Agricultural and Forest Meteorology 223 (2016) 48–59

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet

Energy exchange and evapotranspiration over irrigated seed maize agroecosystems in a desert-oasis region, northwest China

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ARTICLE INFO

Article history:
Received 2 November 2015
Received in revised form 30 March 2016
Accepted 3 April 2016
Available online 8 April 2016

Keywords:
Eddy covariance
Water vapor and energy exchange
Evapotranspiration
Seed maize
Desert-oasis region

ABSTRACT

Investigating the dynamics of energy and water vapor exchange in oasis agroecosystems is important to improve scientific understanding of land surface processes in desert-oasis regions. In this study, water vapor and energy fluxes were obtained by using an eddy covariance technique for two similar irrigated seed maize fields at Yingke and Pingchuan, in northwest China. Seasonal variabilities of evapotranspiration (ET) and relevant environmental and biophysical factors were explored. Results showed that the energy balance closures were reasonable, with energy balance ratio of 0.99 and 0.79 for a half-hourly time scale at Yingke and Pingchuan, respectively. The seasonal changes in net radiation (R_n), latent heat flux (LE), and sensible heat flux (H) of Yingke and Pingchuan were similar. Net radiation was 11.27 MJ m^{-1} day^{-1} during the growing season. Latent heat flux accounted for 67.5% of net radiation, sensible heat flux was 25.0%, and soil heat flux was 7.5%. A reverse seasonal change was found in partitioning energy flux into LE and H. The seasonal variation in energy flux partitioning was significantly related to the phenology of maize. During the growing season, ET was 467 and 545 mm, and mean daily ET 2.84 and 3.35 mm day^{-1} at Pingchuan and Yingke, respectively. "Non-growing" season ET was 15% of the annual ET in the bare field (during October–March) and 85% of the annual ET for maize (during April–September). Daily ET was mainly controlled by net radiation and air temperature, and was significantly affected by leaf area index (<3.0 m^2 m^{-2}) and canopy conductance (<10 mm s^{-1}). Furthermore, irrigation promoted daily ET greatly during the growing season. Accurate estimation of seed maize ET and determination the controlling factors helps to develop exact irrigation scheduling and improve water resource use in desert-oasis agroecosystems.

1. Introduction

Solar radiation provides the basic energy for a variety of physical and biological processes occurring on the Earth's surface (Sen, 2004). Energy and water vapor exchange processes between the land surface and atmosphere drive photosynthesis, evapotranspiration, sensible heat flux, energy storage in vegetation, and heating of the soil (Baldocchi et al., 2000; Gu et al., 2005; Mccaughey et al., 1997). The energy balance in agroecosystems influences regional mass and energy exchange between the surface biosphere and atmosphere, water circulation, and climate changes. Energy flux partitioning is often used to describe the energy balance (Chen et al., 2009; Lei and Yang, 2010). Net radiation is partitioned into sensible, latent, and surface storage heat flux, which are controlled by meteorological factors, biological factors, vegetation condition and phenology, and soil moisture (Baldocchi et al., 2000; Gu et al., 2005; Hao et al., 2007; Wever et al., 2002). The desert-oasis agroecosystems play a crucial role in maintaining the stable ecological environment and agriculture productivity (Zhang and Zhao, 2015b). Understanding the basic characteristics of energy and water vapor exchange in desert-oasis agroecosystems is important for modeling crop production and water balance in desert-oasis region, northwest China.

Eddy covariance (EC) is recognized as the standard method to study energy, water vapor, and CO_2 exchange between the surface and atmosphere (Baldocchi, 2003). EC can accurately calculate evapotranspiration (ET) in boreal, temperate and tropical forests, grasslands, deserts, and agricultural ecosystems (Liu and Feng, 2012; Mccaughey et al., 1997; Yuan et al., 2014). Previous studies on energy and water vapor exchange in agricultural ecosystems have

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http://dx.doi.org/10.1016/j.agrformet.2016.04.002
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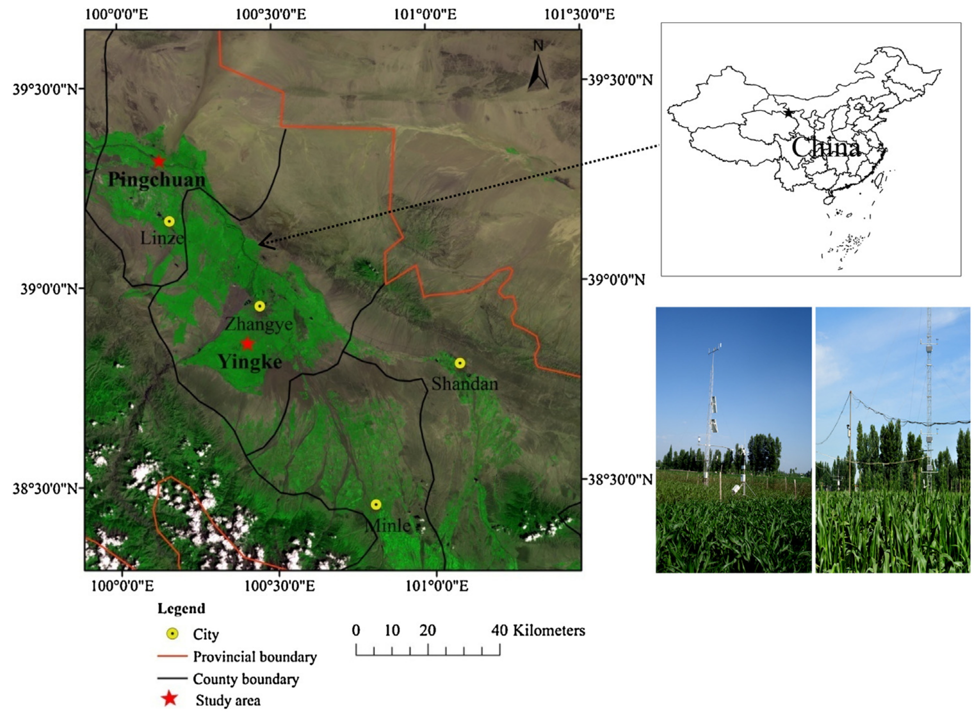

Fig. 1. Location of the two study areas—Yingke (a) and Pingchuan (b).

indicated considerable seasonal, interannual, and regional variation of energy budget and ET for different crop species (Ding et al., 2013; Steduto and Hsiao, 1998a,b; Suyker and Verma, 2008, 2009). Climate condition, vegetation growth, and soil moisture content are the main influential factors (Burba and Verma, 2005; Lei and Yang, 2010; Steduto and Hsiao, 1998b). The seasonal and interannual variability in evapotranspiration based on the long-term fluxes measurements is important for identifying climate, crop factors, and soil water which regulate fluxes at different temporal scales, and is important for developing exact irrigation scheduling and modeling crop production (Burba and Verma, 2005; Ding et al., 2013; Li et al., 2008). Quantitatively research how biotic and abiotic variables affect the energy budget and ET is needed in desert-oasis agroecosystems.

The desert-oasis agroecosystems is critical for food production in this area, and is prone to significant water shortages and drought. The oasis area of the Hexi Corridor in the middle reaches of the Heihe River has expanded since a water diversion scheme was implemented in 2000 (Zhang and Zhao, 2015a). Currently, 86% of the agricultural and domestic water supplied comes from the Heihe River, and 96% of that water is used for irrigation (Chen et al., 2003). Maize seed is one of the main food crops in the Hexi Corridor, northwestern China (Su et al., 2010). Extensive irrigation to ensure the quality of the maize seeds has lead to serious water shortage in recent years. Seed maize agrosystems in the Hexi Corridor have unique planting density, open canopy structure, low leaf area index, and discrepancy of water requirement in comparison to hybrid maize in other regions (Zhao, 2011; Zhao and Ji, 2010). Ground is mulched with plastic film to reduce soil evaporation in the field. To conserve and improve water use efficiency of maize, it is essential to accurately estimate ET and determine the controlling factors. ET comprises 60–80% of net radiation in a growing season in irrigated agrosystems (Suyker and Verma, 2008, 2009). Seasonal and long-term variations of ET are closely linked to ecosystem productivity, water dynamics, and regional climate change (Nemani et al., 2002; Suyker and Verma, 2009). However, fewer studies have investigated seed maize ET with plastic mulch estimated by EC in desert-oasis region.

In this study, two similar irrigated seed maize fields with plastic mulch were measured by EC technique at Yingke and Pingchuan in 2009. The objectives of this study were to: (1) investigate seasonal variation in energy and water vapor fluxes in arid irrigated croplands; (2) examine the seasonal variability of ET; (3) quantify thresholds of variables that affect the magnitude of ET over desert-oasis agroecosystems.

2. Materials and methods

2.1. Study area

This study was conducted in a typical desert-oasis region in the middle reaches of the Heihe River Basin, located in the Hexi Corridor of Gansu Province (100°00′ E-100°30′ E, 38°50′ N-39°30′ N) (Fig. 1). The southern piedmont is an inclined oasis plain, and the northern is the margin of the Badain Jaran Desert. The major landscape types of this region are peripheral desert, desert-oasis ecotone, and central oasis. The study area has an arid climate characterized by cold winters and hot dry summers. The average annual temperature is 7.4 °C. The average annual precipitation is 124 mm with 70–80% occurring from May through September. The average annual pan evaporation is 2190 mm, which is twenty times greater than the annual precipitation. High winds and wind storms often occur in this area (Zhang and Zhao, 2015a,b). The soils are Anthrosols and some basic properties are summarized in Table 1.

In recent years, seed maize production has become the predominant agricultural crop in this desert-oasis region. Monoculture of spring maize with plastic mulching was planted for more than 10 years. Oasis croplands were sown with maize on April 10 and harvested on September 20. The rate of fertilizer application was approximately 300–450 kg^{-1} N ha^{-1}, 90–150 kg^{-1} P_2O_5 ha^{-1}, and 60–90 kg^{-1} K_2O ha^{-1} each year. During the growing season, maize was irrigated 4–7 times with more than 100 mm irrigating amount on each time depending on the soil conditions.