Journal of Hydrology 564 (2018) 667–681

Contents lists available at ScienceDirect

Journal of Hydrology

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

Research papers

# Can plastic mulch save water at night in irrigated croplands?

Shujing Qin[a], Sien Li[a,*], Kun Yang[b,*], Kelin Hu[a]

[a] Center for Agricultural Water Research in China, China Agricultural University, Beijing, China
[b] Ministry of Education Key Laboratory for Earth System Modeling, Department of Earth System Science, Tsinghua University, Beijing, China

ARTICLE INFO

This manuscript was handled by Marco borga, Editor-in-Chief, with the assistance of Michael Bruen, Associate Editor

*Keywords:*
Eddy covariance
Maize
Micro-lysimeter
Plastic mulch
Soil water evaporation

ABSTRACT

Plastic mulching has been widely used in arid regions because it can decrease soil water evaporation and raise soil temperature. Previous studies, however, treated soil water evaporation under plastic mulch to be negligible, assuming that the plastic mulch can prevent water exchange between soil and atmosphere completely. In order to demonstrate validity of this assumption, experiments were conducted from 2014 to 2016 under irrigated maize (Zea mays) field in Northwest China, comparison experiments of soil water evaporation between mulched soil and the bare soil between mulches were carried out in two seed maize fields with different irrigation method, i.e. border irrigation under mulch (Site BM) and drip irrigation under mulch (Site DM), with micro-lysimeters placed under the plastic mulched soil and the bare soil between mulches to evaluate soil water evaporation of each experiment maize field. Our observations indicated that the soil water evaporation under plastic mulch ($E_{ms}$) was about 4.04–7.07% of the total evapotranspiration, among which $E_{ms}$ in the daytime accounted for 3.58–5.37% of the total evapotranspiration and 0.99–2.10% of the total evapotranspiration in the nighttime. Thus $E_{ms}$ was considered not to be negligible. For two experiment sites, soil water evaporation under bare soil between mulches ($E_{bs}$) was obviously higher than the soil water evaporation under plastic mulch ($E_{ms}$) in daytime, but the former was lower than the latter in the nighttime. At night, the mean soil temperature in the mulched soil was higher than that in the bare soil because of the warming effect of the plastic mulch. A soil-mulch-canopy-atmosphere model is used to consider the effects of the mulch, and the modeling results further support this finding. These results provide a new insight for understanding the effect of plastic mulch on water use efficiency.

## 1. Introduction

Plastic mulching is a critical technology for saving water in arid regions owing to its function in warming the soil, preserving soil moisture and increasing crop yield. As such, it has been extensively used in crop production such as wheat, maize, cotton, soybean and other crops in the world. In contrast with the traditional cultivation methods, plastic mulching changes the ground surface reflectance and water vapor transfer resistance, thereby altering surface water balance, energy balance and plant growth processes. However, the mechanism of plastic mulch water-saving effect remains uncertain. Thus, it is of great value to explore the influence from plastic mulching on soil water evaporation in order to optimize agricultural water resource management.

Until recently, numerous studies have been conducted to evaluate the effects of plastic mulching on water and energy transfer in farmland. Such studies have come to the following main conclusions: (1) Plastic mulching can reduce soil water evaporation and increase water use efficiency (Wang et al., 2001; Xie et al., 2005; Ramakrishna et al., 2006; Shen et al., 2012; Tiwari et al., 2016). (2) Plastic mulching enhances the surface radiation reflectance, thereby changing the water and energy balance in farmlands (Liakatas et al., 1986; Wilson et al., 2002; Heusinkveld et al., 2004; Bonachela et al., 2012; Yang et al., 2012; Jafari et al., 2012). (3) Plastic mulching can increase water vapor transfer resistance so that the soil water evaporation under plastic mulching can be assumed to be negligible in the model calculation (Yang et al., 2012; Li et al., 2013b; Wang et al., 2016). (4) The open-hole ratio on the plastic mulch has a vital impact on soil water evaporation under plastic mulching. The larger the ratio is, the smaller the water vapor transfer resistance will be, so that the water vapor will be easier to cross through plastic mulch to atmosphere (Li et al., 2003, 2005; Shi et al., 2013). However, these previous studies mainly focused on the effect of plastic mulch on evapotranspiration and crop growth, but paid little attention to the diurnal dynamic soil water evaporations of mulched and bare soils. The measurements of soil water evaporation under the mulched layer are seldom reported. Also, there are only few

* Corresponding authors.
*E-mail addresses:* lisien@163.com (S. Li), yangk@tsinghua.edu.cn (K. Yang).

https://doi.org/10.1016/j.jhydrol.2018.07.050
Received 6 February 2018; Received in revised form 18 July 2018; Accepted 19 July 2018
Available online 21 July 2018
0022-1694/ 

studies that compared the mulched soil water evaporation and the bare soil water evaporation. In some research conducted in mulched crop field, the researchers just ignored the soil water evaporation under mulch but adopted the soil water evaporation of bare soil between mulches as the all soil water evaporation throughout the crop field (Ding et al., 2013; Jiang et al., 2016). Moreover, no investigation has been made on the effect of plastic mulch on soil water evaporation during daytime or nighttime in arid croplands.

The micro-lysimeter weighing method is a direct method of measuring soil water evaporation and has been widely used in evaluating soil water evaporation under bare soil and canopy due to its small disturbance to surrounding soil, simple principle, handiness and cost-effectiveness (Liu et al., 2002; Mitchell et al., 2009; Cavanaugh et al., 2011; Zhao et al., 2015). Previous studies indicated that soil water evaporation measured by the micro-lysimeter weighing method obtained results consistent with those measured with other instruments (Matthias et al.,1986; Plauborg, 1995) and modeling methods (Li et al., 2013a; Zhao et al., 2015).

To explore the effect of plastic mulch on soil water evaporation during daytime or nighttime in arid croplands, micro-lysimeter weighing method was employed to evaluate evaporation under the mulched layer and bare soil layers under two typical irrigated seed maize field in arid regions: the border irrigation under mulched field and the drip irrigation under mulched field. The former is a traditional irrigation technology which has been widely applied in previous practical agricultural production, while the latter is a new irrigation technology combined drip irrigation and plastic mulch technology and has been widely applied in current practical agricultural production. Thus exploration of mechanism of the water and energy transfer process in the two croplands is of vital important in improving water use efficiency in arid regions. On this basis, the effect of plastic mulch on soil water evaporation was analyzed, as well as the “water saving effect” and control mechanism of plastic mulching were evaluated.

## 2. Materials and method

### *2.1. Experimental site and description*

Three-year continuous experiments were conducted at Shiyanghe Experimental Station of China Agricultural University, located in Wuwei City, Gansu Province of northwest China (N 37°52′, E 102°50′, elevation 1581 m). The experimental site is located in a typical continental temperate climate zone with mean annual temperature of 8 °C, annual accumulated temperature (> 0 °C) of 3550 °C, mean annual pan evaporation of approximately 2000 mm, annual precipitation of 164 mm, the average annual sunshine duration of 3000 h. The groundwater table at the station is 40–50 m below the ground surface (Li et al., 2015, 2016a; Qin et al., 2016).

The comparison experiments were conducted at both border irrigation under mulch seed maize field (Site BM) and drip irrigation under mulch seed maize field (Site DM). Seeds of seeding maize field are divide into male maize seeds and female maize seeds. The two have minor difference from the point of genetic breeding. Male maize seeds are more conducive to the development of stamens in maize plants, while female maize seeds are more conducive to the growth of maize plants reproductive function. Professional semi-automated machines were applied to lay out plastic mulch, open holes and sow in the holes in both seed maize experiment fields. Male maize seeds and female maize seeds were sow in different holes with one line for male plants and several lines for female plants. However, both male maize seeds and female maize seeds were sown fixed distance apart within each row during the three years. One or two seeds were sow in one open-hole. While germination rates were different from each year, and in turn cause different planting density. Besides, when the professional semi-automatic machines open holes above the plastic mulch, the area of open-hole would have minor difference due to influence of artificial work. The plastic transparent mulch applied in both treatments was 8 μm thick with a shortwave transmissivity, reflectivity and absorptivity of 0.85, 0.10 and 0.05, respectively, and a longwave transmissivity of 0.74. The optical properties of the plastic mulch mentioned above were measured by spectrophotometer. And the plastic mulches were laid out along east to west with width of 1.2 m and, there is bare soil with width of 0.4 m between the two plastic mulches. Thus the ratio of the area of mulched soil and bare soil was 3:1.

Specifically, the border irrigation under mulch technology is a widely applied traditional agricultural irrigation technology which built ridges in the field and the field is split into many narrow and long plots, irrigation water from sub lateral canals flow into the plots along the long side of the plots, infiltration and wetting soil layer. Site BM is irrigated seed maize field under plastic mulch with an area of 400 m*200 m during 2014–2016. The field were sown in one-line male plants and four-line female plants in 2014–2015, while one-line male plants and seven-line female plants in 2016, respectively. Five seed rows were covered under one plastic mulch, both female and male seeds were sown 0.3 m apart within each row and the distance between seed rows under the same mulch was 0.25 m (Site BM, see in Fig. 1). Germination ratios were approximately 87%, 87% and 93% during 2014, 2015 and 2016, respectively. The average hole size was approximately 10.2–10.8 $cm^2$ and ratios of the total area of holes opened for seeding to the total plastic mulch area were 1.63%, 1.69% and 1.73% in 2014, 2015, 2016, respectively. Overall planting density was 108,000 plants $ha^{-1}$ during 2014–2015 and 116,176 plants $ha^{-1}$ in 2016. The soil at 1 m depth in the site is silty loam, with an average soil dry bulk density of 1.52 g $cm^{-3}$ and volumetric soil water content at a field capacity ($\theta_{FC}$) of 0.29 $cm^3$ $cm^{-3}$ during 2014–2016.

The drip irrigation under mulch technology is a widely applied new agricultural irrigation technology which combined drip irrigation and plastic mulch technologies. Site DM is irrigated seed maize field under plastic mulch with an area of 2000 m*1000 m during 2014–2015, and 400 m*200 m in 2016. The field were sown in one-line male plants and seven-line female plants in 2014–2015, and one-line male plants and six-line female plants in 2016, respectively. Four seed rows were covered under one plastic mulch, both female and male seeds were sown 0.22 m apart within each row and the distance between seed rows under the same mulch was 0.30 m (Site DM, see in Fig. 1). Germination ratios were approximately 90%, 90% and 91% during 2014, 2015 and 2016, respectively. The average hole size was approximately 10.6–11.8 $cm^2$. Ratios of the total area of holes opened for seeding and the total plastic mulch area were 2.14%, 2.23% and 2.01% in 2014, 2015, 2016, respectively. Overall planting density was 112,500 plants $ha^{-1}$ during 2014–2015 and 109,474 plants $ha^{-1}$ in 2016. The soil texture at 0–0.8 m depth is silty loam, and that at 0.8–1.0 m depth is silt during 2014–2016, with an average soil dry bulk density of 1.52 g $cm^{-3}$, averaged $\theta_{FC}$ of 0.30 $cm^3$ $cm^{-3}$ in 2014, while the average soil dry bulk density and $\theta_{FC}$ is 1.46 g $cm^{-3}$ and 0.29 $cm^3$ $cm^{-3}$ in 2015 and 2016, respectively (Qin et al., 2016).

The total irrigation amount in BM experiment site was 360 mm, 442 mm, 480 mm in 2014, 2015 and 2016, respectively, and 350 mm, 449 mm, 388 mm under DM treatment in 2014, 2015 and 2016, respectively. Detailed description of irrigation and precipitation events has been reported in Qin et al. (2016).

### *2.2. Measurements and data collection*

#### *2.2.1. Soil evaporation*

In our experiment, micro-lysimeters made of PVC tubes were applied to monitor soil water evaporation with the weighing method every day. The micro-lysimeter composed of inner and outer tubes, with the diameter of 11 cm for the outer tube and 10 cm for inner tube. The height of both tubes was 20 cm. The bottom of the inner tube was covered with nylon wire which was convenient for water vapor transfer in vertical direction. When installing the micro-lysimeters in the bare