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Full Length Research Paper

Effect of mulch and irrigation practices on soil water, soil temperature and the grain yield of maize (*Zea mays L*) in Loess Plateau, China

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Agricultural management practices, such as mulching and irrigation can change the characteristics of the soil surface and hence influence the hydrothermal properties of the soil. A two-year field experiment was conducted at the Changwu agro-ecosystem research station to evaluate the effects of mulch and irrigation practices on moisture and temperature in the upper layers of the soil and on crop growth and yield performance in spring maize (*Zea mays L*) fields. Four mulching and irrigation treatments were examined: supplementary irrigation (SI), film mulching (FM), straw mulching (SM; in 2008 only) and a rain-fed (RF) control. The soil water (0 - 15 cm depth range) and soil temperature (0 - 5 cm depth range) were studied during the crop growing season and the treatments' yield performances were compared. Over the whole season, the average topsoil water content was significantly higher (P < 0.05) under the SM (23.3% in 2008), SI (21.4% in 2007, 22.5% in 2008) and FM (20.0% in 2007, 21.6% in 2008) treatments than under RF (17.1% in 2007, 19.6% in 2008). The seasonal trends in atmospheric and soil temperatures were similar under all treatments. The seasonally-averaged soil temperature at 07:00 and 14:00 h was highest under the FM treatment and lowest under the SM treatment. Plant height and leaf and stem biomass were significantly higher (P < 0.05) under the SI treatment than under the RF and FM treatments from silking to physiological maturity. Both the FM and SI treatments significantly improved (P < 0.05) the crop grain yield (GY) and yield components.

Key words: Loess Plateau, soil water, soil temperature, spring maize.

INTRODUCTION

Spring maize (*Zea mays L*) is one of the main crops grown in the Loess Plateau, China. Its high yields, which average around 12 t·hm^{-2}, are assumed to benefit from prolonged sunshine, provided that there is adequate light and heat during the growing season (Xue et al., 2008). However, the Loess Plateau lies in a semiarid region of China, with annual precipitation range of 150 - 300 mm in the North to 500 - 700 mm in the south. Drought is considered to be the primary limiting factor affecting maize production in the area; shortages and uneven distribution of water resources throughout the year restrict crop growth (Kang et al., 2002; Wang et al., 2009; Zhang et al., 2009).

Agricultural management practices can change the characteristics of the soil surface and influence the hydro-thermal properties of the soil. For example, mulching can affect the temperature and moisture content of the soil (Li et al., 1999; Acharya et al., 2005) and directly influence the grain yield of crops (Ramalan and Nwokeocha, 2000;

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Li et al., 2001a, b). Straw mulching (SM) systems can conserve soil water and reduce temperature because they reduce soil disturbance and increase residue accumulation at the soil surface (Baumhardt and Jones, 2002; Zhang et al., 2009). Soil mulching with plastic film, which results in reduced water loss and more even regulation of soil temperature, has been widely used in agriculture (Zhang et al., 2005). Supplementary irrigation (SI) would improve plant water relation as well as grain yield (Hagan et al., 1967; Wang et al., 2001). However, a high crop yield is not the only goal; other constraints such as water availability and the costs of irrigation also need to be taken into account in the management of crops on the Loess Plateau (Kang et al., 2002).

Although a number of researchers have evaluated the positive effects of irrigation and mulching management under rain-fed farming systems (Wang et al., 2001; Zhang et al., 2005; Zhang et al., 2009), most of these studies have concentrated on only one field water management practice; few studies have focused on farmlands with a variety of field management practices. Therefore, we sought to evaluate the impact of irrigation and mulching on: (i) soil moisture (at depths of 0 – 15 cm) and soil temperature (at depths of 0–5 cm) in the upper upper soil layers, and (ii) productivity of spring maize in the Loess Plateau rain-fed ecosystem.

MATERIALS AND METHODS

Site description

The Changwu experimental station is situated on loessial tableland at a location (35.2°N, 107.8°E, ca. 1200 m above sea level) where the loess is more than 100 m thick. The soils are Cumuli-Ustic Isohumosols, according to the Chinese Soil Taxonomy (Gong et al., 2007), with the following characteristics recorded by Liu et al.(2010): 37% clay, 59% silt, and 4% sand contents; pH ca. 8.4; bulk density 1.3 g·cm^{-3}; organic matter and total nitrogen contents of 11.8 and 0.87 g·kg^{-1}, respectively and available phosphorus, potassium and inorganic nitrogen contents of 14.4, 144.6 and 3.15 mg·kg^{-1}, respectively. According to data collected at the station from 1990 to 2008, the average annual precipitation for this period was 578 mm, with 55% of the total precipitation occurring between July and September and an average annual temperature of 9.2°C. Rain-fed agriculture is the dominant production system in the study area. The study described in this paper was conducted in 2007 and 2008.

Experimental design and treatments

Four water management methods – a rain-fed system (RF), supplementary irrigation (SI), film mulching (FM), and straw mulching (SM) (in 2008 only) – were used in spring maize fields. In the RF, FM and SM treatments, rainfall was the sole source of soil water. In the SI treatment, soil water levels were maintained at 70 – 85% of the field water capacity using tap water delivered by furrow irrigation; the crop was irrigated five times in 2007 (May 8, May 20, June 14, July 14 and August 15) and four times in 2008 (May 22, June 5, July 7 and August 4), with the irrigation quota being 33.7 and 25.6 mm in 2007 and 2008 respectively. On May 8 in 2008, around the time of seedling emergence, corn straw (cut into 0.1 m long segments), was applied uniformly (6000 kg hm^{-2}) on both ridges and furrows in the SM plots. The plots in which the different treatments were evaluated were arranged in a completely randomized block design, with four replicates for each treatment. The size of each experimental plot was 50.7 m^2 (7.8 m × 6.5 m).

Ridge cultivation, a common maize cultivation practice across the Loess Plateau, was used in all four treatments. First, 110 kg N hm^{-2} in the form of urea (N 46%), 50 kg P hm^{-2} in the form of calcium superphosphate (P_2O_5 12%), and 100 kg K hm^{-2} in the form of potassium sulfate (K_2O 45%) were broadcast over the soil surface as a base fertilizer. The fields were then plowed to turn the soil and relocate the nutrients to below the surface. Ridges were constructed by banking up soil from both sides to a height of 0.1 m from the base to form a ridge 0.45 m wide at the top and furrows 0.15 m wide at the base. In the plots mulched with plastic, a film (0.7 m wide and 0.005 mm thick) was used to cover the soil surface of the ridges but not the furrows and the edges were secured under the soil in the bottom of the furrows. Spring maize (*Zea mays* L. pioneer 335) was sown in 5 cm deep holes spaced 0.2 m apart along the midline on the top of the ridge, using a man-powered hole-drilling machine, on April 20 in 2007 and April 18 in 2008. Water was added as required before backfilling in order to encourage emergence of seedlings. Additional nitrogen, in the form of urea, was applied at the jointing and tasseling stages, at rates of 80 kg N hm^{-2} and 90 kg N hm^{-2}, respectively, following a nutrient management plan aimed at achieving a final grain yield of 14 t·hm^{-2}. Maize cobs were harvested gradually, according to their ripeness, from 28 August to 13 September 2007 and from 8 to 20 September 2008. Manual weeding was undertaken as required during the crop's growing season.

Sampling and measurements

Sampling and measurement procedures were the same in both crop growing seasons. Soil water in the top 15 cm of the soil was measured volumetrically with a TDR probe at five locations in each plot at 2 – 3 day intervals. The air and soil temperature (at a depth of 0 – 5 cm) was recorded daily at 07.00 h and 14.00 h (the coolest and warmest times of the day, respectively).

Three adjacent plants in a row were sampled randomly from each plot, by cutting off the shoot at the first nodule on the stem, at the 6th leaf stage (V6), 12th leaf stage (V12), silking stage (R1), milk stage (R3), dough stage (R4, only 2008) and physiological maturity stage (R6). A standardized maize development stage system was used to identify the plant development stages (Ritchie et al., 1992). The harvested shoots were killed by heating at 105°C for 30 min, oven-dried for 24 h at 65 - 75°C and then weighed. The leaf and stem biomass in each plot was expressed in terms of kg dry matter hm^{-2}.

At physiological maturity, 9.6 m^2 (4 m × 2.4 m) of maize plants were hand-harvested from the four center rows of each plot. The grain and stover were separated and weighed. Aliquots of grain and stover (for three randomly selected plants) were dried at 65 - 75°C to constant weight to determine the amount of dry matter for each. The Harvest index (HI) was calculated as GY in t hm^{-2} divided by the total above ground dry matter in t hm^{-2}. One thousand dry kernels from each plot were weighed to determine the 1000-kernel weight.

Statistical analyses

The effects of the treatments on the measured parameters were evaluated by one-way ANOVA. When F-values were significant, the least significant difference (LSD) test was used to compare between-treatment differences in means according to Duncan's new multiple range tests. In all cases differences between mean

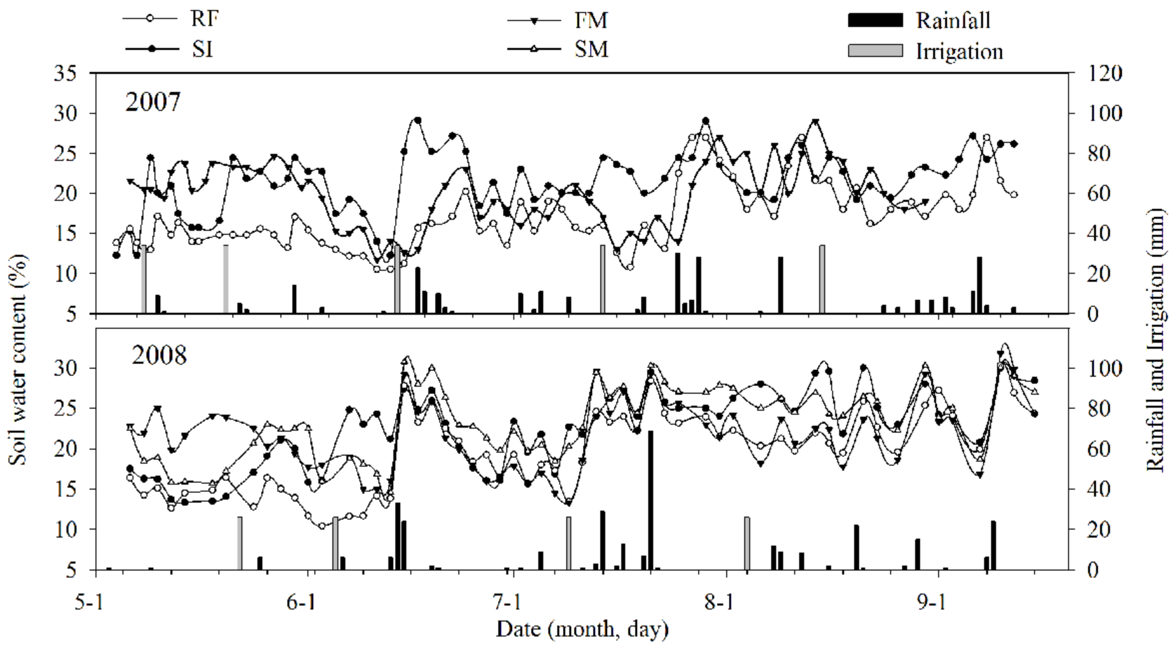

Figure 1. Soil water content (0 - 15 cm) under rain-fed (RF), supplementary irrigation (SI), film mulching (FM) and straw mulching (SM) during the experimental seasons in 2007 and 2008.

Table 1. Averaged soil water and temperature over the growing season under rain-fed (RF), supplementary irrigation (SI), film mulching (FM) and straw mulching (SM) in 2007 and 2008.

Treatments	Soil water content (%)		Soil temperature(07:00 h, °C)		Soil temperature(14:00 h, °C)	
	2007	2008	2007	2008	2007	2008
RF	17.1 ± 1.2 b	19.6 ± 1.1 c	16.9 ± 0.7 b	17.1 ± 0.9 b	26.7 ± 1.3 b	27.7 ± 1.1 b
SI	21.4 ± 0.9 a	22.5 ± 1.3 ab	16.2 ± 0.8 b	16.9 ± 1.1 b	25.1 ± 0.9 b	27.0 ± 0.8 b
FM	20.0 ± 0.6 a	21.6 ± 0.9 b	17.6 ± 0.5 a	18.1 ± 0.7 a	29.2 ± 0.5 a	30.9 ± 0.9 a
SM		23.3 ± 1.0 a		16.4 ± 0.7 b		25.4 ± 1.2 c

Values are given as means ± standard error of means (n = 4). Values followed by different letters within a column are significantly different ($p < 0.05$).significantly different ($p < 0.05$).

values were deemed to be significant if $p < 0.05$.

RESULTS

Soil water content in the 0 - 15 cm soil profile

The study region was characterized by strong seasonal variation in rainfall, with most rain falling in July and September (Figure 1). The maize growing season rainfall was 302 mm in 2007 and 340 mm in 2008, with 58.2 and 65.2%, respectively, of the total annual precipitation occurring in the spring maize growing season.

Soil water content in the upper soil profile (0 - 15 cm) exhibited quite wide seasonal fluctuation during the crop growing season. It was generally low at the crop seedling stage (that is, May and the first half of June) because high soil evaporation removed water from the upper soil profile. The soil water content then increased after the jointing stage (from the middle of June to July) due to precipitation, enhanced canopy shading and root hydraulic lift (Figure 1).

The averaged soil water content (0 - 15 cm) over the maize growing season is presented in Table 1. The averaged soil water content for each of the treatments was ranked as follows: SM > SI > FM > RF. SM, SI and FM significantly enhanced ($P < 0.05$) soil water content in the 0 - 15 cm profile compared to the RF treatment, while there was no significant ($P > 0.05$) difference in soil water content between the SI and FM treatments.

Soil temperature

Under all treatments, the temporal variations in both atmospheric and soil temperatures in the mornings (at

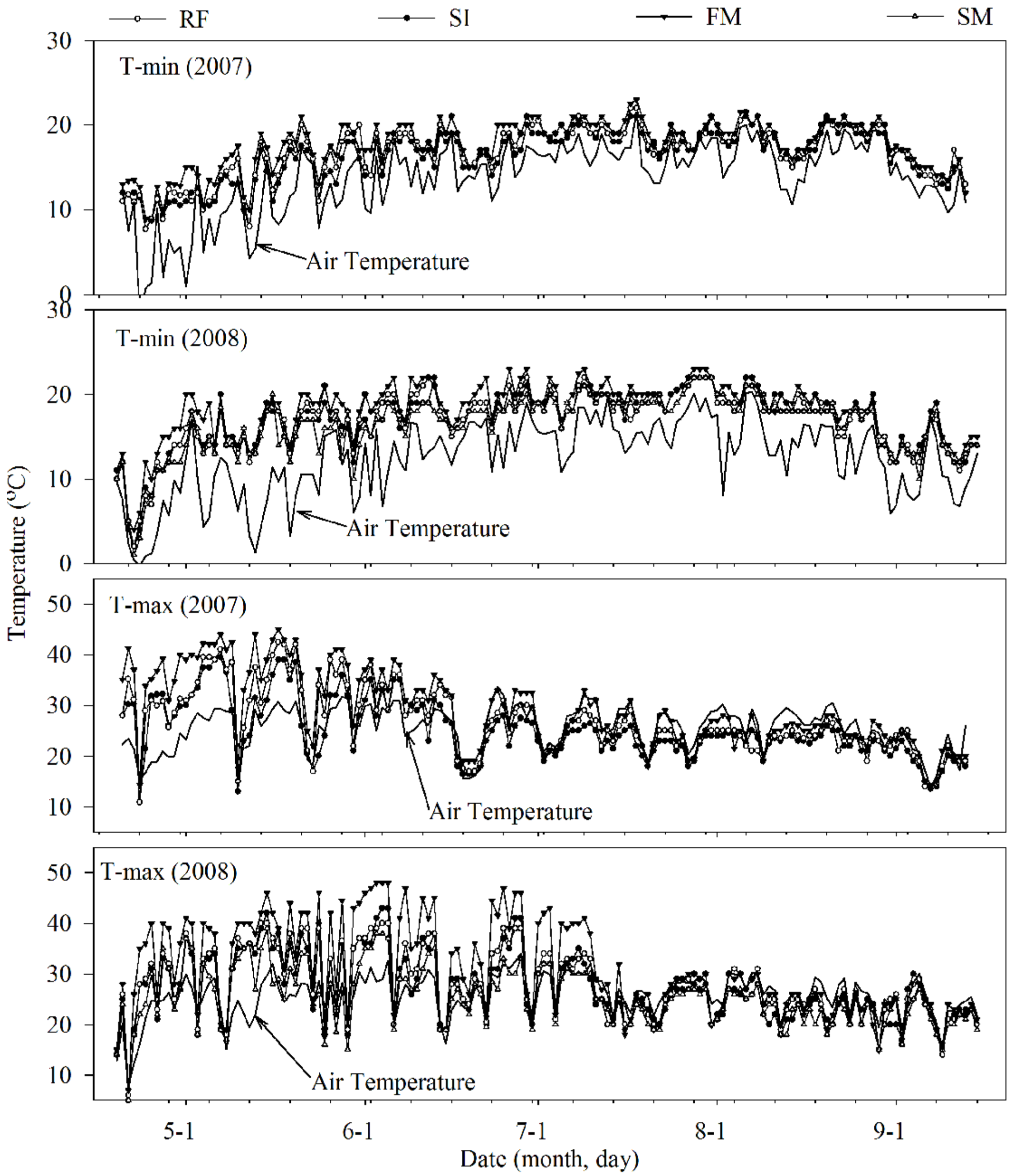

Figure 2. Soil temperature (0 - 5 cm) under rain-fed (RF), supplementary irrigation (SI), film mulching (FM) and straw mulching (SM) and air temperature during the experimental season in 2007 and 2008.

07:00) exhibited similar trends (Figure 2). Soil temperatures were consistently higher than the air temperature, with the maximum difference occurring under the FM treatment. The difference was found to be greater when the air temperature was low. Variation in soil temperature at 14:00 h followed a similar trend to that at 07:00 h. However, the magnitude of the variation the in soil temperature in the afternoon exhibited a more pronounced dependence on the treatment employed. The soil temperature in the upper layer under the FM treatment was significantly higher (3 - 8°C) than in the unmulched controls in the early crop growing stages. This difference became less pronounced towards the end of the crop-growing season (from August to September) (Figure 2).

The mean soil temperature, calculated by averaging the readings taken over the growing season, is presented in Table 1. The mean soil temperature was highest under the FM and lowest under the SM treatments; mean temperatures under unmulched conditions (RF and SI)

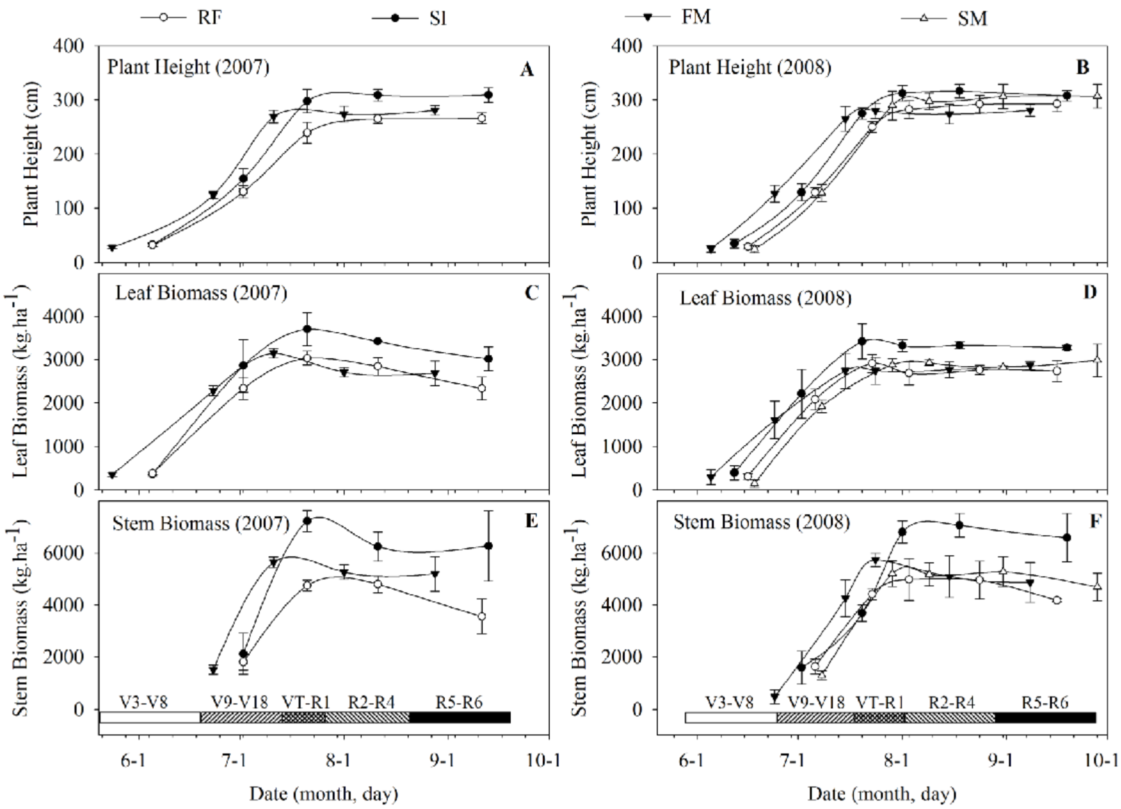

Figure 3. Plant height, leaf and stem biomass under rain-fed (RF), supplementary irrigation (SI), film mulching (FM) and straw mulching (SM) during the experimental seasons in 2007 and 2008. Error bars are twice the standard error of the mean. V3-V8: from 3rd leaf stage to 8th leaf stage (seedling stage); V9-V18: from 9th leaf stage to 18th leaf stage (jointing stage); VT-R1: from tasseling stage to silking stage; R2-R4: from blister stage to dough stage; R5-R6: from dent stage to physiological maturity stage.

were intermediate between these two extremes, but there was no significant difference in soil water storage between the non-mulching treatments.

Crop growth

The plant height and leaf and stem biomass increased dramatically during the vegetative stage, and peaked at the tasseling stage (VT) under all treatments (Figure 3). However, there were substantial differences between the treatments in terms of the kinetics of crop growth with respect to these characteristics. FM promoted vigorous early growth of the maize seedlings, with much greater plant height and leaf and stem biomass being attained during the early vegetative stages (May and June) than under the other treatments. The SI treatment, in which the soil water content was maintained at a high level, may have stimulated vegetative growth such that the plant height and leaf and stem biomass became equivalent to those of plants undergoing FM treatment after the jointing stage (July). The SI treatment resulted in a significantly higher maximum plant height and leaf and stem biomass than the FM and RF treatments from silking to physiological maturity stage. There was no significant difference ($P > 0.05$) in the measured values for these parameters between the FM and RF treatments.

Grain yield

Grain yield components at harvest are shown in Table 2. Under both the FM and SI treatments, the crop GY was significantly greater than under RF ($P < 0.05$), by 24.6 and 19.7%, respectively, in 2007, and by 36.8 and 24.6%, respectively, in 2008. However, there was no significant difference in GY under the FM and SI treatments. The HI under the different treatments ranged from 0.47 to 0.55; ranges of 0.40 - 0.54 have been observed in previous studies (Moser et al., 2006). HI was quite robust under all treatments save for SM, under which HI was significantly lower than under the other treatments. In contrast to HI, the 1000-kernel weight proved to be more variable and was affected by the applied irrigation and mulching treatments in a similar way to GY. The kernel weight appeared to be the primary grain yield component associated with yield performance under the different treatment practices used in our study (Table 2). Despite

Table 2. Grain yield components under rain-fed (RF), supplementary irrigation (SI), film mulching (FM) and straw mulching (SM) in 2007 and 2008.

Treatments	Grain yield ($t \cdot hm^{-2}$)		Harvest index		1000-kernel weight (g)	
	2007	2008	2007	2008	2007	2008
RF	12.2 ± 1.2 b	11.4 ± 1.4 b	0.55 ± 0.03 a	0.49 ± 0.04 ab	263.4 ± 9.2 c	256.4 ± 7.8 b
SI	15.2 ± 0.8 a	15.6 ± 1.8 a	0.54 ± 0.02 a	0.51 ± 0.03 a	303.4 ± 11.1 a	298.5 ± 9.9 a
FM	14.6 ± 0.6 a	14.2 ± 1.0 a	0.53 ± 0.03 a	0.51 ± 0.03 a	281.3 ± 8.7 b	282.0 ± 6.7 a
SM		10.1 ± 1.0 b		0.47 ± 0.05 b		222.2 ± 15.6 c

Values are given as means ± standard error of means (n = 4). Values followed by different letters within a column are significantly different ($p < 0.05$).

soil water content (0 - 15 cm) being maintained at a high level under the SM treatment, GY was relatively low, with the low yield appearing to be associated with consistently significant lower HI and lighter kernels (Table 2). It is possible that this may have been caused by the straw mulching decreasing the soil temperature resulting in decreased root and microbial activities (Gao and Li, 2005).

DISCUSSION

Irrigation in drought-prone areas can markedly promote plant biomass accumulation because it provides relief from drought stress (Çakir, 2004). In our study, maize performance and yield components under the supplementary irrigation (SI) treatment were significantly greater than under the rain-fed (RF) treatment. Improved water availability during the VS (before silking) can result in taller and more robust plants, a larger average leaf area, increased vegetative dry matter and promoted leaf tip emergence, tassel emergence, silking and onset of grain filling (NeSmith and Ritchie, 1992; Abrecht and Carberry, 1993). Sufficient water supply during the RS (after silking) can decrease the interval from silking to pollen shed (Herrero and Johnson, 1981) and prolong the grain filling period (Westgate, 1994).

Mulching, either with plastic film or straw, can significantly affect the soil microclimate (soil temperature and water content) (Ghosh et al., 2006) and hence grain yield and yield components, but these improvements are not necessarily caused by the same mechanisms. The yield of maize under the film-mulched (FM) treatment was higher than in the unmulched control plots (the RF). This phenomenon can probably be attributed to the improvement in soil water and thermal conditions relative to those under the unmulched treatment (RF) in the maize growth seasons (Li et al., 1999, 2004). The film prevents evaporation of water from the soil surface. At the same time, water moves from deeper soil layers to the topsoil by capillarity and vapor transfer, thereby keeping the topsoil water content relatively stable (Wang et al., 1998; Li et al., 1999). The FM treatment also increased the soil temperature, generating the highest soil temperatures observed in both years. The film mulch prevents water exchange between the soil and air, which in turn reduces the latent heat flux and also reduces the exchange of heat between soil and air (Wang and Deng, 1991). At the seedling stage of crop development, the plant canopy was small, permitting the majority of the area of the plastic film to receive solar energy and thus warm the topsoil. The diurnal temperature fluctuation at this stage involved faster warming of mulched soil during the day and slower cooling at night. The plastic film and the water below the film would reduce the effects of long wave radiation and thus reduce the rate of decrease in soil temperature at night (Zhang et al., 2005). This result was consistent with the report by (Zhang et al., 2008a, 2008b). In the middle and later growth stages, the full establishment of the plant canopy led to only a very small increase in the soil temperature as a result of the presence of the plastic film compared with the unmulched plots (Zhou et al., 2009).

Straw mulching (SM) is regarded as one of the best ways of improving water retention in the soil and reducing soil evaporation (Baumhardt and Jones, 2002; Zhang et al., 2009). Several investigators have reported that the soil thermal regime under straw mulching was different from that of bare soil, with soil temperatures often being lower under mulched surfaces than in non-mulched soils (Bristow, 1988; Sarkar et al., 2007). Others have documented cases where straw mulching increased soil temperatures (Ramakrishna et al., 2006) although these could be largely attributed to differences in climatic conditions. Fabrizzi et al. (2005) and Olasantan (1999) observed that soil temperatures under straw mulching were higher during colder weather than during warmer weather when compared with non-mulched soil. The 2008 field experiment demonstrated that soil temperature was reduced in SM plots. Readings taken in the morning showed a mean reduction of 0.7°C for the SM treatment compared to the control (RF). During the afternoon, soil temperatures under SM were as much as 2.3°C lower compared to the RF control. The straw used to cover the soil surface has a higher albedo and lower thermal conductivity than bare soil and consequently reduces the solar energy reaching the soil and reduces the magnitude of the temperature increases during warm conditions

(Horton et al., 1996). Conversely, during colder periods, the solar energy input is lower and there is a net loss of soil heat energy to the atmosphere, resulting in a temperature decrease in the soil profile. The presence of straw mulching on the soil surface insulates the soil and to some extent, reduces loss of heat to the colder atmosphere. Heat loss from the soil is therefore somewhat lower under straw mulching compared with unmulched soil and soil temperatures consequently remain higher (Fabrizzi et al., 2005; Olasantan, 1999).

Conclusion

Soil water and soil temperature regimes were altered by irrigation and mulches in spring maize fields on the Loess Plateau, China. Crop growth was affected by alterations in these regimes, resulting in differences in plant productivities. Mulches were found to improve topsoil water retention when compared with the RF control. In the SM treatment soil water retention increased and soil temperature decreased. The FM treatment significantly increased soil temperature. In contrast, SI raised the soil water and soil heat capacity, resulting in a slightly lower (no significant difference) soil temperature than the RF treatment. The results indicate that both SI and FM practices are capable of producing a high yield from spring maize on the Loess Plateau.

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