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EFFECTS OF DIFFERENT MULCHING MODELS ON SOIL TEMPERATURE, MOISTURE, AND YIELD OF MAIZE (*ZEA MAYS* L.) IN HILLY RED SOIL UPLAND IN SOUTHERN CHINA

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ABSTRACT

In the rain-fed areas of southern China, maize (Zea mays L.) is a main field crop, as it is well adapted to high temperatures and bright sunshine. However, low and variable rainfall and high evapotranspiration rates are common in water–limited environments during the growing season, and often mismatched rainfall events with the critical growth stages, making yield unstable. In this study, the field experiments were conducted from 2012 to 2013 in the Huarong County of China to determine the effects of cultivation with flat mulching on soil temperature, moisture, and yield of maize. Different flat treatments were mulched with plastic film (PE film) (PM), rice straw (RM), or left uncovered (CK). Compared with CK, the soil water storage and soil temperature in flat were significantly higher with the PM treatment during the whole growth stage of maize, evapotranspiration was significantly higher at 15-75 days after planting (DAP), but significantly lower at 75-105 DAP. The RM treatment had the second highest soil water storage and the lowest temperature, while evapotranspiration was significantly lower at 0-15 DAP but significantly higher at 75-105 DAP, when compared with CK. Compared with the control, the two–year mean biomass yields with PM and RM were significantly increased by 13.76% and 3.58%, respectively. The two-year mean maize yields with PM and RM were significantly increased by 26.20% and 9.50%, respectively, while water use efficiency increased by 21.58% and 7.20%, compared with CK. Soil moisture and temperature conditions were improved, while the maize yield was increased when flat were covered with plastic film. Therefore, this treatment may be considered the most efficient for maize production in the hilly red soil upland of southern China.

Key words: plastic film mulching; rice straw mulching; soil temperature; soil moisture; maize yield.

INTRODUCTION

The hilly red soil upland of southern China is characterized by a subtropical monsoonal humid climate, where limited water resources are available for agriculture irrigation. Much of the land in this region is hilly and rainfed. Precipitation is the major water resource for agriculture production; however, water scarcity and depletion of water resources in rainfed regions of southern China are the main constraints to crop production, leading to variable crop production, and low crop water use (Wang et al., 2011). The seasonal drought with heavy winds often occurs in between July and September. Therefore, saving water and increasing water use efficiency (*WUE*) to achieve high yields are key goals in these areas.

Maize (*Zea mays* L.) is the main crop grown in the spring season, especially in the Hunan provinces, where rainfed maize occupies more than 80% of the total maize production areas. Poor germination and slow growth in cool spring weather are major limiting factors to early production for premium market prices. Over the years, some innovative farmers have pioneered planting patterns to make full use of rainwater, which has shown great potential to reduce the impact of the severe water limitations and increase *WUE* in rainfed agricultural regions (Zhou et al., 2009). Plants growing under the plastic mulch are more uniform since they are protected against cold temperature and damage caused by insects, birds and rodents. Now it is widely used in crop production in arid, semiarid and sub-humid areas, especially where irrigation is not available and

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temperatures is low in spring (Zhang et al., 2005). Use of crop residue mulch has profound beneficial effects on soil properties, microclimates, and agronomic productivity (Zhou et al., 2009).

Applications of mulching for soil temperature, moisture, and yield during the spring season has been recommended as potential researchable options in the hilly red soil upland of southern China. However, to date very few field experiments have been conducted on plastic film and rice-straw (*Oryza sativa* L.) mulching. Therefore, the objectives of the present study were to: (1) investigate the effects of different flat mulching cultivation on soil temperature, water use, and yield of maize, to provide a scientific basis for improved rainwater harvesting cultivation; (2) single out an optimum flat mulching water harvesting pattern for maize cultivation in the hilly red soil upland of southern China.

MATERIAL AND METHODS

Site description

The experiments were conducted between 2012 and 2013 at the Huarong County experimental station of the Institute of Soil and Fertilizer Research, Hunan Academy of Agricultural Science, China (29°45′20″ N, 112°18′47″ E). The mean annual temperature was 17.6° C. The total annual sunshine was 1516.8 h and the frost-free period was 262 days. The annual mean precipitation was 1188.6 mm, with 50% falling between April and June, and with 20% between July and September. Rainfall during the experimental period was measured using an automatic weather station (WS-STD1, England) at the experimental site. The daily precipitation and daily mean temperature data in 2012 and 2013 during the maize-growing season are presented in Figure 1. The total precipitation for 2012, and 2013 was 1214.5, and 1227.2 mm, wile the precipitation during the maize-growing season was 599.1, and 611.2 mm, respectively.

The soil type is a Quaternary red soil derived from Quaternary red clay (clay loam). The characteristics of the surface soil (0-20 cm) are as follows: pH 5.70, soil organic matter (SOM) 2.43 g kg^{-1}, total nitrogen 1.36 g kg^{-1}, available N 85.1 mg kg^{-1}, total phosphorous 0.78 g kg^{-1}, available P 6.10 mg kg^{-1}, total potassium 12.7 g kg^{-1}, and available potassium 53.2 mg kg^{-1}. All these values were tested before the experiment was conducted in 2012.

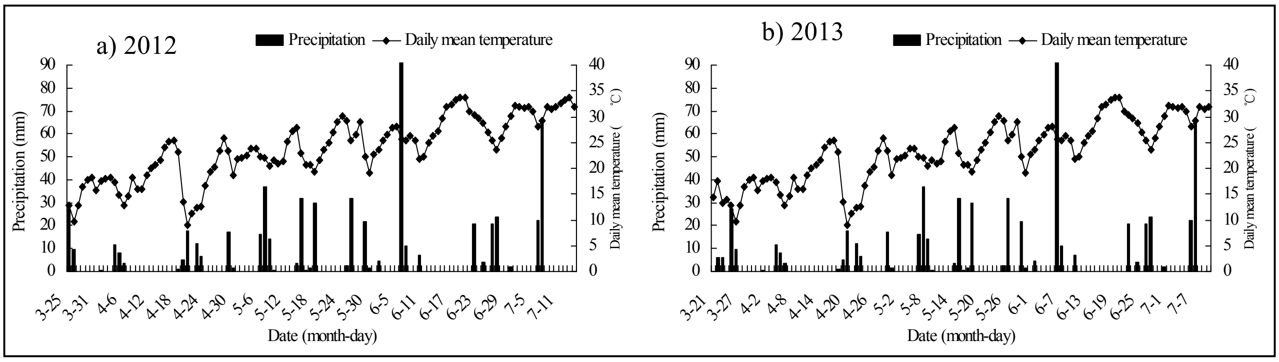


Figure 1. Daily precipitation and daily mean temperature at the study site during the experimental period

Experimental design and field management

The experiment had three treatments: plastic film mulching on flat plot (PM), rice straw mulching on flat plot (RM), or left uncovered (CK). A four row of maize was planted in flat plot (Figure 2). Each treatment had three replicates and each plot was 9.0 m long and 2.4 m wide, with a completely randomised arrangement.

Fifteen days before planting, flat plot were banked up with soil and a base fertilizer containing 112.5 kg N ha^{-1}, 112.5 kg P_2O_5 ha^{-1}, 112.5 kg K_2O ha^{-1}, was spread evenly over the flat and ploughed into the soil layer. Mulching was then applied to the soil surface. The soil surface of the PM were covered with plastic film (LLDPE/LDPE blend resin, the expected life span is 1-2 year; 250 cm wide and 0.008 mm thick, obtained from the Nong wangda Plastic Plant, Jiangsu, China), while the soil of the RM plots were covered with rice straw, respectively. Rice straw was cut into 15 cm long segments and uniformly applied at a rate of 7500 kg ha^{-1} in soil surface with the RM treatment.

Maize (Xiang kangyu 1) was sown at a rate of 49, 500 plants ha^{-1} on 25 March 2012, and 21 March 2013 using a hole-sowing (3 cm in diameter) machine. An additional 25.0 kg ha^{-1} N and 50.0 kg ha^{-1} N was applied as a top dressing in middle April and early May. Crops in the plots were harvested on 14 July 2012, and 10 July 2013. The soil configuration and mulches were retained in the same location after the current crop was harvested and reused in the following year. Weeds were controlled manually as required, during each crop growth season.

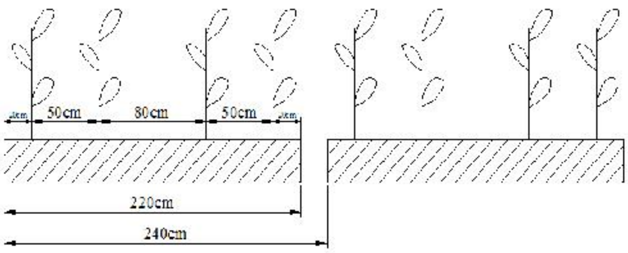


Figure 2 A schematic diagram of the field layout.

Sampling and measurement

Soil temperature

A set of mercur-in-lass geothermometers with bent stems (Hongxing Thermal Instruments, Wuqiang County, Hebei Province, China) were placed in the middle of a flat plot with every treatment plot, at soil depths of 5, 10, 15, 20, and 25 cm. In 2012 and 2013, the soil temperature was recorded at 9:00-10:00 h at the seedling stage (15 days after planting, DAP), the jointing stage (30 DAP), the tasseling stage (75 DAP), and the maturity stage (105 DAP) during the maize growth stages. The mean daily soil temperature was calculated as the mean of the three readings.

Soil moisture

Soil moisture was measured gravimetrically (g g^{-1}) to a depth of 0-20 cm intervals at the time of planting (0 DAP), the seedling stage (15 DAP), the jointing stage (30 DAP), the tasseling stage (75 DAP), and the maturity stage (105 DAP), in 2012-2013. Soil samples were collected randomly using a soil drill at three locations in the middle of the flat plot for each treatment. Soil moisture (soil cores, evapotranspiration) analysis was based on the methods of Chinese Academy of Sciences Nanjing Soil Research Institute, (1983). The water use efficiency (*WUE*) was calculated based on the methods of Hussain and Al-Jaloud (1995).

Crop biomass accumulation, yield and the yield components

The aboveground and underground biomass was measured at the seedling stage (15 DAP), the jointing stage (30 DAP), the tasseling stage (75 DAP), and the maturity stage (105 DAP) throughout the growing season in 2012-2013. Maize biomass accumulation, yield and the yield components was calculated based on the methods of Li et al. (2001).

Statistical analysis

The SAS package (SAS Institute Inc., North Carolina, USA) was used to conduct analysis of variance tests (ANOVA). Least significant differences (LSD) were used to detect differences between the means of treatments. Differences were considered statistically significant when $p \leq 0.05$ (McCullough and Wilson, 2002).

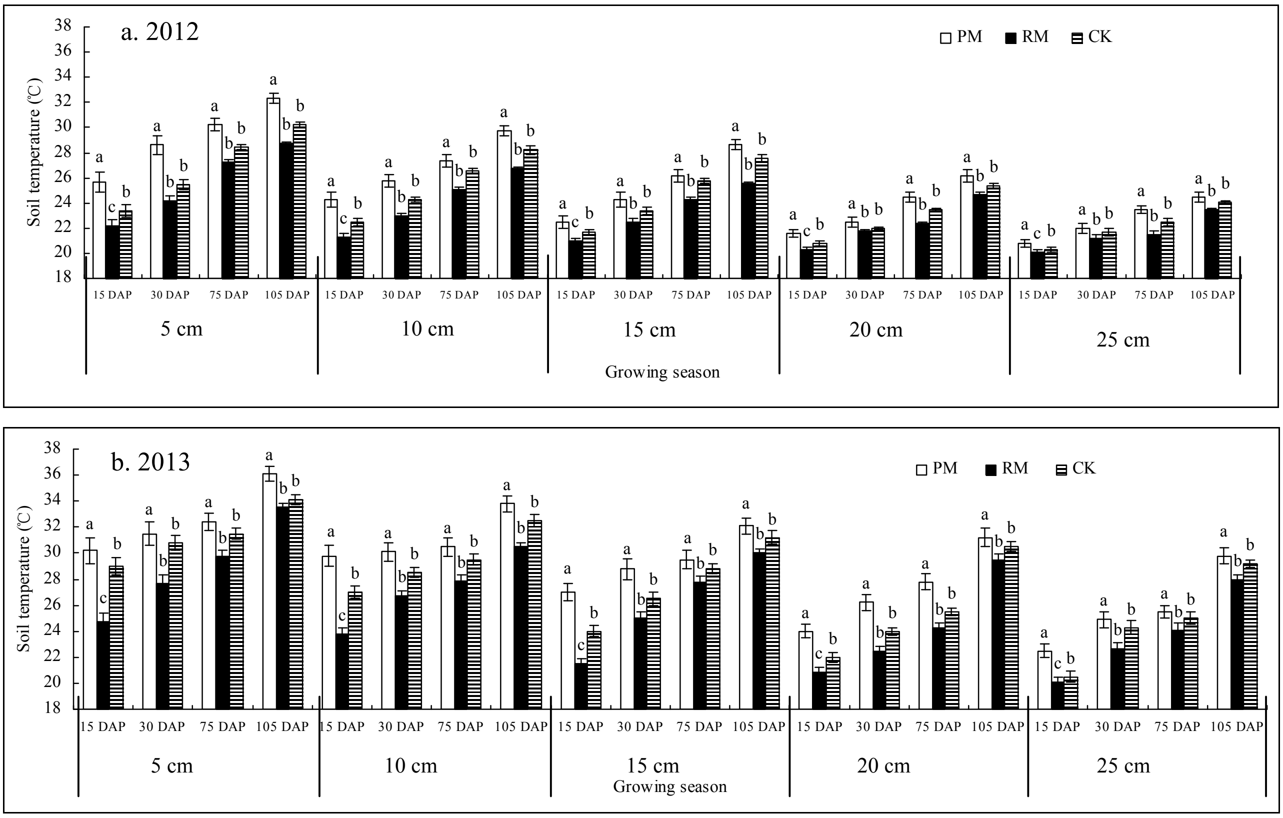
RESULTS AND DISCUSSION

Rainfall during the experimental period

The rainfall during the growing season for maize (*Zea mays* L.) (March – July) was 599.1 mm in 2012 and 611.2 mm in 2013 (Figure 1).

Soil temperature

The temporal variations in soil temperature with all the treatments during 2012-2013 are shown in Figure 3. The soil temperature was consistently highest with PM (20.8-32.2° C in 2012, 22.5-36.1° C in 2013) and lowest with RM (20.1-28.7° C in 2012, 20.1-33.5° C in 2013) in each soil layer. PM produced significantly higher soil temperatures than CK from planting to harvesting, at 5-25 cm soil depths. The soil temperature at 5-25 cm depths was significantly lower with RM than CK, up to (30 DAP). After 30 DAP, there were no differences in soil temperature between RM and CK.



PM – plastic film mulching on flat plot; RM – rice straw mulching on flat plot; CK – left uncovered.
*LSD, least significant difference at 5% level; NS, not significant.

*Figure 3***.** Effects of different treatments on soil temperature at different soil depths and times in 2012 and 2013

We found that the use of various mulching materials in flat had different effects on soil temperature, which agreed with the findings of Subrahmaniyan and Zhou (2008) where it was shown that soil temperature were highest under transparent film mulch, followed by degradable herbicidal film, and black polyethylene film mulches. In contrast, the soil temperature with straw mulch was lower than a non-mulched control in some growth stages of winter rapeseed (*Brassica napus* L.). The PM treatment increased the soil temperature, generating the highest soil temperatures observed in 2012 and 2013. This was because that polyethylene film mulch raised the soil temperature with the suppression of latent heat loss through evaporation (Subrahmaniyan and Zhou, 2008). The temporal variations in soil temperature with RM were similar to CK and the temperature values were always slightly lower with RM compared with CK, which was probably due to the lower light transmission of straw mulching (Lü et al., 2008). Several investigators 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 (Sarkar et al., 2007). Our field experiment demonstrated that soil temperatures were reduced under RM. This was because straw covering of the soil surface has a higher albedo and lower thermal conductivity than bare soil, which consequently reduces the solar energy reaching the soil thereby reducing the magnitude of temperature increases in warm conditions (Horton et al., 1996).

Soil water content

Soil water storage

Normal variations in the rainfall, temperature, soil evaporation, and crop water consumption led to obvious differences in soil water storage (0-200 cm) with the PM and RM treatments and the CK at various maize growth stages (Figure 4). PM and RM treatments had the highest soil water storage at main growth stages of maize. Compared with CK, the averaged soil water storage (0-200 cm) over the 2 years was significantly increased with PM and RM by 33.99 and 11.88 mm at 15 DAP, and by 45.77 and 22.34 mm at 30 DAP, respectively. From 75 to 105 DAP, the soil water storage decreased gradually with all the treatments. PM had the highest soil water storage at 75 and 105 DAP throughout the two–year experiment. Meanwhile, PM had the highest soil water storage during the whole growth stage, and the difference was significant. The RM treatment had slightly higher soil water storage compared with CK from 15 to 30 DAP, but the difference was not significant. From 75 to 105 DAP, differences in soil water storage were significant between RM and CK.

Plastic film mulch on flat can improve the soil moisture condition by collecting water from light rainfall, reducing unproductive evaporation, and promoting rainfall infiltration (Li et al., 2001). Compared with the CK, we found that the flat mulching treatments further inhibited soil evaporation from the flat where maize was planted and the soil water storage was increased by 33.99-47.54 mm during the early growth stage. The soil water storage with PM was always higher than that with RM and CK. There are two possible explanations for this difference, i.e. RM produced a lower soil temperature so plants grew slowly and consumed less water, or flat mulched with plastic film inhibited soil evaporation in the PM treatment but some soil moisture might have evaporated directly from the flat surface of the film thereby preventing the infiltration of light rain (Zhou et al., 2009).

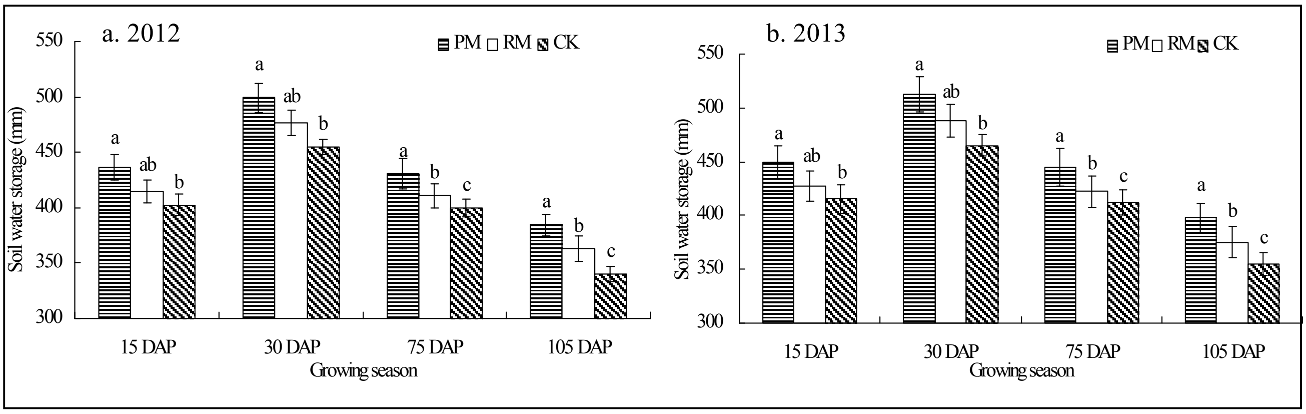


Figure 4. The soil water content dynamics in 0-200 cm layers with different treatments at four maize growing stages in period 2012-2013

Evapotranspiration

There were clear differences in evapotranspiration with different treatments during the maize growing season (Table 1). RM had the largest effect on reducing evaporation, and over the two-year period the mean evapotranspiration was decreased by 4.6 mm at 0-15 DAP, when compared with CK. Maize growth was more vigorous during the middle growth stages (15-75 DAP) (Table 2) when the greater consumption of water resulted in higher crop transpiration. The flat mulching treatments led to higher evapotranspiration than CK. Evapotranspiration at 15-30 DAP was significantly increased with the PM treatment, i.e., by 19.8 mm, when compared with CK. There were no significant differences in evapotranspiration among the RM and CK treatments at 15-75 DAP. In the later growth stage (75-105 DAP), the two-year mean evapotranspiration with PM decreased significantly by 7.2 mm, when compared with CK. However, the evapotranspiration with the RM treatment was increased significantly, by 9.2 mm. During the entire growing season, the two-year mean evapotranspiration with the PM and RM treatments was significantly increased by 23.6 and 13.2 mm compared with CK, respectively, whereas there were no differences between RM and CK.

Table 1. Field evapotranspiration (*ET*, mm) in 0-200 cm soil layers under different treatments during the maize growing season in period 2012-2013

Year	Treatments	0-15 DAP	＞15-30 DAP	＞30-75 DAP	＞75-105 DAP	0-105 DAP
2012	PM	138.4±3.9a	180.3±5.2a	203.2±5.9a	123.8±3.6b	645.7±18.6a
	RM	135.2±3.9b	160.3±4.6b	196.8±5.7ab	144.8±4.2a	637.1±18.4ab
	CK	139.1±4.0a	158.2±4.6b	192.4±5.6b	129.6±3.7b	619.3±17.9b
2013	PM	140.2±4.0a	183.0±5.3a	206.3±6.0a	124.8±3.9b	654.3±18.9a
	RM	135.8±3.9b	169.3±4.9ab	200.7±5.8ab	136.4±3.6a	642.2±18.5ab
	CK	141.0±4.1a	165.5±4.8b	193.8±5.6b	133.3±3.8a	633.6±18.3b

Values followed by the same uppercase letter in the same row are not significantly different according to Duncan's multiple range test ($p < 0.05$).

PM and RM could reduce the water evaporation from soil surface and reduce the total water consumption, but it is not obvious (Fan et al., 2002). In the current study, the treatments had different effects on water consumption during the maize growing season. With PM, the soil temperature was higher, crops grew faster, and evapotranspiration was significantly higher than CK at 15-75 DAP, but significantly lower than CK at 75-105 DAP. With RM, the soil temperature was lower, crops grew slowly and the growing season was extended, and evapotranspiration was significantly lower than other treatments at 0-15 DAP, but significantly higher than other treatments at 75-105 DAP.

Crop biomass accumulation

Table 2 shows that the aboveground and underground biomass was significantly affected by different treatments in all two-years. The biomass was significantly higher at each stages with PM and RM when compared with CK. The biomass was no different with PM compared with CK at 15 DAP, but it was higher than CK at 75 and 105 DAP, which indicated that maize growth was faster during the middle and later stages with this treatment. RM produced a slightly higher biomass than CK during the entire growing season, but the difference was not significant. Previous studies have shown that plastic film mulching can increase the soil temperature (Lü et al., 2008) and soil water content (Li et al., 2001), thereby promoting crop development (Duan et al., 2006). Our study also found that PM clearly increased the temperature, thereby promoting maize development. The RM treatment produced a significantly lower temperature than CK, which may be related to better soil water conditions with RM (Li et al., 2001). PM and RM treatments produced higher aboveground and underground growth at different growth stages compared with CK. Straw mulching reduced the soil temperature and plants grew slowly in the early stage of the growing season, which promoted maize growth in the middle and late stage (Chen et al., 2004). This was also reflected in variations in the water consumption during different periods. There were no significant difference in the maize growth progress and the aboveground and underground biomass between RM and CK, which can be attribute to the similar soil temperature (Figure 3) and water conditions (Figure 4).

Table 2. Aboveground and underground biomass (g plant^{-1}) accumulation of maize under different treatments in period 2012-2013

Year	Item	Treatments	15 DAP	30 DAP	75 DAP	105 DAP
2012	Dry weight of root	PM	4.03±1.12a	34.50±0.67a	23.02±0.28a	16.26±0.80a
		RM	3.80±0.41a	19.28±4.35ab	11.68±0.67b	10.36±2.54ab
		CK	2.86±0.57a	13.60±4.45b	9.69±0.60c	8.09±0.31b
	Dry weight of stem	PM	7.44±0.50a	33.82±0.18a	77.60±1.47a	60.22±1.47a
		RM	6.81±0.48a	30.88±1.51a	72.08±7.02ab	48.83±5.41ab
		CK	5.42±0.49a	29.02±2.18a	54.84±3.43b	41.94±4.42b
	Dry weight of leaves	PM	13.19±1.47a	28.92±0.66a	47.67±0.90a	36.93±1.04a
		RM	12.58±0.92a	23.34±0.86a	45.12±0.62a	30.40±0.91b
		CK	9.16±0.98a	21.99±1.25a	37.23±1.33b	28.09±0.83b
2013	Dry weight of root	PM	4.41±0.02a	31.17±4.17a	34.01±0.94a	21.87±0.21a
		RM	3.68±0.41a	18.3±0.06b	21.44±0.6b	15.02±0.67b
		CK	2.34±0.03b	17.58±4.45b	19.92±2.04b	10.61±1.37c
	Dry weight of stem	PM	7.25±0.01a	30.71±0.66a	110.86±1.34a	90.22±4.57a
		RM	6.8±0.16ab	27.15±3.64ab	73.75±4.27b	60.22±5.41b
		CK	5.76±0.62b	22.88±1.18b	62.61±0.39c	54.21±2.08b
	Dry weight of leaves	PM	14.06±1.97a	24.21±2.37a	47.38±0.79a	40.99±1.41a
		RM	12.58±0.46a	21.01±0.37a	43.13±1.54b	32.40±1.28b
		CK	10.49±0.65a	19.75±0.21a	39.68±1.21b	29.43±0.46b

Maize yield and water use efficiency

In 2012 and 2013, no significant ($p>0.05$) differences between PM, RM and CK were found in ear height, ear length and ear diameter. The kernel number per row, grain number per ear, and 100-kernel weight of maize in the PM was higher than that of the other treatments. The ranking from high to low for kernel number per row, 100-kernel weight and grain number per ear were always PM, RM and CK (Table 3).

Table 3. Yield and the yield components of maize with different treatments in period 2012-2013

Year	Treatments	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	Bare top of maize ear (cm)	Row number	Kernel number (row^{-1})	Grains number (spike^{-1})	100-kernel weight (g)
2012	PM	92.20±2.14a	20.80±0.95a	6.33±0.15a	2.50±0.21b	16.00±0.40ab	40.47±2.88a	648.97±57.98a	28.60±0.21a
	RM	93.33±2.89a	20.47±0.50a	6.03±0.64a	3.13±0.39ab	16.40±0.40a	33.67±1.77b	551.39±24.12ab	28.20±0.23ab
	CK	100.2±6.16a	19.97±0.50a	5.00±0.31a	3.77±0.21a	15.33±0.31b	32.07±0.12b	480.97±9.37b	27.60±0.31b
2013	PM	82.21±2.80a	20.7±1.07a	5.57±0.21a	1.47±0.50a	16.67±0.61a	39.87±0.48a	663.27±24.9a	27.20±0.59a
	RM	86.53±1.21a	20.47±0.50a	4.70±0.50a	1.53±0.15a	16.40±0.38a	37.67±1.67ab	617.79±26.17ab	26.87±0.50ab
	CK	90.01±3.70a	19.53±0.76a	4.60±0.12a	2.13±0.52a	16.47±0.37a	33.87±1.72b	557.31±15.63b	26.40±0.66b

The two-year mean maize yields for each of the treatments were ranked as follows: PM>RM>CK (Table 4). Compared with CK, the mean maize yields with PM and RM were increased by 1925.12 kg ha^{-1} (26.20%), 692.54 kg ha^{-1} (9.50%), respectively. The biomass yields were ranked as follows: PM>RM>CK. Compared with CK, the mean biomass yields with PM and RM were significantly increased by 21 67.29 kg ha^{-1} (13.76%), 564.85 kg ha^{-1} (3.58%), respectively. During the two years of the study, the harvest index (*HI*) was similar for all the treatments, ranging from 0.44 and 0.53. The mean *WUE* with PM and RM was significantly increased by 2.54 kg ha^{-1} mm^{-1} (21.58%), 0.84 kg ha^{-1} mm^{-1} (7.20%), compared with CK, respectively. Our findings indicated that cultivation with mulching further improved the soil moisture and temperature status, and it increased the maize yield and *WUE* by 9.50-26.20% and 7.20-21.58%, respectively. Straw mulching tends to lower the soil surface temperature, which can lead to a reduction in the yield (Gao and Li, 2005). We found that the soil temperature with RM was lower compared with CK, but it had no negative impact on the increased yield and *WUE*. This was probably because the soil water retention was better with RM, and the increased soil moisture compensated for the effects of low temperature on maize growth to some extent.

Table 4. Effects of different treatments on grain yield and harvest index (*HI*), and water use efficiency (*WUE*) of maize in period 2012-2013

Year	Treatments	Grain yield (kg ha^{-1})	Biomass yield (kg ha^{-1})	*HI*	*ET* (mm)	*WUE* (kg ha^{-1} mm^{-1})
2012	PM	9682.50±724.41a	18333.73±529.25a	0.53±0.02a	645.7±18.6a	15.00±0.37a
	RM	8176.50±193.22ab	16654.30±480.77ab	0.49±0.01a	637.1±18.4ab	12.83±0.27b
	CK	7131.03±615.21b	16032.50±462.82b	0.44±0.01b	619.3±17.9b	11.51±0.20c
2013	PM	9110.27±424.39a	17479.73±504.60a	0.52±0.02a	654.3±18.9a	13.92±0.34a
	RM	8151.10±330.38ab	15954.28±460.56ab	0.51±0.01a	642.2±18.5ab	12.69±0.26b
	CK	7811.50±258.81b	15446.88±445.91b	0.51±0.01a	633.6±18.3b	12.33±0.22c

CONCLUSIONS

Synchronizing maize growth with seasonal soil water supply is often the first and foremost step in rainfed agricultural production. Our study showed that the flat with straw mulching was an effective, simple, and feasible measure to conserve soil moisture by reducing rainfall water loss and soil surface evaporation. Compared with the conventional farmers' practice of flat planting, mulching flat with plastic film can inhibit soil evaporation, improve the soil moisture availability in the flat, regulating the soil temperature, thereby significantly increasing the crop yield and the water use efficiency. In the long term, treatment with plastic–covered flat (PM) will bring an increase in the yield of maize. Therefore, this treatment should be popularised and applied as an efficient cultivation pattern for maize production in the hilly red soil upland of southern China.

Acknowledgements

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