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Research Article

Variation in the Meteorological Conditions on the Date of Sowing in Spring and its Effects on the Sowing of Maize in Liaoning Province During 1981–2014

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Abstract

Exploring the effects of meteorological conditions on sowing of corn in spring is helpful to fully understand the changes of the maize planting system, cultivar used, and provide a strong basis to facilitate decision-making for the national food security. Based on climatic data and corn sowing data over 35 years in Liaoning Province, the temporal and spatial variations of climate conditions were analyzed, and their effects on maize spring sowing date were explored. The results showed that, over this period, the rainfall, amount of Available Soil Water at Planting (ASWp) and spring sowing rain tended to increase in most parts of Liaoning Province. The first date when more than 10mm of precipitation was received for three consecutive days seemed to have advanced, indicating that the appropriate water conditions for sowing started much earlier. The average air temperature on the date of sowing in spring increased slightly, and the date when the daily average temperature was equal or more than 8°C advanced, which indicated that the suitable heat conditions for maize sowing came much earlier. All of these showed that climate change contributed to the bringing forward of maize sowing. However, the actual sowing date tended to be postponed because the appropriate growth period was extended as a result of climate warming, owing to high planting density, and because varieties that were adapted for higher base temperature were selected. In addition, sowing date was delayed because of the increased number of frost days and wet soil in spring.

Keywords: Maize; Spring sowing date; Climate change; Soil water content

Introduction

The ratio of area under maize cultivation in Northeast China compared to that of the entire nation was 30.9%. This included an area of 2.33×10^6 hm^2 in Liaoning Province, which accounted for 72.0% of all food crops in 2014. Crop growth is mainly driven by rainfall and temperature [1], as a result, the climate change, resulting in changes in these factors, is a great challenge on food security [2]. Maize production security is an important part of national grain security. Liaoning Province is ideal for maize cultivation in spring. Consequently, exploring the responses of maize production to climate change has important significance to fully understanding the adaptive mechanisms of spring maize to climate change.

Under the background of climate change, rain-fed agriculture has become the most vulnerable agricultural ecosystem [2-4]. The maize production in Northeast China is mainly dependent on the rainfall. The distribution of precipitation in the Liaoning Province is uneven, and especially in the western region, drought occurs frequently, which seriously hampers the stability and increase local maize yield. In the past 50 years, climate change has led to the decrease of potential yield by 2.1% in Northeast China [5]. However, an increase in production can be achieved by adopting appropriate agricultural practices and selecting suitable varieties. Selecting the date for sowing is one such important management measure to improve food production. Many studies [6,7] have reported that early sowing can increase yield and vice versa.

For maize, the choice of sowing date is mainly dependent on soil moisture and air temperature conditions [8]. Maize is a suitable crop when the daily average temperature is stable at a minimum temperature of 8°C and the soil relative humidity range is between 60% and 70%. The most suitable condition for germination is when the daily average temperature is between 18°C and 20°C. When the soil temperature at 10 cm depth is lower than 5°C, the seedlings do not easily emerge. The seed cannot be germinated when the soil relative humidity is lower than 40%. In terms of water condition, when the amount of rainfall is high and the Available Soil Water at Planting (ASWp) is enough, farmland soil can keep more water after freezing, and mudding phenomenon appears in the following year due to thawing of the soil, which is helpful to maize sowing in spring. Furthermore, the date of the first 'soaker' rain, i.e., rainfall that was heavy enough to soak the soil completely, is one of the key water indicators to determine the sowing date for maize crop [9,10]. Pertaining to heat condition, the number of frost days after April and temperature stability pass 8°C are important indexes that indicate the appropriate time to sow maize.

Studies on changes in the hydrothermal conditions have been reported earlier. However, the effect of changing meteorological

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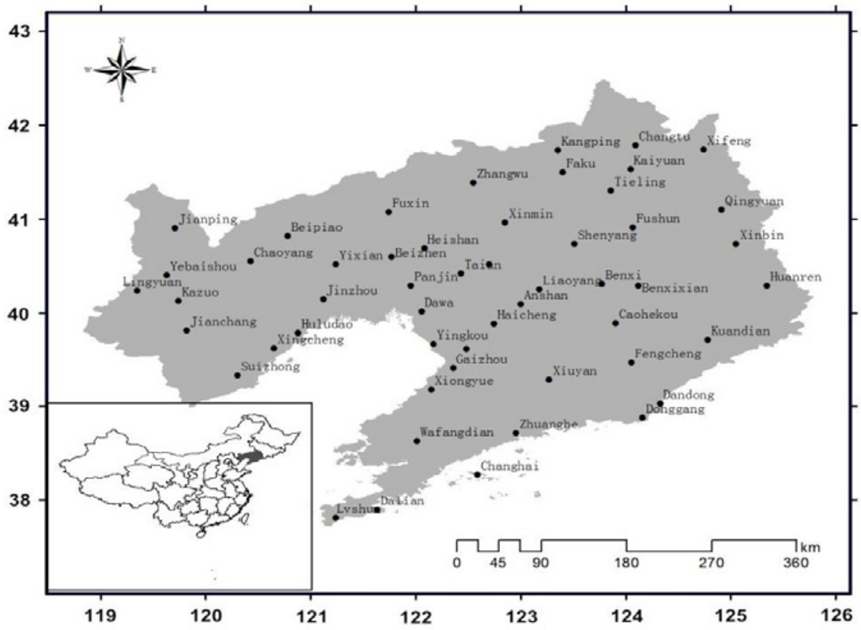

Figure 1: Location of Liaoning Province in Northeast China and 52 meteorological observatories from where the daily precipitation and daily mean temperature data for Liaoning Province were obtained.

condition on maize sowing has been unclear. Thus, the objectives of this study were (1) to analyze quantitatively the varying characteristics of meteorological conditions in spring maize sowing in Liaoning Province, and (2) discuss the effects of changing hydrothermal condition caused by climate change on the spring sowing of maize. This study will provide the scientific basis for developing an adaptive strategy to overcome the effects of climate change, making full use of agricultural climate conditions, and reasonably altering the spring farming activities to ensure a steady, and possibly an increased agricultural production.

Materials and Methods

The study area

Liaoning Province is located in the southern part of the Northeast China (118°53′-125° 40′ E, 38°43′-43° 26′ N). The terrain is mountainous on both the eastern and western sides and there are rectangular plains from northeast to southwest (Figure 1). The region belongs to the temperate continental climate zone. The temperature in this region is warm enough for maize cultivation. There is a vast difference in rainfall among the various regions in Liaoning Province. It is humid in the eastern region, while the rainfall in the hills of the western region is only 400mm, representing the semi-arid climate type. Annual precipitation is mainly concentrated in summer (June–September). Rainfall is relatively stable and consistent with the peak period of the crop's water requirement. Grain cropping system is typically one crop annually, and the main crops include rice, maize, soybean, sorghum, etc. The normal date for spring sowing is from early April to mid-May (Figure 1).

Data

The daily precipitation and daily mean temperature data was obtained from 52 meteorological observatories (Figure 1) and the sowing date for maize was obtained from 17 agricultural meteorological observatories for the period 1981-2014.

Methods

Using the 5 days moving average method, we analyzed the daily average temperature to determine stability at 8°C. The first soaker rain was determined by the first date on which the cumulative rainfall was more than 10mm on three consecutive days during April and May. If a soaker rain appeared later than June 1, that year was considered a no soaker rainfall year. The Available Soil Water at Planting (ASWp), for a given year, was determined as the cumulative rainfall from October 1st to November 30th in the previous year. Spring sowing rainfall was the cumulative rainfall from early April to mid-May.

The change of agricultural hydrothermal conditions was estimated by a linear tendency (b). According to the value of b, the trend of the climate change was judged, i.e., if b>0, it was a rising trend; but if b<0, it was a falling trend. The coefficient of variation represented the stability of change in the variable across the 35 years under consideration in this study. Larger values of this coefficient indicated more instability, and vice versa.

Results

Spatial distribution of perennial water and heat indices during the spring sowing period

In Liaoning Province, the available soil water for any years before sowing was less in the western region and more in the eastern region, and the quantity of rainfall ranged between 26.8mm and 90.5mm from 1st October to 30th November in the previous year. The ASWp before sowing was lower than 40mm in most of the western region, more than 60mm in the eastern region, and between 41.2mm and 63.3mm in the rest of region (Figure 2A). The regional distribution pattern of rain during spring in Liaoning Province was substantially

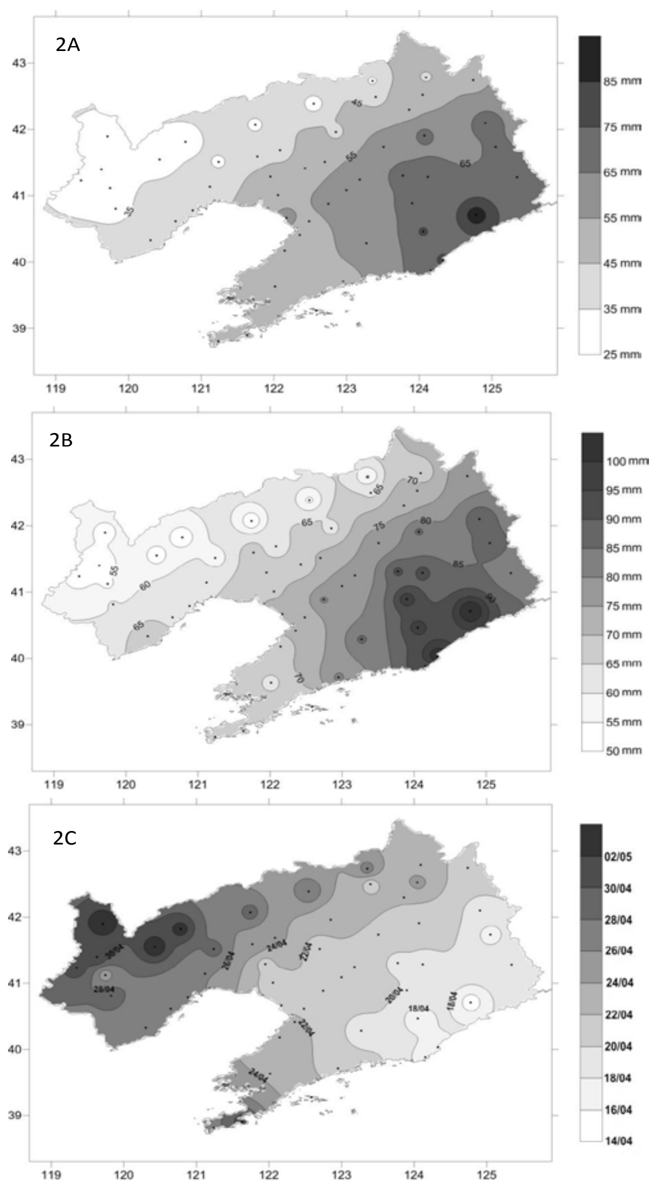

Figure 2: Spatial distribution of the average available soil water at planting (A), rainfall during spring (B), and date of first soaker rain (C) in Liaoning Province during 1980–2010.

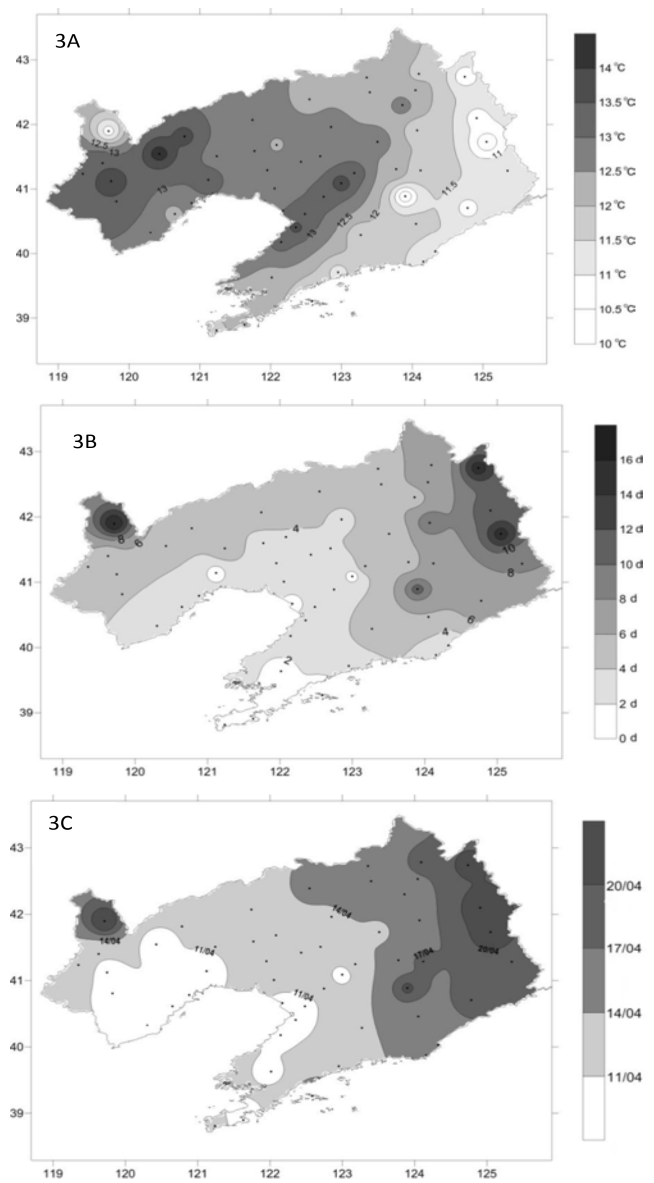

Figure 3: Spatial distribution of the average temperature during spring (A), number of frost days after April 1 (B), and the average date when the temperature was stable at or greater than 8 °C (C) in Liaoning Province during 1980-2010.

similar to the rain received before sowing, i.e., the spring rain, which was between 50.5mm and 105.6mm and lower than 60mm in the northwestern region but more than 80mm in the eastern region (Figure 2B). The first soaker rain appeared in April in most areas of Liaoning Province, but occurred in May in some areas. The first soaker rain in the eastern region occurred most early, which was between 15th and 20th April. In the southern and the western regions, the first soaker rain was recorded later, from April 25th to May 4th (Figure 2).

The average annual temperature in spring was 10.2-14.3°C in Liaoning Province. The average temperature gradually decreased from west to east, but was lower than 12°C in some areas of the eastern, southern, and western regions (Figure 3A). In the period after April 1st, the number of frost days gradually increased when moving away from the Bohai Bay and was approximately 10 days at the two corners of the northeastern and northwestern regions of the Liaoning Province (Figure 3B). Annually, the dates when the average daily temperature was stable at or over 8°C were in April in all parts of the province (Figure 3C). This was around April 14th-23rd, in most areas in the northeastern and western regions of the study area. This was a little later than the dates recorded in other areas, which were between April 7th and 13th (Figure 3).

Variation in the characteristics of the hydrothermal index during the spring sowing period in liaoning province

The ASWp showed an increasing trend in Liaoning. The quantity of rainfall from October 1st to November 30th in the previous year in most of the northeast and parts of the southern areas increased

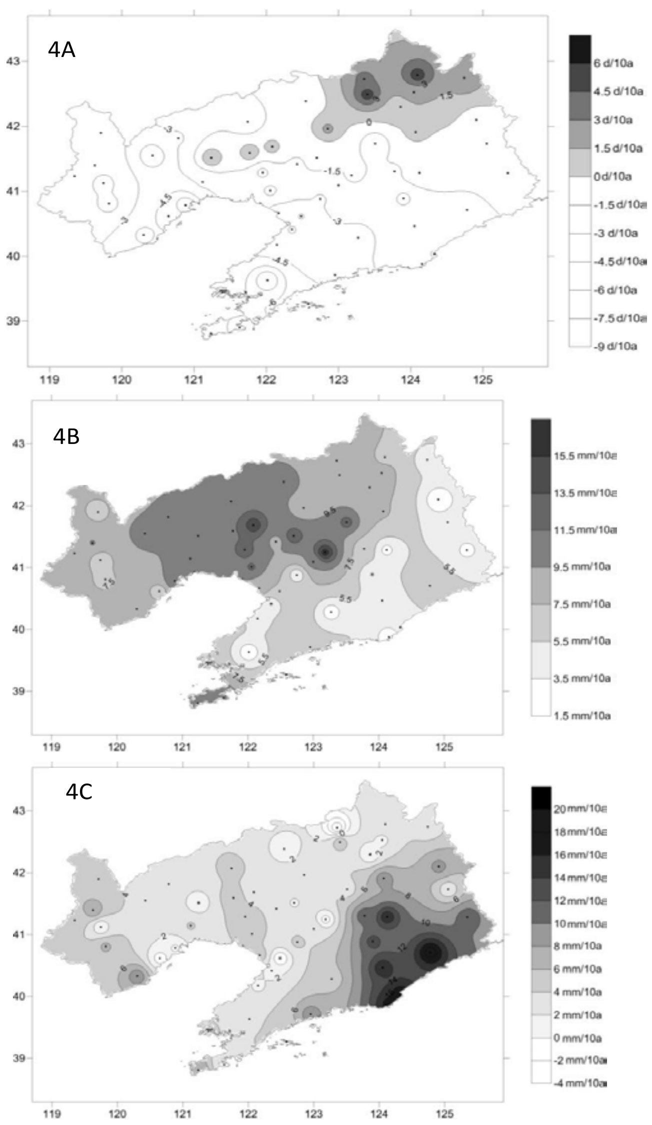

Figure 4: Spatial distribution of rainfall for the available soil water at planting (A), rainfall for sowing (B), and the average date of the first soaker rain (C) in Liaoning Province during 1980-2010.

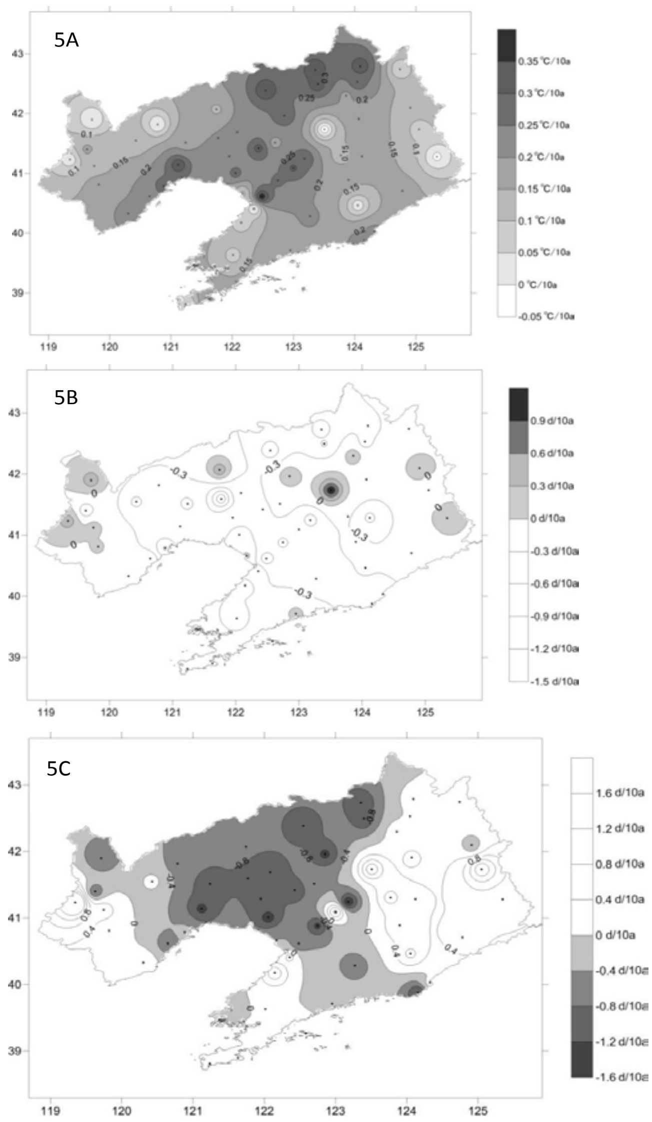

Figure 5: The spatial distribution of the average temperature during Spring (A), the number of frost days after April 1 (B), and the average date when the temperature was stable at or greater than 8 °C (C) in Liaoning Province during 1980-2010.

to 1.5-4.2mm per 10 a. Further, in parts of the mid-western areas, it increased to 10.1-16.5mm per 10 a, which was the largest increase recorded, In the remaining areas, the increase in the soil moisture level was between the above two reported ranges (Figure 4A). The soil moisture before sowing was stable across the years under consideration in this study. Its coefficient of variation was lesser than 0.50 in the northeast and southern areas, and was more than 0.59 in most areas in the western part of the Liaoning Province. From this, it can be inferred that the instability in ASWp has been increasing in the western regions of Liaoning and that a period of serious shortage in the rainfall that contributes to this instability. On the other hand, in the eastern region, it can be inferred that the increasing trend is relatively stable (Figure 4).

Spring rain showed an increasing trend in most areas of Liaoning Province. The largest increase was reported from Dalian, located in the southern tip of Liaoning, where an increase to 13.0-24.5mm per 10 a was recorded. However, six stations presented a decreasing trend, reducing to 0.1-5.7mm per 10 a (Figure 4B). The coefficient of variation in the rainfall during the spring sowing period was lesser than 0.50 in the northeast and central parts of Liaoning and the rainfall before sowing was relatively stable across the years. In most other areas, the coefficient of variation was greater than 0.51 and the rainfall before sowing showed larger changes.

We noted that in most areas of Liaoning, the date of the first soaker rain in spring showed a trend of happening earlier. The date of the first soaker rain was advanced at a rate of 0.4-5.4 d per 10 a in the northern and western regions, and by a rate of 0.2-9.0 d per 10 a in most other areas (Figure 4C). The coefficient of variation of the date of first soaker rain was large in the southeast and north-central regions of Liaoning, which indicated that a large degree of instability in this date existed in these areas in the past years. However, in other

Table 1: The date and variation of the maize sowing date in liaoning province.

Station	Sowing Date		
	Mean date (Month/Day)	Tendency Rate	Coefficient of Variation
Zhangwu	4/28	0.73	0.25
Fuqin	4/23	4.3	0.34
Changtu	4/21	3.52	0.35
Shenyang	4/26	4.8	0.31
Chaoyang	5/8	5.16	0.36
Yebaishou	5/1	0	0.25
Xinmin	4/26	2.92	0.29
Liaoyang	4/28	4.73	0.29
Dengta	4/28	4.73	0.29
Benxixian	4/29	-0.61	0.2
Jianchang	4/23	0.69	0.34
Suizhong	4/27	3.49	0.39
Haicheng	4/29	3.63	0.23
Xiuyan	4/29	-1.96	0.25
Kuandain	4/29	2.32	0.19
Wafangdain	4/24	3.69	0.23
Zhuanghe	4/22	1.9	0.23

areas, this date was relatively consistent.

The trend in the change of average temperature was not significant in some areas of Liaoning Province (trend rate was lesser than 0.03°C per 10 a). The average temperature in most other areas increased at the rate of 0.05-0.34°C per 10 a. The areas that were rapidly warming up were mainly in the northwest (Figure 5A). The coefficient of variation for the average temperature in the northern and some western areas was 0.11-0.12 and its instability across years changed greatly. The coefficient of variation in most other areas was lesser than 0.1 and therefore, the values were relatively stable (Figure 5).

The number of days at freezing temperatures reduced at a rate of 0.1-1.4 d per 10 an in most area. The maximum reduction appeared in western Liaoning. However, in a few areas, the number of days increased at a rate of 0.1-1.1 d per 10 a. The maximum increase in the number of days appears in the central region of Liaoning (Figure 5B). The minimum coefficient of variation of the number of freezing days was 0.43, which appeared in the west. The instability in the number of days at freezing temperatures was large, and the maximum coefficient of variation of the number of freezing days was 0.77, which appeared in the mid region of Liaoning. Its freezing days changed little.

In parts of the eastern and southwestern regions of the province, the date when the average temperature recorded a stable 8°C was delayed at the rate 0.1-2.9 d per 10 a. However, in the other regions it was advanced at the rate of 0.3-1.5 d / 10 a (Figure 5C). The coefficient of variation was substantially lower in the eastern region compared to the western region. To summarize, the average date of reaching a stable temperature of 8°C was delayed and changes were minimal over the years. However, in most areas within the province, the rate of delay was lesser than the rate of advancement.

Variations in the date of sowing of maize in liaoning

In normal years, the sowing date for maize in Liaoning is in April, while in Chaoyang region, it is in the beginning of May. However, earlier sowing dates are reported from the northern areas. The two stations in the eastern mountain area show an advancing in the sowing date (0.6 and 2.0 d/10 a). In the other stations, the date was delayed (0.1-5.2 d/10 a). The postponement of the date of sowing was minimal in the mid-eastern region and western region. The maximum coefficient of variation in the date of sowing was 0.39 in Suizhong, west of Liaoning. The variation of sowing date was very much in this station across years. The minimum coefficient of variation in the date of sowing was 0.19 in Kuandian, east of Liaoning. Unlike in Suizhong, at this station, variation in the sowing date was little across years (Table 1).

Discussion

Effect of spatial variation in the hydrothermal pattern on maize seedling

The soil moisture condition varies from drought in the northwest to wet conditions towards the southeast during spring sowing period in Liaoning province. Taking either ASWp rain or the spring rain into consideration, we can infer that the areas in the east were better than those in the west. When the ASWp rainfall was lesser than 50mm, drought ensues in the spring sowing period. The date of the first soaker rain was seen to gradually advance from the northwestern to the southeastern areas. Because the spring soil is too wet, the maize sowing date is later in the east of Liaoning, in areas including Benxi, Kuandian, and Xiuyan. The sowing date in these areas was around April 29th.

Table 2: Average value of each factor in differ climate condition.

	Thermal condition			Hydration condition			Anomaly of sowing stage (d)			Anomaly of seedling stage (d)			Years Related
Climate types	T1 (°C)	T2 (d)	T3 (d)	H1 (d)	H2 (%)	H3 (%)	Last	Early	Mean	Last	Early	Mean	
T+,H+	0.3	-2	0	-3	8	25	-5	-2	-1	-4	0	-2	1991, 1998, 1999, 2000, 2002, 2005, 1983, 2008, 2009, 2012
T-,H-	-0.6	3	2	1	-21	-18	4	3	4	3	3	2	1984, 1988, 1995, 1996, 2006, 2013, 2014
T-,H+	-0.7	3	2	-1	7	15	-1	5	4	-2	5	2	1985, 1987, 1993, 2010, 2011
T+,H-	0.6	-2	-1	3	14	-17	13	2	2	10	1	1	1994, 1997, 2001, 2003, 2004, 2007
TH+	-0.4	2	-2	4	-3	-13	-8	-5	-4	-5	-4	-3	1980, 1981, 1982, 1986, 1989, 1990, 1992

Notes: T1: Spring sowing temperature anomaly; T2: date anomaly when temperature was stabilized at 8°C; T3: anomaly of frozen days; H1: date anomaly of the first soaker rain; H2: ASWp rain anomaly percentage; H3: spring sowing rain anomaly percentage; T+: good heat condition; T-: bad heat condition; H+: good water condition; H-: bad water condition; TH+: good cooperate between heat and water

ASWp rain plays an important role in determining maize sowing date. In the areas with enough ASWp rain, the sowing date is later. This is seen in Liaoyang (61.3mm) and Haicheng (62.4mm), where the maize sowing date is April 28th and 29th, respectively. This is due to the better ASWp rain, with high spring sowing rain and the advancing of the date of the first soaker rain, which makes the soil too wet. When the soil water condition was appropriate and the necessary temperature conditions could be met, farmers sowed maize cultivars that performed well under high temperatures. However, due to the low ASWp rain and the later date of first soaker rain in the west of Liaoning, the farmer began sowing only when the soil water condition was guaranteed, tending to postpone the sowing to a later date. This is seen in areas such as Chaoyang and Yebaishou, where the dates of maize sowing were later compared to other area.

For sowing maize, temperature in the spring sowing period is a key factor. In areas such as Benxi, Xiuyan, and Kuandian, located in the eastern area, the spring air temperature is lower than that in other locations and the maize sowing is relativity later, around April 28th. However, at the same low temperatures at Changtu in the northern area, the date of sowing was April 21st, which was 7 days earlier than the other areas in the eastern region. This can be explained by the soil moisture level in the northern area.

Effect of hydrothermal time variation on maize sowing

ASWp appears to increase over time, with the intensity of increase greater in the western region compared to the eastern areas. This is conducive for the date of spring sowing to be advanced in the western regions. However, a bigger coefficient of variation in the ASWp rain was seen, which was lower in most years before 2001, after which, higher ASWp rains have been recorded three times. However, the ASWp rain is less in most years. Therefore, this also reflects that the western area is climatically, a typical fragile region. When the inter-annual variation of ASWp rain is large, the sowing of maize is seriously affected by this change in climate.

Overall, the date of the first soaker rain is seen to advance with time. However, this trend did not hold in the northern region. The rise in temperature and earlier date of soaker rain are helpful for an earlier spring sowing. Lower air temperatures and a delay in the soaker rain as seen in the northern region, are more conducive for a later spring sowing.

The average temperature shows a weak increase with time. An earlier date at which the temperature stabilizes at 8°C is seen in the central and western regions. This when combined with an earlier first soaker rain and an increase in ASWp rain, is beneficial for an early date of sowing for maize. As seen in the northern region, a later date at which the temperature stabilizes at 8°C along with a later first soaker rain, is more conducive for sowing maize later.

However, on the ground, most of the actual maize sowing dates was pushed back, implying that, largely, the impact of climate change on spring maize sowing was weaker than agricultural measures employed in spring maize sowing that were prevalent at the same time. Thus, the sowing date depended on the farmer's choice of crop variety and was restricted by factors like access to machinery, planting area, etc. [8]. With global warming, the suitable growth season for maize is prolonged, and farmers have more choice of maize varieties. The base temperature required for each variety differed, and from literature, it is noted that the ideal temperature range for sowing of maize is between 8°C and 12.8°C [11-15]. In recent times, many farmers tend to choose varieties that flourish at high base temperatures, and are unaffected by dense planting. Thus, although the date of the first soaker rain and date at which the temperature stabilized at 8°C were advanced, the actual seedling emergence time was postponed.

Effects of different hydrothermal configurations on the sowing and seedling emergence of maize

Various meteorological conditions over a period of nearly 35 years in Liaoning province were analyzed. It was found that the date of sowing push back has 22 a and be in advance has 13 a, the date of corn sowing and seedling emergence were greatly influenced by changes in the meteorological conditions in most years. In general, the conditions can be divided into five types as follows (Table 2).

(1) When hydrothermal condition is good, maize sowing was controlled by farmers subjectively. For example, under conditions when the average temperature is more than 0.1-0.7°C, the sowing date is 1-3 days in advance, the daily average temperature first stabilized at 8°C, the number of frozen days during sowing stage was lesser than that in a normal year, the spring sowing rain and ASWp is enough, the sowing date advanced by 2-11 days and seedling emergence advanced by 2-8 days in some years. On the other hand, when the farmer is in no hurry to sow, sowing date is delayed by 1-11 days, when the hydrothermal condition are most conducive for corn crop, because of which the sowing progress is faster, and the date of emergence of seedling is advanced by 1-10 days.

(2) When hydrothermal conditions are poor, seedling emergence is delayed. For example, average temperature lesser than 0.1-0.9°C, a 1-8 day delay in the date on which the daily average temperature first reached stability at 8°C, the number of frozen days during sowing stage is more by 1-4 days than that in a normal year, water condition is poor. Under these conditions, the date of sowing is delayed by 1-24 days and the date of seedling emergence by 1-19 days.

(3) When the water condition is appropriate, but the temperature condition is not conducive, the spring maize sowing will be affected. When the average temperature during sowing stage is lesser than 0.1-1.3°C compared to normal years, the date when the daily average temperature first stabilized at more than 8°C is delayed by 1-10 days, and the number of frozen days is greater by 1-3 days than that in a normal year, then the date of sowing is delayed by 1-12 days and seedling emergence is delayed by 3-8 days.

(4) When temperature is appropriate but moisture condition is not, the spring sowing date will be affected. When the average temperature during sowing stage is more by 0.1-0.9 °C than that in a normal year, the date when the average daily temperature stabilizes at a minimum of 8°C is advanced by 1-3 days, the number of frozen days is lesser by 1-3 days than that in normal years; and the date of the first soaker rain is delayed by 1-15 days or when the rain is lesser than 2%-45% during the sowing stage, the date of sowing is delayed by 1-34 days. However, if temperature conditions after sowing are appropriate, then the date of seedling emergence is delayed by 1-29 days.

(5) When water or heat condition is not conducive in overall, but

they meet requirement of sowing in key time. In this condition, the date of spring sowing will not be affected. For example, the water or heat condition during the sowing stage is lesser than that in a normal year, but if at the appropriate time, the soil moisture can meet the requirement of crops, maybe through timely rainfall, then, maize may be sown earlier than normal, and the seedling emergence is advanced.

Conclusion

Under the background of global climate change, the agricultural meteorological conditions in Liaoning Province, and the maize sowing dates for the spring sowing period were analyzed. Our study shows that: (1) the moisture condition in the northeastern region was better than that in the southwestern region in Liaoning Province. ASWp rainfall showed a prevalent increasing trend. Spring sowing rain increased with time in most areas. The date of first soaker rain in spring was advanced. ASWp rainfall was relatively more since 2002, while although this reduced the chances of spring drought, this may have caused spring soil to be too wet, which in turn resulted in a delay in the spring sowing of maize. (2) The heat condition was better in the southern than in the northern area. In most areas, the average temperature during the spring sowing period was higher. The first date when the temperature was stable at or was more than 8°C, was brought forward. However, this date appears relatively later in the northeast. (3) The change in the hydrothermal conditions was advantageous for spring production in Liaoning Province, and provided suitable conditions for timely, and earlier sowing of maize. Nevertheless, the actual maize sowing date is delayed in most areas. Spring soil is too wet, delaying the sowing in the eastern area. Further, the use of maize varieties that are adapted to high base temperatures can cause sowing delays in better hydrothermal condition.

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