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Coincidence of variation in potato yield and climate in northern China

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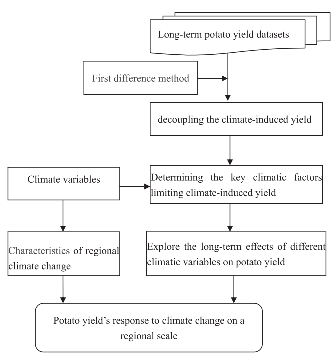
HIGHLIGHTS

- We explored change in yield and regional climate using robust observational evidence.
- We disentangled the contributions of climate change to potato yield.
- We identified the different climatic factors at different potato planting areas.
- We explored the long-term effects of different climatic variables on potato yield.
- Combined effects of different climate variables on potato yield was established.

GRAPHICAL ABSTRACT



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ABSTRACT

Understanding the effects of climate change on crops is vital for food security. We aimed to characterise the coincidence of yield variations with weather variable for potato in northern China using long-term datasets. Daily climate variables obtained from 607 meteorological stations from 1961 to 2014, detailed field experimental data for the period of 1982 to 2012 in northern China, and multivariate linear statistical model were used in this study. In particular, the first difference method was used to disentangle the contributions of climate change to potato yield. We concluded that during the potato growing, the average daily, maximum and minimum temperatures significantly increased by 0.23 °C per decade, 0.20 °C per decade and 0.36 °C per decade from 1961 to 2014 in northern China, respectively. However, average total radiation, total annual precipitation and potential evapotranspiration from April to September all exhibited downward trends, but the variation of evapotranspiration (−9.99 mm per decade) was greater than that of precipitation (−2.65 mm per decade). The key climatic factors limiting potato yields in northern China over the past 30 years at a regional scale were diurnal temperature range, precipitation, radiation and ET_0. The potato yield in northern China was the most sensitive to variation of the diurnal temperature range followed by radiation, precipitation and reference crop evapotranspiration (ET_0). Specifically, when the diurnal temperature range decreased 1 °C, the potato yield increased 543.9 $kg \cdot ha^{-1}$. When the total radiation decreased 1 $MJ \cdot m^2$, the potato yield increased 63.8 $kg \cdot ha^{-1}$. When the ET_0 decreased 1 mm, the potato yield increased 62.7 $kg \cdot ha^{-1}$. When the precipitation increased 1 mm, the potato yield

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increased 62.9 kg·ha^{-1}. A regression model describing the combined effects of different climate variables on potato yield in northern China was established.

1. Introduction

Climate change has become an indisputable fact with the combined effect of natural climate fluctuations and human behaviour (Piao et al., 2010). The first working group from the IPCC 5th assessment report notes once again that world is undoubtedly warming, and the Earth's average surface temperature has increased by approximately 0.8 °C since the late 1800s (IPCC, in press). Furthermore, since the 1970s, each decade has been warmer than the previous decade (IPCC, in press). Among different production systems, agriculture faces significant adverse effects of climate change (Moniruzzaman, 2015). In view of the likely impact of climate change on agriculture, it is urgent to acquire more in-depth understanding of how climate change affects crop yield for both policymakers and scientists (Gregory and Ingram, 2000; Sanchez, 2000; Fuhrer, 2003; Guo et al., 2013; Zhao et al., 2015a,b).

Generally speaking, the effects of climate change on crop yield are non-climatic and climatic (EI-Maayar and Lange, 2013). Non-climatic factors include agricultural inputs (such as the amount of fertilizer), crop variety, technology changes, etc. However, long-term fluctuations in crop yield are closely related with climatic factors such as atmospheric carbon dioxide, temperature and precipitation, as well as interactions between these factors (Zhao et al., 2015a,b).

Potato is the most important non-grain crop worldwide (Haverkort, 1990; Scott et al., 2000), and is central to global food security. Potato optimally thrives in both warm and cool climates potato, but it is not resistant to drought, high temperature or air relative humidity (Wang et al., 2015). However, it is the crop that produces the highest nutrient content despite harsher conditions. As the world's fourth-largest food crop after rice, wheat, and maize (Li, 1985; Haas et al., 2009; Chakraborty et al., 2010), potato is cultivated in several countries worldwide, including China and India (Hijmans, 2003; Hassanpanah et al., 2009; Arab et al., 2011). In China, the acreage and annual potato output are all in the forefront of the world with >533 million hectares and 8000 million tons, respectively (Yao et al., 2013). The yield and quality of potato are both dependent on variety and cultural practices as well as environmental conditions, including rainfall, temperature, light, and CO_2 (Kooman et al., 1996a,b; Dalla Costa et al., 1997; Miglietta et al., 1998).

To anticipate the effects of climate change on potato yields, crop models that describe potato development and growth over time as a function of environmental factors can be used. For example, the Ingram-model (Ingram and McCloud, 1984), the POTATOS model (Wolf, 2002), the APSIM-Potato model (Brown et al., 2011; Lisson and Cotching, 2011), the LINTUL-FAST model (Angulo et al., 2013), the SUBSTOR-potato model (Arora et al., 2013), etc., have all been developed. The impacts estimated from these models depend on input data, specific model structures, parameter values and calibration in addition to climate projections (Wei et al., 2014; Liu and Tao, 2012; Osborne et al., 2013). However, parameter uncertainties in crop models then translate into large uncertainties in the projected responses to climate change, particularly for future scenarios that exceed those in the calibration period (Zhao et al., 2015a,b). Another common approach is to use statistical models, which attempt to represent the effect of weather on crop yields or production using statistical equations calibrated with historical datasets (e.g., Lobell and Asner, 2003; Lobell et al., 2011; Zhang et al., 2008; Zhao et al., 2015a,b). The main advantages of statistical models are their limited reliance on field calibration data, and their transparent assessment of model uncertainties. Disadvantages of statistical models are their contained assumptions that can mislead the naive analyst (Lobel, 2013). For instance, statistical models often (but not always) focus on aggregate measures of weather, such as monthly or growing season averages, and can miss aspects of timing that are important for crop development and growth. However, at broader scales the importance of timing often diminishes (Berg et al., 2010). In recent decades, statistical approaches have benefited from increasing availability of historical crop and weather datasets, and have been applied to various crops and regions (Berg et al., 2010; Lobel, 2013; Zhao et al., 2015a,b).

The impacts of climate change on potato in China at province scales over the past few decades have attracted serious concerns (Wang et al., 2009, 2015; Xie et al., 2012; Xiao et al., 2013). Xiao et al. (2013) analysed the impact of climate change on potato water use efficiency (WUE) in the semiarid area of Guyuan in China, using temperature rise and precipitation simulation testing. They found that when temperature increased by >1.5 °C and precipitation was <310.0 mm, the potato WUE tended to decline. Wang et al. (2015) concluded that to postpone sowing time was a good practice for potato production to adapt to climate warming in Dingxi of the Loess Plateau of central Gansu, China. For each 15-day delay in sowing, the growth duration was reduced by 12 days on average. A significant linear relationship was found between the number of days either from seeding to emergence or from flowering to harvest and mean temperature over the corresponding period. Dry matter accumulation, tuber fresh weight, and final yield were all decreased because of insufficient cumulative temperature over the shorter growing periods. However, few studies have been conducted to quantitatively assess the long-term impact of climate change on potato yield in northern China at a regional scale thus far. Understanding how different climate factors interact and impact potato production is essential when making decisions on how to adapt to the effects of climate change (Asseng et al., 2014; Zhao et al., 2015a,b).

The objectives of the present study are to: (1) understand characteristics of climate-induced potato yield and regional climate change in northern China using robust observational evidence; (2) identify the key climatic factors limiting potato yield using long-term datasets; (3) explore the long-term effects of different climatic variables on potato yield in northern China. These findings are significant for substantially improving our understanding of crop yield's response to climate change on a regional scale in China.

2. Materials and methods

2.1. Study area

Northern China is located at longitude 73–136°E and latitude 31–54° N, with a total area of approximately 499.5 × 10^4 km^2. Northern China is divided into three areas (the northwest, the north and the northeast), and includes the following provinces: Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Heilongjiang, Jilin and Liaoning (Fig. 1). The climate in this area is arid, semi-arid and sub-humid (An et al., 2014). Vegetation types include forests, meadows, grassland, steppes, scrubs, desert and cultivated vegetation. In particular, the northern China is an important area for potato cultivation in China. Potato yield in this region accounted for 38.3% of the total potato yield of China from 2004 to 2012. Usually local potatoes are planted in spring (mid to late April–early May) and harvested in autumn (September), with only one planting season per year.