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Optimizing planting date and supplemental irrigation for potato across the agro-pastoral ecotone in North China

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ABSTRACT

Adjusting planting date along with supplemental irrigation is widely used to improve potato yield in the agro-pastoral ecotone (APE) with high variability of limited rainfall in North China. Optimal planting date and supplemental irrigation time for potato differed greatly with climate and soil conditions, and were not fully investigated via field experiments. In this study, using APSIM-Potato model carefully calibrated and validated with two-years serial planting experimental data, the individual and coupled impacts of planting date and supplemental irrigation time on yield and water productivity (P_{WP}) of potato were quantified across the APE. APSIM-Potato performed well in simulating phenology, leaf area index (LAI), soil water dynamics, biomass of potato, and also captured the trend in potato yields under different planting dates. Based on the long-term simulations from 1981 to 2010, the optimal planting dates were May 10 (local normal planting date), May 20 and May 30 in the eastern, middle and western APE, respectively. Yield and P_{WP} of potato could be increased by 12.5% and 7.0% in the middle APE, 23.3% and 18.3% in the western APE respectively, under the optimal planting date compared with the local normal planting date under rainfed condition. Supplemental irrigation (8-55 mm) from rainwater harvesting could increase potato yield by 3.5-35.2%, 6.9-41.8%, and 9.0-50.8% respectively, in the eastern, middle and western APE. The corresponding P_{WP} could be enhanced by 1.2-22.7%, 6.7-30.8% and 4.5-33.7%, respectively. Combining the optimal planting date with better scheduling the maximal harvested rainwater could increase yield and P_{WP} of potato by 36.8% and 23.4%, 69.2% and 49.2%, 64.3% and 48.8%, respectively for the eastern, middle and western APE, compared with the simulation results under the local normal planting dates and rainfed condition. The study suggested a large potential of increasing yield and P_{WP} of potato across the APE by optimizing planting date and better scheduling the supplemental irrigation from rainwater harvesting.

1. Introduction

Potato is the world's fourth-largest crop, following maize, rice and wheat (FAO, 2014). China produces 9.6×10^7 Mg fresh potato accounting for 25.1% of world total with 29.6% sown area of the world total (FAO, 2014). The agro-pastoral ecotone (APE) in North China is one of staple potato production regions in China due to suitable temperature and soil conditions for potato growth (Hijmans, 2003; Xia et al., 2010; Rykaczewska, 2015; Yu and Wang, 2015). As a staple crop, potato yield accounts for 46.8% of total crop yield in the APE and its sown area has been increasing in recent years (Tang et al., 2016). Therefore, potato production in the APE plays an important role in maintaining local food security (Zhao et al., 2016). However, potato yield in this region is limited seriously by water shortage due to high variability and low amount of annual and growing season precipitation (Wang et al., 1999; Xia et al., 2010; Tang et al., 2016). Average growing season precipitation of 280-370 mm could not meet the water requirement of potato (Haverkort et al., 1990) and 100-300 mm additional irrigations are generally needed across the agro-pastoral ecotone region (Hu et al., 2013; Qin et al., 2013b). Improving both precipitation and irrigation use efficiencies is an important way in enhancing potato yield and ensuring yield stability in the semi-arid region (Liu et al., 2006; Shen et al., 2012; Tang et al., 2016).

Adjusting planting date to match potato water requirement and precipitation distribution during potato growing period has been applied successfully for improving precipitation use efficiency (Tang

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et al., 2016, 2018). In general, early planting of potato would lead to slow emergence and seedling growth rate due to low soil temperature and moisture while delayed planting decreased the growth duration, harvest index and leaf area index (LAI), yield and water productivity of potato (Khan et al., 2011; Shen et al., 2012; Wang et al., 2015a). In the APE, experimental studies showed that potato yield generally decreased with the delay of planting dates, and the optimal planting dates varied across the region, such as April 5 for the eastern APE, May 1 for the middle APE, and May 15 for the western APE (Jia, 2012; Shen et al., 2012; Si and Lu, 2015).

Due to limited surface and groundwater resources in the APE, rainwater harvesting has been an effective way to guarantee the application of supplemental irrigation in the APE (Pan et al., 2007). Supplemental irrigation at planting is needed to ensure the emergence of potato for dry spring seasons (Qin et al., 2013a; Chen et al., 2016; Tang et al., 2016). However, applying the limited irrigation at planting may not maximize potato yield and water productivity for wet spring seasons. Zhang et al. (2011) found that supplemental irrigation at the tuberization stage increased yield and water productivity of potato more than at the seeding stage in the semi-arid region. However, Qin et al. (2013a) concluded that tuber yield and water use efficiency of potato were higher with supplemental irrigation at the vegetative growth stage than that at the tuber bulking stage in the same region. Moreover, the response of potato yield to deficit irrigation varied with sites due to different precipitation distributions (Chen et al., 2016). Therefore, optimal irrigation scheduling at one site may be not extrapolated to other sites in the APE.

The field experiments could help explore the optimal planting date and irrigation schedule (Liu et al., 2006; Katerji and Mastrorilli, 2009; Shen et al., 2012; Florio et al., 2014). However, conclusions from experimental studies varied from site to site due to contrasting climatic conditions and crop growth season (Bassu et al., 2009). Agricultural system models have been widely used in investigating optimal planting date and irrigation schedule, and extended experimental results to different seasons or areas, such as APSIM (Chen et al., 2010; Zhang et al., 2012; Singh et al., 2016; Zeleke and Nendel, 2016), DSSAT (Daccache et al., 2011; Kleinwechter et al., 2016), RZWQM (Kisekka et al., 2017) and others. However, few studies focused on potato in the agro-pastoral ecotone in North China, and investigated the coupled impacts of planting dates and supplemental irrigation on potato water productivity across the region. Therefore the objectives of this study are to: (1) evaluate the performance of APSIM-Potato model in simulating potato growth and development in response to contrasting planting dates in the agro-pastoral ecotone in North China, (2) quantify the effects of planting date and available supplemental irrigation on potato yield, evapotranspiration (ET) and water productivity (P_{WP}) across the region using the APSIM-Potato model and long-term historical climatic data (1981-2010), and propose the most suitable planting date and irrigation schedule for potato across the agro-pastoral ecotone in North China.

2. Materials and methods

2.1. Study region, climate and soil data

Twenty-seven sites roughly uniformly distributed across the APE were selected for this study (Fig. 1) to investigate the impacts of planting date and supplemental irrigation on potato yield, ET and P_{WP}. Three regions (I- Eastern APE, II-Middle APE, III-Western APE) were divided based on the onset of rainy season defined by Marteau et al. (2011). The onset date of rainy season was defined as the first wet day of 5-day spell receiving at least 20 mm without any 10-day dry spell in the following 20 days.

The onset date of rainy season varied from May 20 to June 5, from June 6 to June 20 and from June 21 to July 5 in the eastern, middle and western APE, respectively. Growing season (May-September) average temperature and total precipitation are 15.5 °C and 326 mm in the eastern APE, 15.1 °C and 333 mm in the middle APE, 15.6 °C and 321 mm in the western APE. Potato is planted from late April to early June with normal planting date of the middle May used by local farmers and harvested in late September before the first frost day (Tang et al., 2018). Climate data, including daily maximum temperature (°C), minimum temperature (°C), precipitation (mm) and sunshine hours (h) during the historical period from 1981 to 2012 were available from China Meteorological Administration. Daily solar radiation was estimated from daily sunshine hours based on the Angstrom equation (Wang et al., 2015b).

Soil hydraulic properties and other soil parameters at each site were obtained from the China Soil Scientific Database (http://www.soil.csdb.cn/). The plant-available water content (PAWC) up to 1 m were 162 mm, 120 mm and 109 mm averaged from the sites in the eastern, middle and western APE, respectively. The hydraulic parameters, including soil water content at a lower limit of 15 bar (LL15), drained upper limit (DUL) and saturation (SAT) are shown in Fig. 2.

2.2. Serial planting experiment for calibrating APSIM-Potato model

Serial planting experiments were conducted in 2011 and 2012 at the Scientific and Observing Experimental Station of Agro-environment in Wuchuan County (41°06′N, 111°28′E, altitude 1756 m), located at the centre of the agro-pastoral ecotone in North China (Fig.1). Five planting date treatments (April 26, May 6, May 16, May 26 and May 31) with four replicates were used in each year. Potato was planted in 5 × 5 m plots and the cultivar Kexin_1 was used in all treatments. The planting density was 40,000 plants per ha with the same row and plant spacing (0.5 m). Base fertilizer was applied at planting with 75 kg ha^{-1} of ammonium diammonium phosphate, 37.5 kg ha^{-1} of urea and 37.5 kg ha^{-1} of potassium chloride. To guarantee the emergence of potato, 30 mm of supplemental irrigation was applied at planting for each treatment. The key phenological stages including planting, emergence, tuberization, tuber bulking and maturity were recorded. Leaf area index (LAI) and biomass of each organ (root, tuber, stem and leaf) were measured at an interval of 15 days after emergence by taking 3 plants in each plot. The leaf area was measured by Portable Area Meter (Model: LI-3000C). Soil water content at 1 m depth with the interval of 10 cm was measured using oven drying method at an interval of 15 d. The fresh tuber yield with a moisture content of 80% was measured through harvesting potatoes in four 5 m row in the center of the block with the harvesting area of 10 m^2. Detailed descriptions on experimental data could refer to Tang et al. (2018).

2.3. APSIM-Potato model and its parameterization

APSIM model is a process-based crop model, which has been tested and applied in different regions under variable climate conditions (Chen et al., 2010; He et al., 2017a). It was able to reproduce the phenology, yield and water balance of wheat, maize, canola in main grain production regions of China. APSIM-Potato model has been used in Australia and New Zealand (Brown et al., 2011; Lisson and Cotching, 2011), however, it has not been evaluated in the APE in China. In our study, APSIM version 7.7 was used to simulate the growth and development of potato under different planting dates. The key modules used are potato (Brown et al., 2011), soilwat (Probert et al., 1997), soilN (Probert et al., 1997), SurfaceOM (Probert et al., 1997) and a manage module. APSIM simulates potato development, biomass growth, and tuber yield in response to temperature, photoperiod, solar radiation, soil water and nitrogen at a daily time step (Brown et al., 2011). For phenological development, the duration from planting to maturity is divided into six phases, i.e., planting to germination, germination to emergence, emergence to early tuber (tuberization), early tuber to senescing (tuber bulking), senescing to senesced, and senesced to maturity. Each phenological development stage requires a certain