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Effects of film mulching on evapotranspiration, yield and water use efficiency of a maize field with drip irrigation in Northeastern China

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ABSTRACT

Drip irrigation under film mulching is applied widely in maize field in northeastern China according to the "Water saving and grain increasing action" implemented by Chinese government in recent years. The influence of mulching on water consumption and grain yield still needs systematic investigation for a better evaluation of such managements. In this study, a field experiment was conducted for three consecutive years in northeastern China. Net radiation above canopy (R_n), soil evaporation (E_s) and crop transpiration (T_r), crop growth and yield were measured in film mulching (M) and non-mulching (NM) maize fields with drip irrigation. The results showed that the total evapotranspiration (ET) of the M treatment was between 413.4–471.3 mm, which was 2.8–5.2% lower than those of the NM treatment (430.0–497.4 mm) for the three years. Film mulching reduced the R_n of the maize field, which is an important reason for the lower ET of the M treatment. The total E_s of the M treatment was 45.2% lower, yet, the total T_r of the M treatment was 8.9% higher, than that of the NM treatment. The ratio of E_s to ET was 12.5–14.5% of the M treatment, while the ratio of the NM treatment was as high as 21.7–25.2%. The measured basal crop coefficient during the mid-growth period ($K_{cb\text{-}mid(mea)}$) of the M treatment (0.96–1.17) was 3.6–9.9% higher than those of the NM treatment (0.89–1.13) for the 3 years. However, the mean evaporation coefficient (K_e) of the entire growth period of the M treatment (0.09–0.10) was significantly lower than those of the NM treatment (0.18–0.19). Consequently, the mean crop coefficient (K_c) of the M treatment was 3.2–5.5% lower than those of the NM treatment for the 3 years. The maturity stage was accelerated by 4–5 days in the field with the M treatment. The yield increased by 5.9–8.8% and the water use efficiency (WUE) increased by 10.7–13.1% in the field with the M treatment for the 3 years. Such results are helpful to explicit the influence of mulching on water consumption, and give important reference to develop precise irrigation scheduling in maize field in this area.

1. Introduction

In recent years, water shortages and extreme arid climates have become increasingly severe and frequent globally. However, the development of efficient water-saving agricultural methods is an effective means to solve the contradiction between water supply and demand under a wide range of conditions (Xu et al., 2010). From 2012–2015, the Chinese government implemented the "Water saving and grain increasing action" in four provinces in Northeast China to encourage efficient water-saving irrigation. The micro-irrigation area of 1.35 million hm^2, mainly consisting of maize with drip irrigation under film mulching, accounts for nearly 54% of the total water-saving irrigation area (Wang et al., 2015a). The combination of film mulching and drip irrigation can effectively solve the problems of insufficient accumulated temperature during the early growth period while making fertilization easy (Zhao et al., 2015). Film mulching can increase soil temperature and improve soil moisture (Liu et al., 2015), reduce soil evaporation (Li et al., 2013), promote crop growth and increase yield and water use efficiency (Mbah et al., 2009; Yaghi et al., 2013); therefore, it has been applied worldwide. Many studies have investigated the effects of drip irrigation with film mulching, but most of these have been conducted in arid or semi-arid areas (Wang et al., 2015b; Eldoma et al., 2016) and

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Table 1
Field agronomic, fertilization and irrigation management (sowing, emergence, unfolding, fertilization and irrigation dates and irrigation amount) and precipitation during the growth periods in 2014–2016.

Years	Sowing dates	Emergence dates	Unfolding dates	Fertilization dates	Irrigation dates	Total irrigation amount/mm	Precipitation during the growth periods/mm
2014	4–26	5–2	5–10	6–29, 7–23, 8–8	5–3, 6–2	61	355
2015	4–25	5–3	5–12	7–7, 7–25, 8-6	5–1, 5–8	70	251
2016	4–28	5–5	5–13	7–3, 7–23, 8–6	6–18	45	442

have studied economic crops, such as cotton, fruit trees, and vegetables (Wang et al., 2006; Wei et al., 2015). In the northeastern semi-humid area in China, drip irrigation under film mulching has been applied to plant maize, the main grain crop in this area, according to the "Water saving and grain increasing action" plan. However, the effects of this method on water consumption and grain yield of maize have not been subjected to systematic investigation.

Film mulching influences the soil micro-meteorological and boundary conditions above which soil water evaporates, reduces net radiation of the canopy above which plant water transpires, increases soil heat flux and changes the energy distribution, resulting in changes in field water consumption (Feng et al., 2017). Changes in surface reflectance in response to film mulching can change the canopy radiation transmission and energy distribution (Prieto et al., 2012). The midday latent heat flux of fields subjected to film mulching is lower than that of conventional irrigated farmland and the sensible heat flux is higher, resulting in an increased temperature of the ambient atmosphere (Tarara, 2000). Such increases in temperature often lead to increased vapor pressure deficits and the soil moisture of film mulching fields is often high, both of which benefit transpiration. Although film mulching reduced soil evaporation, the effects on total evapotranspiration (*ET*) in the field are not certain (Fan et al., 2017). Accordingly, it is important to determine *ET* and its components to understand the influence of mulching on field water consumption and develop precise irrigation scheduling to improve water use efficiency in such areas.

Many studies have shown that film mulching changes the soil water content in the field, creating good water, fertilizer, gas and heat conditions, which are beneficial to crop growth and development. Thus, it can increase crop yield and improve water use efficiency (Luo et al., 2015; Ji et al., 2015). However, film mulching does not always cause yield increases. Indeed, its effects depend on soil hydrothermal conditions and the crop's own physiological characteristics. In the case of cucumber and other plants, which are tolerant to higher temperature, the effects of film mulching are significant (Yaghi et al., 2013). However, for crops sensitive to high temperature, film mulching may inhibit crop growth. Wang et al. (2011) showed that film mulching can significantly reduce soil evaporation in the early growth stages of potato and maintain a high soil water content, but that late-stage mulching will cause the soil temperature to be too high, resulting in decreased yield. Accordingly, more studies are needed to determine if increased soil temperature in the late growth stage caused by film mulching will also cause the maize yield to decrease in northeastern areas of China.

In this study, a field experiment was conducted for three consecutive years in northeastern China. During the study period, net radiation above canopy, soil evaporation and crop transpiration, crop growth and yield were measured in film mulching (M) and non-mulching (NM) maize fields with drip irrigation. The main objectives were to (1) quantify differences between the total amount of evapotranspiration and its components in the two treatments, and (2) quantify the effects of mulching on plant growth, yield and water use efficiency (WUE).

2. Materials and methods

2.1. Experimental site

The experiment was conducted at the Heilongjiang Provincial Water Science and Technology Experimental Research Center, located in the Daoli District of Harbin (125° 45′E, 45° 22′N) at an elevation of 220 m. The annual precipitation ranges between 400 and 650 mm, 80% of which occurs in May–September (maize growth period). According to the international classification criteria of soil texture, the 0–100 cm soil layer is silty loam, with organic matter and pH values of 25.94 g kg^{-1} and 8.69, respectively. The bulk density, saturated soil water content and field capacity of the 0–100 cm soil layer were 1.48 g cm^{-3}, 0.466 and 0.350 cm^3 cm^{-3}, respectively, based on the Wilcox method (Wilcox, 1965).

2.2. Experimental design

The experiment was conducted for three consecutive years: 2014–2016. The field was surface drip irrigated and treated with mulching (M) and non-mulching (NM) by plastic transparent film. Three replicates of both treatments were set, with each area being 5.2 m × 20 m. The planted crop was spring maize (*Zea mays* L.), and the variety was Dongfu No.1. Crops were sown at the end of April and harvested at the end of September each year. The growing stages were recorded according to the Leaf Collar method after Abendroth et al. (2011). The growing stages are divided into vegetative (V) and reproductive (R) stages. Vegetative stages are designated with a "V" followed by the total number of collared leaves present. For example, a plant with three visible leaf collars is V3 growth stage. Reproductive stages are designated with an "R" followed by the numbers 1–6. Each specific V or R stage is defined only when 50 percent or more of the plants in the field are in or beyond that stage. Table 1 of Abendroth et al. (2011)'s publication listed all the V and R stages and corresponding common names. According to that table, VE, V6, VT, R1, R3 and R6 are the starts of seedling, jointing, tasseling, silking, milk and physiological maturity, respectively.

Before sowing, the experimental field was rototilled at a depth of 0.25–0.3 m. A ridge with a width of 1 m and a height of 0.15 m forming a ditch 0.3 m wide was then built (Fig. 1). Two lines of maize were sown on the ridge, with row spacing of 0.4 m and plant spacing of 0.25–0.3 m. Drip lines were laid in the middle of the ridge immediately after sowing, and the film were laid at the same time covering above the ridge. The discharge rate of the drip emitter was 1.38 L h^{-1} at the work pressure of 0.1 MPa and the spacing was 0.3 m. The film was polyethylene transparent film with a thickness of 0.01 mm. The film was used for both the M and NM treatment after sowing to ensure the emergence of seeds. For the NM treatment, the film was removed in about one week after emergence, while the film was kept for treatment M. Dates of sowing, emergence and film removal for the 3 years are listed in Table 1. Field management, irrigation and fertilization scheduling were the same for the M and NM treatments.

The irrigation scheduling was determined by the upper and lower limits of soil water content in the NM treatments, and the irrigation amount was kept the same between M and NM treatments, and determined according to Eq. (1):