The impact of climate change on summer maize phenology in the northwest plain of Shandong province under the IPCC SRES A1B scenario

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Abstract. Climate change will affect agricultural production. Combining a climate model and a crop growth model furnishes a good approach for analyzing this effect quantitatively. The purpose of this study is to analyze the effect of climate change on summer maize phenology in northwest Shandong province under the A1B climate scenario using a regional climate model and the CERES-Maize growth model. The results showed that the temperature would increase significantly during the maize growth season in the study region, that the increased temperature would shorten the maize growth stage and result in a potential yield loss using the current cultivar, and that it is critical to breed a heat-resistant and late-maturing cultivar to maintain the yield.

1. Introduction
Long-term observation and scientific study have shown that the earth’s climate has undergone significant changes [1]. Climate change will has a direct impact on agricultural production, resulting in a food security problem. Maize is a major food and feed crop in China. Its yield is only exceeded by that of rice and wheat [2]. Therefore, it is important to study the impact of climate change on maize production.

Based on the output of the CERES-Maize model, Hoogenboom et al. [3] found that no maize growth occurred at air temperatures below 8°C, the maximum plant growth and grain fill occurred at daily temperatures of 34°C, and growth was reduced at higher temperatures up to 44°C, above which no growth occurred. Thus, an appropriate combination of sowing date and variety maturity is crucial to allow maize to grow under temperature conditions suitable for maintaining yield [4]. A longer grain filling period increases the length of time devoted to yield accumulation [5]. Heat shock shortens the period of grain filling and causes both grain abortion and quality degradation via an increased proportion of shrunken grains, resulting in yield loss [6]. In Mozambique, Harrison et al. suggested the postponement of the planting date to escape from the concentration of temperature warming during the critical growth stage of maize under simulated future weather conditions [7]. Thus, it is important to study the impact of the future climate on maize phenology to define adaptation strategies for maintaining yield.

Many future climate scenarios have been proposed by the Intergovernmental Panel on Climate Change (IPCC) [8]. The common feature of these scenarios is the assumption of future increases in CO₂ and temperature. Among these scenarios, the moderate A1B scenario is typically considered to be relatively close to future conditions. The northwest plain of Shandong province is an important maize
planting area in China. This study discusses the influence of climate change on maize phenology in this area under the IPCC SRES A1B scenario by combining a regional climate model and the CERES-Maize growth model.

2. Materials and methods

2.1. Database

2.1.1. Monitoring data
The Yucheng Comprehensive Experimental Station is located in the center of the northwest plain of Shandong province. It is considered an important place for the study of farmland ecosystems in the research region. Maize monitoring datasets from 2008 to 2010 were collected from this station. They contain information on the soil conditions before planting, field management method, maize phenology, yield, and meteorological data.

2.1.2. Climate scenario data
Meteorological data for the period 2030–2090 were simulated with the MIROC-RegCM3 climate model. The dataset contains the following information: daily radiation, precipitation, and highest and lowest temperatures. These data were provided by the Chinese National Climate Center. Additionally, meteorological data from 1960–1990 were used to represent the baseline weather conditions.

2.2. Crop growth model
The CERES-Maize model is a well-known crop model. CERES-Maize 3.5 was used to simulate maize growth based on the input meteorological data, field management method, soil conditions before planting, and other necessary parameters. The model needs to be calibrated if it is used in a new region. The cultivar parameter is always considered important for model calibration [9]. Six cultivar parameters were used in the CERES-Maize model: the thermal time from emergence to the end of the juvenile stage (P1), the photoperiod sensitivity coefficient (P2), the thermal time from silking to physiological maturity (P5), the potential kernel number (G2), the potential kernel growth rate (G3), and the leaf development interval parameter (PHINT). These parameters were calibrated using the monitoring data from the Yucheng Experimental Station.

2.3. Data analysis
The meteorological data from 2031–2060 and from 2061–2090 were first compared to the baseline meteorological data to identify the climate change in the study area. Second, the monitoring data from the experimental station were used to calibrate the CERES-Maize model. During this stage, the ranges of the values of the cultivar parameters were preliminarily determined from a literature review. The values of these parameters were then determined by selecting the group with the minimum yield and phenology forecasting error from all possible combinations of cultivar parameter values in these ranges. Finally, the maize phenology in the periods 1961–1990, 2031–2060, and 2061–2090 were simulated and compared using the scenario data.

3. Results and analysis

3.1. Changes in climate resources

3.1.1. Heat resource
In the research region, the maize growth season begins in the middle of June and ends in early October. Compared with the mean monthly temperature in 1961–1990, the mean monthly temperature in 2031–2060 and in 2061–2090 increases significantly (p≤0.05) during the maize growth season (Figure 1a). Additionally, the mean monthly temperature in 2061–2090 is also significantly (p≤0.05) higher than that in 2031–2060 except in July. In conclusion, the heat resource will increase in this region.
3.1.2. Water resource
During the maize growth season, the mean monthly precipitation shows no significant (p≤0.05) change in the future compared with that in 1961–1990 except in October (Figure 1b). For October, the mean monthly precipitation in 2061–2090 is significantly higher than that in the other two periods. However, as maize is harvested during early October, the increased precipitation has no impact on the final yield.

3.1.3. Radiation resource
The mean monthly radiation shows no significant (p≤0.05) change in 2031–2060 and 2061–2090 compared with that in 1961–1990 except in October (Figure 1c). In October, the mean monthly radiation in 2061–2090 is significantly lower than that in 1961–1990. For the same reasons cited above, the change in radiation during this month has no impact on the final yield.

![Figure 1. Climate change in the northwest plain of Shandong. Bars around points show ±Standard Error. (a) Temperature; (b) Precipitation; (c) Radiation.](image)

3.2. Growth model calibration
After calibration, the CERES-Maize model effectively predicts maize growth in the region. The relationship between the simulated and actual yield has a coefficient of determination ($R^2$) of 0.71 and a relative error (RE) of 5.67%. The relationship between the simulated and actual maize phenology has an $R^2$ of 0.99 and an RE of 7.58%.
3.3. Changes in maize phenology
Maize phenology was simulated for three periods based on the calibrated CERES-Maize model. Note that the maize growth period would be significantly (p≤0.05) shortened under future weather conditions (Table 2). In 1961–1990, maize requires 89 days to complete its life cycle. In 2031–2060 and 2061–2090, it only requires 72 days and 66 days, respectively. In particular, the time from silking to maturity decreases dramatically in 2031–2060 and 2061–2090 compared with 1961–1990. During this period, maize completes its filling stage. The life cycle of maize is shortened because of increased accumulated heat under future weather conditions. An increased rate of development and rapid filling, caused by heat stress, will result in yield loss, as noted by many studies [6,10,11]. Thus, from the perspective of field management, it is suggested that the sowing day be postponed to avoid heat shock during maize filling to maintain the yield. Another aspect of the problem is that it is critical to breed a heat-resistant and late-maturing cultivar.

Table 2. Simulated maize phenology in different periods.

| Growth Stage | Days after planting (d) | Coefficient of variation (%) |
|--------------|-------------------------|--------------------------------|
|              | 1961–1990               | 2031–2060                      | 2061–2090                      |
| Emergence    | 5^a(8.22)b              | 4^b(11.22)                     | 4^b(11.22)                     |
| Silking      | 49^b(6.64)              | 43^b(5.15)                     | 42^b(5.23)                     |
| Maturity     | 89^b(5.33)              | 72^b(13.61)                    | 66^c(14.30)                    |

^a Values in the same row with different capital letters represent significant differences (p≤0.05) between periods (Duncan test).
^b Values in parentheses are coefficients of variation.

4. Conclusions
Under the IPCC SRES A1B scenario, the heat resource will increase dramatically in 2031–2090 compared with 1961–1990. It will shorten the maize growing season and result in yield loss. For field management, postponing the date of sowing of maize is suggested as a method to mitigate yield loss. Moreover, breeding a cultivar with characteristics more suitable for the future climate is critical.

The above conclusions were drawn to adapt to climate change. However, the water resource conditions and the potential change in the cropping pattern in the future were not considered. Further studies need to take all these issues into consideration.

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