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Analysis of Maize Yield under Climate Change, Adaptations in Varieties and Planting Date in Northeast China in Recent Thirty Years

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***Abstract*—**The Northeast China (NEC) was the most important agriculture areas and known as the Golden-Maize-Belt. Based on observed crop data and crop model, we design four simulating experiments and separate relative impacts and contribution under climate change, planting date shift, and varieties change as well change of varieties and planting date. Without planting date and varieties change, maize yields had no significant change trend at Hailun station located in the north of NEC, and presented significant decrease by 0.2 - 0.4 t/10a at two stations, which located in the middle and the south of NEC. With planting date change, yields showed a significant increase by 0.09 - 0.47 t/10a. With varieties change, maize yields had significant increase by 1.8~ 1.9 t/10a at Hailun and Huadian stations, but a non-significant and low increase by 0.2t /10a at Benxi located in the south of NEC. With change of varieties and planting date, yields presented a significant increasing by 0.53- 2.0 t/10a. Their contribution to yields was -25% ~ -55% for climate change, 15% ~ 35% for planting date change, and 20% ~110% for varieties change as well 30% ~135% for varieties with planting date shift. It found that change in varieties and planting date were highest yields and were responsible for significant increases in maize yields, varieties was secondly, and planting date was thirdly. It found that adaptation in varieties and planting date greatly improved maize yields, and increased yields annual variability. The increase of contribution with planting date and varieties change in 2000s was lower than in 1990s. Yields with the varieties change and yields with planting date and varieties change all showed a decreasing trend at Huadian and Benxi since 2002 or so. It indicated that maize yields increasing trend stagnated in the middle and south of NEC, and continued in the north of NEC.

***Keywords*—**Climate change, maize yields, varieties, planting date, impacts.

I. INTRODUCTION

THE Northeast China (NEC) (38ºN-56ºN，120ºE-135ºE) is located in the middle-high latitudes and east of the Eurasian continent, which has a cultivated land area of 21.53 million hm^2, accounted for 16.6% of the country's total cultivated areas [1], which was the biggest commercial grain production zone and provides 30-35 million tons of commercial grain to country every year. In NEC, maize was the major crop and showed that its yield accounted for about 1/3 of the national total maize yield [2]. Therefore, it played an important role to stabilize the grain market and keep sustainable development of China’s national economy. Recent climate variability in China was characterized by increases in mean temperature, complex spatial and temporal patterns in precipitation and decreases in solar irradiance [3]. Most of studies used crop yield data or crop model to study effects of climatic change on crop yields in China [4], [5]. Evaluation on impacts of adaption under recent climate change on crop growth and yields became increasingly concerned in recent decades [6]. Adaptation was a way for reducing climate change negative impacts. The aim of adaptation was the strategies that minimizing the potential negative impacts of climate change while maximizing opportunities for adjustment [7]. This strategies including shifting planting date, sowing density, use of cultivars adapted to warmer climates and irrigation management etc. [8], [9].

For providing valuable insights into development of sustainable agricultural system, it was necessary to understand detailed and separate the affecting factors on crop yields. Some studies applied yields data and crop model assessed the impacts of adaption including shifting planting date, use of cultivars and management measurements on crop yields under future climate change [10], [11]. Meanwhile, to accelerate understanding of recent climate change on crop yields in China, some studies focused on winter wheat, maize of the North of China Plain and Rice, and estimated quantitatively the relative contribution of cultivars, management and recent climate change to winter wheat yields and maize of the North China Plain as well rice by combining crop model with observed crop data since 1980s [12]-[14]. In NEC, annual mean temperature increased significantly by 1.0–2.5°C in recent 30 years and the increase of accumulated temperature extended crop growth duration [15]. Maize yields and total grain production in NEC increased rapidly due to the adaptation measures mainly involved the adjustment of crop planting date and use of different maturing cultivars, as well the adaptation of advanced technologies greatly facilitated agricultural development [8], [15]. However, the individual impacts and quantitatively contribution of climate change, adaption in varieties and planting date on maize yields in NEC is still unclear. For exploring approaches to maintain and increase maize yields in the face of climate, it is necessary to evaluate respective impacts of climate, varieties and planting date in NEC.

Objectives of this study were to (1) establish the four simulation experiments based on the field experiment data with planting date, varieties from 1980 to 2010 at three stations in the NEC, together with a CERES –Maize model, and (2) identify the relative contributions and impacts of variety

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changes, planting date and climate change to maize yield. This study would explore the individual impacts and contribution of climate and adaptation, and answered the question that why the maize yields significantly increased under climate warming over NEC. Meanwhile, it would give some implications for Adaptation potential under climate change in NEC.

II. DATA AND METHODS

A. Study Area

NEC located at relatively high latitudes, and comprises Heilongjiang, Jilin and Liaoning Provinces (Fig. 1).

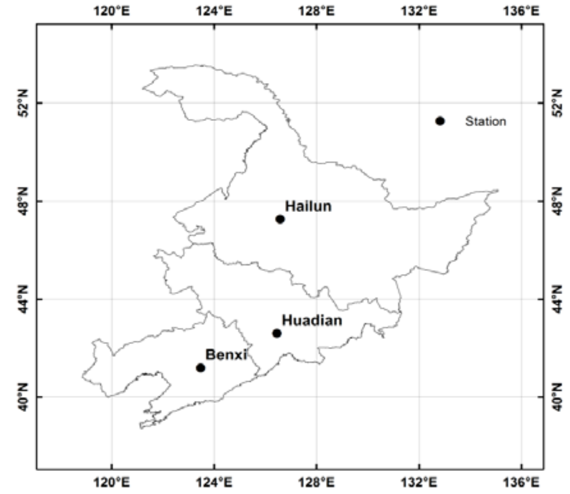

Fig. 1 Location of Heilongjiang, Jilin and Liaoning Province and distribution of agro-meteorological stations in the Northeast China

The Northeast China was one of the coolest regions with long and cold winters in China. There was a short growth season (May-September) and frequent cold extreme events, and maize fields were fed only by rain, so maize yields annual variability were large by 20~30%. According to the details of observed maize fields data, three agricultural stations with continuous and complete 29 year time series were selected, which had different adaptation types in maturing varieties change and planting date shift (Fig. 2). Late maturing varieties with the delay of planting instead of early maturing varieties date were planted, and middle maturing varieties with the ahead of planting date instead of middle late or late maturing varieties were planted. The three stations located the north (Hailun station, 47.26°N), middle (Huadian station, 42.59° N) and south (Benxi station, 41.19°N) of the NEC, respectively (Fig. 1).

B. Data

Average daily minimum temperature (T_{min}), maximum temperature (T_{max}) and mean temperature (T_{maen}) during maize growing season at three stations ranged from 11.8 (Huadian) to15.6°C (Benxi), from 23 (Hailun) to 26°C (Benxi) and from17 (Huadian) to 19°C (Benxi), respectively. Total precipitation ranged from 387 (Hailun) to 606 mm (Benxi), and Total of sunshine hours ranged from 986 (Hudian) to 1239h (Hailun) (Table I). The climate data (1981-2009) were obtained from the Meteorological Information Center of China meteorological Administration (CMA). Sunshine duration for model was converted into daily solar radiation using the Angstrom-Prescotte equation. Maize growth and yield data (1981-2009) including (Sowing, flowing, maturity, yields and above-ground biomass etc.) are collected from the Agro-meteorological Experiment Stations of CMA. Soil data (soil texture, color, bulk density, percentage of clay, silt and sand , organic matter content, slope of each layer of soil, total nitrogen content, soil pH, etc.) from Chinese soil series). The data of climate, crop and soil were used for model calibration, validation and simulation.

TABLE I
INFORMATION OF CLIMATE IN GROWING SEASONS AND SOIL TEXTURE IN THE SELECTED STATIONS

Station	T_{min} (℃)	T_{max} (℃)	T_{mean} (℃)	P_{total} (mm)	SH_{total} (h)	soil texture
Hailun	12.3	23.2	18	473	1239	Clay loam
Huadian	11.8	23.2	17	583	986	Loamy sand
Benxi	15.6	26.0	19	606	1040	Loamy sand

C. Crop Model

The Crop System Model (CSM)-CERES-Maize (DSSAT) version 4.5 based on mechanistic dynamic and deterministic crop model [16] was employed. CERES –Maize simulates complex treatment (cultivar change, planting date shift, and management etc. with different environmental conditions. It has been widely applied under different environment to test the consequence of vary management practice and cultivars characteristic on crop growth and yields, and was able to analyze the interaction and individual roles of these treatments on maize growth and yields [6], [8], [17]. In this study, CERES-Maize model was used to simulate maize yields under four different simulation experiments design based on agronomic treatments on planting date and maturing varieties).

Seven maize maturing varieties are selected for calibration and validation crop model (Table II).

For each variety at each station, one year experiments data were used to calibrate model and calculate varieties genotype coefficients, and the other two years data were used to validate CERES maize model by comparison between observed and simulated data. The Root Mean Squared Error is calculated to estimate the difference between simulated and observed value.

$$RMSE = \frac{100}{\bar{X}_o}\sqrt{\frac{\sum_{i=1}^{n} X_{Si} - X_{Oi}}{n}} \qquad （1）$$

where X_{si} and X_{oi} are the simulated and observed data, respectively, is the mean of observed data, and n is the number of observation. Linear correlation coefficients (r) also are applied to evaluate association between simulated and observed value.

D. The Scheme of Simulating Experiments

The mid-early maturing varieties, medium maturing varieties, and mid-late maturing varieties as well late maturing varieties were alternately planted at each station. The maturing varieties are changed two to three times, and planting date with each variety also frequently shifted at each station (Fig. 2).

TABLE II
EXPERIMENTS OF CALIBRATION AND VALIDATION FOR CROP MODEL AND CALCULATED GENETIC COEFFICIENTS OF MAIZE VARIETIES

Stations	Maturing variety	Experiment for calibration	Experiment for validation
Hailun	M-E80	1981	1983, 1984
	M90	1994	2001, 2003
Huadian	M-L80	1983	1987,1988
	M90	1997	2000, 2001
Benxi	M80	1981	1983, 1984
	M-L80	1988	1992, 1993
	M90	1998	2002, 2003

Due to short of complete and quantitative recorders of fertilizer in each station, we hypothesized that four simulating experiments simulated maize yields under full fertilizer so as to eliminate the interference of fertilizer on yields and to remain the impacts of climate, varieties and planting date on maize yields. Four simulating experiments included (1) change in variety and planting date was consistent with actual observed recorders (S_{VP}), (2) in planting date were consistent with actual observed recorders without variety change (S_P), and (3) in variety were consistent with actual observed recorders without planting date shift (S_V) as well (3) no-change in planting date and variety from 1981 to 2009 (S_{CC}). S_{CC} simulated yields under only climate change（Y_{CC}）, and S_P simulated yields under only change in planting date (Y_P) as well SV simulated yields under only change in variety (Y_V). SVP simulated maize yields under actual varieties and planting date (Y_{SV})， so Y_{SV} was most closed to the actual maize yields among four simulated yields.

Impacts of climate change, planting date shift, and variety change on maize yields as well varieties change with planting shift on maize yield were considered in experiment. Simulated maize yields were used to make regression equations, and the regression coefficients reflected the trend and change rate of maize yields during the past 30 years. Method of many years moving average was applied to present the decadal change, and suggested the trend in decadal change of maize yields.

The coefficient of variability of yields was used for reflecting the inter-annual variability of maize yields.

Simulated maize yields from four simulating experiments were used to calculate the relative contributions of planting shift, variety change and climate change to maize yield. In this study, the contributions expressed that change of maize yields under each planting adaptation (Y_P, Y_V and Y_{VP}) compared to Y_{CC} (Yields without planting adaptation). Simulated experiment V_P was designed according to the actual varieties and planting date of maize, and could simulate yield with actual planting adaptation. Contribution of climate change to maize yields noted that change of maize yields with only climate change (without adaptation in both planting date and varieties change) compared to Y_{VP} (with adaptation in both planting date and varieties) Accounting equations were as,

$$C_v = \frac{Y_v - Y_{cc}}{Y_{cc}} \times 100\ \% \qquad (2)$$

where C_v is the contribution of variety shift to yields (%), Y_v and Y_{cc} are the simulated yields of simulating experiments V and CC, respectively.

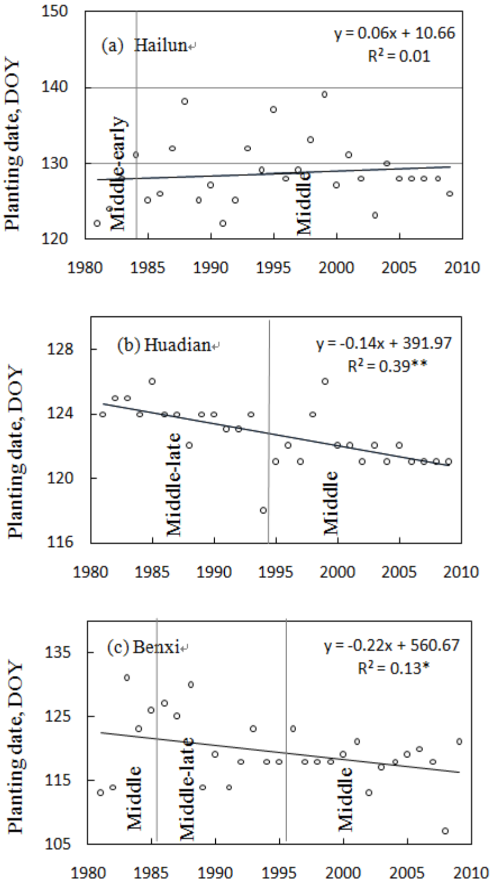

Fig. 2 The changed in Planted maturing varieties and planting date in Hailun (a), Huadian (b) and Benxi (c) stations

$$C_p = \frac{Y_p - Y_{cc}}{Y_{cc}} \mathrm{X}100\ \% \qquad (3)$$

where C_p is the contribution of change in planting date to yields (%), Y_p is the simulated yields of simulating experiments P.

$$C_{cc} = \frac{Y_{cc} - Y_{vp}}{Y_{vp}} \mathrm{X}100\ \% \qquad (4)$$

where Ccc is the contribution of climate change to yields (%), Yvp is the simulated yields of simulating experiments VP.

$$C_{vp} = \frac{Y_{vp} - Y_{cc}}{Y_{cc}} \mathrm{X}100\ \% \qquad (5)$$

where Cvp is the contribution of the varieties and planting date change to maize yields (%).

III. RESULT AND DISCUSSION

A. *Change in Varieties, Planting Date and Observed Yield*

There were two different adaptation types in maturing varieties and planting date (Fig. 2). Varieties change from the middle-early maturity to the middle maturity at Hailun located in north of NEC, and planting date had a no-significant delayed trend by 0.6 d/10a. However, Varieties change from the middle-late to the middle maturity in Huadian located in middle of NEC, from the middle to the middle-late maturity and to middle maturity at Benxi located in south of NEC, and a significant shift in advance by1.40 d/10a(P<0.01) at Huadian and by 2.2 d/10a (P<0.05) at Benxi.

B. Crop Model Validation

The yields, flowing duration were very crucial for the crop model validation for each local variety at specific locations. There was a close agreement between observed and simulated data (Fig. 3). Linear regression presented a significant correlation for yields ($R^2 = 0.92$) and for flowering duration ($R^2 = 0.90$) between the observed and simulated data. Crop model predicted yields within ±15% of measured yields. The simulation analysis showed that RMSE of simulated yields was significantly low (RMSE = 10.1%).

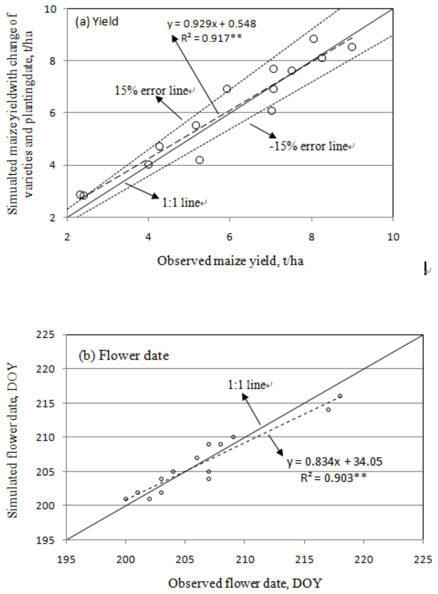

Fig. 3 Comparison between the observed and simulated data of yields (a) and flowering duration (b) at three locations

C. Evaluation Maize Yields Trend and Variability under Climate Change, Planting Date Shift and Variety Change

Four simulated maize yields and changes were presented in Fig. 4. Y_{CC} (black circle) presented that the yields were affected only by climate change. Compared to the other three simulated yields, Y_{CC} is lowest simulated yields, and ranged from 2 to 3 t/ha at Huadian, from 4 t/ha to 5 t/ha at Benxi, and near 3 t/ha at Hailun. Y_{CC} had no significant change at Hailun, but presented significant decrease by 0.2 t/10a (P<0.01) at Huadian and by 0.4t/10a (P<0.01) at Benxi.

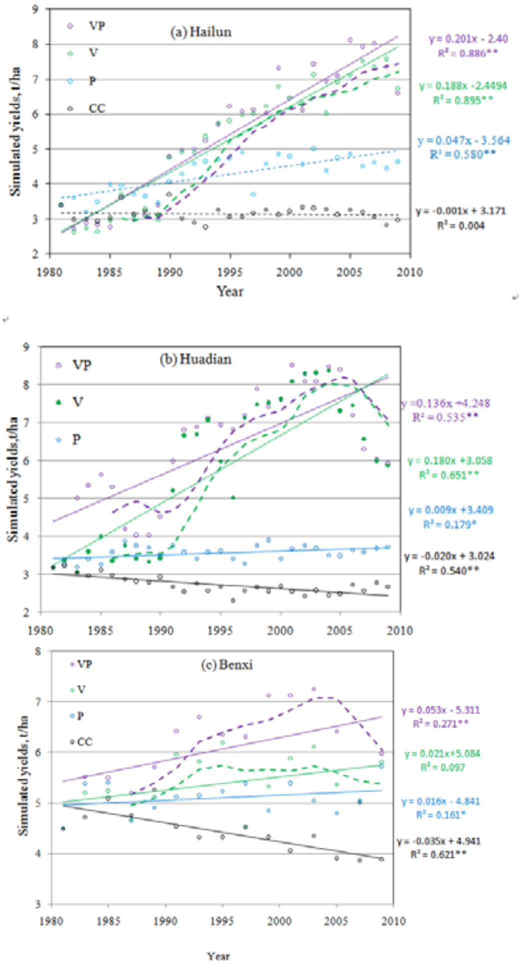

Fig. 4 The simulated yields of four simulating experiments including change of variety and planting date (Y_{vp}, purple line), variety change (Y_v, green line), planting date change (Y_p, blue line), and only climate change (Y_{cc}, black line) from 1981 to 2009 at Hailun (a), Huadian (b) and Benxi (c) stations. Line trend (solid line) and six years moving average line (dot line). *, ** is significant at P<0.05 and P<0.01 level, respectively

The Y_P (blue circle) was the yield that affected by only planting date shift. Change of planting date could gradually increase maize yields in the past 30 years. The extent of Y_P were from 3 to 5 t/ha at Hailun, from 3 to 4 t/ha at Huadian and from 4 to 6t/ha at Benxi. The Y_P had a significant increase by 0.47 t/10a (P<0.01) at Hailun, and by 0.09 t/10a (P<0.05) at Huadian as well by 0.16 t/10a (P<0.05) at Benxi.

Y_V (green circle) was the yield that affected by only change of varieties. The distribution of Y_V crossed from 3 to 8 t/ha at Hailun, 3 to 9 t/ha at Huadian as well 5 to 6 t/ha at Benxi. Y_V had a high and significant increase trend and the rate of increase were by 1.9 t/ 10a (P<0.01) at Hailun and by 1.8 t /10a (P<0.01) at Huadian, but presented a low and non-significant increase trend by 0.2 t/10a at Benxi. It showed that maize yields greatly increased with change of varieties.

Y_{VP} (purper circle) was the yield that affected by change of variety and planting date. The extent of distribution for Y_{VP} was similar to Y_V. Y_{VP} was the highest among four simulated yields.

The extent of Y_{VP} were from 2 to 8 t/ha at Hailun, from 3 to 8.5 t/ha at Huadian and from 5 to 7.2 t/ha at Benxi. Y_{VP} also had a high and significant increasing trend by 2.0t/10a ($P<0.01$) at Hailun, and 1.4t /10a ($P<0.01$) at Huadian, as well 0.53t/10a ($P<0.01$) at Benxi.

Moving average yields of six years (dotted line) for Y_V and Y_{VP} showed that there was a continued increasing trend at the three stations from 1980s to 2002 or so. However, Y_V and Y_{VP} presented a decreasing trend at Huadian and Benxi after 2002 or so. It indicated that yields with planting date shift and varieties change increasing trend stagnated, and appeared decreased trend at Huadian and Benxi.

Coefficients of variability were 5.4% (Hailun) -8% (Huadian) for Y_{CC}, 5.0% (Huadian) -12% (Hailun) for Y_P, and 12% (Benxi) -32% (Hailun) for Y_V as well 22 % (Benxi)-34% (Hailun) for Y_{VP}. It showed that annual variability of Y_V and Y_{VP} became high compared to Y_{CC} and Y_P (Fig. 5).

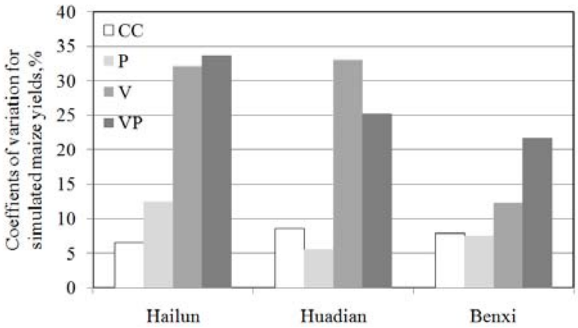

Fig. 5 Annual–variability of maize yields with climate change, planting date shift, variety changes and variety changes with planting date shift

D. Contribution of Planting Date Shift, Variety Change and Climate Change to Yield

The P and V noted simulating experiments with the change in planting date and varieties, respectively, and VP and CC presented simulating experiments with changes and without changes in the two aspects, respectively. Therefore, the simulating experiment could quantitatively calculate the relative contributions of planting date shift, variety change and climate change to yield by comparison between simulated yields of the four simulating experiments (Fig. 6).

The results showed, during the past 30 years, that C_{CC} was -45% (Hailun), -55% (Huadian), and -25% (Benxi). The negative contribution of climate change was highest at Huadian, and lowest at Benxi. The contributions of planting date and varieties change to maize yields were positive. C_P was from 15% (Benxi) to 36% (Hailun), and C_V was from 22% (Benxi) to 111% (Huadian), as well C_{VP} were from 38% (Benxi) to 131% (Hudian). C_P was largest at Hailun, and lowest at Benxi, but C_V and C_{VP} at Hudian were highest among three stations, and was secondly at Hailun. Cvp was largest among three planting adaptations, and Cv was secondly. The positive contribution for Yv and Yvp was far larger than negative contribution of climate change to maize yields in Hailun and Huadian.

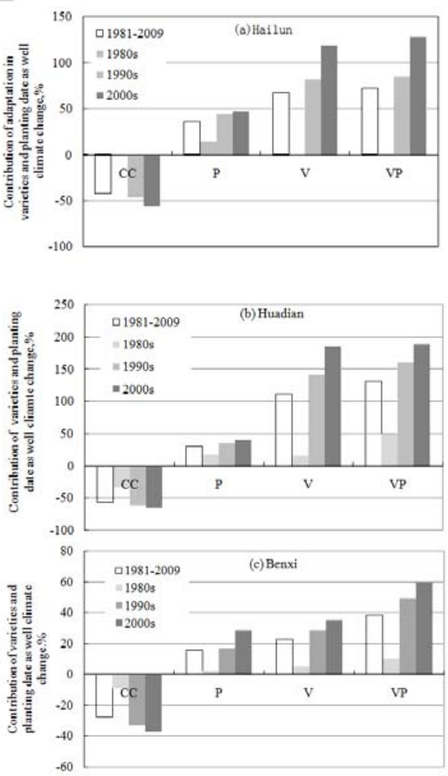

Fig. 6 Contribution of climate change, planting date shift, varieties change, change of planting date and varieties to yield at Hailun (a), Huadian (b) and Benxi (c) stations

Decadal change of contribution to maize yields showed that (1) for Ccc, were from -1.2% (Hailun) to -33% (Hudian) in1980s, -33% (Benxi) to -61% (Hudian) in 1990s, and -37% (Benxi) to -65% (Huadian) in 2000s, (2) for Cp, from 15% (Benxi) - 36% (Hailun) in1980s, 16% (Benxi) - 44% (Hailun) in 1990s, and 29% (Benxi) - 47% (Hailun) in 2000s, and (3) for Cv, from 0.2% (Hailun) - 15% (Hudian) in1980s, 28% (Bnexi) -141% (Hudian) in1990s, and 35%(Benxi) -186% (Hudian) in 2000s, as well (4) for Cvp, from10% (Benxi)-72% (Hailun) in1980s, 49%(Benxi) -160% (Hudian) in1990s, and 60% (Benxi) to189% (Hudian) in 2000s. It showed that decadal contribution of Cp, Cv and Cvp to maize yields presented the increasing trend. However, the increased quantity of Cv and Cvp in 1990s and in 2000s were far larger than in1980s, and the increased extent in 2000s was lower than in 1990s.

IV. CONCLUSIONS

This study investigated the impacts and contribution of climate change and adaptation in planting date shift and varieties based on simulated maize yields by CRESE-maize model in Northeast China. There were two different adaptable types in varieties and planting date to climate change at the three stations. One was that late maturing varieties with the delay of planting date instead of early maturing varieties were planted. Another was that middle maturing varieties with the ahead of planting date were planted instead of middle late or late maturing varieties.

In order to distinguish the impacts of climate change, and

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planting date shift as well variety change, respectively, the four experiments were designed to simulate maize yields without fertilizer stress. The four simulated experiments showed that change in planting date or varieties could significantly improve maize yields. Impacts of both varieties and planting date change on increasing maize yields was most evident among three adaptations, and brought highest yields. Impacts of varieties change on increasing yields were more evident than planting date shift. However, adaptations of varieties change and both varieties planting date change increased inter-annual variability of maize yields compared to planting date shift and no adaptation under climate change.

We found that, for Hailun station located the north of Northeast (47.26^{o}N), maize yields with only climate change had non-significant trend, but for Huadian (42.59^{o}N) and Benxi (41.19^{o}N) stations located in the middle and south of Northeast had significant decreasing trend. It suggested that climate change yet haven’t significant impacts on maize yields in some high latitude region even if crop varieties and planting date hadn’t been changed, but had a significant negative impacts in low latitude region of the Northeast China. Climate change brought negative contribution to yields by -25% ~ -55%. Varieties changes with planting date shift were responsible for significant increases in maize yields, and contributed to yields by 30% ~135%. Varieties change‘s contribution was secondly by 20% ~110%. Planting date change‘s contribution was thirdly by 15% ~ 35%. Since the positive contribution of adaptation in varieties and planting date was far larger than the negative contribution of climate change to maize yield, the maize yields significantly increased in recent thirty years under climate warming over NEC.

The moving average yields showed that varieties change with planting date shift improve maize yields before 2002 or so, but appeared decreasing trend at Huadian and Benxi after 2002 or so. This trend was also found in recent studies on other crop yields. Challinor et al. reported that yields losses were greater under climate change and adaptation by a meta-analysis of crop yields [11]. Zhang et al. found that potential rice yields ceilings decreased and yields stagnation in some areas under climate change in China [18]. This finding also suggested that adaptation potential for late maturing varieties still continual increased in some zones located the north of NEC, and for early or middle maturing varieties with planting date in advance stagnated in some zones located the middle and south of NEC. In this study, without fertilizer stress, simulated yields were affected only by crop treatments (varieties, planting date and irrigation) and climate change. It reported that there was a large yield gap between on farm maize yields and potential yields in NEC, which provided opportunity to increased yields by effective irrigation [19]. It suggested that we also should be considered to change adaptation types in varieties and planting date, and plant later maturing varieties instead of present middle maturing varieties to counteract negative effects of climate warming on maize yields and continually increase maize yields at in some zones located the middle and south of NEC.

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