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Prediction of cotton yield and water demand under climate change and future adaptation measures

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ABSTRACT

Cotton is the main cultivated cash crop in Northwest China. This study is motivated by the challenge of economically growing cotton in the face of climate change, which could lead to changes in cotton variety, phenology, water demand, heat requirement and yield. The APSIM-OzCot crop growth model is used to simulate cotton cultivation at two sites with different climatic conditions (Shihezi and Alaer, Xinjiang Province). The model is fully calibrated and validated using observations. Simulations forced with future climate data downscaled from the HadCM3 Global Climate Model show that the response of cotton phenology, yield and water use to climate change is different for different cultivation, sites, greenhouse gas emission scenarios and time horizons. Under the SRES A1B and B1 emissions scenarios, cotton yield and water use are greater in the future than in the 1961–1990 period while the growing season is shorter. Under the SRES A2 emissions scenario, however, yields at cold sites drop after 2070 due mainly to the shortening of cotton growth periods. Thus, in the cold regions, varieties with short growth periods are replaced by those with long growth periods. The results show that, compared with current local varieties, cotton yields increase by 356 kg/ha with the medium maturity variety "K7" and 473 kg/ha with the late maturity variety "ZM49" under the A2 scenario by 2070. Total evapotranspiration correspondingly increases by 69 mm ("K7") and 92 mm ("ZM49"). However, water use efficiency increases by 0.32 kg/m^3 to 0.34 kg/m^3 (6.3%) and 0.35 kg/m^3 (9.4%) for "K7" and "ZM49", respectively. A reasonable adaptive strategy to maintain cotton yields in the future may be to decrease the area over which cotton is planted and raise water use efficiency.

1. Introduction

Phenology is the most measured parameter in terms of crop response to climate change. Phenological changes over the past decades have been analysed for different crops, including wheat, corn, cotton, and soybean (Chen et al., 2011; Ludwig and Asseng, 2010; Mall et al., 2004; Sacks and Kucharik, 2011). By changing planting dates and growing degree days (GDD), climate-driven phenological changes can result in changes in crop yield and water requirement (Sacks and Kucharik, 2011; Twine et al., 2004). Tao et al. (2012) investigated wheat phenology at over 100 experimental stations across China and noted increasing thermal requirements at each development stage, generally increased yield over the 1981–2007 period. Similarly, Sacks and Kucharik (2011) noted prolonged growth periods and a 14% increase in GDD for both corn and soybean across the U.S over the 1981–2005 period. Under climate change, planting date could advance and GDD increase.

To ensure high yields, slow maturing varieties could be planted as an adaptation measure to warming climates. However, current studies (Hebbar et al., 2013; Keating et al., 2002; Ludwig and Asseng, 2006) have largely focused on current varieties in simulating yield and water use under future climatic conditions. These results are unlikely to reflect reality because farmers may change crop varieties in response to climate change. Simplified crop simulations that predict future crop water use could generate a considerable level of error as prolonged crop growth periods under a warming climate could potentially trigger high crop water demand. Also, with current varieties, shorter growth periods, a common

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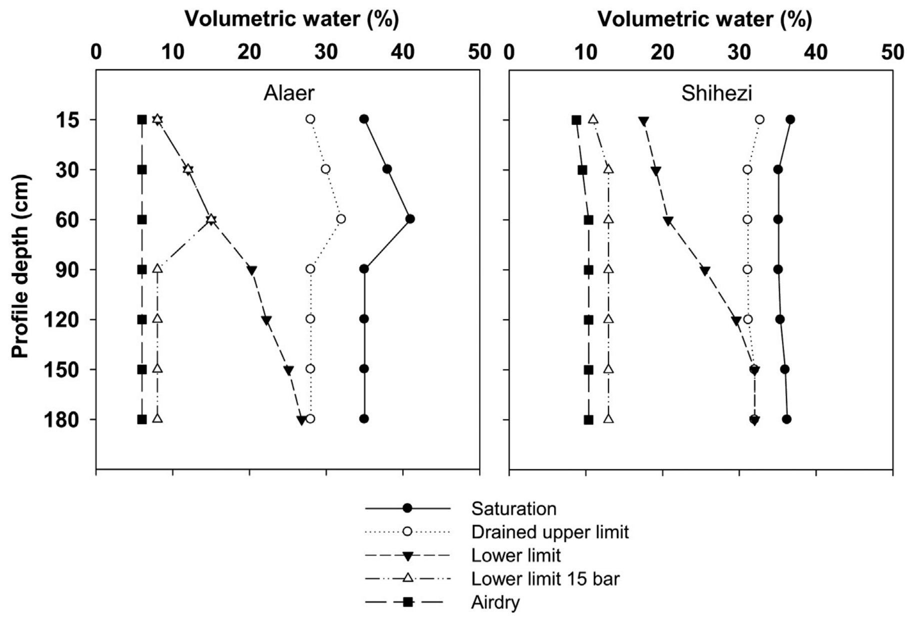

Fig. 1. Hydraulic parameters of soil in Alaer and Shihezi.

crop response to global warming (Gerardeaux et al., 2013; Ludwig and Asseng, 2010; Wang et al., 2008), could result in lower water demand. Such prediction errors could be important, especially in water-scarce regions as in arid/semiarid regions.

This study demonstrates how changes in cotton water use and yield in response to climate change, with and without the adaptation measure of using a slower maturing variety, can be examined. The method involves generating climate projections for two sites in Northwest China using a single Global Climate Model (GCM) and using these as input to simulations of the cultivation of a number of different cotton varieties.

2. Data and methods

2.1. Study sites

The experimental sites locate at the Xinjiang Uyghur Autonomous Region, Northwest China. This has a typical desert climate, with high evaporation and low precipitation. Oasis agriculture, which accounts for only 5% of the area of the region, depends on irrigation water from glacial/snow melt in the surrounding mountains (Fan et al., 2006). Cotton is the dominate crop in the region, which accounts for the majority of China's cotton production. Due to increasing warming conditions in recent decades, runoff/streamflow has steadily increased in the region. However, this trend is predicted to reverse, with runoff/streamflow decreasing as the mountain glaciers/snows dry up in the decades ahead (Piao et al., 2010). There is therefore a need to develop adaptation strategies, including changing cotton variety, based on reliably simulated crop water demand and yield under future hydro-climatic conditions.

For this study, the Shihezi (44.32°N, 86.05°E, altitude 442.9 m) and Alaer (40.55°N, 81.27°E, altitude 1012.2 m) sites, in North Xinjiang and South Xinjiang, respectively, were selected to represent relatively cool and warm climate conditions within the region. The average temperature and average annual precipitation are 7.4 °C and 167 mm, respectively, for Shihezi and 11.4 °C and 49 mm for Alaer. Loam grey desert soils are dominant in Shihezi, while loamy alluvial soils are common in Alaer. The soil hydraulic parameters are shown in Fig. 1.

2.2. Field experiments

Data from field experiments conducted at the two study sites were used to calibrate and validate simulations of the "XLZ8" cotton cultivar at Shihezi and the "K7" and "ZM49" cultivars at Alaer. "XLZ8" is the local variety cultivated in Shihezi, which has an active growth period (from sowing to boll opening) of 120 days. The "K7" and "ZM49" are the local varieties cultivated in Alaer. These have active growth periods of 135 days and 145 days, respectively. The Shihezi experiments were conducted in 2002 and 2003 at an Agricultural Station belonging to Shihezi University. The detailed experimental design at Shihezi is fully documented by Yang et al. (2005).

The Alaer experiments were conducted in 2011 and 2012 using two cotton cultivars—the medium-period growth cultivar "K7" and long-period growth cultivar "ZM49". Each plot was 2 m wide and 3.3 m long. "K7" and "ZM49" seeds were both sown on 20th May 2011 and 1st May 2012. Row and hill spacings were, respectively, 50 cm and 20 cm for both cultivars. The same spacings were maintained in 2011 and 2012 in a west-east row orientation for all treatments. Plants were thinned down to one per hill at about the third true-leaf stage. Topping was manually done on 15th June 2011 and 5th July 2012. Conventional land preparation and insect control measures were used for all treatments. The experiment was designed to study cotton growth under no water and fertiliser limit condition. Therefore, prior to sowing, NPK fertilizer was applied in the following proportion—N = 150 kg/ha (urea), P_2O_5 = 70 kg/ha, and K_2O = 200 kg/ha. As a common agricultural practice in the region, 100-mm flood irrigation was applied two to three weeks before sowing, on the 1st May 2011 and on 20th April 2012, to leach salt from the root zone. Subsequent irrigation was applied as shown in Table 1. Additional fertiliser applications were made after sowing at each irrigation at the rate of 50 kg N/ha and 40 kg N/ha for 2011 and 2012 crop year, respectively.

Three cotton plants per plot were randomly flagged for non-destructive measurement over the entire period of growth. Plant height and the numbers of main-stem nodes, squares, green-bolls, open-bolls and abscised sites were measured for the flagged plants at 10-day intervals from the day after emergence (DAE) to end of the growing season. Leaf area was determined by a LAI-2000 leaf area meter (LI-COR, Lincoln, NE, USA). Phenology (including the days of