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Full Length Article

Plastic Film and Straw Mulch Effects on Maize Yield and Water Use Efficiency under Different Irrigation Levels in Punjab, Pakistan

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Abstract

This two-year field experiment was conducted to assess the effects of irrigation and mulches on yield and water use efficiency (WUE) of maize. Treatments involved three irrigation levels (I_1 = 60% field capacity, I_2 = 80% field capacity and I_3 = 100% field capacity) and two mulches (M_1 = plastic film and M_2 = rice straw). No-mulch was regarded as control. Grain yield of maize was increased as the irrigation levels were increased and yield (6.2 Mg ha^{-1} in both years) in 100% field capacity irrigation level was the highest. Plastic film mulching produced the highest grain yield (5.7 Mg ha^{-1} in 2014 and 5.6 Mg ha^{-1} in 2015) of maize. Mulching decreased total water use in maize from 553 mm in no-mulch to 485.8 mm in plastic film. The WUE in plastic film were 10.2 and 11.4 kg ha^{-1} mm^{-1} in 2014 and 2015 respectively. Straw mulch significantly increased soil organic matter (0.57 to 0.87%) and active carbon (286 to 353 mg kg^{-1}) with a decrease in soil bulk density (1.42 to 1.37 g cm^{-3}) in surface and sub-surface soil layers. Effects of plastic film mulching were more pronounced in improving yield and WUE of maize while straw mulch was more effective in improving soil organic matter and active carbon. In conclusion, mulching improved the soil organic matter and moisture retention with decrease in bulk density and ultimately improved the yield and WUE of maize and net income.

Keywords: Field capacity; Mulch; Soil organic matter; Total water use; Water use efficiency

Introduction

Although expansion of land area under irrigation throughout the world has increased the grain yield during the past century (Miller, 2008) however, efficient use of the water is very important. In view of rapidly increasing population of the world and increased water demand for domestic purposes, there should be reduction in use of fresh water for agriculture specifically in water deficient areas (Ali and Talukder, 2008). The world food demand is expected to increase by two-fold from 2005 to 2050 (Borlaug, 2009). Therefore, the water use efficiency (WUE) is necessary to be maximized (Perry *et al.*, 2009).

Expanding land area under irrigation has limited potential because of the diminishing water resources (Hussain *et al.*, 2018). Pakistan uses most of its fresh water for agriculture and mostly for supplemental irrigation (Shehzad *et al.*, 2007; Farooq *et al.*, 2017). Thus, meager water resources in Pakistan are being rapidly depleted because of improper management, outdated technologies and poor irrigation scheduling which reduce crop yield and WUE (Laghari *et al.*, 2008). Soil water retention is very poor due to low water holding capacity of soil which is caused by low soil organic matter (SOM) and coarse texture (Ahmad *et al.*, 2014). To maintain normal water supply for crops with high water demand (*i.e.*, maize) is a major challenge. Therefore, irrigated agriculture must address the issues of water scarcity using new approaches based on environment-friendly technologies (Pereira, 2006). Practices effective in conserving soil water include; using suitable mulches, adding organic materials, and growing cover crops.

Soil surface should be covered to control the rapid soil moisture loss from soil surface (Eberbach *et al.*, 2011). Mulching is a technique in which soil surface is covered with crop residues and/or plastic sheet to minimize the water loss through evaporation (Zribi *et al.*, 2015). Crop production is negatively affected by water shortage and mulches has good potential in increasing soil moisture retention under water limited conditions (Jabran *et al.*, 2015a). Mulching is an economical and better management practice for conserving soil moisture (Jabran *et al.*, 2016). Mulching improves soil environment for plants and also reduces risks of erosion and water runoff (Irshad *et al.*,

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2007). Mulching is important in increasing soil water availability, reducing weed growth and raindrops impact and moderating soil temperature in arid to semi-arid regions *i.e*., Pakistan (Farooq *et al.*, 2011a). There are increasing evidences that crop yield is increased with residues retention (Farooq *et al.*, 2011b). Govaerts *et al.* (2009) reported the soil water contents and stability are improved with residues retention in conservation agriculture system.

Both straw and plastic mulching can have an imperative role in increasing crop and water productivity. Significant effects of mulches on soil physical quality have also been reported. Pervaiz *et al.* (2009) concluded that applying mulches significantly increased soil water and SOM content and decreased soil bulk density and soil strength. Under conditions of water stress during dry period, significant improvement in crop growth and yield have also been observed by rice husk mulch (Badaruddin *et al.*, 1999). Using wheat straw as mulch can significantly improve water storage in root zone and crop water use under rainfed conditions (Tariq *et al.*, 2001). Plastic mulches as compared to other mulching materials have good potential for growth, yield and saving water (Qamar *et al.*, 2015).

Mulching materials show variable effects on soil properties. Plastic mulch is more effective in rising soil temperature (Pandey *et al.*, 2016). Kahlon (2014) reported the non-significant effect of straw mulch on yield of rice and wheat crops. However, straw yield and water transmission characteristics showed significant behavior. Straw mulch compared with synthetic mulch showed a significant improvement in growth and WUE of wheat (Chakraborty *et al.*, 2010). As compared to polythene, straw mulch is a cheaper source and can be used economically (Chaudhry *et al.*, 2004). On a large scale such water saving can have considerable significance in regions like Central Asia (Bezborodov *et al.*, 2010).

Mulching effects on crops are variable and site-specific. An assessment based on the local data is required for the sustainability of mulching in a semi-arid region considering the various factors such as crops, climatic conditions (temperature and precipitation), soils and management practices (*e.g*., water inputs). Improved soil moisture retention, crop yield and WUE through mulch application is well established. However, scanty information is available on the comparative effectiveness of plastic film and straw mulch applied after crop germination under different irrigation levels on maize yield and WUE under similar agro-environment. Improved soil moisture retention with use of mulches may help save irrigation water and improve WUE in maize. Thus, a 2-year field study was designed to study the effects of plastic film and straw mulches on soil physical properties, and growth, yield and WUE of maize under varying irrigation regimes.

Materials and Methods

Experimental Site

The experiment was conducted at Research Farm, Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad (31.26°N, 73.04°E), Punjab, Pakistan. Fig. 1 represents the meteorological conditions of maize growing seasons during 2014 and 2015. Physico-chemical properties of the experimental soil are given in Table 1.

Crop Husbandry

Seed-bed was prepared 3 days after pre-soaking irrigation by light harrowing to a depth of 4 inches followed by planking. Maize hybrid “Sygenta-8611” was drilled in 75 cm spaced rows using seed rate of 25 kg ha^{-1}. Thinning was done manually 10 days after emergence to keep the plant × plant distance of 20 cm. Amounts of fertilizer application were the same for all treatments. Urea, single superphosphate and sulphate of potash were applied at the rate of 250 N:150 P:100 K kg ha^{-1} respectively. The total amount of P and K were applied as basal at sowing while N was applied in three splits. 1/3rd as urea at the sowing and the remaining was applied in two equal splits at seedling and booting stages. Atrazine (800 mL ha^{-1}) was applied to keep the field weed free after 10 days of weed emergence. Furadan (20 kg ha^{-1}) was applied at 4-leaf (V4) stage to control shoot fly and stem borers.

Treatments and Experimental Design

The experiment was conducted following randomized complete block design with split-plot arrangement having three replications keeping irrigations treatments in main plots and mulches in sub-plots with a net plot size of 5.5 × 4 m. The experiment consisted of three irrigation levels (I_1 = 60% field capacity, I_2 = 80% field capacity and I_3 = 100% field capacity) and two mulching materials (M_1 = plastic film and M_2 = rice straw). No-mulch was taken as control treatment. In irrigation treatments, plots were irrigated up to reach the desired field capacity levels. Irrigation was scheduled based on the soil water deficit at the time of each irrigation (difference between soil water contents at pre-decided field capacity and at the time of irrigation) with intervals of 7 days. The field was pre-irrigated to fill the soil profile to field moisture capacity. Twelve random soil samples from 0-45 cm with 15 cm intervals were taken for field capacity determination before sowing. Field capacity was determined by pressure plate apparatus by placing the samples at -33 kPa pressure. Water was extracted by placing soil on ceramic plates that were placed into high pressure chambers. The samples were weighed after the samples were equilibrated at the target pressure. The samples were oven-dried at 105°C for overnight and soil moisture contents were determined (Topp *et al.*, 1993).

Mulches (plastic film and rice straw) were applied manually on surface 7 days after seeding in between the crop rows to allow plants grow normally and also ensure that the rainwater could infiltrate into the soil. Rice straw (C 53.3%, N 0.63% and C/N 84.6) was applied at 5 Mg ha^{-1}.

Table 1: Physico-chemical properties of experimental soil

Soil properties		Unit	Value
Sand		%	40 ± 2.3
Silt		%	37.5 ± 1.0
Clay		%	22.5 ± 1.8
Textural class		-----	Loam
ECe		$dS\ m^{-1}$	1.48 ± 0.06
pH		-----	8.05 ± 0.04
Field capacity	0-15 cm	$cm^3 cm^{-3}$	0.29 ± 0.03
	15-30 cm		0.27 ± 0.04
	30-45 cm		0.22 ± 0.01
Bulk density		$Mg\ m^{-3}$	1.41 ± 0.06
Soil organic matter		%	0.72 ± 0.14
Total nitrogen		%	0.03 ± 0.01
Available phosphorus		$mg\ kg^{-1}$	6.1 ± 1.3
Available potassium		$mg\ kg^{-1}$	168.6 + 6.4

Values are expressed as mean ± standard deviation (n=3)

White plastic film (60 cm wide; 8 μm thick) was used. Plastic film was stable and not decomposed after crop harvest. Irrigations were applied to fill the soil moisture at pre-decided field capacity levels. The canal water or tube well were used as source of water, depending upon the availability as surface flood irrigation. Required water depth in each soil layer (0–45 cm at 15 cm intervals) for each irrigation level was estimated one day before each irrigation by using the following relationship (Hassanli *et al.*, 2009):

$$D_i = \frac{FC_i - \theta i}{100} \times BD_i \times R_i$$

Where, D_i is water depth (m) required to increase the initial water contents (θ_i) in soil to water contents at field capacity (θFC_i) having bulk density BD_i in i^{th} layer and root zone depth R_i.

Moisture contents and bulk density were determined up to 45 cm depth at 15 cm intervals one day before each irrigation. Soil samples were also collected with a soil auger, weighed immediately and dried at 105°C in an oven till the weight loss was constant. The soil moisture was measured using the gravimetric method. The total water depth to be applied was the sum of the calculated water deficit in each soil layer:

$$D_{0\text{-}45\ cm} = D_{0\text{-}15\ cm} + D_{15\text{-}30\ cm} + D_{30\text{-}45\ cm}$$

Following relationship was used to ensure the exact level of irrigation water to be applied (Buland *et al.*, 1994):

$$t = AD/Q$$

Where t is time (min) required to meet the desired water depth of D (m) in a field having area A (m^2) with a flow rate of Q ($m^3\ min^{-1}$).

A cut-throat flume was used to apply the measured level of irrigation to each plot as per treatment. A 90 cm cut-throat flume having throat of 20 cm was placed at the entry point of the water for measuring the amount of applied irrigation water. Flume was calibrated as per guidelines of International Irrigation Management Institute, Pakistan with deviation of results ranging from 2.2 to 3.8% at 5% probability (Siddiqui *et al.,* 1996). The total amount of irrigation water applied for I_1, I_2 and I_3 were 294, 392 and 490 mm during 2014 and 285, 384, 472 mm during 2015, respectively.

Data Collection and Soil Sampling

Plant height was determined at harvest with a meter rod from the base to the top. A representative sample of the maize was taken from each plot (3 rows of 4 m) by hand harvesting the crop at maturity for determination of straw and grain yields. Plants were dried at 60°C and weighed to record the straw yield. Cobs were removed, then grains were separated and weighed to determine the grain yield. The straw and grain yields were reported at 0% and 14% moisture contents respectively. Harvest index (HI) was calculated as a ratio of grain yield to straw yield and was expressed in percentage.

Soil samples were taken up to 100 cm depth at 20 cm intervals from each plot with the help of auger at harvesting for determination of soil moisture content. Core samples with 50 mm internal diameter were also collected from each plot for bulk density determination. Cores were placed in an oven at 105°C till loss in weight was constant and bulk density determined by dividing the oven dried mass to the core volume (Blake and Hartge, 1986). Bulk density was multiplied with corresponding moisture content for determination of volumetric moisture content. Soil samples from 30 cm soil layer at 15 cm interval were also taken for SOM and active carbon concentrations. The SOM concentration was determined with the Walkley-Black method (Ryan *et al.,* 2001) and biologically active C was determined by spectrophotometer after extraction with 0.02 *M* potassium permanganate (Weil *et al.*, 2003).

Total water use (TWU) was calculated using the following formula of Ram *et al.* (2013):

$$TWU\ (mm) = I + P + \Delta W + CR - D - R$$

Where, TWU (mm) is the total water use in maize crop; P (mm) is the total precipitation in maize growing season; I (mm) is the amount of irrigation applied in each season; 'ΔW' is water content change in soil from sowing to harvesting in 0 to 100 cm depth; R (mm) is the surface runoff; D (mm) is the drainage below root zone; CR is the root zone capillary rise of water (Zhang *et al.,* 2005; Su *et al.,* 2007). Capillary rise and drainage were considered as negligible and were not taken into the formula. The drainage was considered negligible based on the assumption that irrigation water applied was below or at the soil field capacity. WUE was calculated using the following formula:

$$WUE\ (kg\ ha^{-1}\ mm^{-1}) = \frac{\text{Grain yield (kg ha}^{-1})}{\text{Total water use (mm)}}$$

Statistical and Economic Analysis

Experimental data were analyzed by analysis of variance techniques using statistical software IBM SPSS v. 21. Before applying ANOVA, data were checked for normality and were found to be normally distributed. Tukey Honestly Significant Difference (HSD) test at $p \leq 0.05$ was used for mean separation (Steel *et al.,* 1997). Total costs of seedbed preparation, seed, sowing expenses, irrigation, fertilizers, weedicide, pesticide, thinning, harvesting and land rent were worked out. Gross income was computed using existing prices of maize grains and straw for 2014 and 2015 in local market of the country. Net benefit was calculated by subtracting the total cost from gross income. Benefit-cost ratio (BCR) was calculated by dividing the gross income with total cost (Byerlee, 1988).

Results

Growth and Yield Parameters

Maize plant height was altered significantly by irrigation levels, mulches and their interactions. The highest plant height was observed at 100% field capacity irrigation level during both years (Table 2). Plastic film mulching resulted in the highest plant height among the mulching treatments. Plastic film mulching treatment increased plant height by 6.6 and 12.9% over that of the no-mulch during 2014 and 2015, respectively. The highest plant height was observed with 100% field capacity irrigation level in presence of plastic film during both seasons. Straw yield of maize was affected significantly by irrigation levels, mulches and their interaction effects in both years (Table 2). The highest straw yield was recorded with 100% field capacity irrigation level. Straw mulching significantly increased the straw yield by 4.1 and 10.1% over that of the no-mulch during 2014 and 2015, respectively. Regarding the interaction effect, the highest straw yield was recorded with 100% field capacity irrigation level and with plastic film in 2014 and the highest straw yield was recorded with 100% field capacity irrigation level and straw mulch in 2015.

Grain yield of maize increased significantly as the irrigation levels increased, and the highest grain yield was recorded for 100% field capacity irrigation level (Table 2). Mulches effect on grain yield was also significant during both seasons. The highest grain yield was recorded in plastic film mulching which was 28.3 and 32.3% more than that of the no-mulch during 2014 and 2015, respectively. The interaction effects were non-significant for grain yield during both the years. Harvest index for maize was varied significantly by irrigation levels, mulches and their interactions. The highest harvest index was observed at 100% field capacity irrigation level during both years (Table 3). Plastic film mulching resulted in the highest harvest index among the mulching treatments during 2014 while it was the highest in straw mulch during 2015. The highest harvest index was observed with 100% field capacity irrigation level in presence of plastic film during both seasons.

Table 2: Influence of irrigation and mulching on plant height, straw and grain yields of maize

Treatments	Plant height (cm)		Straw yield (Mg ha^{-1})		Grain yield (Mg ha^{-1})	
	2014	2015	2014	2015	2014	2015
			Irrigations			
I_1	175.5C	174.5B	14.4B	14.4B	4.1B	4.1B
I_2	180.8B	174.9B	15.1A	14.6B	5.2AB	5.0B
I_3	187.3A	188.0A	15.3A	15.4A	6.2A	6.2A
HSD (p 0.05)	1.83	1.79	0.67	0.62	1.13	1.11
			Mulches			
M_0	174.8C	166.1C	14.6B	13.9B	4.4B	4.2B
M_1	186.3A	187.5A	15.1A	15.3A	5.7A	5.6A
M_2	182.6B	183.8B	15.2A	15.3A	5.4A	5.5A
HSD (p 0.05)	1.71	1.72	0.49	0.53	0.94	0.92
			Irrigations × Mulches			
I_1M_0	172.3g	160.3f	13.3d	12.4f	3.8	3.5
I_1M_1	179.5de	184.9b	13.9cd	14.5cde	4.3	4.4
I_1M_2	174.7fg	178.2c	14.4bcd	14.1de	4.4	4.4
I_2M_0	175.4efg	164.8e	14.2bcd	13.3ef	4.1	3.9
I_2M_1	184.6c	180.7bc	16.0a	15.8abc	5.9	5.4
I_2M_2	182.6cd	179.0c	15.4ab	14.8bcd	5.5	5.7
I_3M_0	176.7ef	173.1d	15.2abc	15.8abc	5.4	5.3
I_3M_1	194.8a	196.8a	16.2a	15.9ab	6.9	6.9
I_3M_2	190.4b	194.2a	16.1a	16.6a	6.3	6.5
HSD (p 0.05)	4.11	4.14	1.22	1.24	NS	NS

I_1 = 60% field capacity, I_2 = 80% field capacity, I_3 = 100% field capacity, M_0 = No mulch, M_1 = Plastic film, M_2 = Straw mulch

Means sharing the same letters, for main effects and interaction of a parameter during a year, don't differ significantly at $p \leq 0.05$

Table 3: Influence of irrigation and mulching on harvest index, total water use and water use efficiency of maize

Treatments	Harvest index (%)		Total water use (mm)		Water use efficiency (kg grains ha^{-1} mm^{-1})	
	2014	2015	2014	2015	2014	2015
			Irrigations			
I_1	29.8C	30.0C	454.1C	398.5C	9.1	10.4
I_2	33.7B	34.0B	552.3B	497.4B	9.3	10.1
I_3	39.0A	38.6A	649.1A	583.1A	9.5	10.7
HSD (p 0.05)	1.19	1.62	1.31	3.95	NS	NS
			Mulches			
M_0	30.9C	30.3B	553.0A	503.8A	8.0B	8.4B
M_1	36.6A	36.0A	550.3C	489.6C	10.2A	11.4A
M_2	35.0B	36.4A	552.0B	485.8B	9.7AB	11.4A
HSD (p 0.05)	0.88	2.63	0.83	1.14	1.84	2.11
			Irrigations × Mulches			
I_1M_0	28.3e	28.2e	454.4e	411.2f	8.3	8.5
I_1M_1	30.8e	30.4de	454.8e	393.6g	9.4	11.2
I_1M_2	30.3e	31.5de	453.1e	390.6h	9.6	11.4
I_2M_0	29.0e	29.2e	553.5c	501.7d	7.5	7.7
I_2M_1	36.8bc	34.2bcd	552.4cd	495.5e	10.7	10.9
I_2M_2	35.4c	38.6abc	551.1d	494.9e	9.9	11.6
I_3M_0	35.4c	33.4cde	651.1a	597.9a	8.3	8.8
I_3M_1	42.2a	43.5a	648.8b	579.6b	10.6	11.9
I_3M_2	39.4ab	39.0ab	647.4b	571.9c	9.8	11.3
HSD (p 0.05)	3.46	5.21	2.01	2.75	NS	NS

I_1 = 60% field capacity, I_2 = 80% field capacity, I_3 = 100% field capacity, M_0 = No mulch, M_1 = Plastic film, M_2 = Straw mulch

Means sharing the same letters, for main effects and interaction of a parameter during a year, don't differ significantly at $p \leq 0.05$

Soil Water Content, Total Water use (TWU) and Water Use Efficiency (WUE)

Soil water content after harvest in 2014 and 2015 were almost similar ($p > 0.05$) but relatively higher moisture contents were observed in 2014 (Table 4). The higher soil water content in 2014 might be due to the more rainfall in November close to harvesting in 2014. Soil water contents were higher under mulched conditions as compared to no-mulch. A significant increase in total water use was observed with the increasing levels of irrigation (Table 3). The highest total water use was observed from no-mulch plots during both years as compared to that under straw and plastic film mulching. Regarding the interaction effect, significantly higher total water use was observed for 100% field capacity irrigation levels with no-mulch in both seasons. WUE of maize varied significantly with mulches but non-significantly with irrigation levels and their interaction effect. The WUE of maize was the highest under plastic film mulching during 2014. However, the WUE during 2015 was the same for both plastic film and straw mulch mulching. Plastic film and straw mulches increased the WUE by 27.6 and 22% during 2014 and by 36% each during 2015, respectively (Table 3).

Soil Properties

Irrigation levels did not significantly affect soil properties (bulk density, SOM and active carbon). Straw mulch significantly reduced soil bulk density in 0–15 cm layer from 1.42 g cm^{-3} to 1.37 g cm^{-3} during 2014 and 1.44 to 1.42 g cm^{-3} in 15–30 layer (Fig. 2a). Straw mulch also significantly reduced bulk density in both soil layers during 2015. The effect of mulches on SOM content was significant in both soil layers during both growing seasons. Straw mulch increased SOM by 30.5% in 0–15 cm layer and by 46.7% in 15–30 cm layer during 2014 by 29 and 42.6% over that of the no-mulch in 0–15 and 15–30 cm depths during 2015, respectively (Fig. 2b). Straw mulch significantly increased the active carbon content by 31.8% in surface soil and 47.5% in sub-surface soil in 2014 and by 28.4% in surface soil and 43.1% in sub-surface soil in 2015 (Fig. 2c). The interaction effect of irrigation and mulches on soil properties were non-significant during both the years (data not given).

Economic Analysis

Mulch application enhanced the total cost but also improved the gross income, net benefits and BCR of maize at all irrigation levels during 2014 and 2015 (Table 5). Irrigation applied at 100% field capacity level had highest total cost, gross income, net benefit and BCR while these were the lowest for irrigation applied at 60% field capacity level. Plots with plastic film mulching had the highest total cost during both years. Maximum gross income, net benefit and BCR was noted for plastic film mulching followed by straw mulch during both years. Regarding interaction effect, irrigation applied at 100% field capacity under plastic film mulching had the highest gross income, net benefit and BCR while irrigation applied at 60% field capacity with no-mulch resulted in the lowest income and BCR during both years.

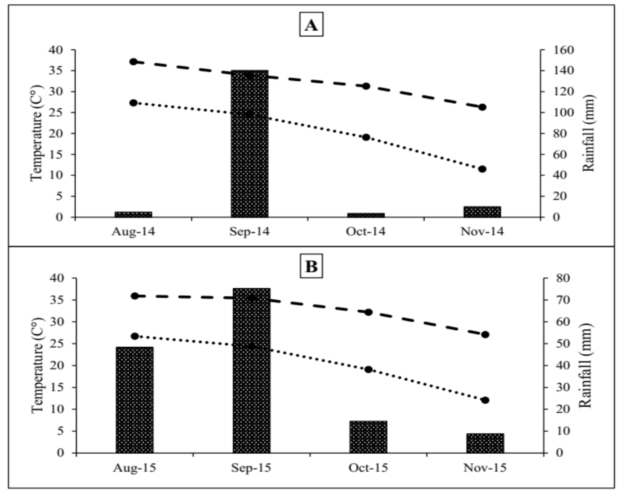

Fig. 1: Mean maximum (—●—) and minimum temperatures (• • ● • •) and total rainfall (▩) during the maize growing seasons of 2014 (A) and 2015 (B) at the experimental site

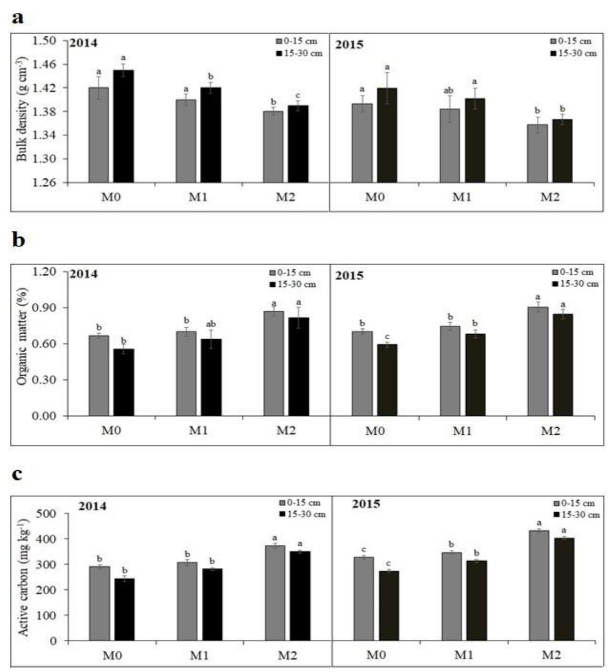

Fig. 2: Influence of mulches on soil bulk density (**a**), organic matter (**b**) and active carbon (**c**) in maize rhizosphere soil. M_0 = No mulch, M_1 = Plastic film, M_2 = Straw mulch
Each bar represents mean of three replications ± standard deviation
Bars sharing the same letters, for a parameter during a year, don't differ significantly at $p \leq 0.05$

Discussion

Application of mulches improved maize growth and yield by improving moisture conservation and soil properties. Plastic film mulching increased grain yield of maize by 28–

Table 4: Volumetric moisture content (cm^3 cm^{-3}) of soil at sowing and harvesting under different irrigation and mulching treatments

Soil depth (cm)	At sowing		At harvest																	
	2014	2015	I_1						I_2						I_3					
			M_0		M_1		M_2		M_0		M_1		M_2		M_0		M_1		M_2	
			2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
0-20	0.26	0.29	0.10	0.10	0.10	0.10	0.11	0.11	0.12	0.12	0.14	0.14	0.15	0.15	0.15	0.15	0.17	0.17	0.19	0.19
20-40	0.23	0.28	0.10	0.09	0.10	0.09	0.11	0.10	0.12	0.10	0.13	0.12	0.14	0.13	0.14	0.13	0.17	0.15	0.18	0.16
40-60	0.24	0.26	0.09	0.08	0.09	0.08	0.10	0.10	0.10	0.11	0.12	0.10	0.14	0.12	0.13	0.12	0.16	0.14	0.17	0.16
60-80	0.19	0.18	0.09	0.09	0.09	0.09	0.10	0.09	0.10	0.09	0.11	0.11	0.13	0.12	0.12	0.10	0.15	0.12	0.16	0.14
80-100	0.14	0.12	0.08	0.10	0.08	0.11	0.09	0.11	0.07	0.09	0.09	0.10	0.10	0.12	0.09	0.10	0.11	0.11	0.12	0.13

I_1 = 60% field capacity, I_2 = 80% field capacity, I_3 = 100% field capacity, M_0 = No mulch, M_1 = Plastic film, M_2 = Straw mulch

Table 5: Economic analysis of maize production by irrigation and mulching

Treatments	Total cost (US\$ ha^{-1})		Gross income (US\$ ha^{-1})		Net benefit (US\$ ha^{-1})		Benefit-cost ratio (BCR)	
	2014	2015	2014	2015	2014	2015	2014	2015
Irrigations								
I_1	742.62	742.62	981.09	981.09	238.47	238.47	1.32	1.32
I_2	781.35	781.35	1171.34	1128.15	389.98	346.80	1.50	1.44
I_3	765.09	765.09	1334.22	1336.53	569.14	571.44	1.74	1.75
Mulches								
M_0	744.70	744.70	1033.18	985.38	288.49	240.68	1.39	1.32
M_1	801.50	801.50	1250.47	1239.26	448.97	437.75	1.56	1.55
M_2	787.97	787.97	1205.30	1223.43	417.33	435.46	1.53	1.55
Irrigations × Mulches								
I_1M_0	742.62	750.71	908.23	839.99	165.61	89.28	1.22	1.12
I_1M_1	781.35	791.00	1001.21	1030.88	219.86	239.88	1.28	1.30
I_1M_2	765.09	791.00	1028.57	1021.65	263.49	230.65	1.34	1.29
I_2M_0	744.70	753.01	976.48	924.06	231.78	171.05	1.31	1.23
I_2M_1	801.50	811.90	1302.89	1219.14	501.38	407.24	1.63	1.50
I_2M_2	787.97	797.87	1225.74	1243.55	437.77	445.68	1.56	1.56
I_3M_0	749.06	757.46	1205.30	1203.31	456.24	445.86	1.61	1.59
I_3M_1	821.36	832.14	1465.77	1458.85	644.42	626.72	1.78	1.75
I_3M_2	811.71	822.13	1368.50	1411.69	556.80	589.57	1.69	1.72

I_1 = 60% field capacity, I_2 = 80% field capacity, I_3 = 100% field capacity, M_0 = No mulch, M_1 = Plastic film, M_2 = Straw mulch
Note: 1 US$ = 133.63 PKR

32% in both years (Table 2). Plots having mulches application retained more moisture and more water was available to plants for better growth and yield (Jabran *et al.,* 2015a). The more pronounced effect of plastic film was observed as compared to that under straw mulch. However, despite mulching type, growth, grain yield and WUE of maize was significantly better in mulched than in no-mulch treatment. Increased soil water retention and reduction in evaporation might be the positive effects of soil mulching which increased the yield (Jabran *et al.*, 2015b). Plastic mulching is more beneficial to reduce soil evaporation in comparison to straw mulch. Sunlight falls directly on soil without mulch and converts water from liquid to gaseous phase, which is then lost to the atmosphere. Mulches provide a barrier for water vapours lost to the atmosphere and as a result evaporation is reduced (Jabran *et al.*, 2015a). Therefore, mulches help provide more water to plants by reducing evaporation and increasing moisture retention in soil (McMillen, 2013).

The data presented in this study suggest that mulching the soil may improve WUE and narrow the yield gap between potential and actual yields. Mueller *et al.* (2012) reported that yield obtained in well managed field trials is only 30–80% of the potential yield. This study indicated the reduction in evaporative demand through mulching helps improve water management to narrow the yield gaps. The results from the current study revealed that with the use of plastic mulch the WUE of wheat was increased by 27–36% compared with no-mulch (Table 3). A significant increase in grain yield with decreased water use and enhanced WUE has also been reported by Tao *et al.* (2015). The application of straw mulch on the soil surface reduces water evaporation, increases soil water content, and conserves water without decreasing grain yield and leads to enhanced WUE (Jin *et al*., 2009). Improvement in plant canopy and better soil water status increased grain yield with use of mulching (Chakraborty *et al.*, 2010; Balwinder-Singh *et al.*, 2011). Soil microbial environment and fertility are directly related to the increased yield in response to plastic film mulching that also improves soil water content and soil temperature regime (Qin *et al.*, 2015).

Generally, the effects of plastic film were more pronounced in improving yield and WUE of maize as compared to rice straw mulch. There may be several mechanisms responsible for the higher efficacy of plastic film than the straw mulch. For example, enhanced availability of nutrients and soil temperature regulations are the significant mechanisms through which plastic film improves the crop yield and WUE (Cook *et al.,* 2006). Although the mechanisms are yet to be explained, however, the plastic film mulching improves the microbial activity, SOM and availability of nutrients, while the straw mulch decreases availability of nutrients (Ghosh *et al.,* 2006). Furthermore, soil water loss through evaporation is greatly minimized probably because of the thickness of plastic film compared with the straw mulch (McMillen, 2013). Thus, the improved growth, yield and WUE of maize in plastic film mulching plots may be due to more effectiveness of plastic film than straw mulch (Hou *et al.,* 2010; Humphreys *et al.,* 2011).

The soil organic carbon is the key factor of improved soil properties (Akhtar *et al.,* 2018). The results of our study show that a significant increase in the SOM and active carbon concentration was observed with a decrease in bulk density for straw mulch compared with that of no-mulch. Straw mulch being a rich source of carbon becomes a constituent of SOM on decomposition (Ram *et al.,* 2013). In the surface soil layer, significant decrease in bulk density with an increase in SOM has been reported widely (Singh *et al.,* 2007; Yadvinder-Singh *et al.,* 2009). Soil bulk density in the upper 0–10 cm depth decreased with residue mulching as reported by Głab and Kulig (2008).

Though mulch application increased the total cost of production, but at the same time it also increased the gross income, net benefits and BCR of maize (Table 5). Economic analysis clearly unveiled the importance of mulching, particularly plastic film mulching, in improving net income and BCR due to significant increase in yield. Higher net benefits and BCR indicated that mulching is a viable management practice for improving crop yield and water saving and similar results have also been reported by Jabran *et al.* (2016). Apparently, plastic and rice straw mulches have positive effects and results of current study indicate that use of these mulches can increase maize yield significantly. However, high labor cost, unavailability of proper straw mulch and difficulties in collection and recycling of plastic film residues are some side-effects of mulching. Therefore, site specific conditions and these side-effects must always be contained within guidelines for recommending mulch practices.

Conclusion

Maize growth, yield and WUE improved by plastic film and straw mulch under different irrigation levels. Plastic film mulching was more pronounced in improving yield and WUE of maize while straw mulch was more effective in improving soil organic matter and active carbon. Thus mulching is quite helpful in improving soil organic matter, active carbon and moisture retention with a decrease in bulk density leading to improved yield and WUE of maize.

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