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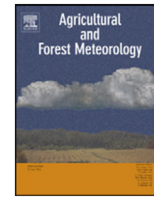

The observed relationships between wheat and climate in China

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ABSTRACT

Recent changes in climate have had a measurable impact on crop yield in China. The objective of this study is to investigate how climate variability affects wheat yield in China at different spatial scales. First the response of wheat yield to the climate at the provincial level from 1978 to 1995 for China was analysed. Wheat yield variability was only correlated with climate variability in some regions of China. At the provincial level, the variability of precipitation had a negative impact on wheat yield in parts of southeast China, but the seasonal mean temperature had a negative impact on wheat yield in only a few provinces, where significant variability in precipitation explained about 23–60% of yield variability, and temperature variability accounted for 37–41% of yield variability from 1978 to 1995.

The correlation between wheat yield and climate for the whole of China from 1985 to 2000 was investigated at five spatial scales using climate data. The Climate Research Unit (CRU) and National Centers for Environmental Prediction (NCEP) proportions of the grid cells with a significant yield–precipitation correlation declined progressively from 14.6% at 0.5° to 0% at 5° scale. In contrast, the proportion of grid cells significant for the yield–temperature correlation increased progressively from 1.9% at 0.5° scale to 16% at 5° scale. This indicates that the variability of precipitation has a higher association with wheat yield at small scales (0.5°, 2°/2.5°) than at larger scales (4°/5.0°); but wheat yield has a good association with temperature at all levels of aggregation. The precipitation variable at the smaller scales (0.5°, 2°/2.5°) is a dominant factor in determining inter-annual wheat yield variability more so than at the larger scales (4°/5°). We conclude that in the current climate the relationship between wheat yield and each of precipitation and temperature becomes weaker and stronger, respectively, with an increase in spatial scale.

1. Introduction and aims

An increase in atmospheric temperature and carbon dioxide concentration, and altered precipitation under climate change are likely to have impacts on agricultural productivity. Despite ongoing improvements in technology and crop varieties, weather and climate are still the main uncontrollable factors affecting agricultural production (Decker, 1994). An average increase in global surface warming of 0.13 °C per decade has been found over the last 50 years with the last years (1995–2006) being the 12 warmest years (IPCC, 2007). The rising temperature in combination with a change in precipitation in some regions has affected crop yield. Lobell and Field (2007) reported a 0.6–8.9% reduction in mean crop (wheat, rice, maize, barley soybean, sorghum) yield per 1 °C rise in temperature at the global scale. A relative decline of about 17% in corn and soybean yield occurred per 1° rise in the growing-season temperature in the USA from 1982 to 1998 (Lobell and Asner, 2003). Rice grain yield has declined by about 10% for every 1 °C enhancement in the growing-season minimum temperature in the Philippines from 1992 to 2003 (Peng et al., 2004). Therefore, recent changes in climate had a measurable impact on crop yield. This indicates that the current temperature is already close to or above the optimum for maximum crop yields in some regions.

In China, the mean annual surface air temperature has increased by approximately 1.1 °C over the last 50 years; almost 60% of the warming occurred in the most recent 16 years (Ren et al., 2003). An analysis of observations by Tao et al. (2006) showed that the warming trends from 1981 to 2000 have had a negative impact on crop yield at six representative stations (including Tianshui, Changsha, Hefei and Zhengzhou) except at Harbin in northeast China. For example, wheat yield at Tianshui station was reduced by 10.2% for each 1 °C rise in growing-season temperature. The increased temperature trends have impacted on wheat yield in China.

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In addition to changes in mean climate, climate variability affects crop productivity. During the growing season, the variation in temperature and rainfall were demonstrated to be the principal factors influencing corn yield in Missouri from 1895 to 1998 (Hu and Buyanovsky, 2003). The response of variation in crop yield to the climate varies widely among regions, depending on the cropping system, climate and spatial scale. Some studies find that temperature is more important and others find that rainfall is the most important factor. For example, the global analysis of Lobell and Field (2007) found a stronger effect of temperature, possibly because rainfall is not nearly as variable at global scales as it is on local scales. In a monsoon country such as India, rainfall is the key determinant of the productivity of rainfed crops. Challinor et al. (2003) showed that 50% of the variability in groundnut yield on the all-India scale could be explained by the variability in total seasonal rainfall from 1966 to 1995. In contrast, the UK inter-annual climate variability can only account for about 10% of crop yield temporal variability (Landau et al., 1998). In China, agriculture has been negatively impacted by frequent disasters such as droughts and floods, and inter-annual crop yield varies in response to the fluctuation of the East Asian Summer Monsoon (EASM) and El Niño-Southern Oscillation (ENSO). Seasonal climate variability associated with EASM and ENSO explained about 14.4% and 15.6% of the variability in maize yield, respectively, from 1978 to 2002 in Henan Province in central China (Tao et al., 2004). It is possible that the associations between climate variability and crop yield also vary at the different spatial scales, but this topic is still little researched. Cool, moist conditions are most favourable for wheat growth. Wheat is highly vulnerable to climate change and variability (Wheeler et al., 1996). It is therefore important to know how climate variability affects wheat yield to understand the response of crops to the climate at different spatial scales.

The objective of this study is to investigate the observed relationships between wheat yield and climate under the current climate in China. An analysis of the observed trends in wheat yield and yield variability at the provincial level over China is presented in Section 3.1. The correlation between wheat yield, rainfall and temperature at the provincial level will be analysed in Section 3.2.1. The crop–climate relationships in China were firstly analysed using two approaches: first-differences (the difference in values from one year to the next) and removal of a linear time trend. The responses of wheat yield to rainfall and temperature at the 0.5°, 2°/2.5° and 4°/5.0° scales are shown in Section 3.2.2 to understand how yield variability is correlated to climate variability at different spatial scales. Finally, the conclusions are presented in Section 4.

2. Materials and methods

China is divided into provinces that are comprised of a number of counties. The area of the provinces is in the range of 34,000 km^2 in Hainan to 1,200,000 km^2 in Xizang (Tibet) and each province includes 4–120 counties. The area per county varies from 56 km^2 to 270,000 km^2. The county level wheat yield data (spring and winter wheat combined) from 1985 to 2000 covering the major wheat planting area of China were calculated from the statistical wheat plantation area and production data at the county level in China. The county level wheat plantation area and production data in China are available from the Climatic Data Centre, Meteorological Information Centre, China Meteorological Administration in Beijing. The provincial level wheat yield (spring and winter wheat combined) for 1978–2000 was obtained from the China Statistical Yearbook (ZGTJNJ, 1979–2001). The spatial distribution of the spring wheat and winter wheat planting regions in China is shown in Fig. 1. The wheat plantation area is divided into spring wheat and winter wheat areas, based on wheat agro-ecological production zones in China (Fig. 1) for analysing the crop and climate correlations. In China, the growing season for spring wheat is normally from April to September, and October to May for winter wheat.

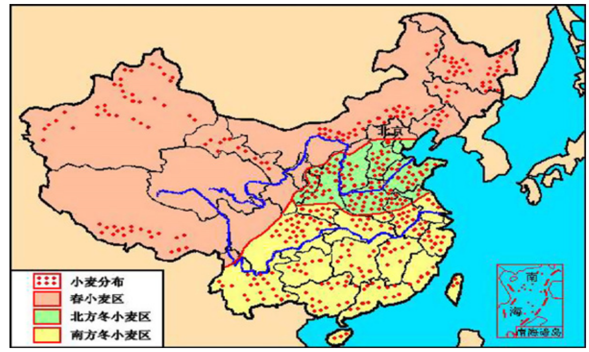

Fig. 1. The spatial distribution of spring wheat and winter wheat planting regions in China. Red points are distribution of wheat, pink areas are spring wheat region, green and yellow areas are winter wheat regions (http://www.dlpd.com/Photo/UploadPhotos/200703/20070327092908652.jpg). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)

The 0.5° CRU climate data from the Climate Research Unit (CRU TS 2.1; Mitchell and Jones, 2005) were aggregated to the provincial level to match the observed provincial level wheat yield. The provincial level yields were linearly regressed against time ($p < 0.05$) in 27 out of 29 provinces in China. Yield anomalies at the provincial level were obtained by removing the linear yield trend from the yield. The correlation between wheat yield anomalies and seasonal mean temperature and total precipitation at the provincial level was analysed using two different detrending methods: (1) removal of a linear time trend of yield, (2) the first-difference time series for yield and climate (i.e. the difference in values from one year to the next; Lobell et al., 2005; Nicholls, 1997; Lobell and Field, 2007).

The observed climate data, including monthly mean precipitation and temperature (minimum and maximum) at the 0.5° × 0.5° scale for 1978–2000 were obtained from the CRU TS 2.1 (Mitchell and Jones, 2005). In order to evaluate the crop/climate relationships at different spatial scales, 2° × 2° and 4° × 4° climate data were obtained by aggregating 0.5° × 0.5° CRU data. For examining the consistency in crop–climate relationships for different climate data, the NCEP (National Centers for Environmental Prediction) Reanalysis data (http://www.cdc.noaa.gov/data/reanalysis/) covering the seasonal monthly mean temperature and total precipitation at the 2.5° × 2.5° scale were also used for analysing the crop–climate relationships. 5° × 5° climate data were obtained by aggregating 2.5° × 2.5° NCEP data. The county level wheat yields were aggregated into 0.5°, 2°/2.5° and 4°/5° scale yields using software ArcGIS to match the climate data. Yield and climate correlations at different spatial scales were evaluated using the first-difference time series for yield and climate because the wheat yields at the 0.5°, 2°/2.5° and 4°/5° scales did not fit the linear regression well in some grid cells.

3. Results

3.1. Yield, yield trends and yield variability

Fig. 2 shows that China's observed national wheat yield obtained from FAO increased dramatically from 1845 kg ha^{-1} in 1978 to 3542 kg ha^{-1} in 1995 with a linear trend ($r = 0.94$, $p < 0.001$). The national wheat yield increased at an average rate of 89 kg ha^{-1} year^{-1} from 1978 to 1995. Rozelle and Huang (2000) reported that in China the increase in wheat yield from 1976 to