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Evaluating effects of four controlling methods in bare strips on soil temperature, water, and salt accumulation under film-mulched drip irrigation

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ABSTRACT

Film-mulched drip irrigation as an effective water saving irrigation method has been widely utilized in arid areas. Unnecessary soil-water loss and excessive salt accumulation from soil evaporation, however, still occur in the bare strips between adjacent films under drip irrigation so that developing a useful method to combat this has been a challenge. Applying the methods of soil evaporation control in the bare strips under film-mulched drip irrigation may alleviate this problem. In 2013 and 2014, we thus adopted four controlling methods (STM: straw mulching, SAM: sand mulching, PAM: polyacrylamide amendment application, and CSS: surface soil compaction) in bare strips to evaluate their effects on soil properties and cotton productivity under film-mulched drip irrigation in southern Xinjiang, northwestern China. The main results showed that the four controlling methods gave more stable daily soil temperatures in bare strips with respect to CK. In general, STM and PAM reduced the soil temperature while CSS and SAM increased it. Moreover, the four controlling methods effectively reduced daily soil evaporation by 34.6–96.2% and 61.1–77.3% in 2013 and 2014, respectively. Lower evapotranspiration was found in the four controlling methods. The salt accumulation amount from late seedling stage to harvest reduced greatly in the four controlling methods, especially in STM and PAM. There were no significant differences in cotton yield and water-use efficiency (WUE), but the WUE for the four controlling methods slightly increased by 10.2–12.2% and 1.1–8.5% in 2013 and 2014, respectively, with respect to CK. The highest yield and WUE were found in SAM during the both seasons, indicating that SAM could be more effective than the other controlling methods at the experimental site. The controlling methods in bare strips under film-mulched drip irrigation can provide an alternative option to prevent the risk of soil salinization and enhance crop productivity in the arid regions of Xinjiang and other similar regions in the world. However, long-term use of the controlling methods in bare strips under film-mulched drip irrigation should be further evaluated.

1. Introduction

Water shortage and soil salinization are two key factors limiting sustainable development of agriculture in arid areas (Li et al., 2016) so that it has forced producers of dryland crops (e.g. cotton) to ensure a favorable soil-water/salt environment in root zone for crop growth (Ji and Unger, 2001). In recent years, the technique of film-mulched drip irrigation combining the benefits of drip irrigation and film mulching has been widely used in arid areas to effectively moderate soil evaporation, prevent the risk of soil degradation, and increase water-use efficiency (WUE) and crop yields (Díaz-Pérez et al., 2005; Miles et al., 2012; Ning et al., 2015; Yang et al., 2016). Water loss and salt accumulation from soil evaporation, however, have taken place in the bare strips which are arranged between adjacent films to allow for soil aeration and transmission of light as well as to avoid high soil temperature stress for crop growth. Therefore, developing a useful method to control the soil evaporation in the bare strips has been a challenging.

Some studies have indicated that different controlling methods, such as straw or sand mulching surface soil, chemical amendments application, and surface soil compaction, can successfully control soil evaporation. Straw mulching as a common method can significantly reduce soil evaporation by decreasing the exchange of water vapor between soil surface and atmosphere (Huang et al., 2005). It can thus alter the water balance between soil evaporation and plant

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transpiration, modify microclimate (e.g., temperature and microbial biomass) (Gupta and Gupta, 1985; Gupta and Acharya, 1993; Kumar and Goh, 1999), and moderate the salt accumulation in root zone (Pang et al., 2010; Zhao et al., 2014; Zribi et al., 2015). Sand mulching is another approach to controlling soil evaporation. This practice can decrease soil evaporation by 10–20% compared with no mulch (Modaihsh et al., 1985; Gale et al., 1993), control the soil salinity in root zone, and improve the management of insect pests (Davenport and Schiffhauer, 2000). Soil compaction can change the continuity and tortuosity of soil so that it may further affect soil water availability, heat fluxes, penetration resistance, and aeration (Hartmann et al., 2012; Schjønning et al., 2013; Siczek et al., 2015). At a proper range of compaction, it can increase soil retention and soil water availability (Warkentin, 1971; Sharma and Bhagat, 1993), and WUE (Sharma et al., 1995). Applying chemical materials is also an effective way to restrain soil evaporation, particularly for polyacrylamide application. Polyacrylamide can promote the ability of porous soils, especially in sandy soils, to store water (Sivapalan, 2006). The practice can also delay wilting where soil evaporation is intense and control or minimize the adverse impacts of salinity (Yang et al., 2014; Al-Uzairy, 2015).

When the controlling methods are applied to the bare strips between adjacent films, it may be helpful in reducing invalid water loss and salt accumulation from soil evaporation, enhancing WUE, as well as achieving a more profitable crop yield under film-mulched drip irrigation. Moreover, the controlling methods may further affect the distributions of water, salinity, and temperature in soil which are complex and difficult to predict. Therefore, a two-year experiment was conducted in cotton field to evaluate the effects of four controlling methods (straw mulching, polyacrylamide application, surface soil compaction, and sand mulching) in bare strips on soil properties (i.e. soil temperature, water, salinity) and cotton productivity (i.e. cotton yield, aboveground biomass and WUE) under film-mulched drip irrigation in southern Xinjiang, northwestern China.

2. Materials and methods

2.1. Experimental site description

The field experiment was conducted at Bazhou Irrigation Experimental Station (41°35′N, 86°09′E, and 901 m a.s.l.) in the Tarim Basin of Xinjiang of northwestern China, during 2013 and 2014 seasons. The site is representative of continental desert climate with a long-term annual precipitation of 58 mm and an average potential evaporation of 2788.2 mm (Wang et al., 2014; Li et al., 2015), making irrigation necessary for crop growth. The predominant soil texture at the site was a silt loam with a texture of 41.4% sand, 54.4% silt, and 4.2% clay according to the United States Department of Agriculture soil taxonomy. The average bulk density and field capacity of 1-m soil profile were 1.56 g cm^{-3} and 0.25 cm^3 cm^{-3}, respectively. The soil salt content of the field in 1-m soil profile varied from 3.24 to 13.5 g kg^{-1}, indicating slight to moderate salinity. The average groundwater table was deeper than 5 m during the two seasons.

2.2. Cotton cultivation and irrigation management

Cotton (*Gossypium hirsutum* L.) was sown after plowing on 26 April 2013 and 3 May 2014 at a density of 22 seeds m^{-2}. The planting pattern and drip lines arrangement in the field followed the local practice of "one film, two drip lines and four rows" (Fig. 1). Four rows of cotton were covered by one white plastic film of 110-cm width and irrigated with two drip lines with emitter intervals of 30 cm and a discharge rate of 2.0 L h^{-1}. The width of the bare strip between a pair of mulches was 30 cm. There was no irrigation at seedling stage (from early May to mid-June) because of a flood irrigation about 300 mm with a salinity of 0.8 dS m^{-1} in mid-April each year. The irrigation schemes during the both growing seasons are illustrated in Fig. 2. The irrigation began in the mid-June and ended in the early September during the two seasons. The field was irrigated 11 and 12 times in 2013 and 2014, respectively. The total amounts of applied water, recorded by water meters with a precision of 0.001 m^3, were 457.5 mm and 495 mm in 2013 and 2014, respectively. The irrigation water was extracted from the Kongque River with a salinity of 0.75 g L^{-1} (fresh water) in 2013 and from groundwater with a salinity of 2.01 g L^{-1} in 2014 (brackish water). Inorganic fertilizers (225 kg ha^{-1} urea with 46.4% N, 375 kg ha^{-1} diammonium phosphate with 46% P_2O_5 and 18% N, and 300 kg ha^{-1} potassium sulphate with 45% K_2O) were applied before sowing. At squaring and flowering stages, 600 kg ha^{-1} urea, 98 kg ha^{-1} diammonium phosphate, and 88 kg ha^{-1} potassium sulphate was applied. Herbicides were used before planting, pesticides were applied every 5–7 days from seedling stage to boll stage with a sprayer pump, and topping was conducted manually at the end of July.

2.3. Experimental setup

The experiment was performed at late seedling stage (16 June 2013 and 14 June 2014) to ensure good seed emergence for all plots. Four controlling methods and an untreated control (CK) were applied to bare strips. The four controlling methods were: (1) STM, the bare strips were uniformly mulched with air-dried cotton straw with 20–30 cm length at a rate of 16.5 t ha^{-1} (nearly complete coverage); (2) CSS, the topsoil of bare strips was compacted by using a concrete plank (30-cm width, 20-cm length, and 4-cm thickness, about 10 kg) and the bulk density of the 0–20 cm layer increased from 1.55 to 1.68 g cm^{-3}; (3) PAM, the bare strips were uniformly applied with polyacrylamide solution at a rate of 42 kg ha^{-1}; (4) SAM, the bare strips were uniformly mulched with air-dried 1–2 mm sand at a rate of 240 t ha^{-1} (about 1.5-cm thickness). All treatments were arranged in a randomized block designed with three replicates. Each plot was 7 × 7 m and adjacent plots were separated by 1 m to eliminate the effect of the lateral movement of soil water.

2.4. Data collection and calculations

2.4.1. Meteorological data

A Davis wireless Vantage Pro2 weather station (Davis Instruments, Hayward, USA) was installed about 30 m away from the experiment field to automatically collect meteorological data, such as rainfall, solar radiation, maximum and minimum air temperature, relative humidity, and wind speed at a height of 2 m. Daily reference crop evapotranspiration (ET_o) calculated using the Penman-Monteith equation (Allen et al., 1998) during 2013 and 2014 seasons are displayed in Fig. 2. The irrigation amount in 2014 (495 mm) was thus higher than that in 2013 (457.5 mm) due to similar ET_o (578.9 mm in 2013 and 584.5 mm in 2014), lower rainfall (60.1 mm in 2013 and 23.3 mm in 2014), and brackish irrigation water during the growing season for cotton in 2014.

2.4.2. Soil temperature and evaporation measurements

Soil temperature in the bare strips for each plot was measured with soil thermometers (Hongxing Thermal Instruments, Wuqiang County, Hebei Province, China) from 5 to 20 cm at 5-cm intervals and recorded daily at 8:00 and 20:00 to calculate daily soil temperature of 20-cm soil profile. Soil evaporation in the bare strips for each plot was monitored daily at 20:00 with microlysimeters (12.5-cm diameter, 20-cm length, and 1.8-mm wall thickness). Details of the microlysimeter arrangement can be found elsewhere (e.g., Hernández et al., 2015; Vial et al., 2015; Wang et al., 2015).

2.4.3. Soil-water content and salinity

Soil samples were collected to determine soil-water content (SWC) and salinity at a 10-cm interval from 0 to 40 cm and at a 20-cm interval from 40 to 100 cm by using an auger with 5-cm diameter in the middle of wide, narrow, and bare strips. The samples were collected at the late