

Declining Potential Yield and Rain-fed Yield of Corn in the Corn Belt of Northeastern China during the Past Three Decades

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Abstract. In the past three decades, corn yield in the Corn Belt of North-eastern China (CBNC) have increased under changing in climate and crop management. Quantifying the changes in crop potential production and rain-fed production is essential to determine the yield-contributing and yield-limiting factors and enhance crop productivity. In this paper we conducted correlation and regression analyses of climate and simulated corn yield over the period 1980 to 2011 in CBNC. It was found that the daily minimum temperature and solar radiation were the dominant factor to corn potential production, especially the climate in the post-silking period; the rain-fed production was susceptible to maximum temperature, precipitation, and relative humidity, and the result was showed that relative humidity had a stronger effect than precipitation. According to a regression analysis of the corn potential yield and the climate factors, the results indicate that corn potential yield decreased 1010 and 1314 kg ha⁻¹ for each 1°C increase growing season mean and minimum temperature, respectively; rain-fed yield declined 2819 and 2437 kg ha⁻¹ for each increase 1°C growing season mean and maximum temperature, respectively.

1. Introduction

North-eastern China, one of the main agricultural regions of the country, accounts for 19% and 30% of the nation's total cultivated land and crop yield, respectively [1]. Corn production in this region will directly affect the supply and demand of Chinese corn market [2]. In the past few decades, corn yields in the region increased rapidly due to newer cultivar and management improvements [3] such as fertilization [4], corn plastic mulching [5]. Moreover, Climate change has a crucial influence on crops because growth and development are affected by sunlight, temperature, and water. The effect of climate change on crop production depends on the interaction of various climatic factors and agricultural management parameters.

Advancing corn productivity of CBNC will play an important role in ensuring China's and global food security. However, this will be a big challenge under the warming future climate [6]. Although, many previous studies showed that crop production might benefit from future warming if suitable adaptations are conducted for cropping system [7, 8] some studies showed that the climate warming might induce tremendous decrease in crop production [9, 10]. An IPCC (Intergovernmental Panel on Climate Change) projection, for instance, expects that a 2.0°C increases in mean air temperature may lead to a further 20% to 40% fall in cereal yield, mostly in Asia and Africa. Effects of temperature increase on crop production, however, can be either negative or positive, depending on the region. Therefore, a better understanding of these yield increases under a changing climate in Northeast China



(NEC) will help ensure sustainable yield in the future. Our objectives were to learn which variables of climate change in the crop growing season were associated with potential yield and rain-fed yield over this 32-year period.

2. Materials and methods

2.1. Study site, soil and climate data

The study site, sipping, is located in the centre of the Corn Belt of North-eastern China. this region is in the north temperate zone and have a semi-humid continental monsoon climate with an average (1980-2011) annual temperature of 5.9°C, annual sunshine hours of 2679 h, 142 d frost-free period, annual cumulative temperature ($> 10^{\circ}\text{C}$) of 3078°C, annual precipitation of 573 mm (65% of annual precipitation occurs from June to August), and mean annual pan evaporation of 808 mm. The soil is frigid Typic Haplustoll with sandy loam texture, formed from Aeolian (the primary soil properties were showed in Table 1).

Table 1. Primary soil physical properties at the experimental fields in Aeolian sandy soil

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	BD (g cm^{-3})	K_s (cm d^{-1})	λ	θ_{FC} ($\text{cm}^3 \text{cm}^{-3}$)	θ_{WP} ($\text{cm}^3 \text{cm}^{-3}$)
0-25	69.6	18.1	12.3	1.53	46.5	0.35	0.227	0.093
25-65	77	13.5	9.5	1.47	73.4	0.304	0.188	0.087
65-117	81.9	12.7	5.4	1.62	151.4	0.27	0.174	0.081
117-150	67.2	25.1	7.7	1.63	90.0	0.201	0.247	0.083

BD, bulk density, measured by undistributed soil core method; K_s , saturated hydraulic conductivity, measured by constant head method; λ is pore size distribution index used to describe the soil water retention curves; θ_{FC} , water content at field capacity; θ_{WP} , water content at wilting point; Clay (<0.002 mm), silt (0.002-0.05 mm), and sand (0.05-2 mm), measured by Pipette Method.

Historic daily weather data at the study site was available from China Meteorological Administration, including daily mean (T_m), maximum (T_{max}), minimum (T_{min}) temperature, precipitation (P), relative humidity (RH), daily average wind speed and sunshine hours (SH). Daily solar radiation (Rn) was estimated from daily sunshine hours based on the Angstrom equation. Growing degree days (GDD) was calculated by taking the average of the daily maximum and minimum temperatures compared to a base temperature. As an equation: $\text{GDD} = (\text{maximum temperature} + \text{minimum temperature})/2 - T$, $T = 10^{\circ}\text{C}$. And GDD was set to be 0°C when it was less than 0°C .

2.2. Experiment design and data analysis

The RZWQM was used to simulate the yield and biomass under potential and rain-fed condition from 1980 to 2011. In addition, we used the potential yield (Y_p) to estimate the yield gap (YG) by combining it with rain-fed yield (Y_r). Planting date was set to 5 May, seeding depth was 5 cm, and planting density was 90000 plants ha⁻¹. The corn cultivar is Xianyu 335. The model input initial soil water content was set to 80% of the field capacity for seeding in each year.

The nine data sets during the crop growing season were calculated to determine the climate change trends since 1980. Liner regression analysis was used to analyse the trend of change in climatic variables. Pearson correlation coefficients were then estimated to identify relationships between the yield, biomass, HI (harvest index), gaps and climate factors over the corn growing season. The slop of linear regression line was evaluated using Student's t-test at 95% and 99% levels. Stepwise multiple linear regressions were used to evaluate the multiple relationships between corn yield, biomass, HI, gaps and climate factors.

3. Results

3.1 Relationships between corn growing indicators and climatic variables

The effect of Tmin, Tm, and GDD on potential yield of corn were very significant ($P < 0.01$), and the Rn and SH were significant ($P < 0.05$) (Table 2). This means that temperature especially minimum temperature and the GDD were the major climate limiting factors for corn potential yield in Northeast China. There were very significant ($P < 0.01$) correlation between rain-fed yield and Tmax, Tm, precipitation, and RH, and a significant ($P < 0.05$) relationship existed between rain-fed yield and Rn and sunshine hours. This means that maximum temperature, precipitation and RH were the major climate limiting factors for corn rain-fed yield in this region. It was found that the Tm, Rn and SH were significant related with potential biomass. There were significant correlation between rain-fed biomass and Tmax, Tm, precipitation, and RH, Rn, sunshine hours and GDD. The HI in the no water stress condition correlated significantly with Tmax, Tmin, Tm and GDD. In contrast, the HI in water limiting condition was only correlated significantly with the relative humidity. There were significant correlation between yield gaps and Tmax, precipitation, and RH, Rn and sunshine hours.

Table 2. Correlation coefficients between climatic factors of corn growth season and corn growing indicators during 1980-2011 in Northeast China

	Tmax	Tmin	Tmean	P	RH	WS	Rn	SH	GDD
Yp	ns	**	*	ns	ns	ns	*	*	**
Yr	**	ns	**	**	**	ns	*	*	*
Bp	ns	**	ns	ns	ns	ns	**	**	ns
Br	**	ns	**	**	**	ns	*	*	**
HIp	*	**	**	ns	ns	ns	ns	ns	**
HIr	ns	ns	ns	ns	**	ns	ns	ns	ns
GAP	*	ns	ns	**	**	ns	**	**	ns

Yp is potential yield, Yr is rain-fed yield, Bp is potential biomass, Br is rain-fed biomass, HIp is potential harvest index, HIr is rain-fed harvest index and GAP is the gaps by potential yield minus rain-fed yield. $GDD = (\text{maximum temperature} + \text{minimum temperature})/2 - T$. $T = 10^{\circ}\text{C}$. GDD was set to be 0°C when it was less than 0°C . * Significant at $P < 0.05$, ** Significant at $P < 0.1$.

Stepwise multiple linear regression analysis resulted in the following equations with the correlations between corn potential yield (1), rain-fed yield (2), potential biomass (3), rain-fed biomass, (4) HIp (5), HIr (6) and yield gaps (7) and climatic variables. Although R^2 values were low, the correlation was significant.

$$Y_p = 16638 - 1217.2T_{\min} + 778.3R_n \quad (n = 32, R^2 = 0.5067 \text{ **}) \quad (1)$$

$$Y_r = 19884 - 1559.2T_{\max} + 441.1RH \quad (n = 32, R^2 = 0.4757 \text{ **}) \quad (2)$$

$$B_p = 14959 - 1268.9T_{\min} + 1722.3R_n \quad (n = 32, R^2 = 0.6406 \text{ **}) \quad (3)$$

$$B_r = 112010 - 3893.9T_{\max} + 19.2R_n \quad (n = 32, R^2 = 0.5150 \text{ **}) \quad (4)$$

$$HI_p = 0.79 - 0.022T_{\min} \quad (n = 32, R^2 = 0.3036 \text{ **}) \quad (5)$$

$$HI_r = -0.11 + 0.0085RH \quad (n = 32, R^2 = 0.2198 \text{ **}) \quad (6)$$

$$GAP = 25728 - 334.8RH \quad (n = 32, R^2 = 0.1756 \text{ *}) \quad (7)$$

3.2 Relationships between corn potential/rain-fed yield and climate factors

The simulated potential yield of corn over the 32 years ranged from the highest value of 15868 kg ha⁻¹ in 1989 to the lowest value of 10051 kg ha⁻¹ in 1994. The potential yield was significantly and positively correlated with crop season total solar radiation ($r = 0.42$, $P < 0.05$) and daily mean sunshine hours ($r = 0.42$, $P < 0.05$), but negatively correlated with T_{min} ($r = 0.63$, $P < 0.01$), T_m ($r = 0.44$, $P < 0.05$) and GDD ($r = 0.50$, $P < 0.01$). Furthermore, it was found that the potential yield was significantly and positively correlated with post-silking period total solar radiation ($r = 0.43$, $P < 0.05$) and daily mean sunshine hours ($r = 0.42$, $P < 0.05$), but negatively correlated with T_{min} ($r = 0.70$, $P < 0.01$), T_m ($r = 0.50$, $P < 0.01$) and GDD ($r = 0.57$, $P < 0.01$). There was no significant correlation between corn potential yield and per-silking period climate factors except minimum temperature. For post-silking period these correlations were significant, suggesting that the climate in this period dominates the effect on corn potential yield.

For the rain-fed yield simulation over the 32 years, the corn yield ranged from the maximum value of 15178 kg ha⁻¹ in 1986 to the minimum value of 2052 kg ha⁻¹ in 2000. The rain-fed yield was significantly and positively correlated with crop season total precipitation ($r = 0.58$, $P < 0.01$) and relative humidity ($r = 0.64$, $P < 0.01$), but negatively correlated with T_{max} ($r = 0.55$, $P < 0.01$), T_m ($r = 0.46$, $P < 0.01$), R_n ($r = 0.38$, $P < 0.05$), SH ($r = 0.37$, $P < 0.05$) and GDD ($r = 0.50$, $P < 0.01$) (Fig. 1). The negatively correlated in maximum temperature toward rain-fed yield led to significant decrease in mean temperature. When considered the per- and post-silking period, relationships between rain-fed yield and climate factors were similar to the relationships with the total crop growing season climatic variables; expect per-silking mean temperature.

4. Discussion and conclusions

In this study, we analysed the effects of the change climatic variables on the rain-fed corn production. A significant, negative correlation was found between corn rain-fed production and the temperatures (especially maximum temperature) and GDD during the full crop growing season, but positive with precipitation, relative humidity, solar radiation and sunshine hours. Compared with the potential corn production, the rain-fed production was susceptible to maximum temperature, precipitation, and relative humidity, and the result was showed that relative humidity had a stronger effect than precipitation. Previous research suggested that, in the future, the increasing in precipitation in NEC will help to improve the water supply, and will increase the crop yields; however, the increased precipitation will still be insufficient to compensate for the increasing in evapotranspiration caused by warming. Thus, there was still insufficient water during corn growing season in NEC, and the corn production will be affected in areas without irrigation [11].

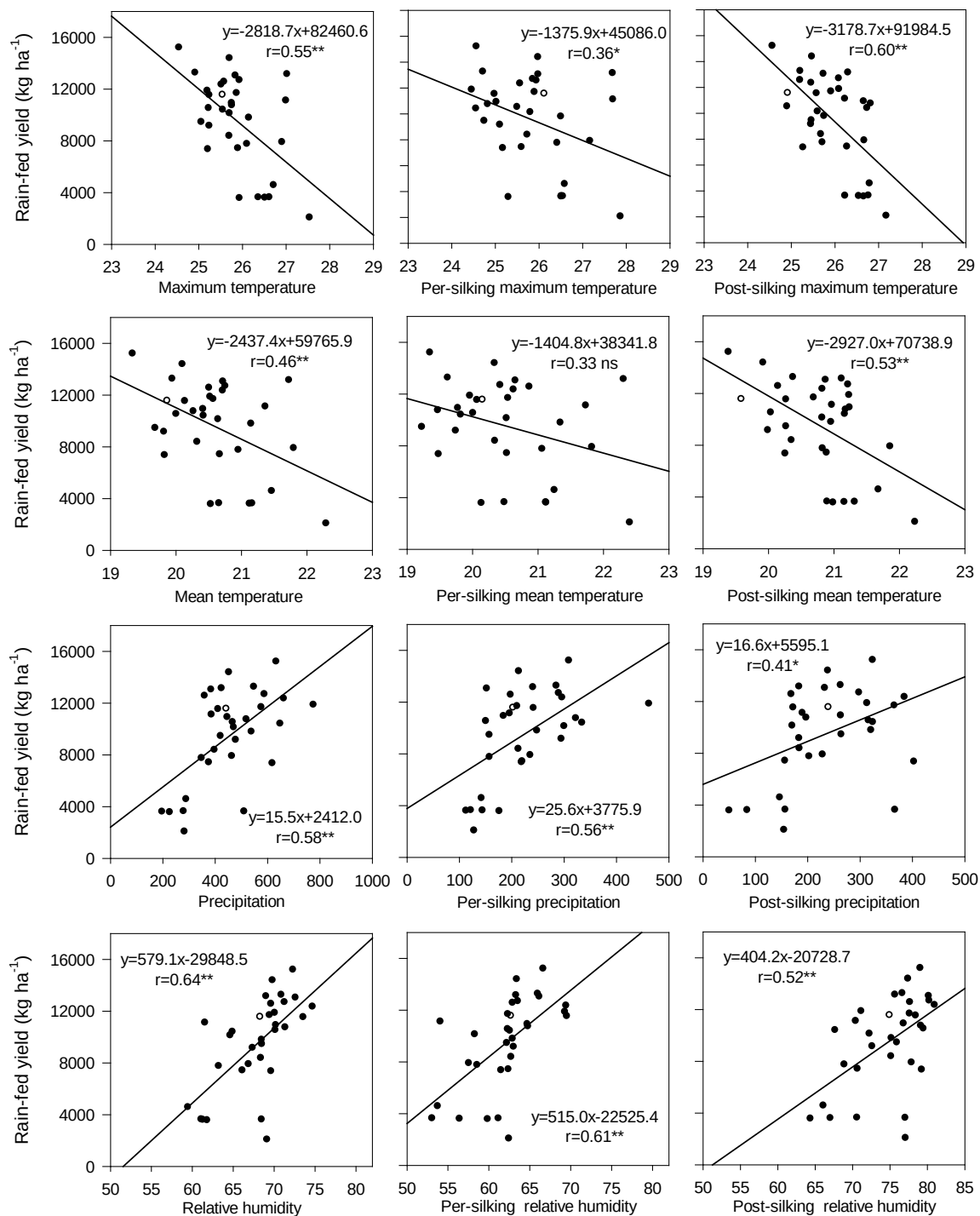


Figure1. Relationships between corn rain-fed yield and climatic factors

Higher temperature may have a negative effect on yields when they exceed 35°C, but this is not a matter of concern so far as the maximum temperature in Northeast China is not higher than 30°C [12]. However, in a more distant future, when maximum temperature continues to raise, more attention, therefore, needs to be paid to the negative effect on yields.

In summary, it was shown that expected changing climate will reduce future corn production in the Corn Belt of North-eastern China if there is no hybrid change and no improvement and innovation in the management. In our study, we only analysed the effects of the changing climate on the corn production in Aeolian sandy soil. A subsequent study should quantify the influence of the soil

condition, changes in other climate variable. These factors were not considered in this study, but they might influence the variation of corn potential and rain-fed production.

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6. References

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