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Impact of climate change on water use efficiency by wheat, potato and corn in semiarid areas of China

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ABSTRACT

Our objective was to elucidate the effects of climate change on crop water use efficiency in the northwest semiarid area of China. Improving crop water use efficiency can increase crop production levels and the efficient use of water resources under climate change conditions. This study investigated the effects of climate change on crop water use efficiency in the northwest semiarid region by statistically analyzing crop yields, soil moisture, rainfall and temperature data over the past 50 years. The results showed that, compared with 1960–1969, a temperature rise of 1.6 °C and an annual rainfall reduction of 105.6 mm occurred between 1990 and 2009 and the water use efficiency of wheat, potatoes and corn increased by 10.7, 4.5 and 12.2 kg hm^{-2} mm^{-1}, respectively. Due to climate warming and to a fall in rainfall over the past 50 years, water use efficiency by wheat (*Triticum aestivum*), potatoes (*Solanum tuberosum*) and corn (*Zea mays*) have significantly increased, which shows that climatic change can improve water use efficiency.

1. Introduction

There have been many studies into the effects of climate change on the water use efficiency of plants. Ogaya and Peuelas (2003) showed that the plants in arid and semiarid areas had a comparatively higher water use efficiency, which mitigated the impact of moisture deficiency and strengthened competitiveness under drought conditions. Tenhunen et al. (2002) reported that climate warming affected the water use efficiency of crops by accelerating plant transpiration and soil moisture evaporation in arid and semiarid areas. The reduction in water use efficiency by plant ecosystems as soil water content decreases indicates that other non-stomatal factors also reduce the photosynthetic rate of plants, in addition to stomatal factors, under the extreme drought conditions. Zhao et al. (2007) found that the net photosynthetic rate and stomatal conductance of spring wheat leaves at the milk and milk-ripe stage dropped and the transpiration rate increased when the temperature rose in semiarid areas. Climate warming had inhibited photosynthesis and dry matter accumulation by the spring wheat, which affected its water use efficiency.

The semiarid areas of China mainly cover northeast Tongliao, Shanxi Datong, northern Shannxi, Ningxia Guyua and Gansu Dingxi. They are areas that are vulnerable to the effects of global warming (Zhang et al., 2011). The exact impact of climate change over the past 50 years and the next 50 years on water use efficiency on these important crops, i.e., wheat, potato and corn, is not clear yet. This study aimed to improve the adaptation of crops to climate change and provide a scientific basis for countermeasures by studying the impact of climate change over the past 50 years on the water use efficiency of wheat, potato and corn by analyzing the agricultural and metrological data from 1960 to 2009.

2. Materials and methods

2.1. Overview of the study area

Ningxia Guyuan was selected as the study area and is located between 35.14″–36.38″ N and 105.20″–106.58″ E. This area is mainly covered by deep layers of loessal soil and helu soil and the land is mainly cultivated. Between 1960 and 2009, the average annual temperature ranged from 6.3 °C to 10.2 °C, with an average of 7.9 °C. In recent years, especially after 1998, the temperature has risen significantly ($P < 0.01$) (Fig. 1). Between 1960 and 2009, the annual precipitation ranged from 282.1 to 765.7 mm with large

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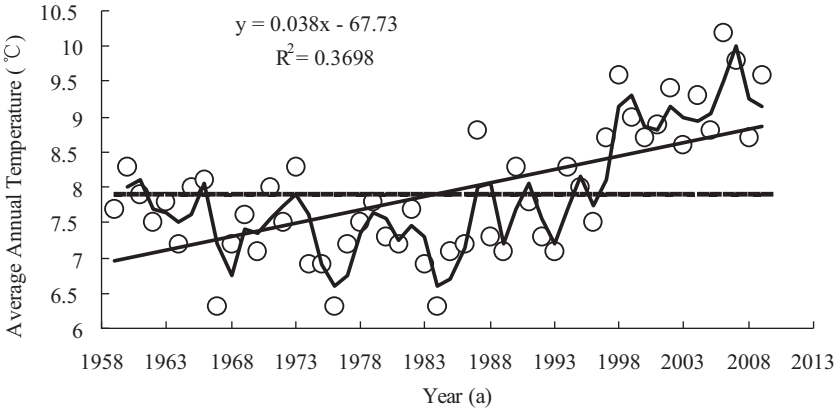

Fig. 1. Temperature trends in the semiarid area of Guyuan from 1960 to 2009.

inter-annual fluctuations. Around 61.8–72.5% of the annual precipitation fell between July and September. The average precipitation over the past 50 years was 448.6 mm and shows a significant downward trend ($P < 0.01$) (Fig. 2). The major crops are wheat, potato and corn producing one crop per year. It is a typical semiarid rain-fed farming region.

2.2. Data source

The precipitation, temperature, growth period, crop yield and soil moisture data for the semiarid area of Guyuan, between 1960 and 2009 were acquired from the China Meteorological Administration. These data were synchronous acquired get, and is sure.

2.3. Calculation of water consumption

The soil water content data during the seeding-sprouting, sprouting-jointing, jointing-blossoming and blossoming-reaping stages for wheat; the seeding-sprouting, sprouting-blossoming and blossoming-reaping stages for potato and the seeding-sprouting, sprouting-bellmouth and bellmouth-reaping stages for corn, between 1960 and 2009, were used to calculate the farmland water consumption:

$$ET_{1-2} = \sum \gamma_i H_i(\theta_{i1} - \theta_{i2}) + P_0 + M + K, \quad (I = 1, 2, \ldots, n)$$

where ET_{1-2} = stage water consumption (mm); i = soil layer number; n = total number of soil layers, consisting of five layers of 0–20, 20–40, 40–60, 60–80 and 80–100 cm; γ_i = soil dry bulk density in layer i (kg cm^{-3}); H_i = soil thickness in layer i (cm); θ_{i1} and θ_{i2} = soil water content in layer i at the beginning and the end of each stage, respectively, as represented by the percentage weight of water-free soil (%); P_0 = effective precipitation (mm); M = irrigation over the period (mm) and K = supplemental groundwater over the period (mm). In the study area, M and K in the above formula were ignored because the crops were not irrigated and the groundwater was 5 m below ground.

2.4. calculation of water use efficiency

$$WUE = \frac{Y}{ET_\alpha}$$

where WUE = water use efficiency (kg hm^{-2} mm^{-1}); Y = crop yield (kg hm^{-2}) and ET_α = actual water consumption of the crops during the growth period (mm), i.e., sum of the water consumption at each stage (Ponton et al., 2006).

2.5. Data processing method

The crop yield, soil moisture, precipitation, temperature and other agricultural and meteorological data were processed and plotted using Microsoft Excel 2003 software.

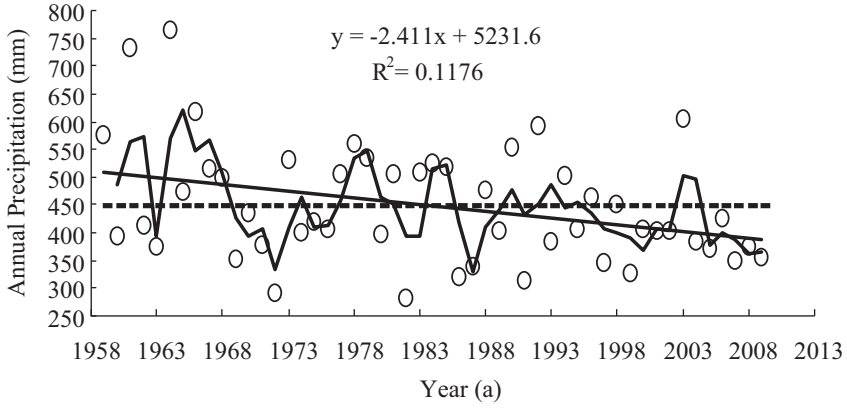

Fig. 2. Precipitation changes in the semiarid area of Guyuan from 1960 to 2009.