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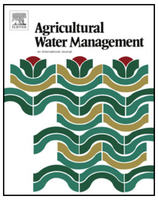

Energy balance and canopy conductance for a cotton field under film mulched drip irrigation in an arid region of northwestern China

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ABSTRACT

Evapotranspiration (latent heat flux) is an important component of the water and energy balance in agricultural ecosystems. Water and energy fluxes were measured for three years (2012–2014) by the eddy covariance system at a cotton field under film-mulched drip irrigation in Xinjiang, an arid region of northwestern China. This region produces over 50% of China's cotton yield, and irrigation accounts for 96.2% of the regional water consumption. The turbulent energy fluxes measured by the eddy covariance accounted for approximately 60%–70% of the available energy. The latent energy (LE) comprised 86%–93% of net radiation during the rapid growing season (June to early August); of this percentage range, 20%–30% was induced by the higher sensible heat advection caused by agricultural irrigation. On the other hand, the sensible heat (H) decreased to very small values and even was negative in July and August, due to the increased evapotranspiration and growth of cotton leaves and thus the decline of surface temperature. The influence of canopy conductance on evapotranspiration showed a threshold effect. A positive relationship between canopy conductance and the Priestley-Taylor coefficient was observed when the canopy conductance was lower than 8 mm/s. Path analysis was used to quantify the direct and indirect effects of meteorological factors (the net radiation R_n, wind speed W_s, air temperature T_a, and saturation vapour pressure deficit (VPD) on LE and canopy conductance (G_c). The variance of LE and G_c are both 0.15, indicating that meteorology can explain 85% of LE andG_c. On a weekly time scale, both G_c and LE were significantly, directly, and positively affected by R_n and T_a and were significantly, directly, and negatively affected by VPD.

1. Introduction

The agricultural sector is the dominant consumer of fresh water, accounting for up to 70% of the world's usage (UNESCO, 2003) and 65% of China's usage (Food and Agriculture Organization of the United Nations, 2015). Agriculture is the main industry in northwestern China (Piao et al., 2010), and irrigation is the lifeblood of agriculture in arid areas such as the Xinjiang Uygur Autonomous Region of China. The irrigated area has been significantly increasing during the past 50 years in Xinjiang (Wang et al., 2004), drastically increasing water consumption, which now accounts for 96.2% of the total regional water consumption (Karthe et al., 2014). Regional water resources are facing serious problems, including induced ecological degradation (Yang et al., 2006; Hou et al., 2007), so that a policy promoting more sustainable agriculture should be prescribed to maximize economic benefits while maintaining environmental quality (Provenzano et al., 2013).

Large-scale irrigation alters the regional hydrological and energy processes (Hossen et al., 2012; Zhu et al., 2014; Liu et al., 2014; Masseroni et al., 2014; McGloin et al., 2014; Timm et al., 2014; Kang et al., 2015). For example, in an oasis of an arid area, irrigation leads to the horizontal advection of sensible heat (Potchter et al., 2008; Zhou et al., 2012). The sensible heat will decrease and the energy supply for evapotranspiration increase when dry surfaces are wetted (Li and Yu, 2007; Ding et al., 2015a; Lei and Yang, 2010; Jaksa and Sridhar, 2015).

The main cause of the consumption of irrigated water is evapotranspiration (i.e., latent heat flux), which is an important component of water and energy balance in agricultural ecosystems (Burba and Verma 2005; Lei and Yang, 2010). The stomata of leaves control the water loss and energy exchange of the plants and the canopy conductance responses to environmental conditions such as humidity, light, temperature, and soil water content (Tang et al.,

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2006). Understanding the mechanisms affecting evapotranspiration and energy balance at different temporal scales and under various environmental conditions is crucial for the modelling of ecosystem production and water balance (Burba and Verma, 2005). Additionally, in-depth studies of evapotranspiration and energy balance in agricultural lands are of great importance for sustainable water resource management in arid areas.

A large body of studies have investigated the evapotranspiration and energy balance of forest, wetland and agricultural ecosystems (Burba and Verma, 2005; Lei and Yang, 2010; Cammalleri et al., 2013; Ding et al., 2013b; Jaksa and Sridhar, 2015). However, very few studies have focused on cotton under drip and sprinkler irrigation (Howell et al., 2004; Farahani et al., 2008; Bezerra et al., 2012). This study aims to improve our understanding of evapotranspiration and energy processes through micrometeorological and eddy covariance measurements in cotton (*Gossypium hirsutum* L.) fields under film-mulched drip irrigation in the oases of the Kaidu-Kongqi River Basin (a source basin of the Tarim River).

Field experiments were conducted in an experimental station in the suburban area of Korla city, Xinjiang Uygur Autonomous Region of China, from 2012 to 2014. The specific objectives of this study are as follows: (i) to quantify the water/energy dynamics at diel and seasonal scales in cotton fields under film-mulched drip irrigation, (ii) to investigate the factors controlling evapotranspiration, and (iii) to explore the influence of advection on evapotranspiration.

2. Materials and methods

2.1. Experimental site

The study area is located in the Korla Oasis Eco-hydrology Experimental Research station (86°12′E, 41°36′N), 22 km from Xiborni town of Korla city in the Xinjiang Uygur Autonomous Region, China (Zhang et al., 2014a,b,c). This location lies on the alluvial plain of the Kaidu-Kongqi River under the southern foot of Tianshan Mountain. The average elevation is 897–902 m. The study area has a continental desert climate with high temperature, scarce precipitation, and intense potential evapotranspiration. Field experiments were conducted during three years (2012–2014). The average relative humidity, net radiation and wind speed during the cotton growth periods of 2012–2014 were 40%, 110 w/m^2 and 1.90 m/s, respectively. During the years 1990–2008, the mean annual precipitation was 58.5 mm, the mean annual temperature was 12.4 °C, and the mean annual accumulated temperature ≧10 °C was 4100 °C. The mean annual sunshine duration was 3036 h, which is favourable for cotton growth. The depth of frozen soil was approximately 60 cm. The texture of the soil is loam, consisting of 30% sand, 5% silt and 65% loam (Yang et al., 2016).

The experiments were conducted in a 3.48 ha area of the cotton (*Gossypium hirsutum L.*) field under drip irrigation with plastic mulch. The cotton planting and drip irrigation tape employed a mode of "one film-one pipe-four rows". The drip irrigation tape was located beneath the middle of the film. Two rows of cotton were distributed symmetrically on both sides of the tape. The film width was 110 cm, and the inter-film zone width was 40 cm. The widths of 3 cotton-row-spaces between 4 cotton rows were 20, 44, and 20 cm, respectively, and the cotton was planted in a uniform distribution with a spacing of 10 cm (Zhang et al., 2014b; Tian et al., 2016). The growth season of cotton is from late April to mid-September. The total irrigation water amount of the experiment field was measured using 8 water meters, and the irrigation depth was calculated by dividing the measured irrigation water volumes by the total experimental area (3.48 ha). The irrigation amounts were approximately 540, 591, and 434 mm in 2012, 2013, and 2014, respectively, as shown in Fig. 1.

2.2. Micrometeorological and eddy covariance measurements

Micrometeorological and eddy covariance (EC) measurements were conducted between April 2012 and September 2014. The EC system and a micrometeorological tower were installed to collect the data. The device placement and data processing programs are described in detail in Zhang et al. (2014a). Daily energy was measured using the EC system, which consisted of a 3D sonic anemometer (CSAT3, Campbell Scientific Inc., Logan, UT, USA), a fast-response open-path infrared gas (H_2O and CO_2) analyser (EC150; Campbell Scientific Inc., Logan, UT, USA), and temperature and humidity sensors (HMP155A; Vaisala Inc., Woburn, MA, USA). A net radiation sensor (LITF2; Kipp & Zonen, Delft, the Netherlands) was installed at the height of 2.25 m above the ground and oriented to the south (Zhang et al., 2014c; Yang et al., 2016). Models CSAT3 and EC150 were used to measure vertical fluctuations in wind, temperature, and water vapour density at intervals of 0.1 s, and the 10-min averages of temperature and humidity were calculated (Yang et al., 2016). The 90% of the source area of flux footprint was estimated using an approximate analytical footprint model developed by Hsieh et al. (2000) to estimate the 90% of the source area of flux footprint. The distribution within the flux footprint area of the dominant wind direction (southeast) for July and August is approximately 150 m. In a radius of 150 m around the flux tower, only a very small fraction of the ground surface (i.e., a field road) is covered by trees, indicating that the measured fluxes were primarily contributed by the cotton field (Yang et al., 2016).

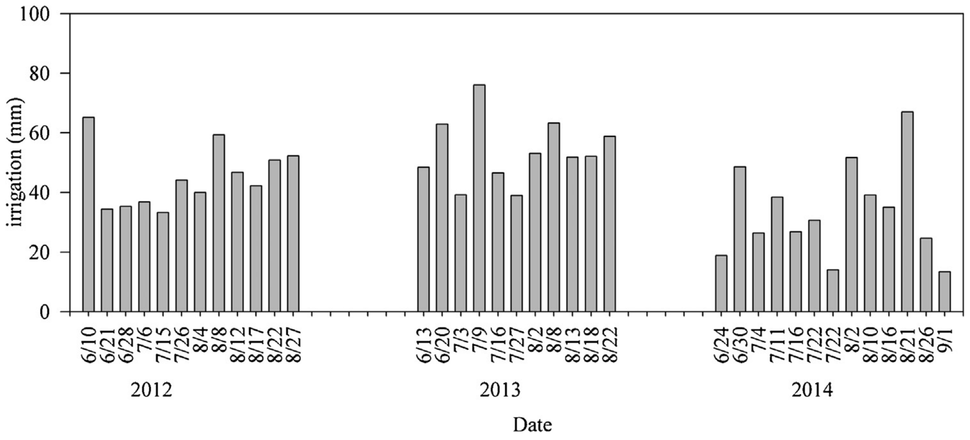

Fig. 1. Irrigation schedule applied in the experimental fields from 2012 to 2014.

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