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Impact of climate change on the water requirement of summer maize in the Huang-Huai-Hai farming region

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ABSTRACT

Crop water requirement and the temporal and spatial changes of this important characteristic provide key information for irrigation scheduling, water resource planning, and future decision-making. In the Huang-Huai-Hai (HHH) farming region in north China, both crop evapotranspiration (ET_c) and evapotranspiration of the applied water (ET_{aw}) in the growing season of summer maize during 1960–2009 were calculated using the SIMETAW (simulation of evapotranspiration of applied water) model and the daily weather data. Inverse distance weighted interpolation (IDW) was used to interpret spatial distribution of ET_c and ET_{aw}. Results showed that: (1) During 1960–2009 in the HHH farming region, ET_c of summer maize during the growing season showed a significant downward trend; the average ET_c decreased from 335.6 mm/decade in the period 1960–1969 to 311.4 mm/decade in the period 2000–2009. The variation of ET_{aw} of summer maize during the growing season did not drop significantly due to yearly fluctuation of the effective rainfall (R_e) in the growing season, and the improvement of irrigation efficiency and cultivation management measures. Although the descent of ET_c might mitigate the agricultural water stress in this area to some extent, the variation of ET_{aw} still depended on the effective rainfall. (2) The average ET_c values per decade presented higher in the eastern and lower in the western regions; inter-regional differences were observed for ET_{aw}, and the highest ET_{aw} value of about 109.6 mm was found in the western regions of the Shandong and Hebei Provinces. Adjusting irrigation system and adopting the different irrigation systems in different region should be taken into consideration to guarantee the maize yield in this area. (3) During 1960–2009, a significant overall increase in temperature, a significant decrease in wind speed, humidity, and solar radiation, and a slight decrease in precipitation were observed. The solar radiation decrease contributed most to the summer maize ET_c decrease, while relative humidity and precipitation were negatively correlated with ET_c.

1. Introduction

The Huang-Huai-Hai (HHH) farming region is one of the most important agricultural regions in China; its production accounted for 35.3% of China's total maize yield from 1996 to 2007 (Liu et al., 2010a). Annual agricultural water consumption for the HHH is about 800–900 mm; this figure is based upon long term observations of evapotranspiration using a large scale weighing lysimeter, for the winter wheat–summer maize double cropping system (Liu et al., 2002). Water shortage in the region has become a serious concern in recent decades (Brown and Halweil, 1998; Chen et al., 2003; Liu and He, 1998). Excessive exploitation of groundwater resources, from shallow and deep aquifers, has resulted in falling water tables and accompanying environmental problems (e.g. land subsidence). In the past 20 years, the groundwater table in the piedmont plain has fallen at a rate of 1 m year^{-1}; further, a number of areas are experiencing severe groundwater depression (Jia and Liu, 2002). Moreover, as climate change has intensified, the region has experienced a precipitation reduction at an average rate of 2.92 mm year^{-1}; this has been accompanied by an average temperature rate increase of 0.2 °C decade^{-1}, and this increase has been steeper for minimum than for maximum temperatures (Liu et al., 2010a). In the light of these changes, the study of crop evapotranspiration (ET_c), evapotranspiration of applied water (ET_{aw}), and effective rainfall (R_e) in the growing season as means to address the water crisis in this region has become increasingly important.

ET_c refers to the crop water requirement in a given growing season; it can be estimated simply by multiplying the reference evapotranspiration (ET_o) and the crop coefficient (K_c) (Kite and Droogers, 2000; Rana and Katerji, 2000). The Penman–Monteith equation (P–M) is a rather complex method of calculating ET_o under

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different conditions. It uses physically based equations that require daily data as temperature, relative air humidity, solar radiation, and wind speed (Abdelhadi et al., 2000; Allen et al., 1998; Bormann et al., 1999; Goyal, 2004; Kang et al., 2003; Xu et al., 2006). Shifts in the above meteorological variables result in changes in ET_o and subsequently in ET_c.

Previous studies have assessed evapotranspiration in the context of increasing climate change to elucidate some of the main factors impacting shifts in this important characteristic. Gao et al. (2006) reported that decline tendencies of solar radiation and wind speed in the same period were the main variables that have contributed to the decreasing trends in ET_o. Roderick and Farquhar (2002) found that the decline in global solar irradiance led to the decreased pan evaporation in the northern hemisphere that has been observed over the past 50 years. Amongst several studies that have evaluated ET_c vis-à-vis climate variability, one study evaluated the decrease in ET_c for winter wheat and summer maize in most locations in northern China over the past 50 years (Liu et al., 2005; Liu and Lin, 2004). Another study showed a decreasing trend of ET_c between 1965 and 1999 in the Hebei Province (Li et al., 2009). Other studies have investigated the impact of climate change on ET_c in northern China and indicated that the change of reference crop evapotranspiration was impacted by sunshine hours, relative humidity, difference of maximum and minimum temperature and wind speed (Liu et al., 2010b; Ma et al., 2010). Tong et al. (2007) found that ET_c gradually increased in the upper reaches of the Shiyang river basin in Northwest China in the last 50 years, while the middle reaches showed a significant decreasing trend, and in other regions no significant trend was found. Song (2009) calibrated and validated the SIMETAW (simulation of evapotranspiration of applied water) (Snyder et al., 2005) model, and subsequently used it to calculate the ET_c of Beijing's main crops (oat, maize, winter wheat, and sweet potato). Despite the above reports, research on the climate change impact on pertinent ET_c indicators and the resulting shifts in ET_c remains scarce. Particularly for the HHH region, the analysis and prediction of ET_c will play an increasingly important role in the adaptation mechanisms for future climate change and water shortages.

This study thus addressed the scarcity of the information stated above, especially considering its significance in present and future agricultural applications. The objectives were (1) to analyze the spatial and temporal variation of ET_c and ET_{aw} of summer maize in its growing season from 1960 to 2009 in the HHH farming region; (2) to represent the changing trend of climate variables from 1960 to 2009 and to quantify the contribution of each climate variable to the variation of ET_c.

2. Materials and methods

2.1. Study area

The Huang-Huai-Hai (HHH) farming region is one of China's major agricultural centers. Making up part of eastern China, it extends between 31°14′–40°25′ N latitude and 112°33′–120°17′ E longitude, and has a total area of 33.104 km^2. The region is characterized by a semi-humid and semi-arid climate, and its environment has been strongly affected by human activities. Solar energy resources in the area are rich, and the annual precipitation is 500–700 mm, with 60–70% of the rainfall occurring in summer (June–August). Most rainfall coincides with summer maize growth, however it remains insufficient for crop water requirement. According to *Farming Systems in China* (Liu and Chen, 2005), the area is divided into seven sub-zones, which are designated according to farming system types (Fig. 1).

2.2. Climate data

Fifty homogeneously distributed meteorological stations were selected and included in this study (Fig. 1). The following daily meteorological data for the period of January 1960–January 2010 from the aforementioned meteorological stations were collected

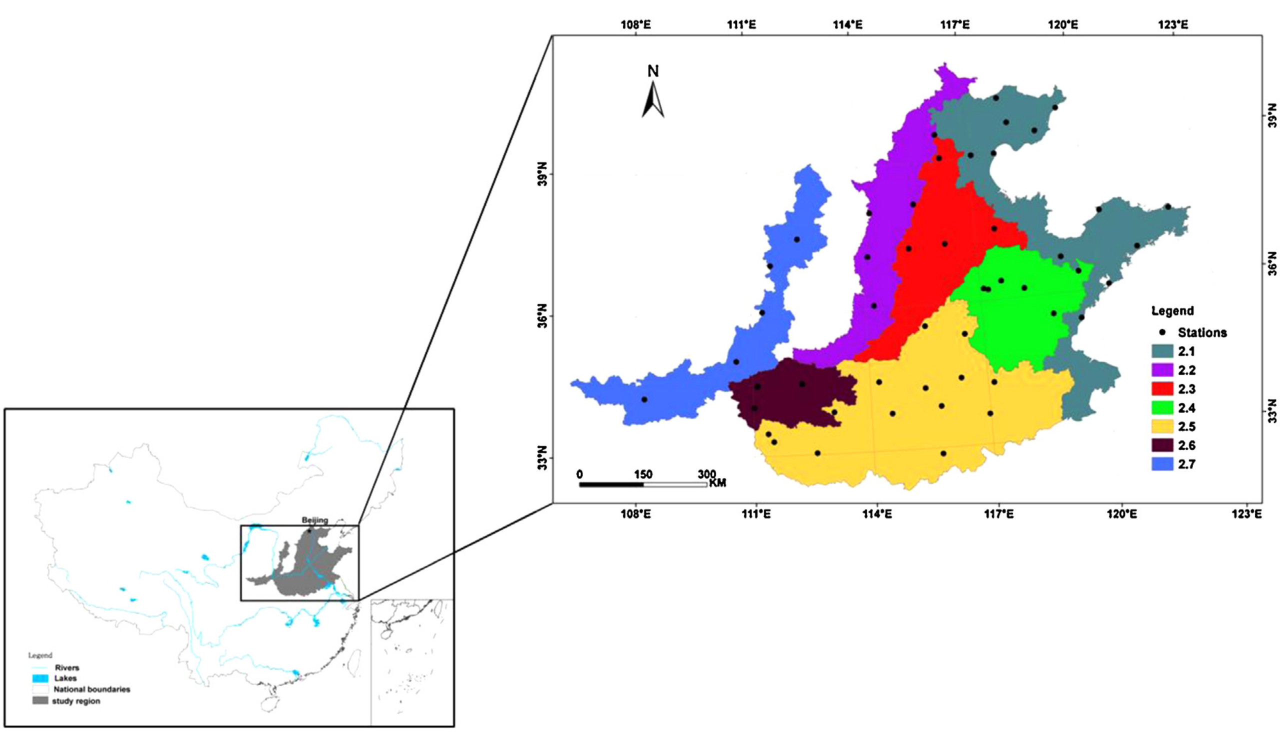

Fig. 1. Distribution of sub-zones in the Huang-Huai-Hai farming region and selected meteorological stations.