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RESEARCH ARTICLE

Stem flow of seed-maize under alternate furrow irrigation and double-row ridge planting in an arid region of Northwest China

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Abstract

Maize is widely planted throughout the world and has the highest yield of all the cereal crops. The arid region of Northwest China has become the largest base for seed-maize production, but water shortage is the bottleneck for its long-term sustainability. Investigating the transpiration of seed-maize plants will offer valuable information for suitable planting and irrigation strategies in this arid area. In this study, stem flow was measured using a heat balance method under alternate furrow irrigation and double-row ridge planting. Meteorological factors, soil water content (θ), soil temperature (T_s) and leaf area (LA) were also monitored during 2012 and 2013. The diurnal stem flow and seasonal dynamics of maize plants in the zones of south side female parent (SFP), north side female parent (NFP) and male parent (MP) were investigated. The order of stem flow rate was: SFP>MP>NFP. The relationships between stem flow and influential factors during three growth stages at different time scales were analyzed. On an hourly scale, solar radiation (R_s) was the main driving factor of stem flow. The influence of air temperature (T_a) during the maturity stage was significantly higher than in other periods. On a daily scale, R_s was the main driving factor of stem flow during the heading stage. During the filling growth stage, the main driving factor of NFP and MP stem flow was RH and T_s, respectively. However, during the maturity stage, the environmental factors had no significant influence on seed-maize stem flow. For different seed-maize plants, the main influential factors were different in each of the three growing seasons. Therefore, we identified them to accurately model the FP and MP stem flow and applied precision irrigation under alternate partial root-zone furrow irrigation to analyze major factors affecting stem flow in different scales.

Keywords: stem flow, alternate partial root-zone furrow irrigation, double-row ridge planting, seed-maize

1. Introduction

Maize is widely cultivated throughout the world and more grain is produced each year than any other cereal crop. Seed breeding industry supply healthy and vigorous seeds and guarantee sustainable breeding of maize. In the United States, which is the largest maize producer and exporter of the world, the seed-maize breeding has become more similar to other high-technology industries and has contributed to the advent of agricultural biotechnologies, molecular genetics and recombinant DNA techniques that have become essential components of US seed development programs (Magnier *et al.* 2010). In some maize importing countries, e.g., Iran, the annual consumption of maize is about 3 million tons, but only 2 million tons were harvested in 2004. So the

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development of seed-maize, which could be supplied from a high-yield variety, is one way to achieve self-sufficiency and thus reduce the import of maize (Pishgar-Komleh *et al.* 2012, 2013; Yasari *et al.* 2012).

The arid region of Northwest China, with the unique geographical advantages in sunshine resources, has developed into the largest seed-maize production area of China and produced almost half of national seed demand (Xiao *et al.* 2010). In this arid region, most seed-maize fields are irrigated with conventional border irrigation. However, most of this area has an annual rainfall below 200 mm, which results in a water shortage for seed-maize production. Saving irrigation water and improving irrigation water-use efficiency (WUE) of seed-maize are essential for sustainable development of seed production in this region. Moreover, the transpiration of different seed-maize parent may be not the same, and irrigation method may also cause different rates of crop transpiration. Thus, investigating the transpiration characteristics of seed-maize and its relationships with environmental factors under new planting pattern and irrigation method will be an efficient way to develop efficient irrigation strategies.

Previous studies showed that ridge planting can increase superficial area of land (Agustin *et al.* 2000; Aggarwal and Goswami 2003), improve the utilization efficiency of light (Wang *et al.* 2004), heat, water and fertilizer, and change microclimate, soil physical properties and microbial biomass (Wang *et al.* 2001; Agustin *et al.* 2006). Zhang L *et al.* (2012) studied the grain yield and WUE of seed-maize in six different cultivation patterns and indicated that covered with plastic film, ridge planting and furrow planting provide an advantage to improve yield and WUE. However, few researchers distinguished the water consumption of maize female and male parent rows. Few reports are available on the effects of double-row ridge planting under alternate partial root-zone furrow irrigation method, which may cause different root growth response of plants on each side of the ridge.

Furthermore, some studies have reported on the high efficient water-saving technology of seed-maize, such as regulated deficit irrigation under film mulching, which could improve grain yield and save 20% of irrigation water compared to conventional surface irrigation (Zhang Q *et al.* 2012). The influence of water deficit at different growth stages under drip irrigation on seed-maize growth and yield was examined, and a set of soil water regulation mode was also proposed (Zhang *et al.* 2009). As a new water-saving irrigation technology, alternate partial root-zone furrow irrigation has some advantages, such as saving water and improving WUE (Kang *et al.* 2000). It has been widely applied worldwide to improve irrigation efficiency on maize, wheat, potato, cotton and soybean (Sepaskhah and Khajehabdollahi 2005; Du *et al.* 2006; Sepaskhah and Hosseini 2008; Thind *et al.* 2010; Pedram *et al.* 2011; Slatni *et al.* 2011; Wang *et al.* 2013). However, it has not been applied on seed-maize production.

The stem heat balance technique to measure transpiration started in the 1980s. After the perfection by Sakuratani (1984), Baker *et al.* (1987) and Steinberg *et al.* (1989), the accuracy of this technique had been improved. This method has several advantages including relatively easy application and no calibration. In recent years, heat balance technique has been widely used to measure stem flow of herbaceous plants (Rosanne *et al.* 2005; Swaef *et al.* 2012; Ding *et al.* 2013), sand plants (Yue *et al.* 2008; Huang *et al.* 2010), woody plants (Nakai *et al.* 2005; Chirino *et al.* 2011) and fruit trees (Lucas *et al.* 2010; Van den Bilcke *et al.* 2013).

Stem flow is closely related to not only meteorological factors such as solar radiation, air temperature and relative humidity (Pfautsch *et al.* 2010; Juhász *et al.* 2011; Lubczynski *et al.* 2012; Bchir *et al.* 2013), but also to soil water content, and temperature, and physiological parameters (Day *et al.* 1990; Vertessy *et al.* 1997; Lundblad and Lindroth 2002; Mellander *et al.* 2004; Tognetti *et al.* 2004; Liu *et al.* 2009; Xu *et al.* 2011). Alarcon *et al.* (2000) indicated that stem flow was significantly related to available soil water content. Shan *et al.* (2013) indicated that water deficit in arid and semiarid regions affects the whole-plant stem flow. In another study on *Yulania wufengensis* trees, the stem flow showed no significant correlations with soil temperature and soil water content on an hourly scale, but significant with soil temperature, soil water content, and solar duration on a daily scale, with the correlation coefficient of about 0.8 (Zhu *et al.* 2012). Furthermore, soil temperature and water content can markedly affect stem flow of *Larix gmelinii*. One unit increase in soil temperature could induce an increase of 0.084–0.123 L cm^{-2} mon^{-1} at the temporal scale of a month (Wang *et al.* 2012). During the entire growing season of a plant, stem flow is also determined by leaf area (Vertessy *et al.* 1995). All the above factors interact with each other. Through the growth of plant, the influencing factors are also different. Therefore, it is necessary to analyze the influence of environmental factors to stem flow by stages.

In this study, stem flow of seed-maize were measured using the heat balance method under alternate partial root-zone furrow irrigation and double-row ridge planting. Meteorological factors, soil water content, soil temperature and leaf area were simultaneously monitored during the 2012 and 2013 growth seasons in an arid region of Northwest China. The objectives were to (1) investigate the variation of stem flow of seed-maize on an hourly and daily scale; (2) analyze the relationships between stem flow and environmental factors at different growth stages; and (3) determine the main driving factors of water consumption of