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A lysimeter study for the effects of different canopy sizes on evapotranspiration and crop coefficient of summer maize

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ABSTRACT

Canopy size has an important and direct influence on water consumption by raising maize (Zea mays L.) transpiration through increased stomata number on leaves and reducing soil evaporation through blocking solar radiation. Evapotranspiration of maize was determined between 2012 and 2013 by weighing lysimeters at National experimental station for precise agriculture in Beijing. The results showed that total water consumption was 386.3 mm and 366.2 mm for maize strain with large (L) and small canopy (S), respectively. From DAS 50 to DAS 80, the difference of water consumption between two maize strains enlarged at a higher rate than other periods, which was about 4.2 mm at intervals of 10 days. Both the highest periodical water consumption and daily water consumption occurred at the Mid-stage, which was 151.8 mm for L and 139.1 mm for S, 5.06 mm/day for L and 4.64 mm/day for S, respectively. The crop coefficient was 1.11 and 1.04 and seasonal crop coefficients at Initial stage, Mid-stage and Late stage were 0.46, 1.53, 1.22 and 0.44, 1.40, 1.09 for L and S, respectively. The duration when daily Kc was bigger than 1(Kc > 1) was 56 days for L and was 5 days more than that of S, respectively. Although bigger canopy consumed more water, a higher water use efficiency of L is not only for its higher averaged yield, but also for its more positive response of yield to ET increment than that of S between two years. The stable yield performance is helpful for a long-term high water use efficiency. The characteristics of water consumption for maize of different canopy size may help to optimize water utilization in semiarid region.

1. Introduction

North China Plain (NCP) accounted for about 22% of total corn yield in China during the last decade from 2004 to 2013 according to official statistics. Irrigation was necessary for high level production of agriculture in this region, because spatiotemporal fluctuation of precipitation was strongly influenced by monsoon climate and global climate change (Wang et al., 2017; Chu et al., 2010). Annual precipitation significantly decreased in the past several decades (1950s-2000s) (Zhai et al., 2005), then germinated persistent multi-year severe droughts in northern China (Yu et al., 2014). Moreover, increasing population and associated food demand lead to more agricultural water consumption. As a result, the sustainability of agriculture in this semiarid area is facing great risks, the management of limited water resource and higher water use efficiency is concerned of national crop production and food security.

Accurate actual evapotranspiration (ET) determination is essential for water management practices and irrigation regime in arid and semiarid area, because maize occupied 54.2% of annual ET within wheat-maize double cropping under drip irrigation in northwest China (Jiang et al., 2015). Averaged ET of summer maize was 423 mm in North China Plain (Liu et al., 2002), a similar result of 424 mm which conducted in northwest China was reported by Kang et al. (2003). For spring maize, ET reached 696 mm in Yellow River Basin (Zhang et al., 2013), resulting from its longer growth duration and consequent more transpiration compared with summer maize. ET was 387 mm- 628 mm for maize grown by drip irrigation (Szeles et al., 2012; El-Hendawy and Schmidhalter, 2010). Irrigation promoted the ability of drought resistance during maize growth period as well as increased its water consumption by about 66 mm- 106 mm (Zhang et al., 2004; Suyker and Verma, 2009). Averaged daily ET varied from 2.63 mm to 6 mm (Li et al., 2003; Watanabe et al., 2004; Wu et al., 2007; Liu et al., 2009), Daily ET usually reach its peak before or after anthesis period as well as LAI, highest daily ET could reach 10 mm to 14 mm (Piccinni et al.,

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Table 1
Crop coefficients of two maize strains.

Year	Canopy	Kc_{init}	Kc_{dev}	Kc_{mid}	Kc_{late}	Kc
2012	L	0.38	1.07	1.38	1.38	0.99
	S	0.34	1.05	1.35	1.27	0.97
2013	L	0.53	1.30	1.67	1.06	1.22
	S	0.54	1.21	1.45	1.11	1.11
AVE	L	0.48	1.18	1.64	1.23	1.16
	S	0.44	1.13	1.48	1.19	1.08

Note: K_{cini}: Kc at the Initial season, K_{cmid}: Kc at the middle season, K_{cend}: Kc at the late season, L: maize strain with large canopy, S: maize strain with small canopy.

2009; Shahrokhnia and Sepaskhah, 2013) (Table 1).

ET is mainly comprised by canopy transpiration, soil evaporation accounts to 30% of ET and is considered little contribution to crop production (Liu et al., 2002), cultivation practices usually apply crop residue or plastic mulch in order to reduce useless evaporation (Tolk et al., 1999; Ding et al., 2013; Yan et al., 2017), and provide adequate water supply aiming at guaranteeing water requirement from transpiration requirement (Irmak et al., 2016; Paredes et al., 2014; Giménez et al., 2016). Many studies demonstrated that the effects of environmental variables on ET usually achieved by influencing canopy transpiration. Change of growth temperature and precipitation had an evident effect on plant transpiration (Sun et al., 2010; Yang et al., 2012), one of popular understandings about these effects was that high temperature led to decreased stomatal conductance and increased vapor pressure deficit, then inhibited plant transpiration (Duursmaa et al., 2014; Heinlein et al., 2017). Raising carbon dioxide concentration also reduced canopy evapotranspiration by restraining stomatal conductance (Hussain et al., 2013). Previous studies of actual evapotranspiration estimation applied maize as one kind of land covers, or focused on the effect of environmental factors and cultivation practices on ET, few research reported the diversity of ET caused by different maize hybrids. Actually, there are thousands of maize hybrids applied in China, and huge diversity of canopy structure and performance existed among them, the effect of maize with contrast canopy size on ET need further explored.

The objective of this study was to evaluate the effect of canopy size on evapotranspiration, and its periodical and daily characters under semi-arid climate of North China Plain. Crop coefficient (Kc) was obtained by measuring the ETc using 12 lysimeters and the ETo using the Penman-Monteith method with climatic data collected nearby experimental site, the relationship between LAI and Kc was also developed.

Materials and methods

1.1. Experimental site

The experiment was carried out during 2012-2013 at the National Experiment Station for Precise Agriculture, a Beijing Academy of Agricultural and Forestry Sciences comprehensive station (40.17′N,116.39′E, 50 m altitude),located in northwest of Beijing, China. During maize season: the precipitation was 422.4 mm for 2012 and 333.6 mm for 2013, respectively. The average sunshine duration was 606.8 hours and the average accumulated temperature higher than 10 °C is 2536 °C.

1.2. Experimental procedures

Maize(Zea mays L.) was planted from 14, June to 24, September in 2012, and from 17, June to 3, October in 2013. Two varieties were used: CF 1002 (Small canopy, S)and CF 3330 (Large canopy, L). Plant density was controlled to 6 plants m-2 with same row spacing in 50 cm for all treatments. 6 lysimeters were applied for each treatment as duplicates. 40 mm water was irrigated through a rubber tube in order to avoid the adverse effects of previous winter wheat, the amount of mineral fertilizer included urea and phosphoric anhydride and potassium sulfate applied in each lysimeter was 225 g, 120 g and 120 g, respectively, all the phosphoric anhydride and potassium sulfate as well as half urea was applied with seeding simultaneously, the remaining portion was served as supplementary fertilizer when the maize grown to13 leaves. Also, to maintain a similar environment, the crop in same plant type and density was grown in the lands surrounding the lysimeters. The identical cultivation practices such as tillage depth, application time and dosage of fertilizer, sowing and harvest date and weed management was applied to both inside and outside lysimeter.

The employed lysimeter is a suspended weighed type, it has a steel box with the size of 1m × 0.75m × 2.3m, isometric original soil was transported from near field in order to retain field soil property. Considering the possible micro environmental perturbation and the water exchange between lysimeter interior and surrounding field, the soil surface inside the lysimeter was kept flush with the surrounding field surface yet the border is slightly higher than the ground level. Evapotranspiration of maize for each season was measured by 24 lysimeters in an interval of 5 minutes with a high precision of 0.05-0.1 mm. The calibration of lysimeters was conducted at the middle of the maize growing season so the precision can be ensured.

Meteorological parameters: air temperature, air humidity, air pressure, wind speed at 2 m above ground, net radiation, sunshine hours, rainfall were recorded in a standard weather station located at the experimental site next door to the lysimeter. The field is flat and the data from the weather station therefore represent that of the lysimeter site.

Data was filtered based on the degree of dispersion before it was tested in ANOVA, 3 and 4 lysimeters with smaller variability were selected out of each 6 lysimeters to represent different maize strains as duplicates in 2012 and 2013, respectively. Comparisons between groups were tested by One − Way ANOVA analysis and LSD test using SPSS 22.0 software package.

1.3. Calculation of reference crop evapotranspiration ETo and crop coefficient Kc

Reference crop was defined by FAO as a hypothetical crop with an assumed height of 0.12 m, with a surface resistance of 70 s m-1and an albedo of 0.23, closely resembling the evaporation and transpiration from abroad surface of green grass of homogeneous height, actively growing and without water deficit. The FAO Penman-Monteith method uses standard climatic data that can be easily measured or derived from commonly measured data:

$$ETo = \frac{[0.148\Delta(Rn - G) + (\frac{900\gamma}{T = 273})U_2(e_s - e_a)]}{\Delta + \gamma(1 + 0.34U_2)}$$

Where Rn is the net radiation at the crop surface (MJ m-2 per day), G is the soil heat flux (MJ m-2 per day), T is the average air temperature (°C),U2 is the wind speed at 2 m height (m s-1), (es-ea) is the vapor pressure deficit (kPa), Δ is the slope of the vapor pressure curve (kPa °C-1), γis the psychrometric constant (kPa °C-1), and 900 is the conversion factor.

Crop coefficient Kc is the ratio of the crop evapotranspiration to the reference evapotranspiration and can be calculated by different method, such as single and dual crop coefficient method (Jensen et al., 1990; Allen et al., 1998). In this study, crop coefficient was calculated from the estimated ETc by weighing lysimeters and ETo by Penman-Monteith equation according to the single crop coefficient method: $Kc = \frac{ETc}{ETo}$ Where ETc and ETo represented the estimated and calculated evapotranspiration, respectively (Fig. 1).