Journal of Pure and Applied Agriculture (2022) 7(4): 36-45
ISSN (Print) 2617-8672, ISSN (Online) 2617-8680
http://jpaa.aiou.edu.pk/

Effects of plastic film mulching on soil moisture dynamics, water loss and water use efficiency of grain maize

Hyder Ali Khaskheli[1], Rajesh Kumar Soothar[1, 2]*, Yaosheng Wang[2], Muhammad Ali Kapri[1], Mashooque Ali Talpur[1], Shakeel Ahmed Soomro[1] and Abdul Latif Qureshi[3]

[1]Faculty of Agricultural Engineering, Sindh Agriculture University, Tandojam, Pakistan
[2]Chinese Academy of Agricultural Sciences, Beijing, China
[3]US-PCAS-W, Mehran University of Engineering and Technology, Jamshoro, Pakistan

***Corresponding author: Rajesh Kumar Soothar (rk_engr195@yahoo.com)

Abstract

The field trials were carried out at Malir farm, Sindh Agriculture University Tandojam, Pakistan during cropping season 2020 and 21 to examine the effects of various mulching strategies on evaporation rate, grain yield, economic return, and water productivity. The experiment consisted of five treatments i.e., (1) control treatment (conventional basin cultivation without mulch CK), (2) plastic mulching only on ridges under furrow irrigation cultivation (RPM), (3) partial plastic film mulching (PPM), (4) full plastic film mulching (FPM) and (5) residual straw mulch (RSM). The results revealed that plastic mulch significantly increased the soil moisture content up to 24.18 % under FPM, followed by 22.43%, 21.21%, 21.08% and 17.78% under PPM, RPM, RSM and CK treatments, respectively. The evaporation rate was significantly different among the treatments. Moreover, the maximum yield and water use efficiency was found in the PPM as compared to control treatment (CK). The average irrigation water use efficiency increased by 14, 45, 43 and 40 under RPM, PPM, FPM and RSM, respectively, compared to CB treatment. The income was also higher by 210419 PKR ha^{-1} as compared to CK treatment. The results concluded that the PPM is an effective approach that enhances soil moisture, reduces soil evaporation, and increases grain maize yield and water productivity of maize crop.

Keywords: Economic benefit, Evaporation, Grain yield, Mulching techniques, Plant growth, Root development

To cite this article: Khaskheli, H. A., Soothar, R. K., Wang, Y., Kapri, M. A., Talpur, M. A., Soomro, S. A., & Qureshi, A. L. (2022). Effects of plastic film mulching on soil moisture dynamics, water loss and water use efficiency of grain maize. *Journal of Pure and Applied Agriculture*, *7*(4), 36-45.

Introduction

Worldwide, plastic film mulching is becoming the most important agriculture technique that increases the crop yield with small consumption of water (Tiwari et al., 2003; Lobell and Field, 2007; Kasirajan and Ngouajio, 2013). In the recent years, many researchers have carried out field experiments to find substitutes for plastic mulching, including techniques with PF and crop straw, but there weren't any significant impacts observed (Ren et al., 2017; Li et al., 2016; Moreno, et al., 2016). Mulch is a prophylactic layer of natural or inorganic material applied to the topsoil that reduces moisture loss from the soil, prevents evaporation from sunlight, drying winds, controls weed growth, improves soil condition. It also provides shelter for earthworms and natural winds enemies found in the soil and reduces soil compaction from heavy rainfall (Ramakrishna et al., 2006). Natural mulches, for example, straw, manure, hay, grass, or leaf matter can give various advantages to natural farms. They are good for controlling weed growth, soil moisture and soil surface temperature. They improve the overall quality of the soil by increasing the overall soil moisture, soil porosity and water retention. Further mulching improves soil vitality and increases nutrient availability (Kumar et al., 2003).

Mulching is a water management practice that can be used to conserve soil moisture content by preventing surface evaporation, regulating soil surface temperatures, improving overall soil quality (Patil et al., 2013). Mulching could be very beneficial in protecting soil water content in the dry land areas after a decrease in the evaporation rate (Yang et al., 2015). However, it plays a vital role to repair soil moisture, reduce soil evaporation, adjust soil temperature, keep soil fitness, and enhances WUE and agricultural productions (Zribi et al., 2015; Kader et al., 2017). Mulching the soil can decrease the evaporation, change the temperature of the soil and thus affects the yield as one of the most important traditional methods (Wei et al., 2015). Many research studies have been conducted to determine the evaporation loss of water from the soil surface and the transpiration of plants, but still a lot of room is available.

Maize grown with the plastic film mulching can increase the growth of crop, root water, nutrient intake, water efficiency and yield of maize (Gan et al., 2013 and Jia et al., 2018) because significantly improves water storage in the upper layer of soil and heat environment, mostly at the beginning of the growth period (Chandio et al., 2013; Gong et al., 2015; Wang et al., 2015; Gao et al., 2017). Adoption of half mulched furrows and ridges with plastic mulching beds have been generated and widely used to grow field crops in the arid to semi-arid climatic condition in China (Li et al., 2001; Zhang et al., 2019). Plastic mulching can collect small sediment (5 mm in diameter) into furrows, which improves soil moisture and promotes the growth of different crops (Qin et al., 2014) increasing. Entire field covered with plastic film mulch in smooth planting increases utilization of soil water during the maize planting period (Wu et al., 2017a). Partial plastic film mulching (PPM) under smooth planting also resulted in a maximum grain yield as compared to the control treatment (Gao et al., 2014). However, the wheat straw mulch has been a successful growing practice that can decrease soil surface water losses. It protects the soil surface from rain drops, increases soil aggregation; promotes soil fertility (Blance-Canqu and Lal, 2009; Sharma et al., 2011) and conserves freshwater resources around 35% during maize growing season. Recently, developing nations have adopted mulching techniques to enhance agricultural production. Previous research has shown that mulching is an important cultural practice that can reduce the amount of work required in gardening, helps in growing healthier plants such as vegetables (Kader et al., 2017; Zribi et al., 2015). The effect of non-living mulching such as plastic film on yield, plant growth, biomass and WUE as compared to plants grown without mulching, produced 15-26% higher grain yields (Xu et al., 2015). The increase in crop yields was attributed to significantly improved dry matter accumulation before peeling as compared to the no mulching. The mulch is spread over the soil surface to reduce the evaporation rate and increase the water holding capacity of the soil. Runoff and sediment transport are complex hydrological phenomena. Previous soil moisture conditions, topsoil and rainfall rates, and over irrigation play a most important role in the runoff process and, as a consequence, in water and soil loss (Roomkens et al., 2001). In addition, it also improves the soil environment for plants and reduces the risk of erosion and water runoff (Dahiya et al., 2007). The practices of plastic, gravel and straw mulching can be used to prevent the water evaporation from the surface of the soil in the atmosphere and improve the plant transpiration rate (Li et al., 2013a; Zhang et al., 2020). Water scarcity is a major obstacle to crop production and growth in the arid and semi-arid regions and trapped of water in the upper soil is simply off track through the evaporation of surface.

Material and Methods

Study area

This research was conducted at the experimental site of Malir farm, Sindh Agriculture University, Tandojam using various plastic film mulch practices to examine their effects on evaporation rate, grain yield, economic return, and water productivity. The experimental site lies in an arid to semi-arid climatic zone. The 30 years data on average rainfall, ETo, humidity and temperature at the site are presented in Fig. 1.

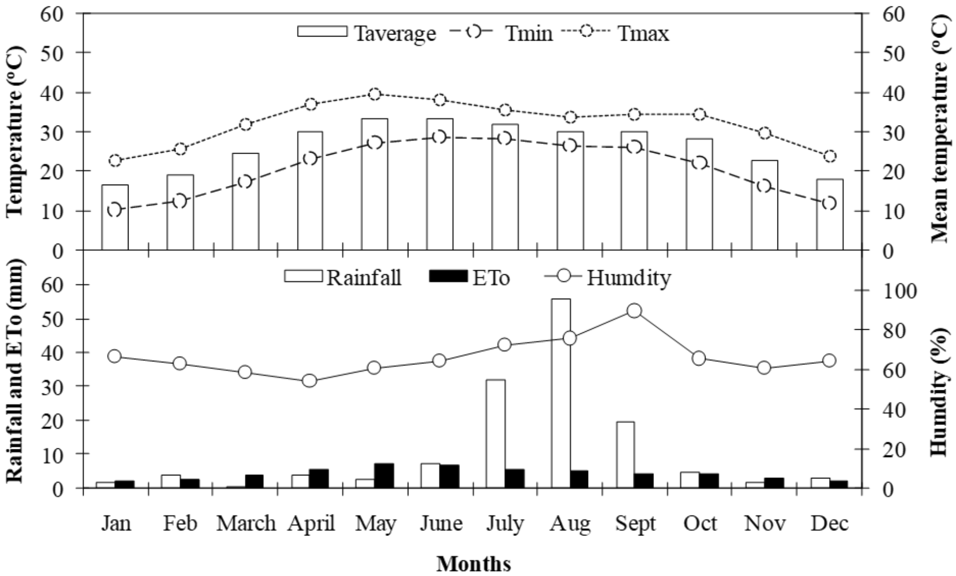

Fig. 1 Weather condition at Tandojam during January to December (thirty years average data) monthly air Temp °C (average, min., and max.) and rainfall (mm), ET_o (mm) and humidity

Experimental setup

This study was based on randomized complete block design that include five treatments i.e., CK = Control treatment (conventional basin cultivation without mulch), RPM = Plastic film mulching only on ridges under furrow irrigation cultivation, PPM = Partial plastic mulching, FPM = full plastic film cover (mulching), and RSM = mulch with wheat residual straw with 3 replicates. The maize seeds were sown at plant to plant spacing of (35 cm and row to row distance 75 cm as practices adopted by local farmers. All recommended planting practices, fertilizers doses and plant protection methods (MINFAL, 2005) were applied to raise a very healthy maize crop as followed by MINFAL (2005).

Field conditions

Before the experiment, samples were collected from each plot at the depth of 0-20, 20-40, 40-60, 60-80, 80-100, 100-120, 120-140 and 140-160 cm. The collected soil samples were analyzed for the SMC on dry basis, soil dry bulk density, soil texture, field capacity and soil porosity in the Department's laboratory. The results on these basic properties are shown in Table 1.

Table 1 Initial soil properties of experimental site

Soil property	Soil layer (cm)	Values	Soil property	Soil layer (cm)	Values
Soil texture	0-20	Silty clay loam	Soil moisture content (%)	0-20	18.84
	20-40	Silty clay loam		20-40	19.67
	40-60	Clay loam		40-60	20.07
	60-80	Silty clay loam		60-80	20.81
	80-100	Silty clay		80-100	22.31
	100-120	Silty clay		100-120	23.23
	120-140	Clay loam		120-140	24.18
	140-160	Silty clay loam		140-160	26.18
Bulk density	0-160	1.45g cm^{-3}	Water holding capacity	0-160	288 mm m^{-1}
$EC_{1:5}$	0-160	0.23	Soil pH	0-160	7.38

Irrigation plan

Irrigation plan depends on soil moisture depletion; each irrigation application was done at 50% soil moisture depletion according to the on-farm water management (MINFAL 2005). During this study, depth and frequency of irrigation water was calculated by CROPWAT model. CROPWAT version 8.0 software runs with last 30 years average climatic data. The required depth of irrigation water was supplied to field by standard procedure (Soothar et al., 2019; Vistro et al., 2021). The total volume of irrigation water applied, water consumed in each treatment and rainfall data are shown in Table 2.

Table 2 Average water applied, soil moisture deficit, rainwater and total water consumed over the base period

Treatment	Irrigation (mm)	Soil moisture deficit (mm m-^{1})	Rainfall (mm)	Water consumed	
				(mm)	($m^3 ha^{-1}$)
CK	522	39.48	12	573.486	5734.863
RPM		18.03		552.040	5520.396
PPM		2.87		536.872	5368.716
FPM		-14.17		519.826	5198.263
RSM		-1.31		532.686	5326.863

Data analysis and measurement

Soil moisture contents (SMCs)

To determine SMCs, the compost soil samples were collected at the 0-20, 20-40, 40-60, 60-80 and 80-100 cm soil depths under various mulching and control treatments. The SMCs were measured regularly at the different plant growth stages, and SMCs was calculated by following formula.

$$\theta_d = \frac{W_w - W_d}{W_w} x100$$

Where, Θ_d = Soil moisture (%), W_w = Weight of wet soil (g) and W_d = Weight of dry soil (g)

Measurement of soil evaporation with mini-lysimeter

Mini-lysimeter (ML) was made by PVC pipes. ML was used to monitor soil evaporation rate on each irrigation event using a weighting method. In RPM and PPM experimental plots, soil evaporation rate was measured under mulch and non-mulch surface. Similarly, in CK and RSM treatments, assuming the uniform soil evaporation losses, only one location was selected for measurement.

Plant growth, yield and irrigation water productivity

Plant height and leaf area were determined regularly on different days after sowing. At physiological ripeness, all selected cobs were harvested, and the yield of corn grains was determined. Similarly, irrigation water productivity of grain maize was calculated by equation given by Soothar et al. (2019).

Root dry biomass

To determine the dry root biomass per plant root of the maize plant, the soil samples were collected under different soil monolith methods at four different crop growth stages. The soil monolith surface size of 25-15 cm was selected to excavate down to three different soil depths (i.e., 30, 40 and 60 cm) and at three different growth stages. While at harvesting stage soil samples were excavated down at 20 cm interval of three soil depths using soil monolith to determine root distribution in rooting zone of each soil monolith. Further, procedure in this study was followed as stated by Thider et al. (2020).

Economic benefits and statistical analysis

The economic benefits were analyzed under various mulching treatments. All costs such as labor charge, cultural practices, seed, fertilizer etc were included for different treatments. The obtained data was determined statistically using ANOVA techniques following the CRB design with three replications. The corrections were developed using Excel spreadsheet using SPSS package (SPSS version 20.0, USA).

Results and Discussion

Soil moisture content pattern at various depths across the rooting zones

The soil moisture contents (SMCs) were measured in the month of February 24, March 03, 14 and 26, April 05, 2021, and harvesting stage of maize crop at the soil depths 0-20, 20-40, 40-60, 60-80 and 80-100 cm in each replicated plot under different treatments during experimental period (Fig. 2). However, the highest average SMCs (24.1 %) was observed in the FPM treatment mainly in the uppermost soil layers at depth 0-60 cm, followed by 22.4, 21.3 and 21% in the PPM, RPM and RSM treatment, respectively. While the lowest average SMCs (17.7 %) was recorded in the CK treatment.

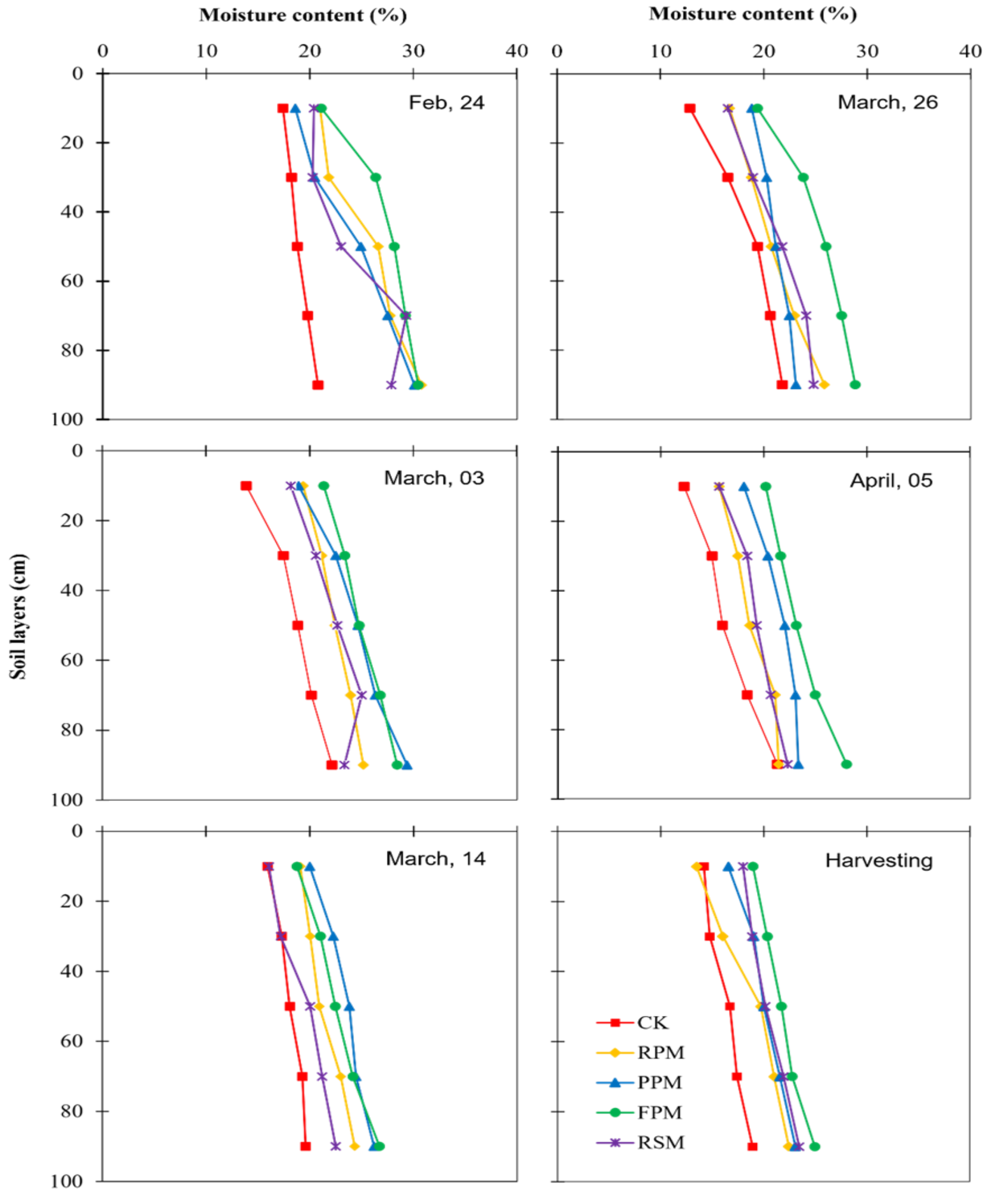

Fig. 2 Moisture content throughout the growing season, there was a temporal change in SMCs at soil depth (0-100 cm) under various mulching techniques. The values are means ± SE (n=3)

Measurement of soil evaporation with min-lysimeter

During the experiment, soil evaporation losses were significantly different among the treatments (Table 3). Cumulative evaporation rate of experimental plot sown under RPM, PPM, RSM and CK treatments were 56.1, 66.1, 73.0 and 94.8 mm, respectively in the base period. RPM was the lowest evaporation, and then followed by PPM > RSM > CK showed the lowest. When compared for the entire growing season, the lowest soil surface evaporation loss was observed at 0-65 DAS, whereas the highest evaporation rate was observed at 65-85 DAS

.

Table 3 Soil evaporation rate (mm) at the 0-64, 65-87 and 88-140 day after sowing (DAS) under different mulching treatments. Different letter shows the significantly differences according to Duncan's multiple range test at p<0.05

Treatment	Soil evaporation (mm)			
	DAS			
	0-65	65-87	88-140	Total
MD[1]	20	15	10	45
CK	30.9±1.9[a]	31.6±1.2[a]	32.3±0.4[a]	94.8±1.1[a]
RPM	15.4±0.4[c]	22.3±1.2[b]	18.4±0.4[d]	56.1±0.2[d]
PPM	18.2±0.9b[c]	26.3±0.1[b]	21.5±0.3[c]	66.1±0.3[c]
FPM	-	-	-	-
RSM	22.8±2.3[b]	24.9±2.0[b]	25.3±0.6[b]	73.0±0.3[b]
Total	87.3	105.1	97.5	-

[1] MD, the assess days for soil surface evaporation loss at different growth stages of grain maize crop

Plant height and leaf area plant^{-1}

The plant height of grain maize plant was measured on 15, 30, 45, 75, 90, 110 and 140 days after sowing (DAS). The average plant height across the mulching practices was significantly different between treatments throughout the growing season (Fig. 3). The highest plant height (290 cm) was produced in the PPM treatment on 140 DAS, followed by 282 cm, 265 cm, and 249.3 cm under FPM, RSM, and RPM treatments, respectively, while lowest plant height (242.6 cm) was recorded under CK treatment. However, the different mulching practices significantly increased the plant height up to 19.5 % in PPM and 16.2 % in FPM, as compared to CK throughout the growing season.

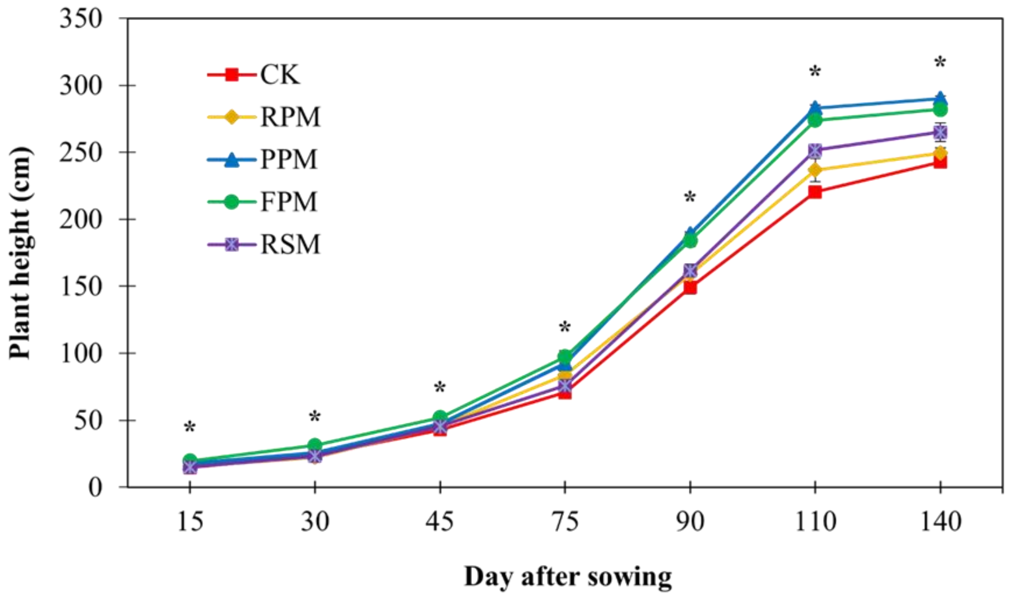

Fig. 3 Plant height of grain maize as influenced by different mulching strategies throughout the growing season. CK, RPM, PPM, FPM and RSM indicate the treatments. The values are means ± SE (n=3). The small bars are standard error. * Shows the significant differences under different mulching treatments according to Duncan's multiple range test p≤0.05 level

Root dry biomass

The maize root dry biomass was measured from different mulching treatments at 45, 75, and 110 DAS, whereas at harvesting stage (140 DAS) the root dry biomass was measured under various soil depths (0-20, 20-40, 40-60 cm (Table 4). Result clearly indicates that the maximum root dry biomass (0.3 g plant^{-1}) and (5.3 g plant^{-1}) were noticed on the 45 and 75 DAS under RPM treatment, respectively, while on 110 DAS, the maximum dry root biomass (15.3 g plant^{-1}) was obtained under the FPM treatment. While the lowest dry root biomass (7.8 g plant^{-1}) was found in the RSM on 110 DAS. Although at harvesting stage (140 DAS), the maximum root dry biomass (10.5 g plant^{-1}) and (3.9 g plant^{-1}) were observed at soil depth (0-20, and 20-40 cm) under FPM treatment, respectively, whereas lowest root dry biomass (4.5 g plant^{-1}), (2.2 g plant^{-1}) and (1.1g plant^{-1}) were found at soil depth (0-20, 20-40 and 40-60 cm), respectively, under CK treatment. However, results indicated that the plastic and residue straw mulching significantly increased the root dry biomass as compared to CK treatment.

Table 4 Average root dry biomass distribution as influenced by various mulching strategies throughout the growing season. Different letters show the significant differences under different mulching treatments according to Duncan's multiple range test p≤0.05 level

Treatment	45 DAS	75 DAS	110 DAS	140 DAS		
				0-20 cm	20-40 cm	40-60 cm
CK	0.1±0.02^{d}	2.2±0.28^{c}	11.6±2.92^{a}	4.5±0.33^{b}	2.2±0.07^{b}	1.1±0.06^{d}
RPM	0.3±0.01^{a}	5.3±0.14^{a}	12.9±0.43^{a}	5.9±0.02^{b}	2.5±0.29^{b}	2.3±0.09^{a}
PPM	0.1±0.01^{bc}	3.4±0.23^{b}	13.5±3.46^{a}	7.7±1.65^{ab}	2.1±0.06^{b}	1.9±0.02^{bc}
FPM	0.2±0.03^{b}	4.7±0.06^{a}	15.3±1.88^{a}	10.5±0.36^{a}	3.9±0.91^{a}	1.8±0.17^{c}
RSM	0.1±0.01^{cd}	3.1±0.40^{b}	7.8±0.17^{a}	10.0±1.24^{a}	2.5±0.01^{b}	2.2±0.13^{ab}

The data represent means ± SE.

Grain yield of maize, water productivity and economic benefits

The experimental results for grain yield and IWUE of maize crop as affected by different treatments are presented in Table 5 and Fig. 4. The results clearly indicate that higher grain yield (8459 kg ha^{-1}) was observed at PPM treatment, followed by 8098, 7717 and 5393 kg ha^{-1} in the FPM, RSM and RPM treatment, respectively, while minimum grain yield (4633 kg ha^{-1}) was noted under CK treatment. Similarly, the IWUE was the highest (1.62 kg m^{-3}) at the PPM treatment; intermediate 1.55 kg m^{-3} under FPM, 1.48 kg m^{-3} under RSM and 1.0 kg m^{-3} under RPM treatments; and the lowest 0.89 kg m^{-3} under CK treatment (Fig. 4). The mean IWUE increased by 14%, 45%, 43% and 40% under RPM, PPM, FPM and RSM treatments, respectively, as compared to CK treatment. Total input cost under different treatments plots during the experimental period is presented in Table 5. The output results or values were ranked as follows: PPM > FPM > RSM > RPM > CK treatment and similar ranks was found under grain yield. The net benefits and input ratio were the highest under PPM, respectively, as compared to CK treatment. The output value of the RSM treatment was also higher than the CK treatment.

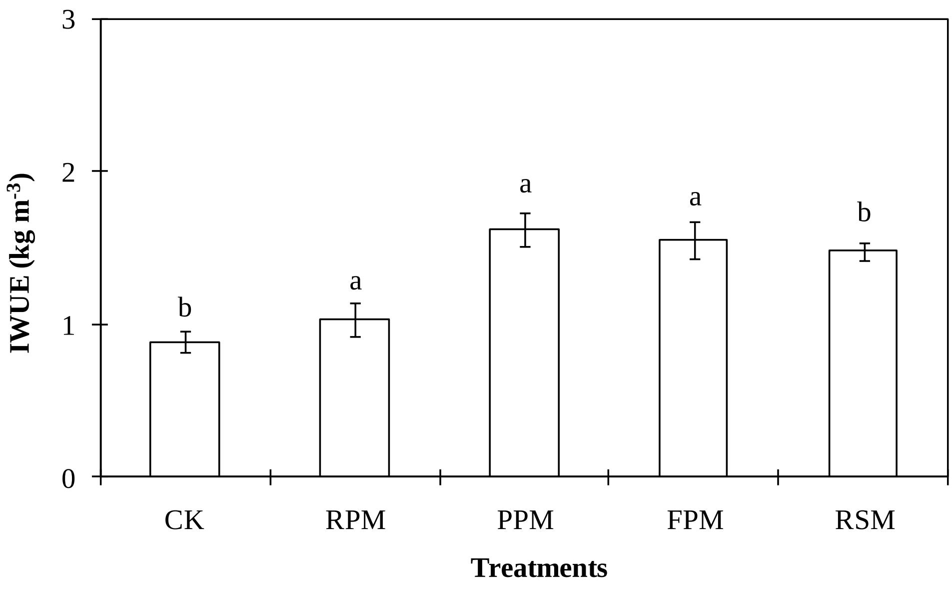

Fig. 4 Irrigation water use efficiency (IWUE) as influenced by different mulching strategies throughout the growing season. CK, RPM, PPM, FPM and RSM indicate the treatments. The values are means ± SE (n=3). The small bars are standard error.

Table 5 Grain yield and economic benefits in Pakistan rupee (Rs per hectare) of grain maize yield under all the treatments

Treatments	Grain yield (kg ha^{-1})	Labor costs	Mulching cost	Tractor cost (PKR ha^{-1})	Seed and fertilizer cost	Total input value	Total output value	Output/input	Net income	Net income difference from CK
CK	4633	6600	0		53422	73222	254819	3.480	181597	0
RPM	5393	7800	40000		53422	114422	296609	2.592	182187	590
PPM	8459	7800	40000	13200	53422	114422	465238	4.066	350816	169219
FPM	8098	7800	80000		53422	154422	445415	2.885	290993	109396
RSM	7717	7200	0		53422	73822	424451	5.749	350629	169032

Note: 600 Rupees labor charges per day; cost of plastic mulching was 250 Rs Kg^{-1}. The above rates were according to the local markets.

The lack of water in the soil is a major factor in the growth of the plant and production, especially in the arid regions and semi-arid regions. The capillary water in the watery zone of the soil is simply lost due to the soil evaporation (Li et al., 2013b). Likewise plastic mulching and straw mulching prevents the water surface from evaporating into the climate and increases the plant transpiration rate (Zhang et al., 2020). In our experiment SMCs were significantly higher at sowing time under plastic and straw mulched treatments as compared to the CB treatment (Fig. 2). Moreover, the results showed that the highest SMCs were observed in the plastic and straw mulching from sowing to harvesting time while the performance of straw mulching was lower than that of plastic mulching during the period of this study. It was generally because plastic mulching kept topsoil-water moisture content relatively stable by in habiting during the growing season. According to (Thider et al. 2020), the mulching practices significantly affected the soil moisture content as followed by non-mulch treatment. Mulching significantly retained SMC in the topsoil (Li et al., 1999; Thiam et al., 2003; Zhou et al., 2009; Wang et al., 2011; Li et al., 2013b). The straw mulch treatment also retained soil moisture in a similar fashion as of FPM treatment, but maize yield was not the highest as compared to the plastic film mulching treatment because of less efficient water use. This result is attributed to soil moisture loss due to control treatments due to strong evaporation from the soil surface under direct sunlight and dry atmosphere at different stages of crop growth during the growing season, while different mulching treatments meant a more efficient approach reducing irrigation depth, evaporation losses and maintaining soil temperature to counteract the scarcity of available soil water and improve water use efficiency.

In this study, evaporated water losses were significantly affected by different treatments at different stages of corn growth (Table 3). Results showed that the average values of evaporation rate throughout study period in the different treatments, CK treatment gave the highest value followed by RSM. According to Li et al., 2013a; Li et al., 2013b and Thider et al., 2020, the evaporation losses are a severe limitation in flat dry lands and are similar to runoff of the total irrigation water received in non-mulched areas. According to Wu et al. (2017b), when fully treated with plastic mulching, evaporation usually occurred only from the gaps between the plants and the plastic sheeting, as well as from the zone of destruction by weeds, wind, farmer activities and the seed pit. The evaporation rate of RSM was also significantly minimum as compared to the CK treatment as same results have been reported by Phillips (1983); Unger at al. (2012); Li et al. (2013b). Moreover, plastic film mulching increases soil temperature particularly in top layer (Zhao et al., 2012). Many experimental observations have shown that the ridge-furrow water conservation planting method leads to significant water conservation and decrease evaporation rate by mulching on ridge furrow (Ramakrishna et al, 2006; Gan et al., 2013).

Pinjiri (2007) reported that the plant height and dry matter accumulation per plant of maize crop significantly improves in the polythene film mulch treatment over the control treated plant (Figure 3). Our results in agreement with Uwah and Iwo (2011); Zerga et al. (2017) and Priya et al. (2018). Our observation is also in line with Wajid (1990) and Awal and Khan (2000), they reported that the plant growth parameters were significantly affected by the irrigation levels and different mulching materials. Similarly, the grain yield was significantly affected among the different treatments (Fig. 4). Our findings agreed with Wang et al. (2015) and Mebrahtu et al. (2019), they reported that the s plastic film mulch promoted plant growth more than RSM and CK treatments from the early growth stages. Different studies examined that suitable moisture in the root zone leads to increase above plant biomass and grain yield of maize (Li et al., 2013b). Thus, increased SMCs contributed to the root development system (Ramakrishna et al., 2006; Gan et al., 2013; Mo et al., 2017).

Irrigation water productivity (IWP) of maize crop was significantly affected among the different treatments (Fig. 4). According to Wang et al. (2011), they reported that the plastic film mulching with various irrigation practices significantly improved the WUE upto 22.43% in the furrow irrigated raised bed sowing with plastic mulching, 10.97% in the flood irrigated flat sowing with plastic mulching and 4.60% when sowing ridges with furrow irrigation using plastic mulching. Our results are also consistent with those of Sajid et al., (2015). Abbas et al. (2005), found the highest WUE of grain maize under mulching treatments in Pakistan, this was mainly because mulching increased WUE. Moreover, plastic film mulching significantly increased WUE and flat cultivation under plastic film mulching that enhances the soil moisture content by controlling soil evaporation rate (Li et al., 2010). Xu et al. (2015) observed that the WUE of maize crop in the plastic film mulching treatment increased by 16% as compared to the control treated plant, although the overall evapotranspiration was similar between the two treatments.

Conclusion

On the average, the average SMC measured at distinct soil layers were significantly high under the plastic and straw mulching treatments as compared to control treatment (CK), especially in the FPM treatment in upper soil layer (0-60 cm). The lowest evaporation rate was recorded under RPM, and it followed the pattern as PPM > RSM > CK. Both plastic and straw mulching treatments significantly increased the grain yield of grain maize. Both plastic and straw mulching treatments significantly increased the IWUE of grain maize as compared to CK treatment. Net income and output/input ratio was highest in the PPM treatment, where net benefits increased by 169219 Rs ha^{-1} as compared to the control treatment. Similarly, the output value of the RSM treatment was also higher than the CK treatment. Plastic film mulching techniques provide appropriate use of irrigation water, prevent evaporation loss from soil surface and save water in the root zone.

Acknowledgements: The authors would like to acknowledge the support provided by Farm Incharge, Malir Agricultural farm, Sindh Agriculture University Tandojam and Laboratory Incharge, Department of Irrigation and Drainage, Faculty of Agricultural Engineering.

References

Abbas, G., Hussain, A., Ahmad, A., & Wajid, S. A. (2005). Water use efficiency of maize as affected by irrigation schedules and nitrogen rates. *Journal of Agriculture and Social Sciences*, *1*(4), 339–342.

Awal, M. A., & Khan, M. A. H. (2000). Mulch induced eco-physiological growth and yield of maize. *Pakistan Journal of Biological Sciences, 3*(1), 61-64.

Blanco-Canqu, H., & Lal, R. (2009). Corn stover removal for expanded uses reduce soil fertility and structural stability. *Soil Science Society of America Journal, 73,* 418–426.

Chandio, A. S., Lee, T. S., & Mirjat, M. S. (2013). Simulation of horizontal and vertical drainage systems to combat waterlogging problems along the Rohri canal in Khairpur district, Pakistan. *Journal of Irrigation and Drainage Engineering*, *139*(9), 710-717. doi:10.1061/(ASCE)IR.1943-4774.0000590

Dahiya, R., Ingwersen, J., & Streck, T. (2007). The effect of mulching and tillage on the water and temperature regimes of a loess soil. *Soil Tillage Research, 96*(1), 52-63. https://doi.org/10.1016/j.still.2007.02.004

Gan, Y. T., Siddique, K. H. M., Turner, N. C., Li, X. G., Niu, J. Y., Yang, C., & Liu, L. P. (2013). Ridge-furrow mulching systems-an innovative technique for boosting crop productivity in semiarid rainfed environments. *Advance in Agronomy*, *118,* 429–476. https://doi.org/10.1016/B978-0-12-405942-9.00007-4

Gao, X., Gu, F. X., Hao, W. P., Mei, X. R., Li, H. R., Gong, D. Z., Mao, L. L., & Zhang, Z. G. (2017). Carbon budget of a rainfed spring maize cropland with straw returning on the Loess Plateau, China. *Science of The Total Environment, 586,* 1193–1203. https://doi.org/10.1016/j.scitotenv.2017.02.113

Gao, Y. H., Xie, Y. P., Jiang, H. Y., Wu, B., & Niu, J. Y. (2014). Soil water status and root distribution across the rooting zone in maize with plastic film mulching. *Field Crops Research*, *156*, 40-47. https://doi.org/10.1016/j.fcr.2013.10.016

Gong, D. Z., Hao, W. P., Mei, X. R., Gao, X., Liu, Q., & Caylor, K. K. (2015). Warmer and wetter soil stimulates assimilation more than respiration in rainfed agricultural ecosystem on the China Loess *Plateau. Plos One, 216*(5), 315-324. doi:10.1371/journal.pone.0136578

Jia, Q. M., Chen, K. Y., Chen, Y. Y., Ali, S., Manzoor, A., Fahad, S., & Sohail, A. (2018). Mulch covered ridges affect grain yield of maize through regulating toot growth and root bleeding sap under simulated rainfall conditions. *Soil and Tillage Research, 175,* 101-111. https://doi.org/10.1016/j.still.2017.08.017

Kader, M. A., Senge, M., Mojid, M. A., & Nakamura, K. (2017). Mulching type-induced soil moisture and temperature regimes and water use efficiency in central Japan. *International Soil and Water Conservation Research, 5,* 302-308. https://doi.org/10.1016/j.iswcr.2017.08.001

Kasirajan, S., & Ngouajio, M. (2013). Erratumto: polyethylene and biodegradable mulches for agricultural applications: a review. *Agronomy for Sustainable Development,* 33, 501-529. https://doi.org/10.1007/s13593-011-0068-3

Kumar, D., Singh, R., Gadekar, H., & Patnaik, U. S. (2003). Effect of different mulches on moisture conservation and productivity of rainfed turmeric. *Indian Journal of. Soil Conservation, 31*(1), 41-44.

Li, F. M., Guo, A. H., & Wei, H. (1999). Effects of clear plastic film mulch on yield of spring wheat. *Field Crops Research, 63*(1), 79–86. https://doi.org/10.1016/S0378-4290(99)00027-1

Li, R., Hou, X., Jia, Z., & Q. Han. (2016). Mulching materials improve soil properties and maizegrowth in the Northwestern Loess Plateau, Chna. *Soil Research, 54*, 708–718. doi:10.1071/SR15175

Li, R., Hou, X., Jia, Z., Han, Q., Ren, X., & Yang, B. (2013a). Effects on soil temperature, moisture, and maize yield of cultivation with ridge and furrow mulching in the rainfed area of the Loess Plateau, China. *Agricultural Water Management, 116*, 101-109. https://doi.org/10.1016/j.agwat.2012.10.001

Li, S. X., Wang, Z. H., Li, S. Q., Gao, Y. J., & Tian, X. H. (2013b). Effect of plastic sheet mulch, wheat straw mulch, and maize growth on water loss by evaporation in dryland areas of China. *Agricultural Water Management, 116,* 39-49. https://doi.org/10.1016/j.agwat.2012.10.004

Li, X. Y., Gong, J. D., Gao, Q. Z., & Li, F. R. (2001). Incorporation of ridge and furrow method of rainfall harvesting with mulching for crop production under semiarid conditions. *Agricultural Water*

Management, 50(3), 173–183. https://doi.org/10.1016/S0378-3774(01)00105-6

Li, Y., Yang, S. J., Li, S. Q., Chen, X. P., & Chen, F. (2010). Growth and development of maize (*Zea mays* L.) in response to different field water management practices: resources capture and use efficiency. *Agricultural and Forest Meteorology, 150*, 606–613. https://doi.org/10.1016/j.agrformet.2010.02.003

Lobell, D. B., & Field, C. B. (2007). Global scale climate–crop yield relationships and the impacts of recent warming. *Environmental Research Letters, 2*, doi:10.1088/1748-9326/2/1/014002

Mebrahtu, Y., & Mehamed, A. (2019). Effect of different type of mulching and furrow irrigation methods on maize (*Zea mays* L.) yield and water productivity at Raya Valley, Northern Ethiopia. *Journal of Biology, Agriculture and Healthcare, 9*(20); doi: 10.7176/JBAH/9-20-02

MINFAL. (2005). Irrigation agronomy field manual. *Federal Water Management Cell, Ministry of Food, Agriculture and Livestock, Government of Pakistan, Islamabad, 6*, 289-292.

Mo, F., Wang, J. Y., Li, F. M., Nguluu, S. N., & Ren, H. X. (2017). Yield-phenology relations and water use efficiency of maize (Zea mays L.). In ridge-furrow mulching system in semiarid east African Plateau. *Scientific Reports, 7*, 3260. https://doi.org/10.1038/s41598-017-03372-x

Moreno, M. M., Cirujeda, A., Aibar, J., & Moreno, C. (2016). Soil thermal and productive responses of biodegradable mulch materials in a processing tomato (Lycopersicon esculentum Mill.) crop. *Soil Research, 54*, 207-215. doi: 10.1071/SR15065

Patil S., Kelkar, T. S., & Bhalerao, S. A. (2013). Mulching: A soil and water conservation practice. *Research Journal of Agriculture and Forestry Science, 1*(3), 26-29.

Phillips, R. E. (1983). Soil moisture. In: Phillips, R.E., Phillips, S.H. (Eds.), No-Tillage Agriculture, Principles and Practices. *Van Nostrand Peinhold Company, New York*, 66–86.

Pinjari, S. S. (2007). Effect of integrated nutrient management and polythene mulch on the performance of sweet corn under lateratc soils of Konkan. Ph. D. (Agri.) Thesis, Dr. Balasaheb Sawant Konkan Krish Vidyaeeth, Daoli and Dist. Ratnagiri (M.S.).

Priya, N., Ramulu, V., Rao, P. V., & Uma, D. M. (2018). Effect of drip irrigation schedules and plastic mulching on plant growth, yield and leaf water potential of rabi maize. *International Journal of Pure and Applied Bioscience, 6*(1), 183-191. http://dx.doi.org/10.18782/2320-7051.5912

Qin, S., Zhang, J., Dai, H., Wang, D., & Li, D. (2014). Effect of ridge-furrow and plastic mulching planting patterns on yield formation and water movement of potato in a semi-arid area. *Agricultural Water Management, 131*, 87–94. https://doi.org/10.1016/j.agwat.2013.09.015

Ramakrishna, A., Tam, H. M., Wani, S. P., & Long, T. D. (2006). Effect of mulch on soil temperature, moisture, weeds infestation and yield of groundnut in Vietnam. *Field Crop Research, 95*, 115-125. https://doi.org/10.1016/j.fcr.2005.01.030

Ren, X., Chen, X., Cai, T., Wei, T., Wu, Y. S., Zhang, P., & Jia, Z. K. (2017). Effects of ridge furrow system combined with different degradable mulching materials on soil water conservation and crop production in semi-humid areas of China. *Frontiers in Plant Science, 8*, 1877; doi: 10.3389/fpls.2017.01877

Roomkens, M. J. M., Helming, K., & Prasad, S. N. (2001). Soil erosion under different rainfall intensities, surface roughness, and soil water regimes. *Catena, 46*(2-3), 103-123. https://doi.org/10.1016/S0341-8162(01)00161-8

Sajid, H., Iqbal, M., Aziz, O., Murtaza, G., Iqbal, S., Mehmood, S., & Rasool, S. (2015). Effect of different irrigation practices and plastic mulch on water use efficiency, growth and yield of spring maize. *Basic Research Journal of Agriculture Sciences and Review, 4*(11), 1-7.

Sharma, P., Abrol, V., & Sharma, R. (2011). Impact of tillage and mulch management on economics, energy requirement and crop performance in maize–wheat rotation in rainfed sub humid inceptisols, India. *European Journal of Agronomy, 34*, 46–51. https://doi.org/10.1016/j.eja.2010.10.003

Soothar, R. K., Zhang, W., Liu, B., Tankari, M., Wang, C., Li, L., Xing, H., Gong, D., & Wang, Y. (2019). Sustaining yield of winter wheat under alternate irrigation using saline at different growth stages: A case study in the North China Plain. *Sustainability, 11*(17), 4564. https://doi.org/10.3390/su11174564

Tiam, Y., Su, D., Li, F., & Li, X. (2003). Effect of rainwater harvesting with ridge and furrow on yield of potato in semiarid areas. *Field Crops Research, 84*(3), 385–391; https://doi.org/10.1016/S0378-4290(03)00118-7

Tiwari, K. N., Singh, A., & Mal, P. K. (2003). Effect of drip irrigation on yield of cabbage (Brassica oleracea L. var. capitata) under mulch and non-mulch conditions. *Agricultural Water Management, 58*, 19–28.

Thider, M., Gong, D., Mei, X., Gao, L., Li, H., Hao, W., & Gu, F. (2020). Mulching improved soil water, root distribution and yield of maize in the Loess Plateau of Northwest China. *Agricultural Water Management, 241*, 106340. https://doi.org/10.1016/j.agwat.2020.106340

Unger, P. W., Baumhardt, R. L. & Arriaga, F. J. (2012). Mulch tillage for conserving water. Soil Water and Agronomic Productivity (Advances in Soil Science). *CRC Press, Taylor and Francis Group, New York*, 427–454.

Uwah, D. F., & Iwo, G. A. (2011). Effectiveness of organic mulch on the productivity of maize (Zea mays L.) and weed growth. *Journal of Animal and Plant Sciences, 21*, 525-530.

Vistro, R. B., Mangrio, M. A., Siyal, A. G., Abbasi, A. Q., Ahpun, A. A., & Soothar, R. K. (2021). Evaluating the performances of surface drainage efficiency in left bank outfall drain (LBOD) at Sanghar component. *Journal of Pure and Applied*

Agriculture, 6(1), 78-8.

Wajid, S. A. (1990). Effect of different mulching material and irrigation levels on growth and grain yield of maize. *M.Sc. (Hons.) Agri. Thesis. Department of Agronomy, University of Agriculture, Faisalabad.*

Wang X, Li, Z., Xing, Y., Clothier, B. E., Dierickx, W., Oster, J., & Wichelns, D. (2015). Effects of mulching and nitrogen on soil temperature, water content, nitrate-N content, and maize yield in the Loess Plateau of China. *Agricultural Water Management, 161*, 53-64. https://doi.org/10.1016/j.agwat.2015.07.019

Wang, T. C., Wei, L., Wang, H. Z., Ma, S. C. & Ma, B. L. (2011). Responses of rainwater conservation, precipitation-use efficiency and grain yield of summer maize to a furrow-planting and straw-mulching system in Northern China. *Field Crops Research*, *124*(2), 223–230. https://doi.org/10.1016/j.fcr.2011.06.014

Wei, Q., Hu, C., & Oenema, O. (2015). Soil mulching significantly enhances yields and water and nitrogen use efficiencies of maize and wheat meta-analysis. *National Inst. of Health Scientific Reports, 5*, 16210. doi:10.1038/srep16210

Wu, Y., Haung, F., Jia, Z., Ren, X., & Cai, T. (2017a). Response of soil water, temperature, and maize (*Zea mays* L.) production to different plastic film mulching patterns in semiarid areas of northwest China. *Soil Tillage Research, 166*, 113-121. https://doi.org/10.1016/j.still.2016.10.012

Wu, Y., Du, T., Ding, R., Yuan, Y., Li, S., & Tong, L. (2017b). An isotope method to quantify soil evaporation and evaluate water vapor movement under plastic film mulch. *Agricultural Water Management*, *184*, 59–66. https://doi.org/10.1016/j.agwat.2017.01.005

Xu, J., Li, C., Liu, H., Zhou, P., Tao, Z., Wang, P., Meng, Q., & Zaho, M. (2015). The effects of plastic film mulching on maize growth and water use in dry and rainy years in Northeast China. *PLoS ONE*, *10*, 5. https://doi.org/10.1371/journal.pone.0125781

Yang, N., Zhan, X., Shan, L., & Zheng, M. (2015). Plastic film mulching for water-efficient agricultural application and degradable films materials development research. *Materials and Manufacturing Processes, 30,* 1080. https://doi.org/10.1371/journal.pone.0125781

Zerga, K., Alemu, M., Tebasa, F., & Tesfaye, B. (2017). Impacts of different mulching material on seedling emergence and growth performance of hot pepper (Capsicum annum L.) at Gurage zone, Ethiopia. *International Multidisciplinary Research Journal*, *7*, 1-4. doi: 10.25081/imrj.2017.v7.3362

Zhang, D., Wang, Q., Zhou, X., Liu, Q., Wang, X., Zhao, X., Zhao, W., He, C., Li, G., & Chen, J. (2020). Suitable furrow mulching material for maize and sorghum production with ridge-furrow rainwater harvesting in semiarid regions of China. *Agricultural Water Management, 228,* 105928. https://doi.org/10.1016/j.agwat.2019.105928

Zhang, X. D., Kamran, M., Xue, X., Zhao, J., Cai, T., Jia, Z., Zhang, P., & Han, Q. (2019). Ridge-furrow mulching system drives the efficient utilization of key production resources and the improvement of maize productivity in the Loess Plateau of China. *Soil Tillage Research, 190,* 10–21. https://doi.org/10.1016/j.still.2019.02.015

Zhao, B., Qi, W. Z., Liu, H. H., Liu, P., Dong, S. T., Zhao, B. Q., So, H. B., Li, G., Liu, H. D., & Zhang, J. W. (2012). Morphological and physiological characteristics of corn (*Zea mays* L.) roots from cultivars with different yield potentials. *European Journal of Agronomy*, *38*(1), 54–63. https://doi.org/10.1016/j.eja.2011.12.003

Zhou, L. M., Li, F. M., Jin, S. L., & Song, Y. J. (2009). How two ridges and the furrow mulched with plastic film affect soil water: soil temperature and yield of maize on the semiarid Loess Plateau of China. *Field Crops Research*, *113*, 41–47. https://doi.org/10.1016/j.fcr.2009.04.005

Zribi, W., Aragues, R., Medina, E., & Faci, J. M. (2015). Efficiency of inorganic and organic mulching materials for soil evaporation control. *Soil Tillage Research*, *148*, 40-45. https://doi.org/10.1016/j.still.2014.12.003