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Response of Corn to Climate Warming in Arid Areas in Northwest China

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Abstract: Based on surface observations, response of corn (*Zea mays* L.) to climate warming in the Hexi Corridor in the arid northwest of China was investigated. Results show that in the last 20 yr and more the response of corn to climate warming took the form that its growing season came in advance and its growth period became shorter period. And such response is related to the critical temperature. In case the mean temperature during the corn's growth period was less than the critical temperature, an increase in temperature shortened its growth period. When the mean temperature was higher than the critical temperature, then a rise in temperature no longer showed a tendency of shortening. The continuous increase in temperature in future may cause the mean temperature of corn's growth period to exceed the critical temperature, thus leading to lengthening of corn's growth period. In addition, response of corn to climate warming varied in its different growing stages. An increase in temperature shortened corn's phase of vegetative growth prior to the tasselling phase, prolonged the generative growth phase in the tasselling-milk stage, and cut down the generative growth phase in the milk-maturity stage. These characteristics may correlate with the climatic condition in the arid areas in the northwestern of China, the crop's physiological properties, and the variation of temperature increase in various seasons.
Key words: arid areas in Northwest China; growth period; corn; climate warming; response

The study of global change, started in the 1980s, has drawn great attention from the governments of various countries, the scientific circle and the public due to its vital environmental and scientific importance to future development (Zhang *et al.*, 1997; Zhang and Sun, 1999; Ye *et al.*, 2002). The change of terrestrial ecosystem and its relation to change in non-bio process are the essential part of the study on global change (Zhang *et al.*, 1997; Zhang and Sun, 1999; Shang, 2000; Ye *et al.*, 2002; Gao *et al.*, 2003). With the rapid development of scientific research, monitoring and computer simulation, the study on the response of the terrestrial vegetation to climate change has been one of the important scientific research subjects and has achieved much progress in respect to various zonal, seasonal and species response in recent years.

Studies have shown that climate warming varies greatly in regions and seasons in China, featuring the north warming and the south cooling versus winter warming and summer cooling (Sha *et al.*, 2002). The response of vegetation to climate changes in China also differs in regions and seasons. Both the terrestrial net primary production (NPP) and the normalized difference vegetation index (NDVI) showed an increasing trend in the four seasons from 1982 to 1999. Spring was the season with the largest increasing rates of NPP and NDVI while summer had the greatest increment of NPP. The response of vegetation to climate change was mainly characterized by the forward growing season over the last 18 yr in China; the regions where the increment of vegetation principally takes place in summer were located in the arid northwest of China and the Qinghai-Xizang (Tibet) Plateau. In the eastern monsoon climate region the growing season was advanced and in the northern part of the Daxinganlin (Da Hinggan Ling) Mountains and the north slope of the Tianshan Mountain the growing season in autumn extended (Xie *et al.*, 2002; Piao and Fang, 2003; Piao *et al.*, 2003). The response of vegetation to temperature change in the Northern Hemisphere also varies distinctly in regions and seasons (Melillo *et al.*, 1993; Zhou and Zhang, 1996; Myneni *et al.*, 1997; Fang *et al.*, 2001; Gong *et al.*, 2002; Gong and Shi, 2004). Artificially controlled experiments suggested that the response of seedlings of three dominant shrubs to climate warming differed in the Ordos Plateau; a rise in temperature had a positive effect on seedling growth of *Caragana korshinskii* and *Hedysarum froticusum* and had a minor effect on *Artemisia ordosica* (Xiao *et al.*, 2001). Field observations showed that various climatic factors had different effects on growing periods of the prairie plants in the Ordos Plateau and one climatic factor might affect differently on their various growth stages as well (Huang *et al.*, 2001). An increase in

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temperature gave rise to the shortening of the growth period (from seeding to maturity), and a decrease in the dry matter accumulation and yield of winter wheat in Yongning and Guyuan (Gao *et al.*, 1995). Many studies on the response of vegetation to climate change has been carried out; the majority of the studies has been conducted on large space scale, which is helpful in probing into the overall response of vegetation to global warming. However due to the lack of surface observations, only a few studies on the response of specific regions and specific ecosystems to global warming, and on the bio-mechanism of the response have been undertaken. Therefore to carry out further studies on the response of specific regions and specific ecosystems, particularly the agro-ecosystem, which is highly related to human activities, to global warming, and on bio-mechanism of the response will be of great significance in research into the global changes in future (Zhang *et al.*, 1997; Ye *et al.*, 2002).

1 Data Source

All the data concerning corn employed in this study were collected in the period of 1981 to 2002 from Wuwei Agricultural Experimental Station of Gansu, located in the east of the Hexi Corridor in the arid northwest of China. The data concerning corn development were collected in the period from 1981 to 2002 and those related to biomass were collected during 1994 and 2001. Meteorological data were collected in the period of 1981 to 2002 from Wuwei Meteorological Station.

All the data were collected in line with *Agricultural Meteorological Observation Criterion* issued by China Meteorological Administration. The site for the data collection of corn, 300 m away from the meteorological observation site, had remained unchanged for 22 yr. The regression equations in this study have all been tested at the confidence level (95%).

2 Seeding Time and Rises of Early Temperature

After comparing the sowing data over the period of 1981 to 2002, the earliest seeding time of corn was on 4 April. And March was chosen to represent the season of temperature changes prior to corn's seeding. The seeding time and the mean temperature changes in March over the 22 yr are presented in Fig.1. During the 22 yr (1981-2002) the mean temperatures of March showed an increasing trait while the seeding time of corn tended to get earlier. The correlation between the seeding time and the mean temperatures of March is expressed as $y = -2.14x + 14.03$ (where y is the seeding time and x the mean temperature of March), $R^2 = 0.473$. Every increment of 1 ℃ corresponded to 2 d forward of the seeding time. Compared with the first 11 yr (1981-1991), likewise the mean temperature of March in the last 11 yr (1992-2002) had risen by 1.0 ℃ and the seeding time had been 2 d earlier than the normal phase. This showed that a rise in temperature before sowing in spring brought forward the growing season of corn in the Hexi oases, which is in agreement with the principal way of the response of vegetation to climate change in China (Piao and Fang, 2003).

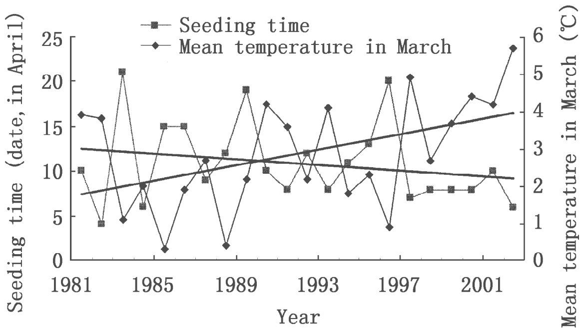

Fig.1. Seeding time and mean temperature changes.

3 Growth Periods and a Rise in Temperature Within Them

A growth period refers to the span within which crops complete their lifecycle, i.e. from seeding to maturity. Regardless of variety, the correlation between the growth period of corn and the change of the mean temperature within the period from1981 to 2002 are presented in Fig.2a (labeled as Integrated). In order to find out the responses of different corn varieties in the same growth period to climate warming, the correlation between the growth period of corn variety Zhongdan 2 and Zhangye 488, and the mean temperature change within the growth period are respectively presented in Fig.2b, c. The results indicated that there was an overall shortening of the growth period of corn with the mean temperature rising, i.e. an increment of 1 ℃ against a 5 d cut of the growth period on average. The findings reveal that a temperature rise cuts down the growth period of corn in the Hexi oases, which is consistent with the conclusion of the related study on wheat (Gao *et al.*, 1995).

Yet further analysis showed a figure of a conic expressing the response of corn's growth period to temperature change. When the mean temperature of corn's growth period was less than the critical temperature (expressed as X_0), with an increase in temperature, corn's growth period shortened accordingly; if the mean temperature of corn's

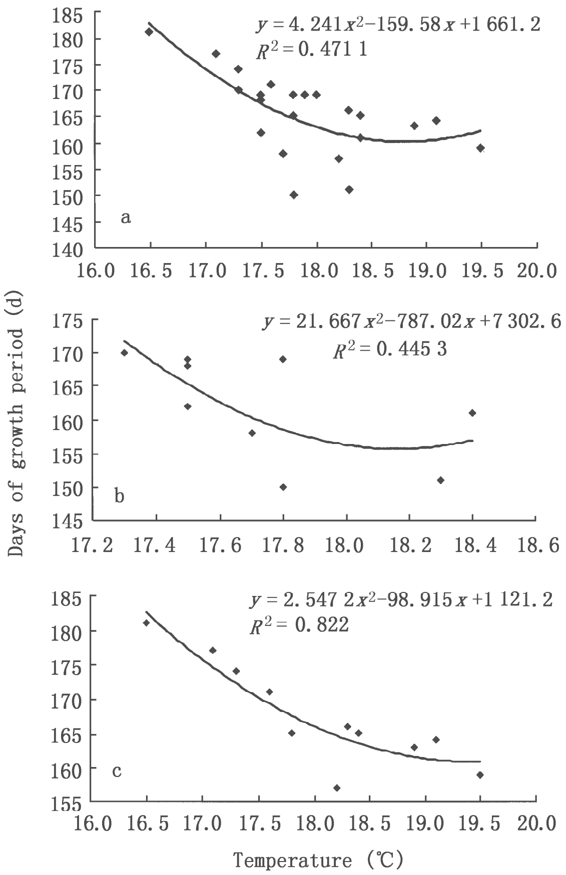

Fig.2. The growth period of corn and temperature change. **a.** Corn, Integrated. **b.** Corn, Zhangye 488. **c.** Corn, Zhongdan 2.

growth period was higher than the critical temperature, with a rise in temperature, corn's growth period no longer showed the trend of shortening as a result. This property had nothing to do with different varieties, although various varieties of corn showed difference in their individual critical temperatures. Irrespective of the factor of variety, the critical temperature X_0 as Integrated was 18.8 ℃. The critical temperature for Zhangye 488 corn was 18.2 ℃ and that for Zhongdan 2 was 19.4 ℃. This suggested that the response of corn to a temperature rise was a complicated process. The rise in temperature in most of the 22 yr has not made the mean temperature in the growth period of corn exceed the critical temperature. Therefore a temperature increase tended to cut down the growth period of corn by and large, which may cover up the complexity of the response of corn to climate warming. According to UN IPCC predictions from the third assessment report, the mean global surface temperature is predicted to rise by 1.4 - 5.8 ℃ during the period of 1990 - 2100 (Sun *et al.*, 2002). Yet the mean temperature of corn's growth period in the 22 yr in the Hexi oases was 17.9 ℃, which may exceed the critical temperature in most years in the future. As a result, the response of corn to climate warming may be an extension of corn's growth period in the main with the increase in temperature.

The characteristics of the response of corn to a rise in temperature may be related to its physiological property. The normal development of crops goes on within a certain optimal temperature range. When the actual environmental temperature is beyond either the upper or lower limits of the optimal temperature, it will handicap the development of crops (Wang *et al.*, 2003). Seasonal changes of the environmental temperature and difference in response of a rise in temperature in various seasons may cause the environmental temperature in a certain phase of the growth period of corn to exceed the optimal upper limit, which will form an obstacle to the development of corn (Wang and Lin, 2003), hence the growth period will be prolonged. As a result, if the environmental temperature in all phases of the growth period is below the optimal upper limit, a rise in temperature will promote a rapid growth of corn, and may shorten the growth period in the oases in northwest China. The extension of the growing season of natural vegetation in autumn caused by a rise in temperature is probably the result of postponement of the lower limit of growth temperature and that of corn's growth period presumably results from the temperature exceeding the upper limit of growth temperature during its growth period. Therefore the biological mechanisms, leading to the two changes, are different.

4 Development Stages and Temperature Variation

In order to present directly the relation between development phases of corn and temperature changes, the mean temperature during the growth period of corn over the 22 yr were displayed in an increasing order and labeled from No. 1 to No.22, simultaneously the days of different development phase in corn growth periods, and the mean temperature corresponding with No.1 - 11 and No.12 - 22 are listed statistically in Table 1.

The results showed that corn exhibited different responses to temperature changes in its different phases of development in the Hexi oases. The responses in the growth period consisted of three stages on the whole, viz. the sowing-tasselling, tasselling-milk and milk-maturity stage. In both the sowing-tasselling and milk-maturity stages, with the temperature rise, all the development phases were moved up and days of all the development phases reduced or unchanged. In the tasselling-milk stage with the temperature mounting up, all the phases were advanced and days of all the phases increased. This suggested that the

Table 1 Corn's development phases vs. days, mean temperatures

Development phases	No.1-11			No.12-22			No.12-22-No.1-11		
	Date (d/m)	Days (d)	Temperature (℃)	Date (d/m)	Days (d)	Temperature (℃)	Date (d)	Days (d)	Temperature (℃)
Seeding	12/4	-	-	11/4	-	-	-1	-	-
Seedling emergence	3/5	21	11.7	1/5	20	12.1	-2	-1	0.4
Seven leaf	4/6	32	16.2	2/6	32	17.1	-2	0	0.9
Shooting	1/7	27	19.2	28/6	26	20.2	-3	-1	1.0
Tasselling	28/7	27	21.1	24/7	26	22.3	-4	-1	1.2
Milk maturity	27/8	30	21.5	25/8	32	22.9	-2	2	1.4
Maturity	26/9	30	15.3	20/9	26	17.4	-6	-4	2.1
Seeding-maturity	-	167	17.4	-	162	18.6	-	-5	1.2

climate warming made all the development phase of corn get earlier, shortened the vegetative phase before the tasselling phase, extended the reproductive growth phase in the tasselling-milk stage, cut down the reproductive growth phase in the milk-maturity stage, and reduced the whole growth period in the arid northwest of China. The response of corn in all its development phases to climate warming in the arid northwest of China is partly the same as that of other crops in other regions (Gao *et al.*, 1995; Monteith *et al.*, 1997; Sun *et al.*, 2002).

This is likely related to the characteristics of the climate in the Hexi oases, physiological property of corn and the difference in temperature rise in various seasons. The optimal temperature for corn growth ranges from 18 ℃ to 24 ℃ while the mean temperature was 15.3 ℃ over the years from April to June in the oases where the observation spot is situated. Taking into account a rise in temperature and the big diurnal temperature range, the mean temperature is still in the range of optimal temperature of corn. Temperature adaptation in corn's vegetative phase is not very strict. A rise in temperature quickens corn's growth, shortens its growth stage, and makes its development phases get earlier as well. The mean temperature of the stage of July to August was 20.7 ℃, due to the wide range of diurnal temperature and the frequent attacks of consecutive high temperature of 30 ℃ during daytime lasting for 3 to 5 d or more, an increase in temperature might further increase this kind of disaster. The reproductive phase of corn is more sensitive to temperature changes. A temperature rise hampered its development (Wang and Lin, 2003), by extending the tasselling-milk stage during which the advancing of the development phases resulted from the moving up of the preceding development phase. The mean temperature of September was 15 ℃; an increase in temperature expedited corn's growth, shortened its growth stage and made its development phase earlier as well.

5 Biomass in the Development Phases and Temperature Changes

Data on the leaf areas, leaf area indices, biomass of leaves, blade sheaths, stems, ears, and the whole plants of corn in its different development phases in the Hexi oases during the period from 1994 to 2001, and the temperatures in the corresponding development phases had been collected and tested.

No significance of correlation ($\alpha > 0.5$) was found between leaf area, leaf area index, biomass of leaves, stems etc., and temperature change. This indicated that the response of biomass of corn to temperature change was not significant, which may be related to either inadequate data acquisition or insensitive to temperature change. The Hexi oases are typical irrigated agricultural area; without irrigation, there would be no agricultural production (Zhang and Hu, 2002). As the climate in this area is getting drier, the shortage of water resource becomes a serious problem. Consequently irrigation is a restraint to crop growth.

Despite of the non-significance in the biomass in all the developmental phases of corn and the corresponding annual temperature changes between 1994 and 2002, a comparison showed that with a continuous rise in temperature, there was an increasing trend of the leaf area indices in all the development phases, and the greatest increment was in the shooting-tasselling stage (Fig.3), i.e. the largest increment was in July in the Hexi oases, which is in agreement with the studies related (Piao and Fang, 2003). With an increase in temperature the fresh weight of leaves, leaf sheaths, and stem were increased before the shooting phase and decreased after the tasselling phase. With the temperature increase the weight (fresh and dry) of corn increased before the tasselling phase and then decreased afterwards. This may be related to the nutrition transfer in different developmental phases and high temperature impacts in the Hexi oases (Wang and Lin, 2003; Wang *et al.*, 2003) as well.

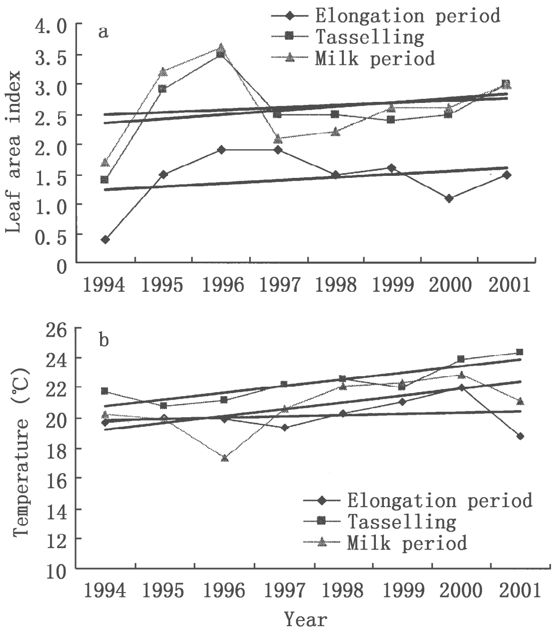

Fig.3. Leaf area index (**a**) and temperature (**b**) change.

6 Conclusions

(1) A rise in temperature made corn's growing season get earlier and shortened its growth period in the Hexi oases.

(2) When the mean temperature of corn's growth period was less than the critical temperature, an increase in temperature cut down the growth period of corn but if the mean temperature of corn's growth period was higher than the critical temperature; with a rise in temperature, the growth period no longer showed a trend of shortening.

(3) The response of corn to temperature rise varied in its different development phases. A rise in temperature shortened its vegetation phase before the tasselling phase, extended the reproductive phase in the tasselling-milk stage and cut down the reproductive phase in the milk-maturity stage.

(4) Likewise in the last 20 yr or so, the response of corn to climate warming in the Hexi oases mainly took the form of the growing season getting earlier and the growth period shorter as well. However the continual increase in temperature in the future may prolong the growth period of corn in the arid northwest of China.

(5) In the recent years the study on response of the terrestrial vegetation to climate warming has progressed greatly by analysis of remote sensing data (Piao and Fang, 2003), which has brought about a new approach for research into global change. A combination of surface observations and remote sensing data will be more helpful in obtaining more details and biological mechanism of response of vegetation to climate warming.

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