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Energy partitioning and evapotranspiration of hot pepper grown in greenhouse with furrow and drip irrigation methods

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ABSTRACT

Studying crop energy partitioning and evapotranspiration for different irrigation methods is important in optimizing efficient water-saving irrigation, developing suitable irrigation scheduling and improving crop water use efficiency. Two experiments were conducted to compare the energy partitioning and evapotranspiration of hot pepper (*Capsicum annum* L.) between furrow and drip irrigation methods under two adjacent solar greenhouses in northwest China. Results indicate that irrigation method affected the energy partitioning and evapotranspiration of hot pepper plants and these results were corroborated in a greenhouse study. Compared to drip irrigation, furrow irrigation increased daytime average net radiation (R_n), latent (λET) and sensible (H) heat fluxes by 12–29, 37–53 and 9–23%, respectively, but decreased soil heat flux (G) by 7–19%. Furrow irrigation also resulted in higher $\lambda ET/R_n$ and lower H/R_n and G/R_n and increased total evapotranspiration by 55.5% and produced a higher crop coefficient. Total evapotranspiration was 562.3 and 361.6 mm over whole growth stage for furrow and drip irrigation methods, respectively. And drip irrigation increased the total yield and water use efficiency by 18.2 and 80.4%, respectively, before late fruit bearing and harvesting stage. In conclusion, drip irrigation is an effective and water-saving irrigation method in hot pepper production to be used in greenhouse.

1. Introduction

There are numerous studies on crop energy partitioning and evapotranspiration, e.g. wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) (Baldocchi, 1994; Kang et al., 2003; Li et al., 2008; Shen et al., 2004; Zhang et al., 2004), rice (*Oryza sativa* L.) (Oue, 2005) and grapevine (*Vitis. vinifera* L.) (Spano et al., 2003; Trambouze et al., 1998; Yunusa et al., 1997; Zhang et al., 2007). Zhang et al. (2004) indicated that 83–87% of available energy (R_n–G, R_n is net radiation and G is soil heat flux) is used for the evapotranspiration of winter wheat and maize. In a vineyard, the ratios of R_n to G and latent (λET) and sensible (H) heat fluxes at different growth stages are 4–7%, 29–38% and 57–65%, respectively (Zhang et al., 2007). The partitioning of R_n into λET and H is determined by meteorological factors and irrigation practices (Spano et al., 2003). Before senescence, $\lambda ET/(R_n–G)$ is linearly correlated with leaf area index (*LAI*) for both wheat and maize, but it is not significantly correlated with soil water content (Shen et al., 2004). The evapotranspiration of maize over the whole growing season is 424.0 mm (Kang et al., 2003), and is affected by the meteorological factors, crop growth and surface properties (Li et al., 2008).

Due to the greenhouse structure, light transmission is reduced by 20–60%, so R_n is reduced during the daytime (Bello, 1984; Kittas et al., 1999). Under greenhouse conditions, the evapotranspiration rate is lower (Orgaz et al., 2005) because air speed is nearly zero (Zhang and Lemeur, 1992) and relative humidity is often higher (Jolliet and Bailey, 1992). All these factors affect crop energy partitioning and evapotranspiration under greenhouse conditions. So far there are some studies about the effect of whitening, misting and ventilation on crop energy partitioning and evapotranspiration (Baille et al., 2001; Fuchs et al., 1997; Katsoulas et al., 2001; Kittas et al., 2001), but few studies about the effect of irrigation methods on them are found under greenhouse conditions. Therefore, two experiments for furrow and drip irrigation methods were conducted under two adjacent solar greenhouses in the arid region of northwest China, our objectives are to compare (1) diurnal variations of R_n and G; (2) energy components and partitioning; and (3) evapotranspiration, water use efficiency and crop coefficient of hot pepper between two irrigation methods, so as to provide scientific basis for optimizing efficient water-saving irrigation, developing suitable irrigation scheduling and improving crop water use efficiency under greenhouse conditions.

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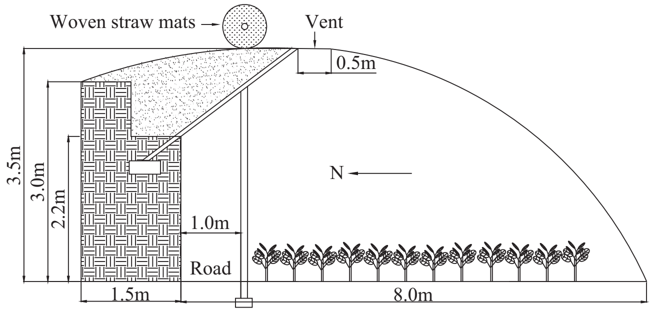

Fig. 1. A sectional diagram of solar greenhouse in northwest China. The shaded section of 1.5 m width and the stippled area are the back insulated wall and rear slope which are often built with soil and slag, respectively, for maintaining the interior temperature.

2. Materials and methods

2.1. Experimental site and methods

Two experiments were conducted at Shiyanghe Experimental Station for Water-saving in Agriculture and Ecology of China Agricultural University, located in Wuwei city, Gansu Province of northwest China (N 37°52′, E 102°51′, altitude 1581 m) from September 2009 to July 2010. The experimental site is in a typical continental temperate climate zone with annual precipitation of 164.4 mm and pan evaporation of 2000 mm. The groundwater table is below 25 m. It is rich in solar radiation with mean temperature of 8.8 °C, mean sunshine duration of 3000 h and frost-free period of 150 d.

Treatments included furrow and drip irrigation methods. In the drip irrigation, irrigation water was applied with pressure-compensated drip emitters with discharge rate of 2.3 L h^{-1}. The distance between two emitters was 50 cm and one drip line controlled every two rows.

The experiments for furrow and drip irrigation methods were conducted at two adjacent solar greenhouses. They were 38 m long × 8 m wide with a planting area of 202 m^2, covered with a 0.2 mm thick thermal polyethylene sheet. And the greenhouses were east–west orientation and passively ventilated by roof vents (Fig. 1). The soil is irrigated desert soil (Siltigic-Orthic Anthrosols) with a sandy loam texture, mean dry bulk density of 1.50 and 1.47 g cm^{-3}, field soil water capacity (θ_f) of 0.376 and 0.326 (cm^3 cm^{-3}) for furrow and drip irrigation, respectively. The experimental hot pepper was a local leading variety (*Capsicum annum* L. × Lonjiao 3). The growth stages of hot pepper can be divided as follows: seedling (Stage I, September 22 to November 14, 2009), flowering and fruit setting (Stage II, November 15 to January 12, 2010), early fruit bearing and harvesting (Stage III, January 13 to April 27) and late fruit bearing and harvesting stages (Stage IV, April 28 to July 1).

The planting pattern for hot pepper was wide-narrow row with two seedlings per hole (Fig. 2). The width of the wide and narrow row was 75 and 40 cm, respectively. Two rows of seedlings were evenly transplanted to the narrow row (40 cm between rows and 50 cm within rows) with density of 7.45 plants m^{-2} on September 22, 2009. The plant rows were north–south orientation. In order to keep the seedlings alive and rapidly growing, two irrigation events were carried out with 19 mm of water per irrigation for both greenhouses at transplanting and 10 days after transplanting (DAT), respectively. At 15 DAT, the crop field was covered with clear polyethylene film to reduce soil evaporation and enhance soil temperature.

After 10 DAT, furrow irrigation was scheduled when the average volumetric soil water content at the 0–50 cm layer decreased to 75 ± 2% of θ_f. In each irrigation event, the amount of irrigation water can be calculated as follows:

$$Q = 10 \times (\theta_1 - \theta_2) \times H \quad (1)$$

where Q is the amount of irrigation water in each irrigation event (mm); θ_1 is the upper irrigation limit (cm^3 cm^{-3}), i.e. 90% of θ_f; θ_2 is the actual soil moisture content before irrigation (cm^3 cm^{-3}); H is planned moisture layer, i.e. 50 cm.

Water amount per irrigation under drip irrigation was designed as 50% of that under furrow irrigation. Crops with drip irrigation were irrigated at the same time when furrow irrigation was scheduled.

The greenhouse management was carried out according to weather conditions. In general, narrow ventilation system was opened to decrease air temperature and relative humidity when air temperature was close to about 30 °C in the morning, and closed one hour before sunset from the middle of November 2009 to the end of April 2010. At night, woven straw mats about 2.5 cm thick covered the top of the greenhouse to maintain the interior temperature. From the beginning of May, the woven straw mats were removed and the ventilation system was always opened in the greenhouse, which was partially overshadowed with part of woven straw mats around noon on sunny days to avoid excessive interior temperature. During the experimental period, crops had similar fertilization, pollination and pest control in the two greenhouses.

2.2. Measurements

2.2.1. Soil moisture content

Soil moisture content was measured using a portable device (Diviner2000, Sentek Pty Ltd., Australia). 24 PVC access tubes (1.0 m in length and 0.05 m internal diameter) were evenly installed in wide-row and narrow-row position in the two greenhouses, respectively (Fig. 2). Measurements were made at 0.1 m intervals with maximal soil depth of 1.0 m every 5–7 days. Soil water contents measured by Diviner 2000 were calibrated by the oven-drying method (105 °C, 8 h).

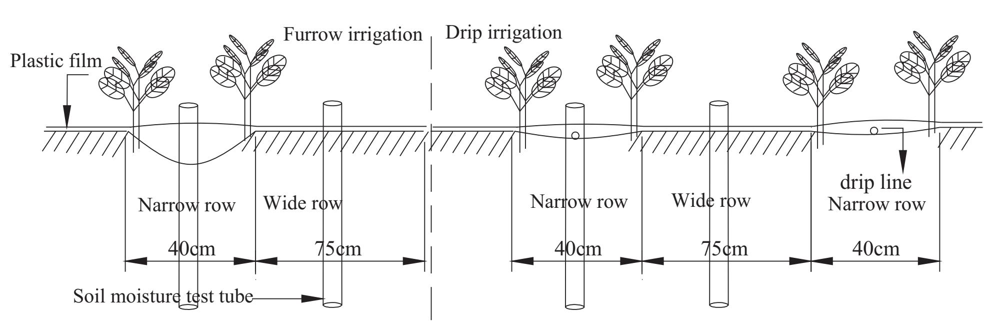

Fig. 2. Plant spacing of hot pepper and tube layout for soil moisture measurement under furrow and drip irrigation methods.