

Analysis of Climate Change Impacts on Spring Maize Yields in the Loess Plateau

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Abstract: Using daily climate projection data from Agricultural Production Systems sIMulator (APSIM) and the Sixth International Coupled Model Comparison Program (cmip6) Scenario Model Comparison Program (ScenarioMIP), the impacts of climate change on maize yields in Yuzhong were assessed under two future social development pathways, namely, SSP126 (low greenhouse gas-emitting sustainable development) and SSP585 (high GHG-emitting conventional development) two future social development pathways, the impacts of climate change on maize yields in Gansu were assessed. It was found that under the baseline and SSP126、SSP585 climatic conditions, spring maize yield was 206 kg ha⁻¹ higher in the N200 treatment than in the N150 treatment, and 736 kg ha⁻¹ and 373 kg ha⁻¹ in the SSP126 and SSP585 scenarios, respectively, and that increasing N application could effectively increase yield. There were significant spatial and temporal differences in the effect of climate change on spring maize yield under the same N application level treatment, when the N application level was 150 kg ha⁻¹, compared with the baseline (1980~2014) regional spring maize annual average yield increased by 1335 kg ha⁻¹ (SSP126) and 516 kg ha⁻¹ (SSP585); when the N application level was 200 kg ha⁻¹ (SSP126) and 683 kg ha⁻¹ (SSP585); when the N application level was 200 kg ha⁻¹, the average annual spring maize yield increased by 1865 kg ha⁻¹ (SSP126) and 683 kg ha⁻¹ (SSP585) compared to the baseline region, and the regional climatic changes favored the production of spring maize, and the effect of the yield increase was higher in SSP126 than in the SSP585 climatic scenario.

Keywords: Spring maize; APSIM model; Climate change.

1. Introduction

Maize is the world's largest food crop, but also China's largest planted area, the highest total output of major food crops, the healthy development of its industry to ensure national food security and meet market demand plays an important role¹. Climate change has led to significant changes in the growth and development processes and yields of crops around the world. Maize has developed thermophilic characteristics during its phylogeny, and is a thermophilic, short-day crop that can be widely grown in areas where the average temperature of the hottest month is higher than 20 °C. In the context of climate change, due to heat resources, maize is a major food crop. In the context of climate change, the plantable area of thermophilic crops is expanding due to a significant increase in heat resources, and climate change has already led to a northward shift of the northern boundary of maize cultivation in China^[1], a lengthening of both the theoretical growing season and the actual fertility period^[2], and an expansion of the plantable area of medium- and late-maturing varieties. At the same time, climate warming has led to some acceleration of crop growth and development rates^[3], and shortening of the fertility period of crops without changing varieties, which is not conducive to the accumulation of biomass and the formation of yields^[4]. Globally, climate change has led to a 3.8% decline in maize

yields^[5]. In addition, deeper relevant scientific research and increased levels of agricultural production can offset the adverse effects of climate change to some extent^[6]. For example, the renewal of varieties contributes 40-60% to the improvement of yield^[7]; the application of nitrogen fertilizer is also an important guarantee to maintain high yields of maize, and rational application of fertilizer on the basis of nutrient adequacy not only ensures stable maize yields and increased yields, but also reduces the risk of environmental pollution. Rational fertilization is one of the key agricultural management measures affecting the growth and development of crops, as well as one of the measures to effectively improve the yield and quality of spring maize.

With the in-depth study of the effect of fertilizer treatment on crop yield and the application of crop simulation technology, many researchers have been based on field trial data, based on different types of fertilizer treatment on maize yield to make research. Corn yield is inextricably linked to fertilization, and corn is sensitive to nitrogen fertilization, which can significantly promote corn growth. At the same time, crop simulation technology has been used to simulate the growth and development, yield formation and sensitivity analysis of maize in different research areas². The APSIM model is a model with a strong mechanistic basis, and it has a better simulation ability for crop cropping system, crop physiological and ecological mechanisms of crop rotation.

Compared with other crop models, the APSIM model has wider application and higher accuracy.

In this study, the APSIM-maize model was calibrated and validated using existing research data in the Loess Plateau region, and the validated APSIM-maize model was used to simulate spring maize yields with different levels of nitrogen application based on two future climate scenarios: low-level greenhouse gas emissions (SSP126) and high-level greenhouse gas emissions (SSP585), and the simulated yields were based on the regional historical climate. yields as a baseline. The objectives of this study were (i) to clarify the spatial and temporal changes in the future climate of the Loess Plateau region under the two emission scenarios, and (ii) to predict the appropriate nitrogen application and yield changes of spring maize under the two climate scenarios, with a view to providing theoretical support for addressing climate change.

2. Materials and Methods

2.1. Study area

The experimental area is located in Yuzhong County (35°54'N, 104°05'E), Gansu Province, with the landscape of the Loess Plateau hilly and gully area, and a continental temperate monsoon climate, with an average annual temperature of about 6.7°C, an average annual precipitation of about 388 mm, with about 48-67% of rainfall occurring in July-September, and a frost-free period of about 130 days.

2.2. Data

The data for future climate scenarios are obtained from CMIP6 (Sixth International Coupled Model Intercomparison Program) in the Global Climate Models (GCMs) provided by the World Climate Research Program (WCRP) (<https://esgf-node.llnl.gov/search/cmip6>). SSP1 denotes the economic convergence sustainable development pathway, and the radiation intensity reaches 2.6 W·m⁻² and SSP5 is a fossil fuel-driven development pathway with a radiation intensity that can reach 8.5 W·m⁻². In this study, the low-emission sustainable development (SSP126) and high-emission conventional development (SSP585) scenarios were selected to assess the impact of the projected climate scenarios on the regional spring maize yield.

2.3. APSIM-maize model

The APSIM model is a crop growth simulation model developed by the Australian Agricultural Research Establishment [8], which has a good simulation of crop yield, biomass, and soil water and nitrogen cycling [9], and has been used to simulate the impacts of climate change, management practices, etc., on crop growth [10] and is widely used in various regions of the Loess Plateau [11].

In this study, APSIM-maize version 7.10 was used to assess the effects of climate change and nitrogen application levels on regional spring maize yields, and the APSIM-maize model

was driven by daily climatic data (maximum temperature, minimum temperature, precipitation, radiation) to simulate the growth of spring maize under different climate scenarios and management practices.

2.4. Model calibration and validation methodology

In this study, the APSIM-maize model was calibrated using data from existing previous studies, and three metrics were used to assess the accuracy of climate data predictions and the performance of the APSIM-maize model. This study used three indicators to evaluate the accuracy of climate data prediction and the performance of the APSIM-maize model, including R² (the coefficient of determination), RMSE (The root mean square error) and d (Willmottagreement index).

$$R^2 = \left(\frac{\sum_{i=1}^n (o_i - \bar{o})(s_i - \bar{s})}{\sqrt{\sum_{i=1}^n (o_i - \bar{o})^2 \sum_{i=1}^n (s_i - \bar{s})^2}} \right)^2$$

Where, o_i is the observed value, s_i is the simulated value, \bar{o} is the mean value of observations, \bar{s} is the mean value of simulations, and n is the number of observations.

$$d = 1 - \frac{\sum_{i=1}^n (s_i - o_i)^2}{\sum_{i=1}^n (|s_i - \bar{o}| + |o_i - \bar{o}|)^2}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (o_i - s_i)^2}{n}}$$

Lower RMSE and higher R² and d indicate good agreement between simulated and observed values.

3. Results and Analysis

3.1. Model calibration and validation

In this study, the measured meteorological data from 1980 to 2014 in Yuzhong County were used to fit with the CMIP6 historical forecast data, and the results showed that the CMIP6 historical forecast data had a high accuracy, the R² of the predicted value and the measured value was in the range of 0.82 to 0.91, d was in the range of 0.93 to 0.95 directly, and the RMSE of the highest temperature, the lowest temperature, the radiation, and the precipitation were 5.07°C, 5.49°C. The RMSE of the highest temperature, the lowest temperature, the radiation and precipitation were 5.07°C, 5.49°C, respectively, 2.49 MJ·m⁻² and 80.22 mm, and the main parameters of spring maize in Yuzhong County have been determined and rate-determined using field trials. On the basis of this experiment, the calibrated APSIM model simulated spring maize yield with high accuracy, and the R² between the simulated and measured values was 0.91, d was 0.87, and the RMSE was 774 kg·ha⁻¹.

The calibrated APSIM-maize model crop parameters are shown in the following table:

Table 1. Crop parameters

Parameter	Value
tt_emerg_to_endjuv/(°C·d)	130
photoperiod_crit/h	12
photoperiod_slope/(°C·d)	22
tt_flower_to_maturity/(°C·d)	650
Head_grain_no_max	620
Grain_gth_rate/(mg·kernel ⁻¹)	12

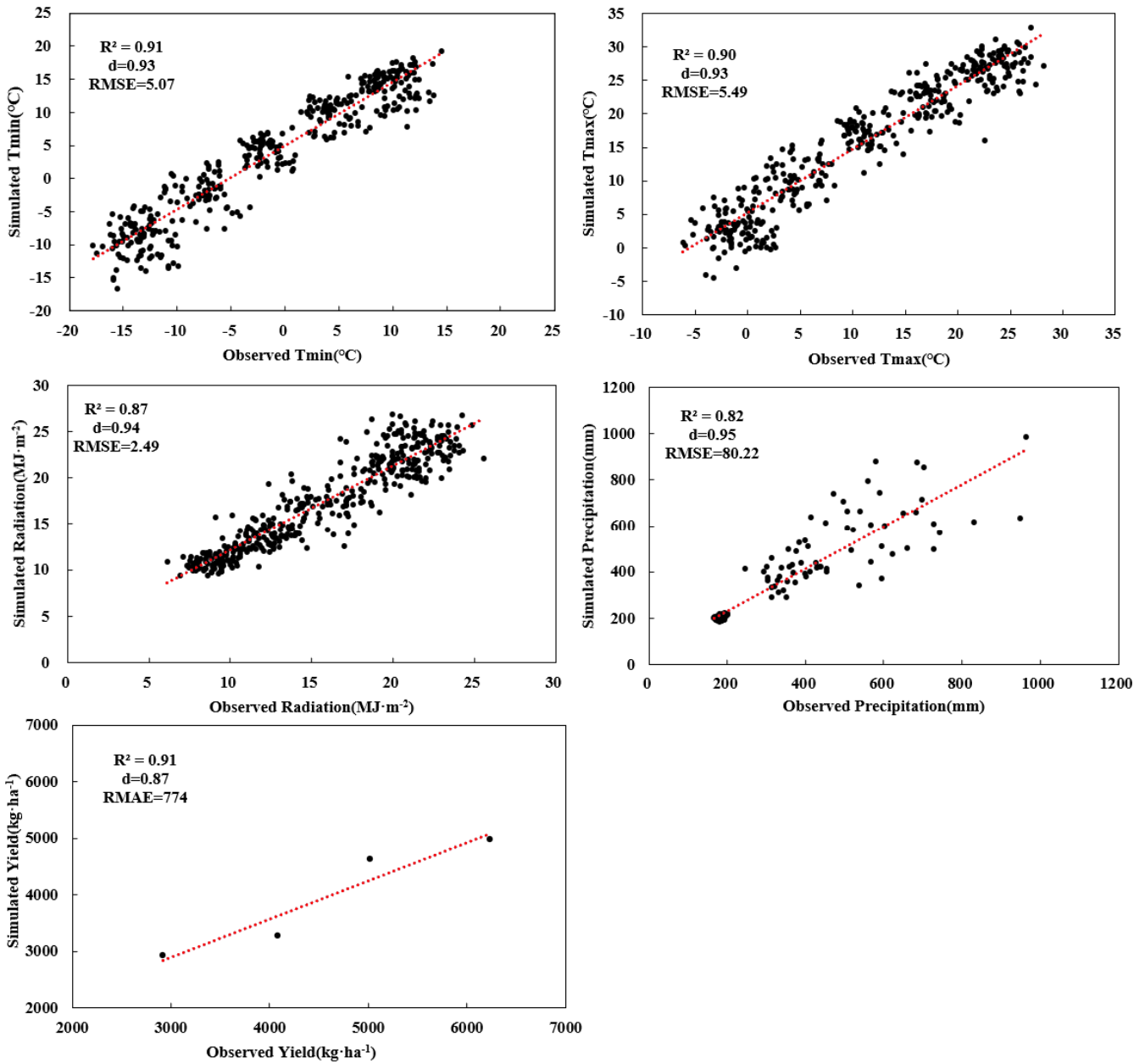


Figure 1. The curves of historical simulated and measured climate, yield

3.2. Long-term effects of fertilizer application on maize yield under different climatic scenarios

Fertilization is one of the key agricultural management practices that affect soil properties and crop growth and development. Different fertilization treatments have significant effects on crop yield. The results of maize yield through long-term simulation showed that the trend of average yield change of spring maize under different fertilization systems basically showed N80>N60, and the increase of nitrogen fertilizer application could effectively increase the yield of spring maize.

Compared with the baseline, the spring corn yields in the three stages of 2030s (2030~2055)\2060s (2056~2075) and

2090s (2076~2100) under the SSP126 climate scenario were significantly higher than the baseline, and the spring corn yields increased gradually with the change of climate. The spring maize yields in the three stages of 2030s (2030~2055) and 2060s (2056~2075) under the SSP585 climate scenario were significantly higher than the baseline, and the spring corn yields increased gradually with the change of climate. 2060s (2056~2075) stages of spring maize yield was higher than the baseline, but the 2090s (2076~2100) stage yield was lower than the baseline, and the nitrogen application level of N80 yielded less than that of N60, which may be due to the drastic changes in the climate that led to the spring maize being stressed by soil moisture and other factors, and in the event of crop water scarcity, the increase in the amount of nitrogen applied was detrimental to the growth of the crop.

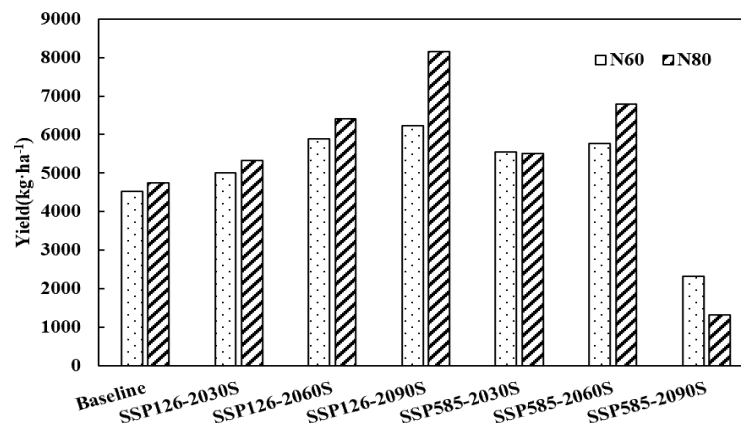


Figure 2. Bar chart of maize yield simulation

4. Discussion

In this study, on the basis of meteorological data, we analyzed and simulated the changes of spring maize yield under different climatic backgrounds with different nitrogen application levels, taking maize in Yuzhong County as the research object. The results showed that the APSIM model could basically simulate the effects of different fertilization treatments on spring maize yield accurately. The results showed that nitrogen fertilization also had a more obvious promotion effect on spring maize yield. Different types of fertilization treatments have more obvious effects on crop yield^[12]. The study shows that when the temperature increases or decreases, the corn yield will also increase or decrease. When the temperature increased by 4°C, the corn yield decreased, which may be related to the shortening of corn fertility period and insufficient irrigation due to the increase in temperature^[13], which is consistent with the result that the yield of N80 was lower than that of N60 treatment in 2090S under the scenario model of SSP585 in the present study. In addition, Nitrogen fertilizer as an important factor affecting corn yield, reasonable application of nitrogen fertilizer is one of the necessary factors to achieve high corn yield. Therefore, rational application of nitrogen fertilizer in combination with climate change is an important measure to guarantee high corn yield.

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