Changes of Accumulated Temperature, Growing Season and Precipitation in the North China Plain from 1961 to 2009*

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(Received December 29, 2009; in final form March 28, 2011)

ABSTRACT

Using the high-quality observed meteorological data, changes of the thermal conditions and precipitation over the North China Plain from 1961 to 2009 were examined. Trends of accumulated temperature and negative temperature, growing season duration, as well as seasonal and annual rainfalls at 48 stations were analyzed. The results show that the accumulated temperature increased significantly by 348.5°C day due to global warming during 1961–2009 while the absolute accumulated negative temperature decreased apparently by 175.3°C day. The start of growing season displayed a significant negative trend of –14.3 days during 1961–2009, but the end of growing season delayed insignificantly by 6.7 days. As a result, the length of growing season increased by 21.0 days. The annual and autumn rainfalls decreased slightly while summer rainfall and summer rainy days decreased significantly. In contrast, spring rainfall increased slightly without significant trends. All the results indicate that the thermal conditions were improved to benefit the crop growth over the North China Plain during 1961–2009, and the decreasing annual and summer rainfalls had no direct negative impact on the crop growth. But the decreasing summer rainfall was likely to influence the water resources in North China, especially the underground water, reservoir water, as well as river runoff, which would have influenced the irrigation of agriculture.

Key words: North China Plain, agriculture, climate change

Citation: Song Yanling, Zhao Yanxia, and Wang Chunyi, 2011: Changes of accumulated temperature, growing season and precipitation in the North China Plain from 1961 to 2009. *Acta Meteor. Sinica*, **25**(4), 534–543, doi: 10.1007/s13351-011-0412-1.

1. Introduction

At present, 40% of the earth's land surface is cropland and pasture (Foley et al., 2005). In developing countries, nearly 70% of people live in rural areas where agriculture is the largest supporter of livelihoods. For China, as a large developing country, the total population reached 13 billion with 73% of them pursuing agriculture, and the cropland was 1.2 billion ha in 2008 (CMA, 2009). About 20% of the global population lives in China supported by only 7% of the world's cultivated land. Although Chinese agriculture has undergone tremendous structural changes over the past decades, the average staple crop productivity has doubled in 25 years while the population increased by 25% (NBSC, 2009). Until now, agriculture is still the most important industry for China since it supplies food for the 13-billion population.

The interannual, monthly, and daily distributions of climate variables (e.g., temperature and precipitation) affect a number of physical, chemical, and biological processes that influence the productivity of agriculture. The latitudinal distribution of crop is affected by the current climatic and atmospheric conditions, as well as the photoperiod (e.g., Leff et al., 2004). The total seasonal precipitation as well as its variability pattern are both of major importance to agriculture (Olessen and Bindi, 2002). Short-term natural extremes such as droughts and floods, interannual

*Supported by the National Science and Technology Support Program of China (2007BAC29B05), China Meteorological Administration Special Public Welfare Research Fund for Meteorological Profession (GYHY200806008 and GYHY201106021).

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and decadal climate variations, as well as large-scale circulation changes, i.e., the El Niño/Southern Oscillation (ENSO), all have important effects on crops. Over the North China Plain, crop growth and productivity are also strongly influenced by weather, especially temperature and precipitation, which determine both phenological development and growth rate of crops (Bauer et al., 1984). In particular, Chinese agriculture is strongly affected by the East Asian monsoon system, which often causes regional and large-scale droughts or low temperature. As a result, the agriculture production fluctuates interannually with varying meteorological conditions.

In addition to interannual variability, regional climate in China is undergoing a change. The average annual temperature in China as a whole has increased by 1.5°C during 1961–2009 (NCC, 2010), while the total precipitation has decreased over the last 50 years (Zhai et al., 1999, Song et al., 2005). It is doubtless that the agriculture meteorological resources are changing greatly due to the climate change. Many studies in China have focused on temperature change (Gao et al., 2001; Hulme et al., 1994; Tao et al., 2004; Xu et al., 2005; Zhao et al., 2003), but relatively few studies have dealt with the change of other agriculture meteorological resources.

In this paper, based on the observed daily meteorological data, the changes of agro-climate resources, including accumulated temperature, absolute accumulated negative temperature in winter, the start, end, as well as length of growing season, and seasonal and annual precipitation, were analyzed in the North China Plain from 1961 to 2009. Particularly, the possible influence of thermal conditions and precipitation on agriculture and irrigation was discussed. Then, some insights for agricultural decision making were provided.

2. Material and methods

2.1 Study area

The North China Plain includes Hebei, Beijing, Tianjin, Henan, Shanxi, and Shandong, covers temperate, semi-humid, and monsoon-controlled climatic zones with an annual mean temperature of 10–15°C. Summers are rainy and hot (monthly mean temperatures range from 22 to 28°C), whereas winters are dry and cold (monthly mean temperatures range from –10 to 1°C). The total annual precipitation generally ranges from 400 to 800 mm (CMA, 2000), depending on circulation patterns and topographic features, with only about 90 mm in spring. Furthermore, strong East Asian monsoons often bring colder winters (Tao et al., 2004), while dust storms and droughts occur frequently during springtime.

In the North China Plain, the agriculture production amounts to 1.38 billion ton, 26.2% of the total production in whole China in 2008 (NBSC, 2009). In this region, the winter wheat, maize, cotton, as well as potato can be planted, and the total arable area amounts to 26.5 million hectares, of which 61.3% was irrigated agriculture in 2008 (NBSC, 2009).

2.2 Methods

Using the daily meteorological data provided by the China Meteorological Administration (CMA), accumulated temperature and negative temperature, start and end of growing season, and growing season time-span were calculated. Then, the precipitation affecting agriculture irrigation and crop growth was analyzed (Table 1). Linderholm (2006) supplied 5 definitions of the start and end of the growing season, and we use $T_{\mathrm{mean}} \geqslant 5$°C after frost and the first frost in autumn in this paper, which were proved to be suitable in China (Song et al., 2010).

Table 1. Definitions of accumulated temperatures and growing season. Ground minimum temperature $\leqslant 0$°C is used as a frost criterion

	Index	Definition
1	Accumulated temperature	$T_{\mathrm{mean}} \geqslant 5$°C during January–December
2	Accumulated negative temperature	$T_{\mathrm{mean}} < 0$°C during December–February
3	Start of growing season	5 days with $T_{\mathrm{mean}} \geqslant 5$°C (after frost)
4	End of growing season	First autumn frost ($T_{\mathrm{mean}} \leqslant 0$°C)
5	Length of growing season	5 days with $T_{\mathrm{mean}} \geqslant 5$°C (after frost)/first autumn frost

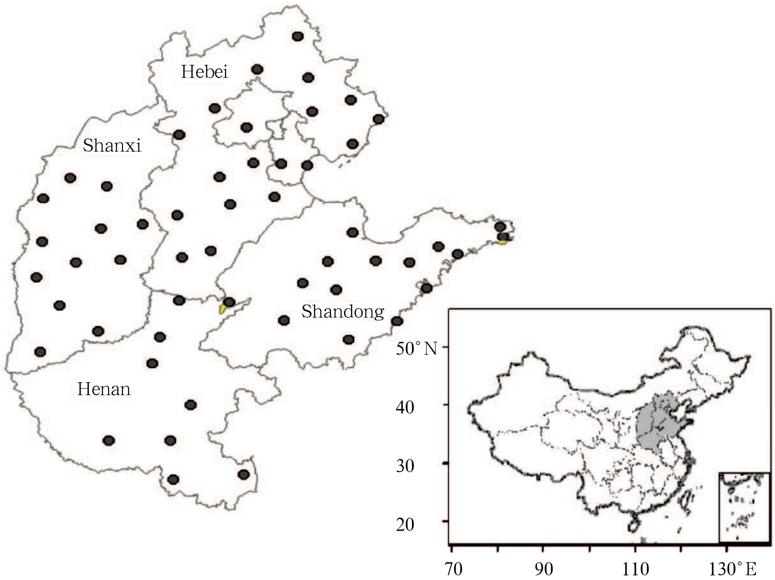

Fig. 1. The location of the stations over the North China Plain.

2.3 Data

In order to investigate the change of agro-climate resources, the daily mean temperature, precipitation, and daily ground minimum temperature data provided by the CMA for the period 1961–2009 were used. Only station series covering 49 yr and having a low rate of missing data ($\leqslant$ 5%) were chosen. Special attention was paid to the thermal conditions and precipitation changes. Out of all the 82 stations over the North China Plain, only 48 stations were found to be suitable and were used in the analysis (Fig. 1). The linear trends of accumulated temperature, growing season length, and precipitation were analyzed by using the Mann-Kendall trend test with the 95% significance level (Yue et al., 2002).

3. Results

3.1 Accumulated temperature

Accumulated temperature influences plant growth and development. Crops flower and mature until accumulated temperature amounts to a threshold that meets the crop's need. For example, winter wheat and maize are the main crops over the North China Plain; winter wheat matures when the accumulated temperature amounts to 1800–2500 °C day with accumulated negative temperature higher than –400°C day for winter dormancy, while summer maize matures until the accumulated temperature changes between 2500 and 2800 °C day, and spring maize needs 2000–3600 °C day to mature. In the North China Plain, summer maize is usually planted after winter wheat is ripe, so it often cannot mature completely when autumn comes.

In the North China Plain, the mean accumulated temperature was increasing significantly by 348.5°C day due to global warming during 1961–2009 (Fig. 2b). For example, the mean accumulated temperature was 4528.4°C day in the 1960s, 4521.6 and 4568.3°C day for the 1970s and 1980s, respectively, while it amounted to 4702.0°C day in the 1990s, 4796.8°C day during 2001–2009. Furthermore, 43 stations showed significant positive trends, with trend values > 500 °C day at 3 stations. The strongest trend was found in Xingtai, Hebei Province, being 632.6°C day (Fig. 2a). As a result, the winter wheat and summer maize can have more thermal to grow due to increased accumulated temperature.

The agriculture region in the North China Plain encloses temperate, semi-humid, and monsoon-controlled climatic zones. The growth and yields of winter wheat in this region were usually affected by freezing injury in winter. Freezing injury induced by

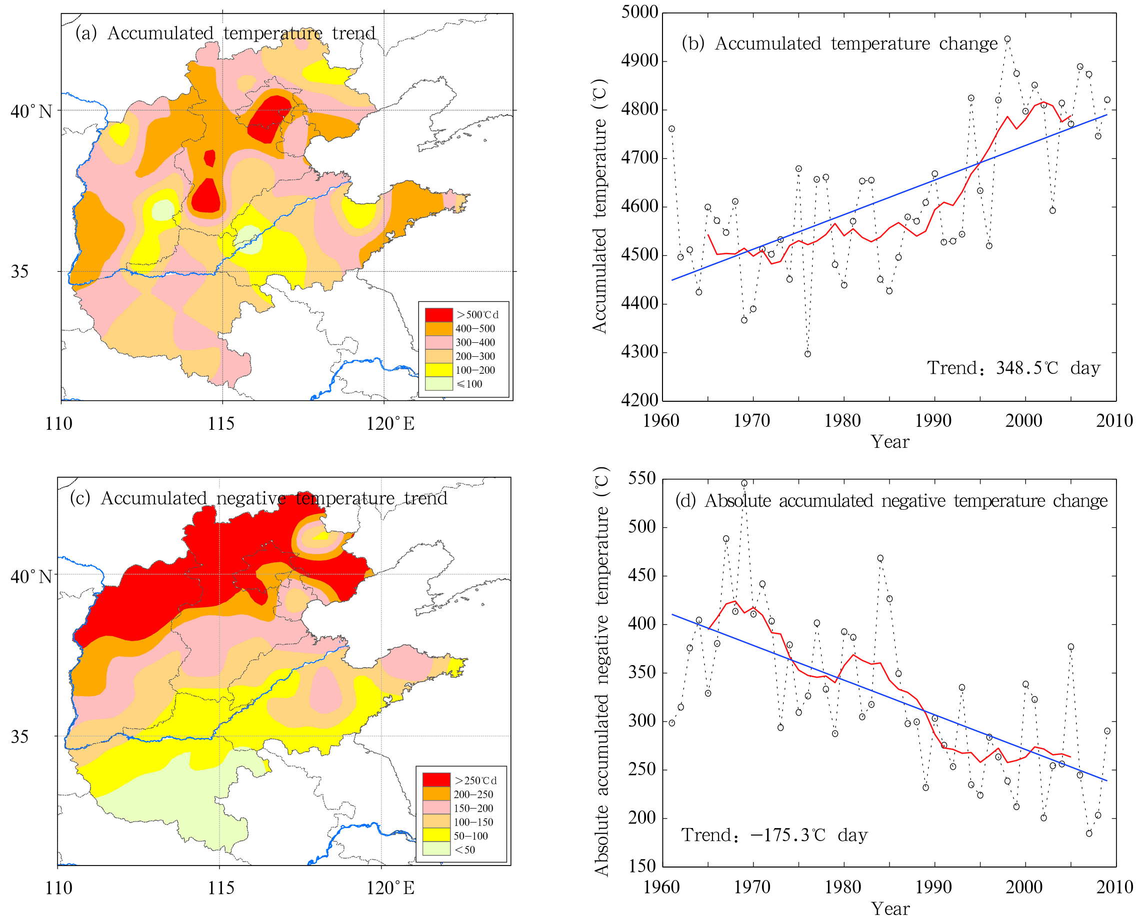

Fig. 2. Regional distributions of the trends of accumulated temperature (a) and negative temperature (c), and temporal distributions of accumulated temperature (b) and negative temperature (d) in North China from 1961 to 2009. Dotted lines denote interannual variability, straight lines indicate trend, and curves represent 10-yr moving average.

cold winds from Mongolia often happens in North China. For example, freezing injury persisted in each of the 5 winters during 1949–1953, and the yields of winter wheat decreased by 30% in Beijing. About 30% of the winter wheat was killed due to freezing injury in Hebei in 1980 (Jin, 1996).

Figures 2c and 2d show the features of the accumulated negative temperature in the North China Plain. The absolute value of accumulated negative temperature $\sum(0\text{–}t)$ decreased apparently by 175.3°C day (Fig. 2d). It amounted to 259.4 °C day during 2001–2009, which was only 65.5% of that in the 1960s. Furthermore, all the stations showed increasing trends in accumulated negative temperature, with 45 stations having significant trends. As we know, the freezing injury to winter wheat is induced by low temperature. It may be alleviated partly if absolute accumulated negative temperature is decreased. Song et al. (2006) found that the damage to winter wheat caused by freezing injury had been thus alleviated, based on simulations by a crop model. Jin (1996) also pointed out that the freezing injury had been alleviated in winter over the North China Plain.

3.2 Thermal growing season

In this study, we utilize the same growing season (GS) indices as those used by Walther and Linderholm (2006) for the Greater Baltic Area, northern Europe, to calculate the trends in start, end, and length of the GS in China. In general, a T_{mean} threshold is used to identify a certain number of consecutive days in order to determine the start/end of the GS. The GS start is defined as the date when the ensuing 5-day running mean $T_{\mathrm{mean}} \geqslant 5°\mathrm{C}$ after the last frost, and the GS end is defined as the first frost day. Here, ground minimum temperature $\leqslant 0°\mathrm{C}$ was used as a frost criterion. After computing the particular start and end, GS length was then calculated as the number of days between these two dates.

To understand the temporal and spatial distributions of the GS in North China, average start, end, and length of GS were calculated for the 1971–2000 reference period using the above indices. The results (Table 2) show that GS starts on the 70th–90th Julian day on average (around March) in most parts of North China, and averagely GS ends on the 290th–305th Julian day (around October). The GS length was found to be about 210–240 days for most parts of North China.

Significant trends ranging from –22.7 to –7.0 days in the start of the GS during 1961–2009 appeared at 33 stations out of 48 stations (figure omitted). The largest significant trend was found in Jinan, Shandong Province, with a linear trend of –22.2 days over the study period. Twenty-three stations showed trends exceeding two weeks. Furthermore, 15 stations displayed negative and insignificant trends of an earlier start of the GS. No stations showed positive trends of delayed GS. Averagely, the start of GS displayed significant negative trends by –14.3 days during 1961–2009.

During 1961–2009, significant positive trends in GS end were only found at 3 of the 48 stations in the North China Plain, ranging from +6.9 to +11.4 days (figure omitted). Insignificant positive trends were found at 17 stations, with values less than +6.7 days. Insignificant negative trends were found at 25 stations. Overall, the end of GS delayed in significantly by 6.7 days.

As seen in Fig. 3a, significant positive trends of 20–27.3 days in the length of GS in 1961–2009 were found at 21 stations (43.8% of the 48 stations). Twenty-four stations showed insignificant positive trends of less than 20 days. Over the North China Plain as a whole, the mean GS length increased by 21.0 days on average (Fig. 3b). The largest significant trend in GS length occurred in Wuzai, Shanxi Province with an increase of 27.3 days. These results were in agreement with earlier findings of extended GS length elsewhere during the 20th century for most of the Northern Hemisphere (Penuelas et al., 2002; Frich et al., 2002; Parmesan and Yohe, 2003; Root et al., 2003; Menzel, 2003; IPCC, 2007).

3.3 Precipitation change

In the North China Plain, droughts often occurred on the regional scale and seriously influenced winter wheat and maize yields. The annual precipitation in this region is about 580 mm while the spring precipitation is only 90 mm, 16% of the total. In spring,

Table 2. Changes of accumulated temperatures, growing season, and precipitation in North China from 1961 to 2009.

	1960s	1970s	1980s	1990s	2001–2009	Trends during 1961–2009
Accumulated temperature (°C day)	4528.4	4521.6	4568.3	4702.0	4796.8	**348.5**
Absolute value of accumulated negative temperature (°C day)	396.2	356.9	338.6	266.0	259.4	**–175.3**
Start of growing season (Julian day)	79.9	78.7	76.9	72.9	66.2	**–14.3**
End of growing season (Julian day)	294.6	294.1	296.1	295.9	301.9	6.7
Lengh of growing season (day)	214.7	215.4	219.2	223.0	235.0	**21.0**
Annual precipitation (mm)	626.8	593.3	587.2	576.3	594.4	–39.2
Precipitation in spring (mm)	92.6	81.8	96.0	95.0	99.2	17.0
Precipitation in summer (mm)	400.0	390.2	358.9	355.0	356.7	–59.7 **–70.8(1962–2006)**
Precipitation in autumn (mm)	126.9	111.8	110.4	107.0	112.7	–19.3
Annual precipitation days	73.7	71.0	78.6	73.7	76.5	3.7
Precipitation days in spring	16.7	15.2	18.2	17.1	16.8	1.2
Precipitation days in summer	35.8	35.4	33.2	31.9	32.2	**–5.3**
Precipitation days in autumn	18.8	17.5	18.0	17.2	17.0	–2.5

Bold figures indicate significant trends with $p < 0.05$

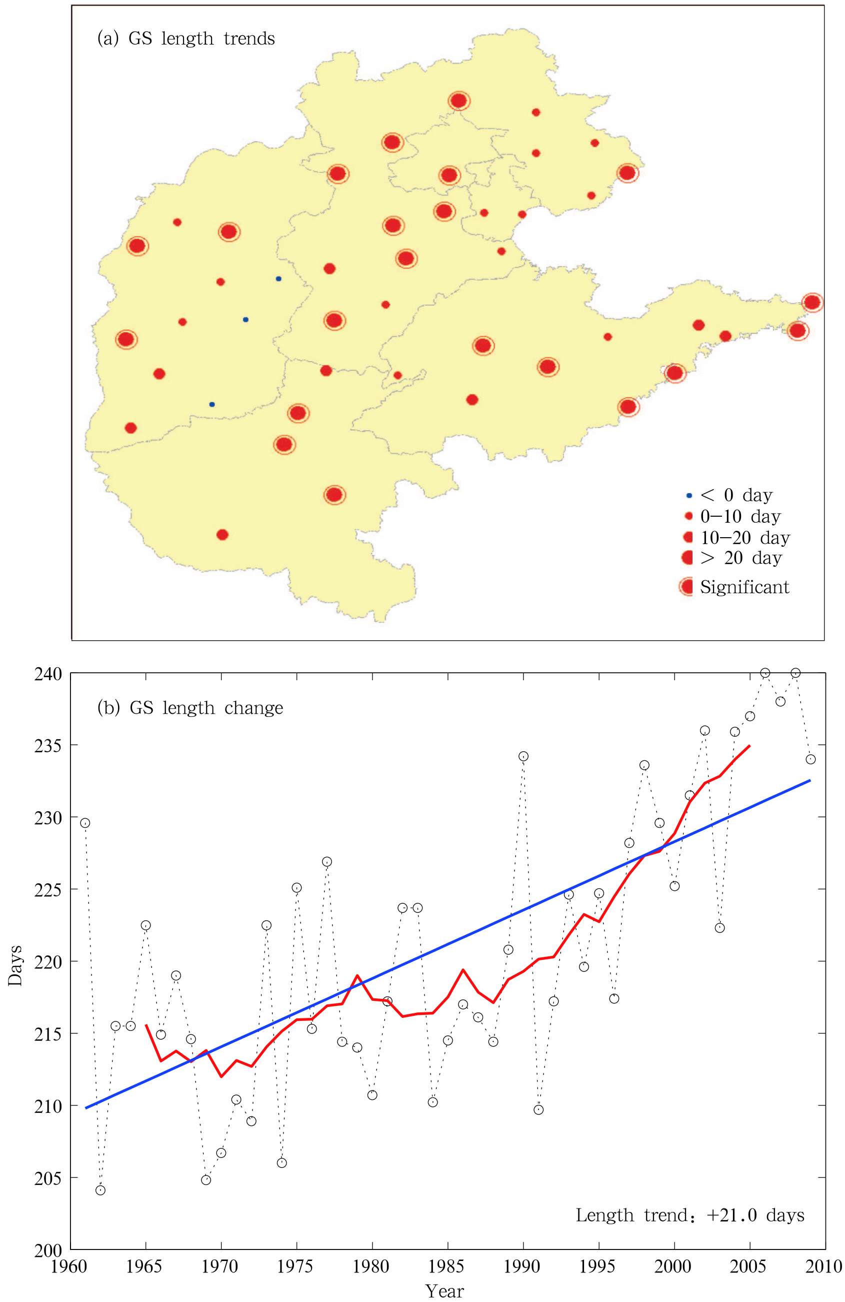

Fig. 3. (a) Regional distribution of trends of GS length, and (b) change of GS length over North China from 1961 to 2009. In (a), the dot with an outside circle denotes a trend value at the 95% significance level. In (b), dotted lines indicate interannual variability, straight lines denote trend, and curves represent 10-yr moving average.

winter wheat was tasseling, flowering, and filling, needing more water for maturity than other crops, and maize as well as potato began to grow. The droughts often happened due to less precipitation in spring, and the yields of winter wheat as well as the growth of spring maize and potato were often influenced strongly. Therefore, it was necessary to study the changes of precipitation in the North China Plain.

Figure 4 and Table 2 show the precipitation changes in North China during 1961–2009. It is seen that the annual precipitation was 585.6 mm in the normal years during 1971–2000, and it decreased slightly by 39.2 mm with no significant trends. For example, the annual precipitation was 626.8 mm in the 1960s, and it decreased continuously in the 1970s, 1980s, and 1990s, being 593.3, 587.2 and 576.3 mm, respectively. In spring, the normal-year precipitation of this season was only 90.4 mm, which often induced droughts in the North China Plain. Table 2 shows that the spring rainfall increased by 17.0 mm during 1961–2009. Although the trend was not significant, the rainy days also increased slightly. This was a good trend which can have positive influences on the growth of crops. The normal summer rainfall was 368.0 mm, about 63% of the annual rainfall. The results indicate that summer rainfall decreased insignificantly by 59.7 mm during 1961–2009, with a significant decreasing trend of 70.8 mm during 1962–2006. Furthermore, summer

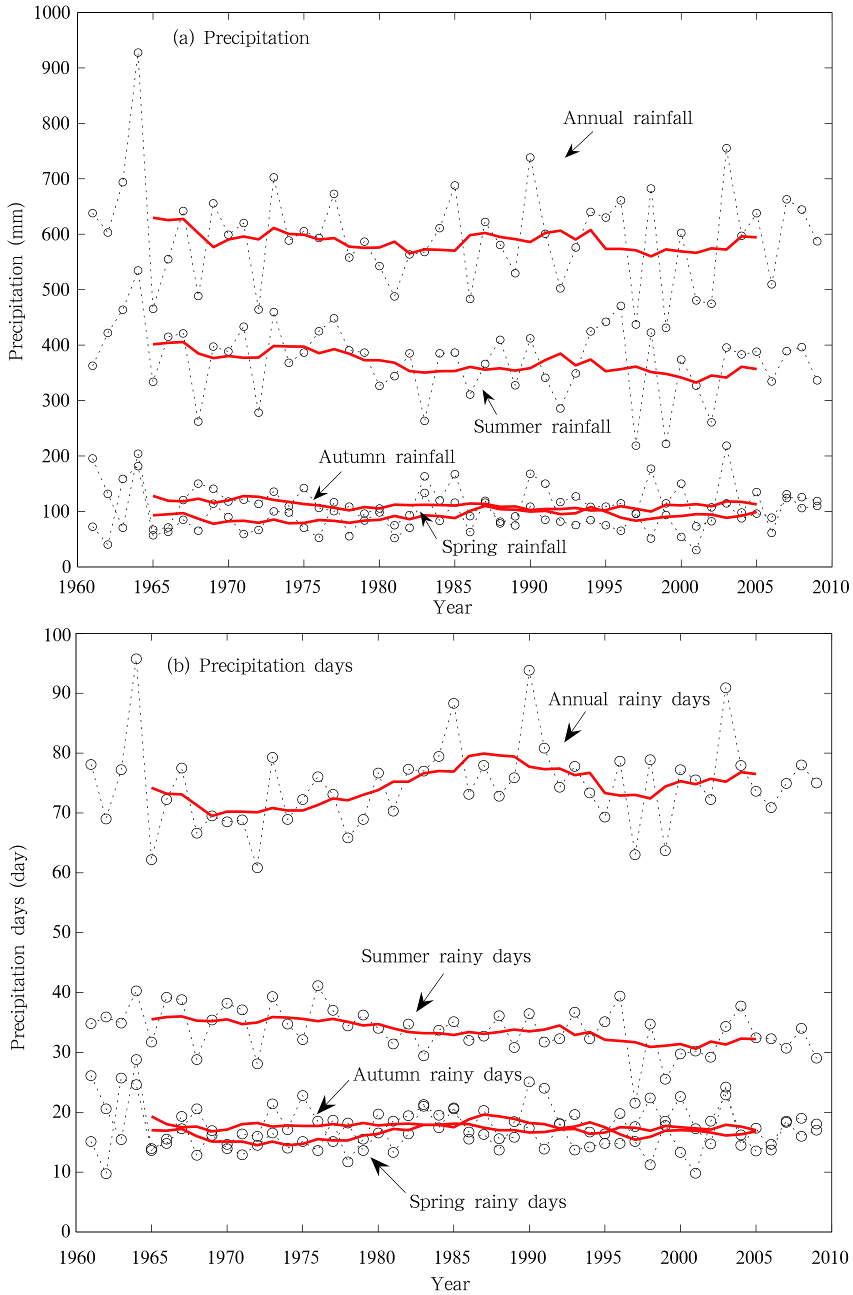

Fig. 4. Changes of precipitation and precipitation days for spring, summer, autumn, and annual total in North China during 1961–2009. Dotted lines indicate interannual variability and solid lines represent 10-yr moving average.

rainy days also decreased significantly by 5.3 days from 1961 to 2009. In summer, the winter wheat becomes mature, and spring maize, summer maize as well as potato are growing; they need about 200–300-mm precipitation to grow well. Thus, the decreasing summer rainfall generally can still support the growth of crops in the North China Plain. As a result, the decreasing summer rainfall had no direct negative impact on the growth of crops. The normal autumn precipitation was 109.7 mm, and it also decreased slightly.

As a whole, the annual and autumn rainfalls decreased slightly and the summer rainfall as well as the summer rainy days decreased significantly, but they can still support the crop growth in the North China Plain. Furthermore, the spring precipitation increased slightly, but with no significant trends. These results indicate that the changes of precipitation had no apparent negative impacts on crop growth over North China. This is in agreement with Song et al. (2005), who pointed out that the winter wheat production was not influenced apparently by the decreasing precipitation, based on the simulation by a crop model.

4. Conclusions and discussion

Over the North China Plain, the crop growth and productivity were strongly influenced by weather, especially temperature and precipitation. Therefore, this study examined the change of these agriculture meteorological resources in this region and provided insights for future agricultural decision making.

The results show that the accumulated temperature was increasing significantly by 348.5°C day due to global warming during 1961–2009, and it amounted to 4796.8 °C day during 2001–2009 over the North China Plain. At the same time, the absolute value of accumulated negative temperature was decreasing apparently by 175.3 °C day during 1961–2009, and it amounted to 259.4 °C during 2001–2009, only 65.5% of that in the 1960s. For the thermal growing season, the start of growing season displayed significant negative trends by –14.3 days during 1961–2009, and the end of growing season delayed insignificantly by 6.7 days. As a result, the length of growing season increased significantly by 21.0 days from 1961 to 2009.

The above results indicate that the thermal condition was improved to benefit the crop growth over the North China Plain during 1961–2009. Provided that an extension of the growing season is accompanied by increased temperatures, such an increase in the length of growing season may advance the potential crop production at high latitudes and promote the potential number of harvests and hence seasonal yields for perennial forage crops (Berner et al., 2004). In the 1960s and 1970s, in Shandong, Hebei, Shanxi, and Henan provinces, summer maize was planted after maturity of winter wheat, and it often could not mature fully when the first frost came. In the 1980s and 1990s, the accumulated temperature and growing season length increased. As a result, the summer maize had more thermal and time to grow, so the production of summer maize increased. Furthermore, the damage to winter wheat induced by freezing injury also happened in the 1960s and 1970s. Now, the absolute value of accumulated negative temperature decreased, so the freezing damage to winter wheat was alleviated.

The annual and autumn rainfalls decreased slightly and the summer rainfall as well as the summer rainy days decreased significantly, but they can still support the crop growth in the North China Plain. Furthermore, spring precipitation increased slightly, although with no significant trends. These results indicate that the changes of precipitation generally had no negative impacts on crop growth.

However, decreasing summer precipitation influenced strongly the water resources in North China. Because the runoff of rivers and water of reservoirs originate mainly from summer rainfall. For example, the water areas of Miyun and Huairou reservoirs, the largest reservoirs of Beijing (NCC, 2008), increased by about 10% because of more summer rainall in 2008. Contrarily, the runoff of rivers and water of reservoirs can be impacted negatively by decreased summer rainfall. During 1951–2000, about 40% of the rivers in length of 10000 km or more had been changed to be seasonal rivers in the North China Plain, and the average annual inflow to the Pacific Ocean decreased by 80% compared with that in 1950. Compared with the

1950s, the wetland decreased from 10000 to 1000 km^2, which was just 10% of that in the 1950s (Jia et al., 2002). Liu et al. (2001) pointed out that the average groundwater level dropped from 7.23 m in 1983 to 11.52 m in 1993 with a declining rate of 0.43 m yr^{-1}, based on surface observations from 600 shallow groundwater wells.

These studies indicated that the water resources decreased partly because of the decreasing summer rainfall. As a result, the irrigation of agriculture would be influenced. As we know, 61.3% of the total arable land needs to be irrigated over the North China Plain, and the water for irrigation mainly comes from rivers, reservoirs, as well as underground water in this region. Furthermore, the decreasing level of groundwater will also cause some ecological problems. Thus, this study on the changes of the agriculture meteorological resouces in the North China Plain is of practical significance.

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