

Effects of Changes in Temperature and CO₂ Concentration on Maize Yields in the Loess Plateau

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ABSTRACT

Addressing the impact of climate change on food security is now one of the most important challenges facing humanity in the twenty-first century. As one of the three major food crops in China, maize is widely planted on the Loess Plateau and is also a major source of local agricultural income. Therefore, accurately assessing the impacts of climate change on local maize production and formulating corresponding adaptive measures are of great theoretical and practical value in reducing the impacts of climate change and guaranteeing the sustainable development of local agriculture. In this study, we calibrated and validated the parameters of the APSIM model using maize field trial data from 2009 to 2012 in Yuzhong County to assess the applicability of the model in the local area. Effect of using measured climate data from 1979 to 2018 and changes in climate data based on measured data and different CO₂ concentrations (350 ppm, 450 ppm, 550 ppm, 650 ppm and 750 ppm) on maize yield in the region. The results showed that under the same CO₂ concentration gradient, with the increase of temperature, corn yield basically showed a decreasing trend, in which the CO₂ concentration at 350 ppm corn yield decreased at the greatest rate, the temperature increased by 5 °C compared to the baseline yield decreased by 30%; at the same temperature, with the increase of CO₂ concentration, corn yield had a small increase, in the baseline temperature case, CO₂ concentration at At 750 ppm, corn yields increased by 9% compared to yields at 350 ppm.

KEYWORDS

CO₂, Climate change; APSIM model; Maize

1. INTRODUCTION

Combating climate change is one of the greatest challenges facing humanity in the 21st century [1]. The Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (The Intergovernmental Panel on Climate Change, IPCC) (2014) points out that global warming is an indisputable fact, and it is predicted that by the end of this century, the global average temperature will increase by 0.3°C~4.8°C, while China will have warmed by 1.3°C~5.0°C [2]. Agriculture is one of the most sensitive and vulnerable areas to the impacts of climate change [3]. Climate change has a

predominantly adverse impact on global food. Securing global food production to meet growing demand under climate change has become a serious challenge. Since 1980, climate change has led to a 3.8% cent and 5.5% decline in global corn and wheat production, respectively [4]. The impact of climate change on our agricultural production and food security is all the more serious as we are the most populous country in the world, but have only 7% of the world's arable land [5]. In China, maize is currently the largest sown area, the highest yield of important food crops. some scholars predict that by the middle of the 21st century, without taking any adaptive measures, the future climate change will be on China's three major food crops (rice, wheat and maize) to varying degrees of adverse impacts, respectively, yield reduction of 4~14%, 2~20% and 0~23% [6]. Therefore, how to cope with the adverse effects of future climate on agriculture has become a common problem faced by scientists all over the world.

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 the yield of spring maize based on different climate change data and CO₂ concentration, and to clarify the effects of changes in temperature and CO₂ concentration on the yield of spring maize.

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

Climate data (1979~2018) came from the actual monitoring data of China Meteorological Station, soil parameters and field management parameters came from field experiments, the climate change data used in the APSIM model were changed from the measured data, the baseline was the measured climate data from 1979~2018, Tem+2°C was from the minimum temperature and maximum temperature increased by 2°C in the measured climate data from 1979~2018 The baseline is the measured climate data from 1979 to 2018, Tem+5°C is the minimum and maximum temperature increased by 5°C in the measured climate data from 1979 to 2018, and precipitation and radiation remain unchanged from the original monitoring data.

2.3. APSIM-maize Model

The APSIM model is a crop growth simulation model developed by the Australian Agricultural Research Establishment [7], which has a good simulation of crop yield, biomass, and soil water and nitrogen cycling [8], and has been used to simulate the impacts of climate change, management practices, etc., on crop growth [9] and is widely used in various regions of the Loess Plateau [10].

In this study, APSIM-maize version 7.10 was used to assess the effects of temperature and CO₂ concentration changes on regional spring maize yields, and the APSIM-maize model was driven by daily climatic data (maximum and minimum temperatures, precipitation, and radiation) to simulate the growth of spring maize under different temperatures and CO₂ concentrations.

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 R^2 (the coefficient of determination), RMSE (The root mean square error) and d (Willmott agreement 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 R^2 and d indicate good agreement between simulated and observed values.

3. RESULTS AND ANALYSIS

3.1. Model Calibration and Validation

On the basis of this experiment, the calibrated APSIM model simulated spring maize yield with high accuracy, and the R^2 between the simulated and measured values was 0.908, d was 0.875, and the RMSE was 775 kg-ha⁻¹. The measured meteorological data of Yuzhong County from 1979 to 2015 were used in this study.

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

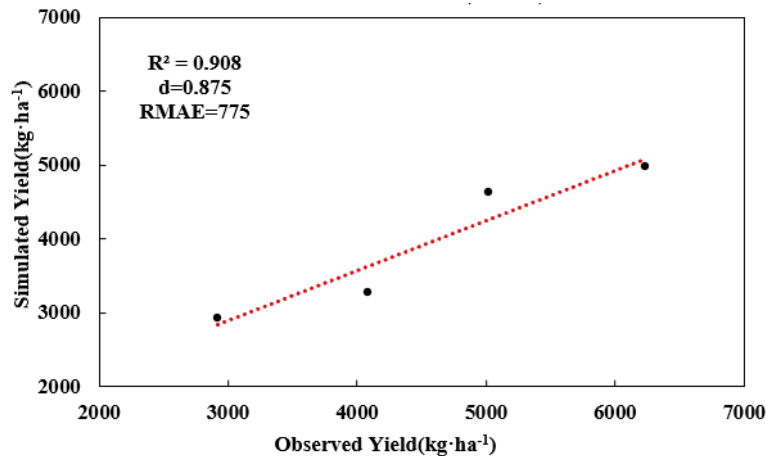


Figure 1. The curves of historical simulated and measured yield

Table 1. Crop parameters

Parameter	Value
tt emerg to endjuv/(°C·d)	90
photoperiod_crit/h	12
photoperiod_slope/(°C·d)	22
tt flower to _maturity/(°C·d)	600
Head_grain_no_max	620
Grain_gth_rate/(mg·kernel ⁻¹)	12

3.2. The Effect of Increasing Temperature on Maize Yield

As can be seen from the figure, under the same CO₂ concentration gradient, with the increase in temperature, corn yield basically showed a downward trend, in which the CO₂ concentration of 350 ppm corn yield decline rate is the largest, the temperature rise of 5 °C compared to the baseline yield decreased by 30%, the CO₂ concentration of 650 ppm corn yield decline rate is the smallest, the temperature rise of 5 °C compared to the baseline yield decreased by 16%, temperature rising was negatively correlated with corn yield.

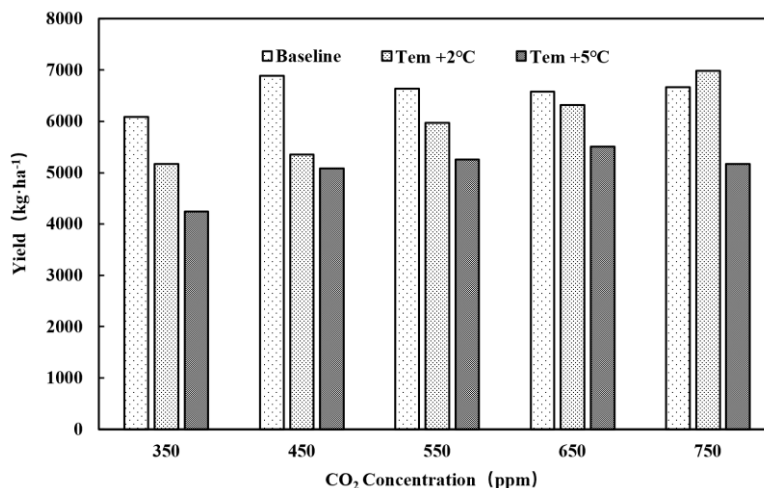


Figure 2. Effect of temperature change on yield

3.3. Effect of CO₂ Concentration on Maize Yield

As can be seen from the figure, at the same temperature, with the increase of CO₂ concentration, there is a small increase in corn yield, in the case of baseline temperature, CO₂ concentration at 750 ppm corn yield can reach 6663kg ha⁻¹, compared with CO₂ concentration at 350 ppm case yield increased by 9%, baseline temperature and Tem +5 °C case CO₂ The increase in CO₂ concentration at baseline temperature and Tem+5°C had a small effect on crop yield increase, while the increase in CO₂ concentration at Tem+2°C had a large effect on crop yield increase.

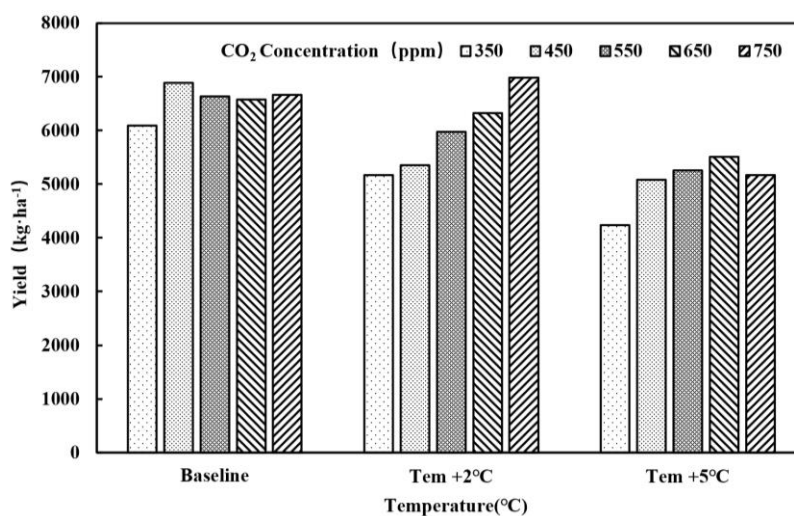


Figure 3. Effect of changes in CO₂ concentration on yield

4. DISCUSSION

Temperature is an important meteorological factor affecting the growth and development of maize, the results of this study showed that with the increase in temperature, maize yield showed a decreasing trend, this is probably because in the appropriate temperature range, the increase in temperature will increase the photosynthetic rate, which will have a positive impact on the dry matter accumulation and maize yield, but if the temperature rises above the threshold, it will lead to the acceleration of the crop's growth and development rate, resulting in the formation and accumulation of dry matter mass cycle shortening, dry matter accumulation decreasing, and yield decreasing [11-13].

The response of maize to climate warming and changes in CO₂ concentration is a complex, interacting process. The results of this study indicate that elevated CO₂ concentration has a positive but very limited effect on corn yield formation. This is mainly due to the fact that maize, as a C₄ crop, benefits from elevated CO₂ concentration much less than C₃ crops [14]. The results of the current study also suggest that the fertilizing effect of CO₂ has a limited role in increasing maize yield [15-17].

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