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Impacts and adaptation of the cropping systems to climate change in the Northeast Farming Region of China

Xiaogang Yin[a,b], Jørgen E. Olesen[b], Meng Wang[a], Isik Öztürk[b], Hailin Zhang[a], Fu Chen[a,*]

[a] College of Agronomy, China Agricultural University; and Key Laboratory of Farming system, Ministry of Agriculture of China, Beijing, 100193, China
[b] Department of Agroecology, Aarhus University, Blichers Alle 20, DK-8830 Tjele, Denmark

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A B S T R A C T

The Northeast Farming Region of China (NFR) is a very important crop growing area, comprising seven sub-regions: Xing'anling (XA), Sanjiang (SJ), Northwest Songliao (NSL), Central Songliao (CSL), Southwest Songliao (SSL), Changbaishan (CB) and Liaodong (LD), which has been severely affected by extreme climate events and climatic change. Therefore, a set of expert survey has been done to identify current and project future climate limitations to crop production and explore appropriate adaptation measures in NFR. Droughts have been the largest limitation for maize (*Zea mays* L.) in NSL and SSL, and for soybean (*Glycine max* L. Merr.) in SSL. Chilling damage has been the largest limitation for rice (*Oryza sativa* L.) production in XA, SJ and CB. Projected climate change is expected to be beneficial for expanding the crop growing season, and to provide more suitable conditions for sowing and harvest. Autumn frost will occur later in most parts of NFR, and chilling damage will also decrease, particularly for rice production in XA and SJ. Drought and heat stress are expected to become more severe for maize and soybean production in most parts of NFR. Also, plant diseases, pests and weeds are considered to become more severe for crop production under climate change. Adaptation measures that have already been implemented in recent decades to cope with current climatic limitations include changes in timing of cultivation, variety choice, soil tillage practices, crop protection, irrigation and use of plastic film for soil cover. With the projected climate change and increasing risk of climatic extremes, additional adaptation measures will become relevant for sustaining and improving productivity of crops in NFR to ensure food security in China.

1. Introduction

Climate change and its impacts on agriculture have been observed across the world during the last 50 years (IPCC, 2013). The Northeast Farming Region of China (NFR) is one of the areas that are most susceptible to climate in China (Piao et al., 2010), which is also one of the most important grain production regions of China (Yin et al., 2016c), where maize, rice and soybean are the three principal crops, accounting for more than 18% of Chinese total grain production (PINC archives, 2011). About 30% of China' maize, 40% of japonica rice and 33% of soybean are produced in this region (Liu et al., 2012; Wang et al., 2012a; Zheng et al., 2012). Normally, maize and soybean are grown as rain-fed crops, whereas rice is always irrigated during the crop growing season in NFR. The productivity of agriculture in NFR is generally high because of the suitable climate conditions and high soil quality, particularly in central NFR, which is known as the Golden-Maize-Belt of China (Liu et al., 2013b). However, the crop production in NFR has been considerably affected by climate change and extreme climate events, which have led to enormous yield reduction during recent decades (Zhang, 2004; Chen et al., 2012; Ju et al., 2013; Yin et al., 2016a,c).

During the recent 50 years, the annual mean temperature in NFR increased 0.38 °C per decade, and the mean temperature increased at a rate of 0.31 °C per decade during the crop growing season (Chen et al., 2011; Jia and Guo, 2011). Meanwhile, sunshine hours declined at a rate of 0.11 h per decade during the last decades (Jia and Guo, 2011). There was a slight declining trend in precipitation and it fluctuated largely during the last decades (Piao et al., 2010; Jia and Guo, 2011). The decreased precipitation associated with increasing temperature made drought occurrence higher, which has caused substantial yield loss, particularly in the western NFR where precipitation is much lower compared to other sub-regions (Zhang, 2004; Yu et al., 2013). NFR is very sensitive to drought due to its large area with rain-fed crops (mainly maize and soybean). Approximately 26% of the cultivated land area was regularly affected by drought (Xu et al., 2013). Drought frequently occurred in spring

* Corresponding author.
E-mail address: chenfu@cau.edu.cn (F. Chen).

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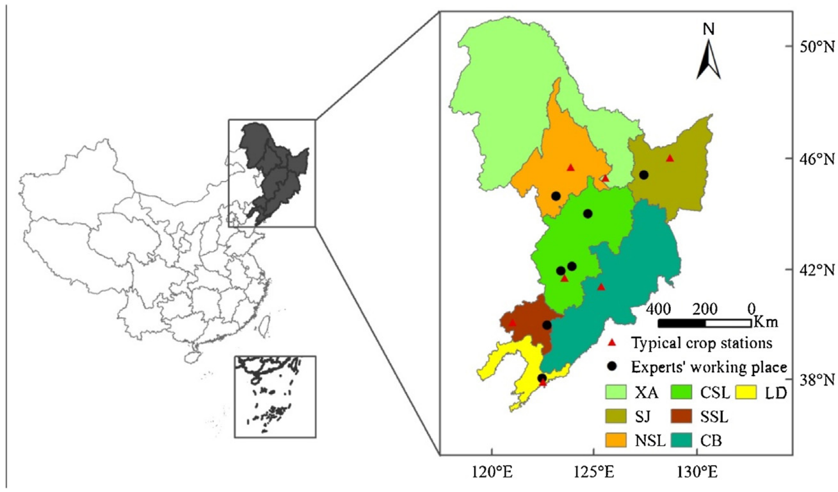

Fig. 1. Distribution of experts in the Northeast Farming Region of China (NFR), the black point represents the experts' working place, and the triangle represents the representative crop yield station in each sub-region. Different colors show different sub-regions in NFR, including Xing'angling (XA), Sanjiang (SJ), Northwest Songliao (NSL), Central Songliao (CSL), Southwest Songliao (SSL), Changbai (CB) and Liaodong (LD).

during the last 50 years, which is particularly severe in the 2000s (Song et al., 2013a; Yin et al., 2016a). In spite of the increase in temperature, chilling damage has also occurred frequently during the last 50 years (Zhao et al., 2009). There are two main types of chilling damage in NFR, one is the sterile-type which is caused by low temperature in critical growing periods of plant then leads to considerable yield loss, such as booting and flowering, which is mainly occurred in rice production (Ma et al., 2007b; Jiao et al., 2008). In specific, the mean temperature is lower than 17 °C within two (or more) continuous days during the booting stage will lead to the sterile-type chilling damage, and the mean temperature is lower than 19 °C within two (or more) continuous days during the flowering stage will lead to the sterile-type chilling damage (Ma et al., 2007b). Another type is the prolonged chilling damage which is caused by the continuous low temperature during the crop growing season that extends the growing season thus enhances the risk of crop damage from early autumn frost, the prolonged chilling damage occurred more frequently in crop production (maize, rice and soybean) compared to the sterile-type chilling damage. Generally, maize and rice are more easily affected by chilling damage compared to soybean in NFR. Previous research has reported that the chilling risk in rice production in XA, SJ, NSL and CB was extremely high during 1961 and 2000 (Ma et al., 2007b). Large amount of maize and rice yield loss was caused by chilling damage during the last 50 years, and the chilling risk may increase with the increasing rice and maize area considering the use of longer growing season varieties in the future (Jiao et al., 2008). Flooding and wind damage and hailstorm are the other two common climate extreme events in crop production in NFR, which has led to substantial yield loss (Gao et al., 2012; Zhang et al., 2014). On the other hand, heat stress also frequently occurred during the last 50 years, which have negatively affected maize and soybean yield (Zheng et al., 2009; Yin et al., 2015, 2016c). In addition, climate warming could shorten the development period of pests and lengthen the living period for most plant diseases and pests, thus made crop production more susceptible to plant diseases and pests. Climate warming also accelerated the population growth of pests, which in turn led to multiple generations and expanded the area of occurrence northwards, thus significantly aggravated the severity of damaging attacks in the area (Huo et al., 2012; Wang et al., 2012a).

With continued emissions of greenhouse gases, climate models have projected that the average temperature in NFR will increase further by 1–3 °C by 2050 depending on emission scenarios (Ding et al., 2006; Zhao and Luo, 2007; IPCC, 2013). The perceived uneven and irregular distribution of precipitation may lead to more severe flooding and droughts, which may have negative impacts on crop production in the future (Ding et al., 2006; Zhao and Luo, 2007; Ju et al., 2013). In general, it was projected that extreme climate events may occur more frequently in the future under different climate scenarios in NFR (Zhao and Luo, 2007; Piao et al., 2010). Given the important role of NFR for China's food security, it is crucial to evaluate the effects of climatic change and extreme climate events on the cropping systems and develop appropriate adaptation measures to maintain or improve grain yields. However, there are very few studies that have integrated the observed and projected effects of climate change across the cropping systems to identify vulnerable regions and farming systems (i.e. except one from Europe Olesen et al. (2011)). Such assessments are needed to precisely identify the needs for changes in agricultural policy and crop management in response to climate change. This subject is of a complex nature, and in some respects too challenging to be handled by models or historical analyses alone, and it may alternatively be assessed through expert evaluations (Olesen et al., 2011). Therefore, a questionnaire survey was conducted with experts in a semi-quantitative manner on their perception of likely vulnerabilities and impacts of climate change for major crops in their geographical area. This study aims (1) to identify the climatic limitations on the specific cropping systems of NFR during 1981–2010, (2) to assess projected impacts of climate change on the cropping systems by 2050, and (3) to investigate the trends in observed adaptation measures and the suitability of future adaptation measures in crop production in NFR.

2. Materials and methods

2.1. Area description

The study area is located in Northeast China, comprising the northeast part of Inner Mongolia, Heilongjiang, Jilin and most parts of Liaoning province, including 304 counties, with 1.42×10^7 ha farmland. NFR is a big plain with chernozem in central, sandy soil in west and clay soil in east. The region is located in high latitude between 40° and 54° North, which is a temperate semi-humid zone. The annual accumulated temperature above 10 °C is 1700–3600 °C and the frost free period normally starts at 28th March, and ends on 2nd October in NFR. The annual mean sunshine duration is 2400–2900 h. Annual precipitation is 500–800 mm, 80% of which