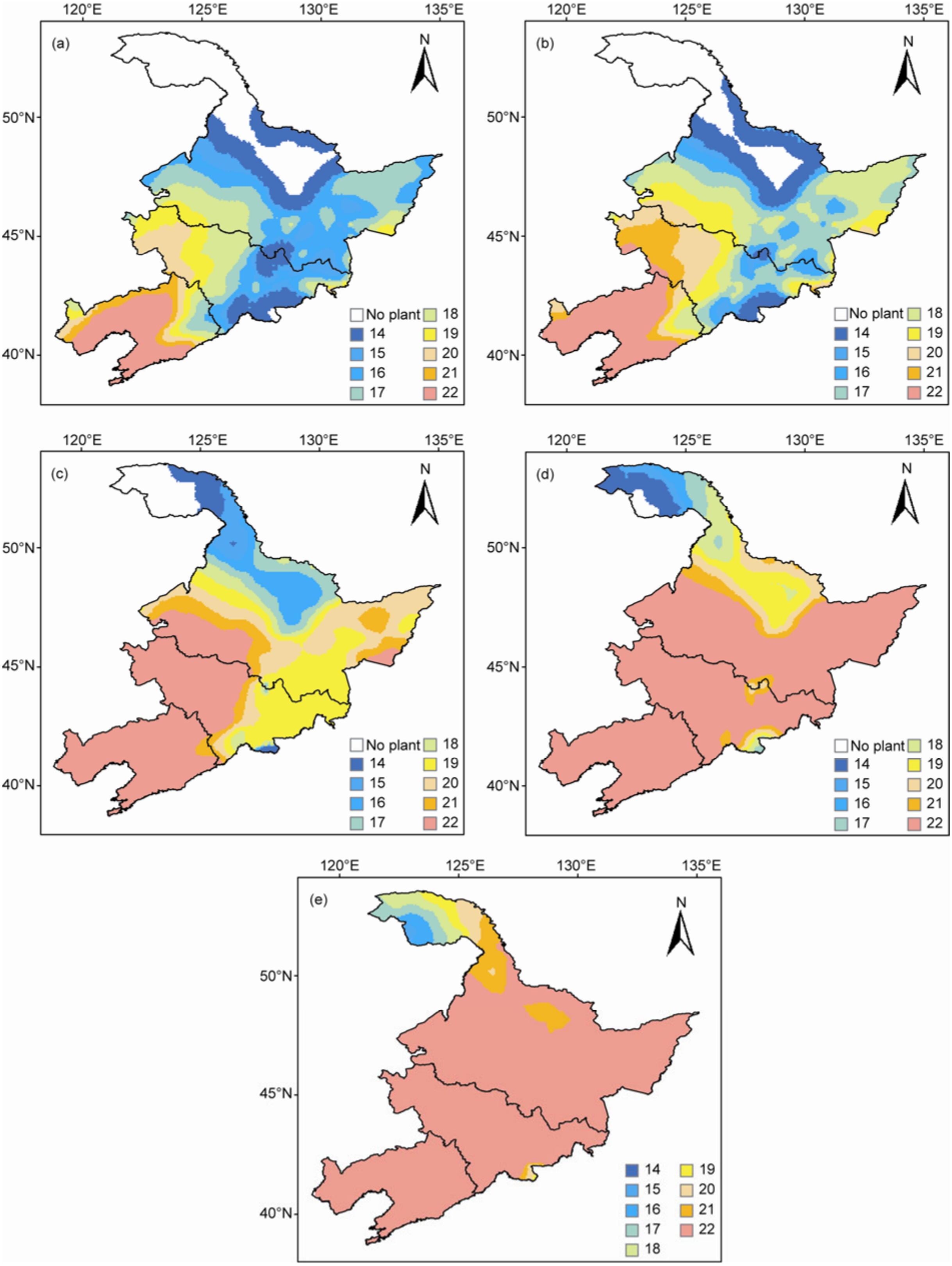

Figure 4 Variety distribution of maize for different periods in Northeast China under the guarantee rate of 80%. (a) 1951–1980; (b) 1981–2010; (c) 2011–2040; (d) 2041–2070; (e) 2071–2100.

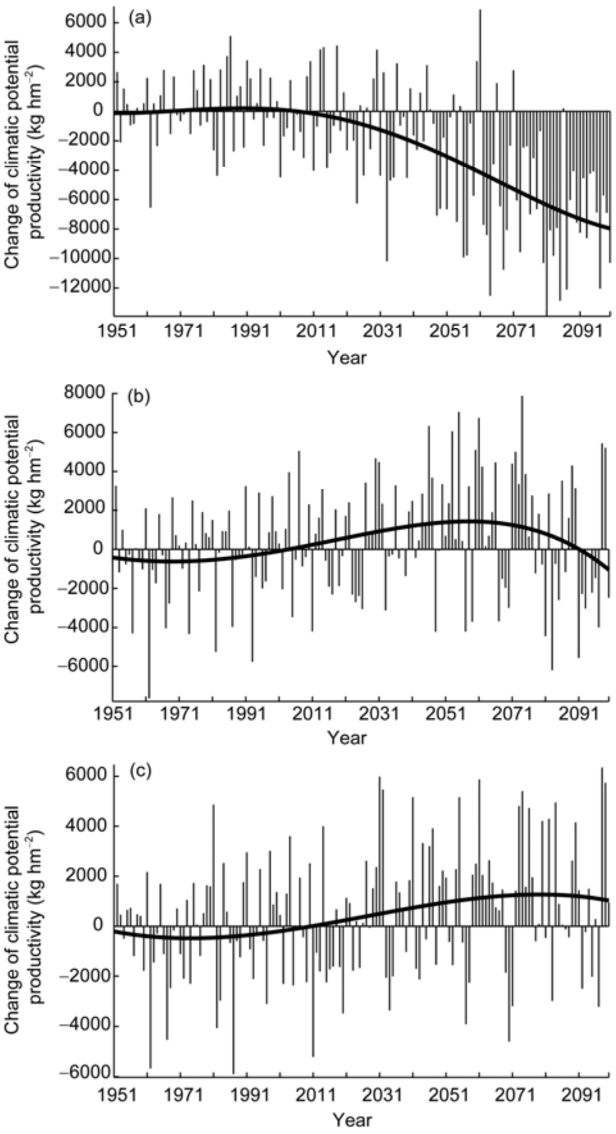

Figure 5 The change of maize climatic potential productivity from 1951 to 2100 in Northeast China. (a) Liaoning Province; (b) Jilin Province; (c) Heilongjiang Province.

theoretically the excessive heat resources met the requirements of the spring maize planting, the climatic potential productivity would decrease rather than increase if we took the currently sowing approach in terms of the initial date daily average temperature stably passing 10°C. Therefore, from the perspective of gain, after 2050, the Liaoning region should appropriately adjust the sowing period of spring maize to avoid the unfavorable period of high temperature and improve yields.

The maize climatic potential productivity in Jilin Province was slightly smaller in 2000, but after 2000 the climatic potential productivity began to increase, and reached the highest during 2051–2070. Though the maize climatic potential productivity would gradually decrease after 2070, it was still higher than that of the benchmark period. Thus, the increasing of the heat resources had a positive effect on the maize's climatic potential productivity in Jilin Province. With the increase of the heat and the extension of the growing season, the maize variety in Jilin had made a gradual transition to the late variety, and the heat resources were fully utilized.

Heilongjiang Province was the agricultural zone with highest latitude, and the lack of heat resources was the main factors limiting the high and stable yield of agriculture in this area. Therefore, in future climate warming and effective accumulated temperature increase under favorable conditions, maize of late variety would gradually be applied, the maize's climatic potential productivity would increase in line with the climate warming. As a result, the increase of heat resources would generally have a favorable effect on the maize production in Heilongjiang.

The significant changes in the different stages of heat resources had changed the maize variety distribution accordingly, which resulted in the dramatic differences of the maize climatic potential productivity (Figure 6).

Compared to the climatic potential productivity during 1951–1980, the 1981–2010 witnessed an overall increase, especially the Three-River Plain and the southern of Heilongjiang, but a decline in Liaoxi corridor. The annual climatic potential productivity in Liaoxi corridor during 2011–2040 continued to decline, and gradually withdrawed from the high yield area. Most of Liaoning Province and central Jilin was still in the high yield area of the climatic potential productivity, while the Heilongjiang Province saw a clear increasing trend in the climatic potential productivity, and Xiao Hinggan Mountains area was ranked as most obvious area in climatic potential productivity increase. There was a significant decreasing trend of the climatic potential productivity in Liaoning Province during 2041–2070, amongst which the Liaoxi corridor had become the low areas of the climatic potential productivity, while the high yield in climatic potential productivity moved gradually to Jilin Porvince. Overall, there was a trend, i.e. the area of high yield of climatic potential productivity had shifted from west to east, from south to north. This trend would become more obvious during 2071–2100, which meant that most of Liaoning Province and the Northeastern plains had translated from the area of high yield in climatic potential productivity to the area of low yield. The area of high yield in climatic potential productivity continued to move northeast.

The increase in the above phenomenon was closely related to the increase of heat resources. In an overheated area with the increase of the heat resource, the employment of the initial date daily average temperature stably passing 10°C would result in the drop of production potential. While in a heat shortage area, with the increase of the heat resource and the extension of the growing season, the variety of maize would make a gradually transition from the early variety to late variety, heat resources could be fully utilized to increase production potential.

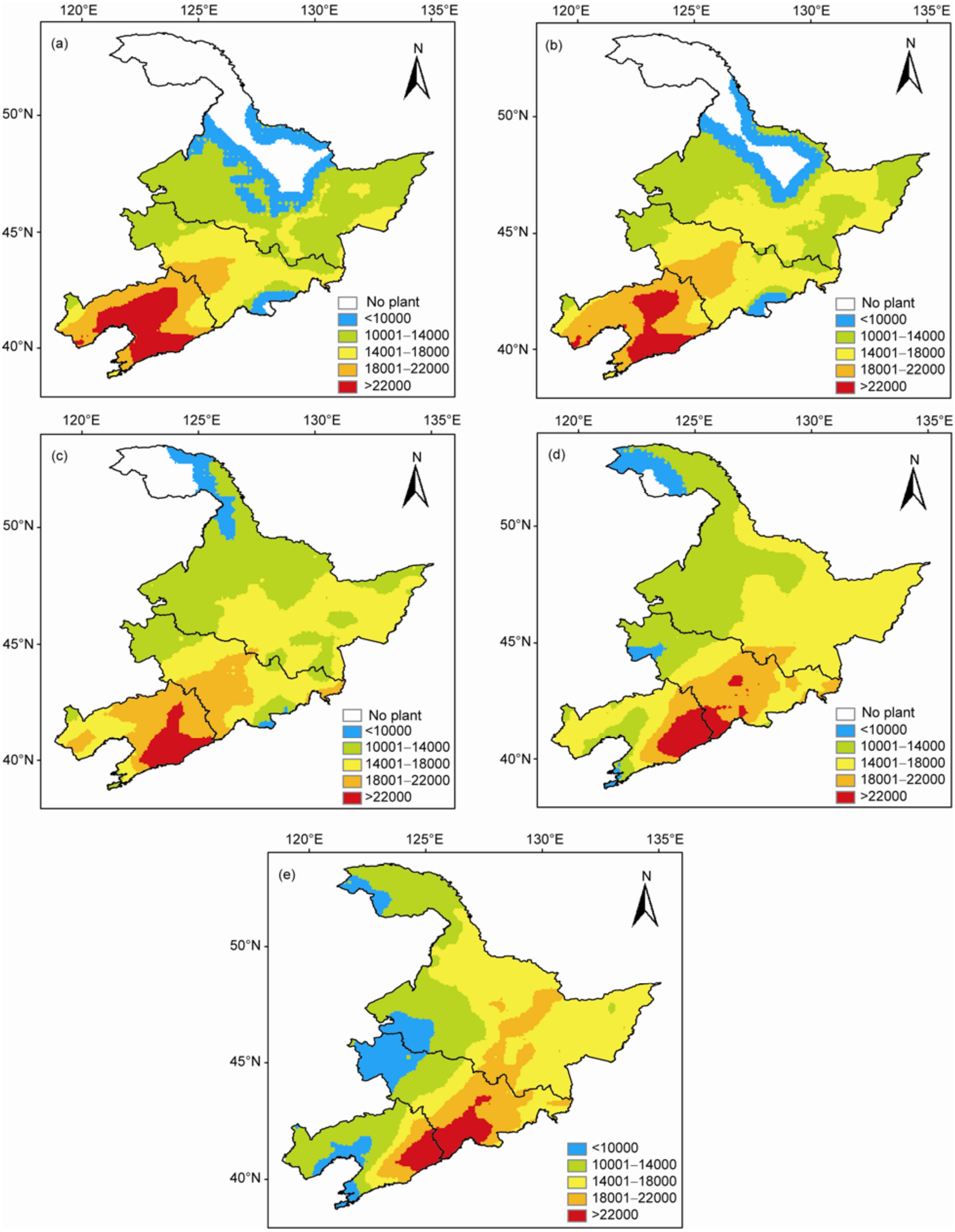

Figure 6 The maize climatic potential productivity distribution for different areas in Northeast (kg hm^{-2}). (a) 1951–1980; (b) 1981–2010; (c) 2011–2040; (d) 2041–2070; (e) 2071–2100.

2.5 The effect of adjusting sowing data on climatic potential productivity

The analysis mentioned above showed that the climatic potential productivity of spring maize in Liaoning Province began to decline after 2011 due to rising temperature. To avoid adverse high-temperature phase, sowing postponing method was employed to maximize the maize production. The climate resources were very different due to different regions at different latitude, longitude, and altitude, so it was difficult to determine a uniform sowing delay days. Therefore, the two pilot sites in Liaoning Province were selected as the research object, under precondition that the maize can fully ripen, to analyze the rate of change relative to postponement of sowing data in terms of maize climatic potential productivity by delaying the sowing data to 10, 20, 30, 40, 50 d separately in the traditional way (shown in Figure 7).

It could be seen that before 2045, for the relative shortage of heat resources test point b (123.25°E, 41.5°N), sowing temporarily could not be postponed; while the test point a (122.25°E, 39.5°N) had a relatively abundant heat resource, the sowing date could be postponed appropriately number of days, so as to improve the climatic potential productivity effectively. After 2045, the postponement of sowing days had played a more significant role for the two pilot sites. As the temperature gradually increased, the more the number of days was delayed, the more the climatic potential productivity was improved, but there were large fluctuations among each year. Apparently, as the climate in Northeast region was gradually warming, for those areas with excessive heat resources, appropriate sowing date postponement could improve the maize climatic potential productivity effectively. But to Liaoning Province, there was less heat resource in some regions than the test point b, so the adjustment of the sowing days was undesirable for these areas for now. The entire northeast region had a big temperature fluctuation each year due to the geographical and climatic conditions differences. How to determine the most appropriate number of sowing days postponement still sounded a very complicated issue, with many factors needed to be considered.

3 Discussion and conclusions

As the constant climate warming, the agro-climatic resources in Northeast region had been changed significantly,

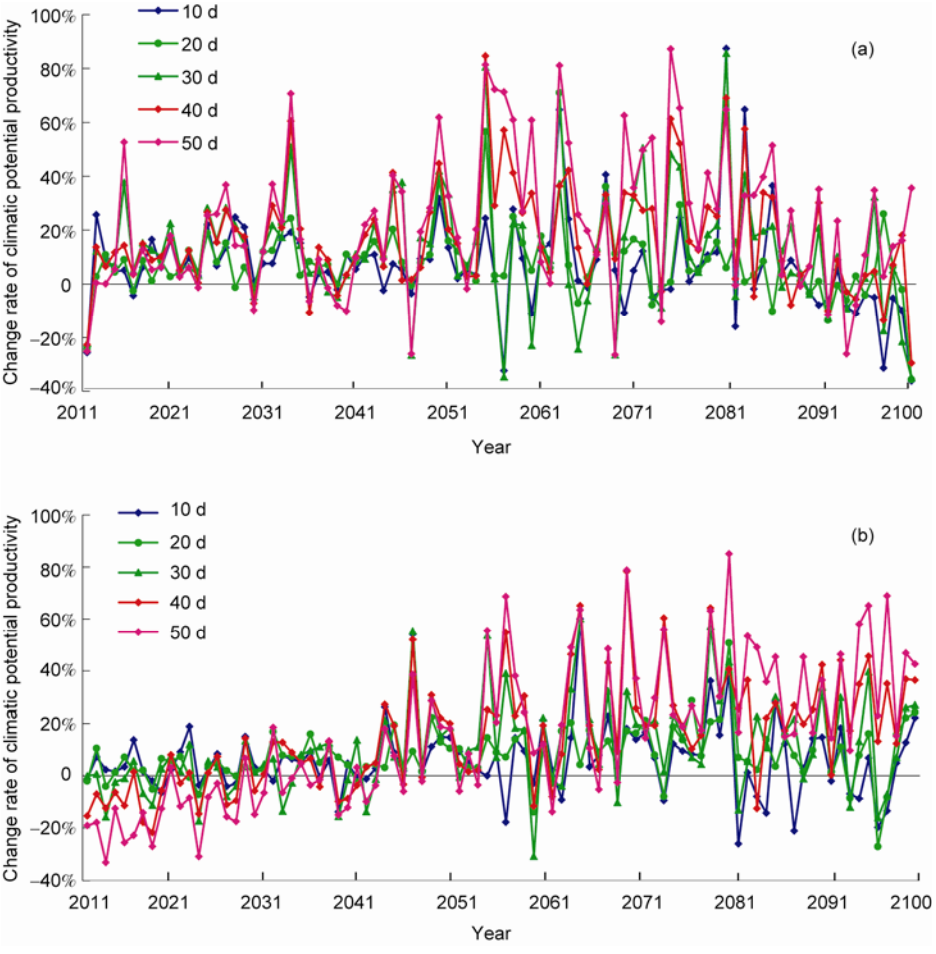

Figure 7 The change rate of climatic potential productivity after the delay of different sowing days. (a) 122.25°E, 39.5°N; (b) 123.25°E, 41.5°N.

especially for the obvious increase found in the heat resource. Compared with 1981–2010, the suitable sowing date of maize in Northeast China had been significantly advanced after 2011, i.e. sowing days were generally about 20 d in advance in 2100. The first frost date in the region was significantly delayed, and the growing season was extended. The region's growing season would be generally extend for 30–40 d in 2010. The ⩾ 10°C active accumulated temperature showed a significant increase trend in Northeast China. The increase of heat resources had changed the variety distribution of maize, and the early-maturing variety had been gradually replaced by late-maturing varieties. Theoretically, after 2041, except for the small part of Xiao Hinggan Mountains, the late-maturing variety could basically been planted all over Northeast China. The cultivation boundaries extended northward and eastward, the areas where was not suitable for the maize cultivation now would become suitble gradually.

With the increase of the heat resource, the early-maturing variety was gradually being replaced by late-maturing variety, and the maize climatic potential productivity had changed significantly. The traditional method according to ⩾10°C initial date to determine the sowing date failed to take full advantage of local climatic resources, causing reduction in yield. Based on the climatic potential productivity change, if we regarded the initial date of ⩾10°C as the sowing date, when the temperature increased to a certain extent, the maize growth process, particular for the maturity period, would experience the adverse effects due to high temperature in Liaoning Province, resulting in the decline of yield. To avoid high temperature and to improve the production efficiency, the sowing date could be adjusted or high temperature preventive maize variety should be planted. For Jilin Province and Heilongjiang Province where there was insufficient heat, maize climatic potential productivity had gradually improved owing to the increase of the heat resource after 2000. However, due to the different climatic resources in different years over different regions, how to determine an appropriate delaying sowing days was a complicated issue, needing to consider many factors.

As for future climate data from the simulation results of climate model, although certain preliminary data error corrections had been made, there were still some differences from the actual results, which would have some impacts on our research results. Limited by the number of observation stations, we only modified the temperature, precipitation, relative humidity, and wind speed. However, the radiation data was taken directly from the model results. Therefore, there were still some uncertainties in the study results.

This study analyzed the impact of climate change on the maize variety distribution and climatic potential productivity over the next 100 years in Northeast China based on the climate resources under the criterion of 80% maturity, which had certain scientific proofs. But for the adjustment of the sowing date, there was a different number of days for the different years in the different locations, therefore the optimum sowing date needed to further researches. Meanwhile, maize production was also subject to the social productive forces factors and human factors, which had differences between theory and practice. The actual production of a region was affected by many factors such as climate, soil and socioeconomic. While the climatic potential productivity was just one of the important tools for evaluation of agro-climatic resources, climatic potential productivity and actual yield was not completely consistemt. Therefore, how to reasonably consider the contribution of the socioeconomic factors for crop production was also one of the important tasks for future researches.

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