Effects Of Climate Change On Maize Yield (Zea Mays L.) In Hebei Province Of China

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Abstract

Maize is one of major crop in Hebei province in northeast China which is under threat for yield instability due to climate change effects. Previous studies argued on the significance of the impact of climate change on maize yield variability. We used weather data from 2000 to 2010 then we simulated predictive maize yields under regional PRECIS A2 and B2 scenario using Maize Production Emulation System (MPES). Our results projected that, the LAI, for the same field there is different LAI and ET Significant upward trend in the growth of maize during the average temperature rise high amplitude were 0.07°C/year and 0.067 °C reached to the significant level with $P \leq 5\%$, $r=0.64^{**}$, $r=0.58^{**}$. The maize yield change up to 20% change is expected due to rain increase amount, but this change will fail down by 2050s and even serious around 2070s in most simulated sites in Hebei province.

Keywords: Climate Change, Maize Yield, Regional Scale, PRECIS scenario, Hebei Province China.

1. Introduction

Maize (Zea mays L.) is one of the most important feed crops in China and it is also one of the main crops in Huang-Hai-Plain (HHP) china including Hebei province. For example HHP, known as the “bread basket” of China (World Bank, 2002), has only 7.7% of national water resources, yet it produces 39.2% of national grain supply and 32.4% of gross domestic product (Tian, 2006). Thus, the ability to meet future demand may hinge on proper assessment of medium- and long-term agricultural vulnerability to climate change and the measures taken to adapt accordingly (Lin, 1996).

The decline of the productivity in this area continues to be a major concern to policy makers due to its impact on food security (Liu, et al. 2012). At national and regional scale, differences in climate projections often have larger influence on changes in crop yields. How significant these changes in climate affect maize yield and food security?

Previous studies showed different views on the significance of the impact of climate change on maize yield. Fulu Tao et al. (2009) demonstrated that for all maize cultivation grids across Henan province China, the maize yield changes based on super ensemble simulations with 60% probability maize yields could decrease by 8.4% by 2020 and 13.3% by 2050 under A1F1 scenario and 18.1% under B1 scenario.

Allison et al. 2006 showed in the study of climate change impacts on agriculture in Huang-Hai Plain (HHP) that, the specific development under scenario A2 or B2 did not significantly alter the sequestration crop potential of the region but future precipitation increases simulated would prove beneficial to both crop yields and soil organic matter.

Chi-Chung Chen et al. (1999) investigated on the yield variability influenced by climate change has an interesting positive impact, so this might have been achieved at the expense of
increased yields risk confirming work by Anderson and Hazel. More rainfall causes maize yield level to rise, while decreasing yield variance. Temperature has the reverse effect on maize yield levels and variance.

Some other results have shown by Meng Wang et al., (2011) that, using uncertainties of the future climate change projection, the maize yield in Jilin province China is highly likely to decline in western and central regions of the province but increases in the east part. The average maize yield in west and central regions is projected to decrease 15% or more by 2050 and around 30% in 2070 under A2 and B2 scenarios respectively. David B. Lobell and Marshall B. Burke (2010) used CERES to show that with +2°C increase on temperature, the maize yield loss is between 11.4% and 12.7%.

However, Liming Ye et al, (2012) carried out some research on the same area. Their results predict that food crop yield will increase from+3% to 11% under A2 and +4% under B2 scenarios by 2030 and 2050 respectively. The maize yield in northeast China is projected to respond negatively to climate change the 2015 under SRES A2 scenario but overall, the maize yield is projected to increase at 0.2-0.3% per year at national scale during period 2011-2040 under A2 scenario and the yield change of 10% in 2040 under B2. Their demonstrated that their results showed largely positive effects of climate change on crop yield in China. ZhiJuan Liu et al. (2012) show that climate change is no longer a worry by using the good farm management (new varieties, planting density etc.).

The argument between two sides is a challenge because of uncertainty of the climate change issues. We propose to examine this problem using MPES simulation model to simulate the impact of the change in rain and temperature under regional PRECIS A2 and B2 scenarios. It is an additional view to the existing results.

This research examines the impact of climate change on maize yield in Hebei province China. We use Maize Production Emulation System (MPES) model, Li Shijuan and Yeping Zhu (2008) to simulate maize yield variability under regional climate change scale then compare the result to the observed maize yield.

The objectives of this work are focusing on the evaluation of the performance of the MPES for simulating maize growth, development and yield under climate change conditions with the climate drivers (Temperature, Rain); the identification of the impact of the local climate
change on the maize yield variability; the prediction of the future maize yield under PRECIS A2 and B2 climate scenarios and the display of different thematic map using GIS.

2. Material and Methods

2.1 Study area

In this study, 9 simulation sets in different 9 counties (Quzhou; shenzhou; xinji; ningjin; zhengding; qingxian; dahe; luanxian and huailai) from 2000 to 2010 located in 7 different cities (Handan; Hengshui; Shijiazhuang; Xingtai; Cangzhou; Tangshan and Zhangjiakou) of Hebei province China (36° 01‘ to 42° 37’ North and113° 31 to 119° 53 East ), Figure 1. Hebei province has a continental monsoon climate, with cold, dry winters, and hot, humid summers. Temperatures average −16 to −3 °C in January and 20 to 27 °C in July; the annual precipitation ranges from 400 to 800 mm, concentrated heavily in summer. The main annual temperature is between 11-13°C.

2.2 MPES model description

The MPES model is a computer software system serving field experiment and simulation of the intelligent agriculture laboratory of the Chinese academy of agricultural sciences. MPES is issued from the CERES-maize model adapted on the cropping situation in Northern China, Li Shijuan and Zhu Yeping (2007). MPES integrated many technologies such as system theory, simulation; artificial intelligent; visualization and network technology, Yan Ding-Chun et al., (2007).

This MPES model can provide plant management mean and decision making information after processing computer simulation. Basic parameter database consists of the information about location, fertilizer type and management, irrigation management, cultivation variety, phenology data, soil texture and soil parameter, among which phenology data; also the water content before sowing, and organic matter percent, volume weight, NH4-N, NO3-N and PH of every soil layer, Li Shijuan and Zhu Yeping (2008). This model can simulate the effects of cultivars, sowing date and density, solar radiation, air temperature, rainfall, soil moisture, and nitrogen on crop growth, development and yield. Simulating the crop yield according to the weather drivers such as Temperature, Sun radiation and Precipitation, and then forecasting the maximum yield is one of the important functions of MPES, Yeping Zhu and Zhang Jian Bin (2001).

2.3 Data collection

In this study, 9 meteorological stations in Hebei province china were selected from the weather stations operated by the National Meteorological Networks of China Meteorological Administration. 9 simulation sites across Hebei province were selected based on 10 years (2000-2010) length data. In each simulation site, we used the nearest meteorological data where maize growth and yield observed information are available. Hence, we used 4 of the 10 stations were used in all the 9 sites for the model calibration and validation by utilizing available phenological and climate data Table 1.

The soil parameters and cultivars were obtained from database of the institute of soil fertilizer of Hebei province’s academy of agricultural sciences, Zhao Tong-ke et al., (2001). Soil nutrient in 2007 with reference to the location in samples depth (0-100cm); bulk density 1.26-1.4g/cm3); PH (5.8-8.83); NH+4_N and NO3- _N, organic matter (OM). The cultivar using in this work are the zhenda958 and nongda108 the maize varieties adapted to the Hebei Province’s environment, Table 2. The monthly mean sun radiation was from NASA website http://power.larc.nasa.gov/cgi-bin/cgiwrap/solar/agro.cgi?email=agroclim@larc.nasa.gov . The mean temperature range during the growing period is between 26.8°C and 23.7°C; the maximum temperature range is between 41.1°C and 39.2°C and the minimum temperature 15.9°C and 11.9°C. The future climate scenario using in this work is PRECIS A2 and B2 scenario from Inter-governmental Panel of Climate Change (IPCC). This future climate is generated using WGEN based on 2000-2010 baseline Hebei Province weather data Figure 2.
2.2 Research Method

A three-step approach has been developed in this research. First, we collected weather, soil, crop, and management data from 4 different meteorological stations of the China Meteorological Administration and the solar radiation from NASA as well as the historical observed maize yield from the Chinese statistical book year. Secondly we inputted weather data into the MPES model after checking its sensibility to weather drivers (Temperature (0%, ±20%), Rain (0%; ±20%)) and simulated the maize yield relative to each under the same soil parameters. After the simulation, we compared the maize yield simulated using correlation parameters. After the simulation, we compared maize yield relative to each under the same soil parameters. And then the ArcGis software precipitation, average temperature, and growing period total represented respectively in year t yield, growing period as shown in relation (4).

We analyzed the spatial and temporal maize yield change, evapotranspiration (ET) and leaf area index (LAI) using ANOVA for SAS version 8.0 and SigmaPlot version 11.0 as well as different results graphics under PRECIS A2 and B2 scenarios. And then the ArcGis software version 9.3 is used to show the different maps display of the results.

2.4.2 Data Analysis

This research used the Time-series to define relation between the yield and climate factors relation (1) Nathaniel Beck (2006) and Lence (2009), which can be seen as (2) Saha, Schumway and Talpaz (1994). The difference between two yields at the same site at different period as shown in (3) as maximum likelihood error, Saha, Havenner and Talpaz (1997); David E. Schimmelpfennig et al., (1999). The Pearson correlation coefficient r; RMSE was calculated as shown in relation (4).

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3. Results and Discussion

3.1 MPES model calibration

Maize Production Emulation System (MPES) was used by Li Shijuan and Zhu Yeping in 2008, to show that using actual experiment data under deferent water conditions in 1996 and 1997 in Hebei province, we calibrated and validated Maize Production Emulation System based on cooperative models. Our results indicated the system has good prediction performance and strong applicability. The RMSE of yield and biomass predicted by system were 426.3kg/ha, 477.5kg/hm² and 1029.8 kg/ha, 1356.0 kg/ha respectively. The relative RMSE were 6.78%, 5.55% and 7.60%, 7.50%, all less than 10%.

The maize varieties using in this simulation are nongda 108 and zhengda958. The initial parameters in the first simulation with 10% change the results show different with relative RMSE gap of 546.5Kg/ha in Luanxian and the smallest 42.72Kg/ha in Shenzhou. For different cultivars with new parameters including the auto-regressive process for region i and time period t, demonstrated by Im, Pesaran, and Shin(1997, 2003 and 2005) propose as a series of unit root test statistics in dynamic heterogeneous panels based on individual Dickey-Fuller, David E. Schimmelpfennig et al., (2007), regressions as equation (3) using the Maximum Likelihood Error

\[
\Delta y_{it} = \alpha + \beta X_{it} + \epsilon_{it}, \quad i=1, \ldots, N; \quad t=1, \ldots, T
\]

Where \( \Delta y_{it} = y_{it} - y_{i,t-1} \) is the variation of the yield simulated at i simulation site at year t. \( X_{it} \) represents the weather factors (Temperature, Rain) \( \beta \) is the MPES model parameter and \( \epsilon \) represents error. And the RSME calculations were obtained using the following relation. The root mean square error is defined by the relation (4).

\[
RMSE = \sqrt{\frac{\sum_{i=1}^{n} (Y_{ob,i} - Y_{model,i})^2}{n}}
\]

Where \( Y_{ob,i} \) and \( Y_{model,i} \) represent respectively the yield observed and simulated at site i.
grain per plant per hectare but the harvest time difference is no significant.

3.2. MPES sensibility to weather

The maize yield changes according to the high temperature and low temperature change and with an additional rain during the 2000-2010 growth periods. The LAI indicated that, for the same field there is different LAI and ET Significant upward trend in the growth of maize during the average temperature rise high amplitude were 0.07°C/year and 0.067 °C reached to the significant level with $P \leq 5\%$ ($r=0.6421^{**}$, $r=0.576^{**}$) the graphics show in different site across the study area in Figure3a.

3.3 Climate Change effects on maize yield

3.3.1 Rain impact under PRECIS A2 and B2 scenario

The annual rain in this study is between 627 and 461 mm per year, this amount is mostly during the maize growing season from late may to September. There is significant change in the maize growth due to the change in the rain as it’s shown by We noticed with the change of 20% in rain, the yield change as well in all simulation sites. Figure3b.

3.3.2 Temperature impact under PRECIS A2 and B2 scenario

The temperature is around 40°C as a maximum and 39°C as a minimum in the different selected meteorological stations but during the growing period, the maximum is about 30°C to 35°C. With an additional degree on the usual temperature, the ET changed as shown by the figure. It shown that the change in the yields is no significant, about -5% to 2% change in yield in the grain per plant and the late harvest time in north part (Huailai, Luanxian) and early in the south (Qingxian, Quzhou, Shenzhen and Ningjin) and center (Xinji, Luquan and Zhengding) Figure3c.

3.3.3 Temperature and Rain impact under PRECIS A2 and B2 scenario

In all simulation sites, the combination of the change under A2 and B2, showed yield trends in 2020s, 2050s and 2070s. There is serious decrease in yield in the 2070s scenario due to high additional rain (17%) and Temperature (4.5°C) for A2 scenario and the B2 scenario Table3. This trend will affect seriously the crop production thus the food security by the end of the century.

However there is no significant difference between the yield trends under A2 and B2 in most of the sites during 2020s.

4. Conclusion

The maize yield is in threat under PRECIS A2 and B2 scenarios. We noticed that the elevated in temperature contributed to the variation in the harvest period. There is not significant change in maize yield due to temperature. The rain is a key factor in the growing system. In fact there is serious change in the yield due rain variation in all simulation sites as shown in the results.

The argument on the impact of climate change on crop production whether the yield will increase or decrease depending on the position and the soil fertilizer uptake is no longer in debate. All information we have now notify clearly the crop will be in threat due to environmental change. To insure the under increasing maize production in Hebei Province Chine farmer should improve the sustainable management techniques focusing on cultivars improvement and the efficient fertilizer application otherwise water and soil degradation will speed up then the total agriculture’s environment in danger.

Acknowledgements

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References


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Figure 1: Study Area (Hebei province with simulation sites)

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<th>Experiment Site</th>
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<th>Bulk Density (g/cm³)</th>
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<th>pH</th>
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Table 1: Different nearest meteorological stations to the simulation sites
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Table 2: Simulation sites and soil information

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<th>Soil Type</th>
<th>Depth</th>
<th>% Clay</th>
<th>%Sand</th>
<th>%Silt</th>
<th>pH</th>
<th>EC</th>
<th>Excess Water Capacity</th>
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<tbody>
<tr>
<td>Nongda Huailai County (in Zhangjiakou region)</td>
<td>0-20</td>
<td>1.45</td>
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<td>8.1</td>
<td>2.331</td>
<td>14.4</td>
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<td>1.843</td>
<td>18.1</td>
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</table>

Figure 2: (a) the year sun radiation in Hebei Province (b) Yearly distribution of the Precipitation in Hebei Province (c) year temperature (Maximum and Minimum) in Hebei province (baseline 1980-2010)
Figure 3a LAI of different simulation sites

Shenzhen

Year vs Observed Yield
Year vs Simulated Yield

R² = 0.075
RMSE = 193.35 kg/ha

Dahe

Year vs Observed Yield
Year vs Simulated Yield

ET in Luanxian(Lx) baseline 2070s
Xinji under A2 and B2 (2070s)

Year
2068 2070 2072 2074 2076 2078 2080 2082
Yield (Kg/ha)
13000 14000 15000 16000 17000 18000 19000

Simulated Yield under A2 and B2 (2070s)
Maize Yield under A2 Scenario
Maize Yield under B2 Scenario

Zhending

Year
Yield (Kg/ha)
7800 8000 8200 8400 8600 8800 9000

Year vs Observed Yield
Year vs Simulated Yield
RMSE=147.98 kg/ha

Zhengding under A2 and B2 (2020s)

Year
2018 2020 2022 2024 2026 2028 2030 2032
Yield (Kg/ha)
0 2000 4000 6000 8000 10000 12000

Simulated Yield under A2 and B2 (2020s)
Maize Yield under A2 Scenario
Maize Yield under B2 Scenario

Quzhou

Year
Yield (Kg/ha)
4500 5000 5500 6000 6500 7000 7500

Year vs Observed Yield
Year vs Simulated Yield
RMSE=334.41 kg/ha
### Quzhou under A2 and B2 (2020s)

<table>
<thead>
<tr>
<th>Year</th>
<th>2018</th>
<th>2020</th>
<th>2022</th>
<th>2024</th>
<th>2026</th>
<th>2028</th>
<th>2030</th>
<th>2032</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield (Kg/ha)</td>
<td>2300</td>
<td>2400</td>
<td>2500</td>
<td>2600</td>
<td>2700</td>
<td>2800</td>
<td>2900</td>
<td>3000</td>
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</tbody>
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### Quzhou under A2 and B2 (2050s)

<table>
<thead>
<tr>
<th>Year</th>
<th>2048</th>
<th>2050</th>
<th>2052</th>
<th>2054</th>
<th>2056</th>
<th>2058</th>
<th>2060</th>
<th>2062</th>
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</thead>
<tbody>
<tr>
<td>Yield (Kg/ha)</td>
<td>2000</td>
<td>2200</td>
<td>2400</td>
<td>2600</td>
<td>2800</td>
<td>3000</td>
<td>3200</td>
<td>3400</td>
</tr>
</tbody>
</table>
Quzhou under A2 and B2 (2070s)

Year
2068 2070 2072 2074 2076 2078 2080 2082

Yield (Kg/ha)
1900 2000 2100 2200 2300 2400 2500 2600 2700

Simulated Yield under A2 and B2 (2070s)
Maize Yield under A2 scenario
Maize Yield under B2 Scenario

Ningji

Year

Yield (Kg/ha)
4500 5000 5500 6000 6500 7000 7500

Year vs Observed Yield
Year vs Observed Yield
Year vs Simulated Yield

RMSE = 527.57 kg/ha

Luanxian

Year

Yield (Kg/ha)
4000 5000 6000 7000 8000 9000

Year vs Observed Yield
Year vs Observed Yield
Year vs Simulated Yield

RMSE = 546.54 kg/ha

Qingxian

Year

Yield (Kg/ha)
2000 3000 4000 5000 6000 7000

Year vs Observed Yield
Year vs Observed Yield
Year vs Simulated Yield

RMSE = 68.59 kg/ha

Qingxian under A2 and B2 (2020s)

Year
2018 2020 2022 2024 2026 2028 2030 2032

Yield (Kg/ha)
1900 2000 2100 2200 2300 2400 2500 2600 2700

Simulated Yield under A2 and B2 (2020s)
Maize Yield under A2 Scenario
Maize Yield under B2 Scenario

Qingxian under A2 and B2 (2050s)

Year
2048 2050 2052 2054 2056 2058 2060 2062

Yield (Kg/ha)
1800 2000 2200 2400 2600 2800

Simulated Yield under A2 and B2 (2050s)
Maize Yield under A2 Scenario
Maize Yield under B2 Scenario

RMSE = 2595 kg/ha
The RMSE in Qingxian for 20s; 50s and 70s respectively. RMSE= 181.2385kg/ha; RMSE= 128.4438kg/ha; RMSE=488.4484kg/ha

RMSE=152.4Kg/ha
The RMSE in Shenzhou for 20s, 50s and 70s respectively are: RMSE=42.72416; RMSE=284.9282 and RMSE= 418.347

The RMSE in Ningji for 20s; 50s and 70s respectively.
RMSE = 181.2385; RMSE = 128.4438; RMSE = 488.4484

The RMSE in Luanxian for 20s; 50s and 70s respectively:
RMSE = 46.88501; RMSE = 284.0237; RMSE = 468.5486

Figure 3b, 3c: simulation yield and observed yield under PRECIS A2 and B2 scenario in different sites.