

## Effect of Plastic Film and Straw Mulch on Wheat Yield, Water Use Efficiency and Soil Properties in Punjab, Pakistan

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## EFFECT OF PLASTIC FILM AND STRAW MULCH ON WHEAT YIELD, WATER USE EFFICIENCY AND SOIL PROPERTIES IN PUNJAB, PAKISTAN

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### ABSTRACT

A two years (2014-15 and 2015-16) field experiment was performed to find out the effect of plastic film and straw mulching on yield, water use efficiency (WUE) of wheat (*Triticum aestivum* L.) and selected soil properties. There were three treatments i.e. control, plastic film and straw mulch. No mulch was added in control. Rice straw was applied on the surface at a rate of 5 Mg ha<sup>-1</sup>. Soil samples in 0-15 cm and 15-30 cm depths were taken and analyzed. Soil water contents at 20 cm interval every 7 days were determined in 0-160 cm soil depth before sowing, after harvesting and during growing seasons. Results showed that grain yield was increased significantly by 29.8 in 2014-15 and 35.6% in 2015-16 over that of control under straw mulch. Straw mulch also decreased total water use with an increase in WUE. Soil bulk density was decreased significantly with a significant increase in porosity, water stable aggregates, active carbon, organic matter and soil water contents after harvesting. Soil water storage was higher under straw mulch for most sampling times. In conclusion, mulching soil with straw can sustain wheat yield and improve WUE and soil properties.

**Key words:** Active carbon, mulch, water use efficiency, total water use, soil water storage.

### INTRODUCTION

Serious water scarcity problems due to higher evaporation rates of soil-moisture and limited rainfall are being faced particularly by arid and semi-arid regions (like Pakistan) of the world. As a result, farming practices with the aim of soil water conservation have been developed in those regions. Saving water resources for ensuring sustainable use of the agriculture lands have occurred by several practices. Transpiration of soil water, increase in infiltration rate and interception of rain drops reduce soil erosion due to presence of covers (mulch) on the soil (Kader et al., 2017). Irrigated agriculture must address the issues of water scarcity using new approaches based on environment-friendly technologies (Pereira, 2006). Soil conservation practices on agricultural fields are being done by the using the protective plant covers in every climatic zone (Gyssels et al., 2005). Terracing,

reduction in tillage and mulching are different soil-moisture conservation techniques that have been practiced now in agricultural production in every part of the world.

Small scale and poor farmers of Asia are ignoring the use of mulches, where it is required the most. There are some social and economic issues that prevents the adoption of mulches. It has been reported that sometimes crop yield may be decreased in the initial years of mulch application (Pannell et al., 2013). Adequate availability of good quality mulch materials is major constraints of wide-spread use of mulches and mulch spreading also requires more labor (Kasirajan and Ngouajio, 2012). Crop residues are removed and sold as livestock fodder for gaining quick economic benefits (Jaleta et al., 2015). For logistic reasons, straw mulching is practiced in conjunction with conservation agricultural (CA)

systems including residue retention and cover cropping (Lal, 2015).

Effects of different mulches on soil moisture are largely dependent on climatic and precipitation factors. Reduction in the evaporation rate by mulching conserves soil water and in summer surface evaporation rate is controlled due to influence of mulching on soil water regime. Soil structure, soil-moisture retention capacity is improved and weed growth is suppressed by mulching (Mutetwa and Mtaita. 2014). However, variation in soil water under different mulch types is not uniform. Different mulching types have different effects on the soil water conservation under different climatic conditions and soil types. In comparison to bare soil having no mulch, higher soil moisture is stored by the mulching treatments generally (Zhao et al., 2014).

Soil chemical and physical properties are influenced by the various mulches at the soil surface that also improve soil hydrological properties as reported by Smets et al. (2008). Soil structure, soil aeration and organic matter content are improved because soil quality deterioration is reduced due to runoff and erosion reduction by mulches (Jordan et al., 2010). Soil bulk density reduces; organic matter content, soil porosity and aggregate stability improve due to increased rate of mulch application.

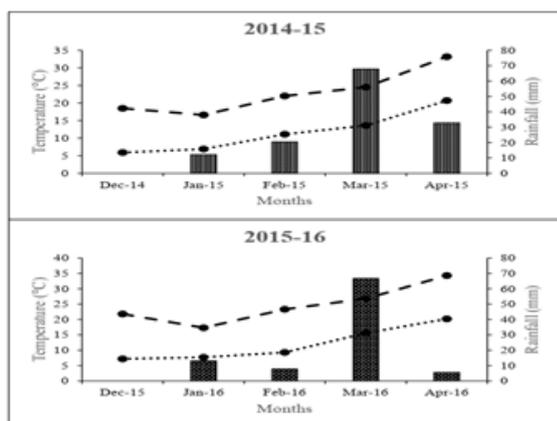
The mulches effect on soil water is focused by other studies in different parts of the world (Almeida et al., 2015; Filipović et al., 2016). Plastic film mulching was proved to be very effective in improving crop-water use efficiency and reducing soil evaporation (Dong et al., 2009). Higher economic value for farmers due to high product quality and yield by the plastic mulching are the benefits of mulches on soil properties (soil moisture and temperature control) in short-term (López et al., 2015). Effects of mulches on environmental pollution, soil health, eco-

system services and farm profitability need to be considered in long-term for farmers' perceptions and public awareness (Steinmetz et al., 2016).

Crop growth, yield and microclimate are greatly affected by both organic and inorganic mulches (Atreya et al., 2008). Plant agronomy which is a good indicator of increased crop production in agricultural is influenced by microclimates. Microclimates influenced by mulching materials can have beneficial of harmful effects on crop yield and physiology. Contrasting results under different mulching materials were also reported regarding soil-moisture storage. Rice straw mulching was found to have more positive effect than plastic mulching (Khan et al., 1988) while straw mulching results in the highest soil water storage among different mulch treatments as reported by Begum et al., (2001). Javed et al., (2019) reported that although the total cost of production increased through mulch application, but at the same time it also increases the gross income and net benefits. Higher net benefits shows that mulching is a viable management practice for improving crop yield and water saving (Jabran et al., 2016). There is prediction of increase in the variability of precipitation continuously due to climate change. Climatic conditions, especially precipitation, vary greatly among years in Pakistan and there is little literature on how WUE and soil water contents might be influenced in rich versus poor precipitation years by different mulching materials. It was hypothesized that mulching will improve yield and WUE of wheat by improving soil quality. Therefore, a two years field study was performed to find out the influence of straw mulch and plastic film on yield, WUE of wheat and soil properties. The findings may be helpful to sustain wheat yield and improve soil properties in semi-arid regions of Punjab, Pakistan and area with similar climate.

## MATERIALS AND METHODS

The two years field experiment using wheat as the test crop was conducted at Research Farm of Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Punjab, Pakistan. Faisalabad climate is semi-arid and meteorological conditions of wheat growing seasons are presented in Fig. 1.



**Figure 1:** Mean maximum (—●—) and minimum temperatures (··●··) and total rainfall (▒▒▒) during the wheat growing seasons.

Source: Agriculture Meteorology Cell, University of Agriculture Faisalabad.

Temperatures and rainfalls are monthly means and total respectively.

The experimental soil was alkaline (pH 8.05), non-saline (EC 1.48 dS m<sup>-1</sup>), deficient in organic matter (0.72%), nitrogen (0.03%), phosphorus (6.1 mg kg<sup>-1</sup>) and sufficient in potassium (168.6 mg kg<sup>-1</sup>) with bulk density of 1.41 Mg m<sup>-3</sup>. There were three treatments i.e. control (CT), plastic film (PM) and straw mulch (SM). No mulch was added in control treatment. Treatments were planned in a randomized complete block design (RCBD) having three replicates with a plot size of 5.5 × 4 m. Wheat variety “AARI-2011” was sown at a seed rate of 125 kg ha<sup>-1</sup> with a single row hand drill. Chemical control was done to control weeds and

insects. 120:85:65 kg ha<sup>-1</sup> of N:P:K recommended by Govt. of Punjab Agriculture Department respectively. Application of whole of P and K in form of single super phosphate (SSP) and sulphate of potash (SOP), respectively was done at the sowing as side dressing while N was supplied in two equal splits. At sowing, half of N was applied as urea while other half was applied with 1<sup>st</sup> irrigation at crown root initiation stage as side dressing. Rice straw and plastic film mulches were applied between crop rows manually on surface 7–10 days after seeding. Rice straw having carbon 53.3%, nitrogen 0.63% and C:N ratio 84.6 was spread on surface at the rate of 5 Mg ha<sup>-1</sup>.

Crop was harvested in each plot and plants were dried at 60 °C. Then grains were separated and weighed to determine the grain yield. Grain yields was reported at 13% moisture contents. Soil samples with steel cores having internal diameter of 50 mm were taken from 0-15 and 15-30 cm depths in each plot for determination of bulk density. Cores were oven dried at 105 °C for 24 hours and oven dried mass was divided by core volume for bulk density calculation (Blake and Hartge, 1986). Total porosity (ft) of soil was calculated as follows:

$$\text{Porosity (cm}^3 \text{ cm}^{-3}\text{)} = 1 - \frac{\rho_b}{\rho_p}$$

Where

$\rho_p$  is particle density (2.65 Mg m<sup>-3</sup>) and

$\rho_b$  is the bulk density.

Soil samples were also taken from 0-15 cm and 15-30 cm depths with auger for soil organic matter (SOM), active carbon (act. C) concentration and water stable aggregates (WSA). SOM concentration was determined with the Walkley-Black method (Ryan et al., 2001). In 500 mL conical flask, 1g of soil sample was taken.

10 mL of  $K_2Cr_2O_7$  (1N) + 20 mL of conc.  $H_2SO_4$  was also added in it. It was titrated till greenish end point against Ferrous Sulphate (0.5M) using Diphenylamine as indicator. Biologically act. C was estimated by using spectrophotometer (Weil et al., 2003). 0.5 g of dry soil was extracted with 0.02 M potassium permanganate solution filled in 50 mL centrifuge tube for the estimation of biologically active carbon. Absorbance at 550 nm was determined with a spectrophotometer. Small rainfall simulator was used to measure water stable aggregates (WSA) from disturbed samples (Moebius et al., 2007).

Soil volumetric water contents were measured at 20 cm intervals with Time Domain Reflectometry (TDR) in 0-160 cm between the crop rows in soil profiles in each plot. Water contents were determined at a interval of 7 days during whole crop season and also at sowing and harvesting. Soil water storage (SWS) was calculated using following formula:

$$SWS (mm) = SWv (\%) \times l (cm)$$

where 'l' is soil depth.

Total water use (TWU) was estimated by using following relationship (Ram et al., 2013):

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

where, P is the precipitation in mm during wheat growing season; I is the irrigation water applied in mm in each season; ' $\Delta W$ ' is water content change in soil between sowing and harvesting; D is the drainage in mm below root zone; CR is the root zone capillary rise of water and R is the surface runoff in mm (Su et al., 2007). Capillary rise and drainage were neglected and were not taken in formula. WUE was calculated using:

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

The collected data was analyzed using analysis of variance using RCB design. Mean comparison was performed using Tukey's Honestly significant difference (HSD) test at  $P \leq 0.05$ .

## RESULTS

Effect of mulches on grain yield of wheat during both years was significant (Table 1). Grain yield was maximum under straw mulch (SM) and the increase was 29.8 and 35.6% over that of control during 2014-15 and 2015-16 growing seasons respectively. The difference between plastic film (FM) and straw mulch was not significant in 1<sup>st</sup> season.

Mulches also affected the total water use in wheat significantly during both years. The maximum water use was observed from unmulched (CT) plots during both years as compared to that under straw and plastic film mulches. The lowest water use was recorded under straw mulch treatment in 2014-15 and under plastic film in 2015-16. But the differences were not significant during both years. Straw mulch significantly improved WUE of wheat. WUE was in order of SM>FM>CT in both seasons (Table 1).

Bulk density and porosity of soil was affected significantly by the application of mulches in upper as well as lower layers during both years (Figure 2a and 2b). Bulk density decreased, and porosity increased with the application of mulches. Significantly lower bulk density and higher porosity were observed in both soil layers straw mulch treatment in both seasons. Difference between plastic film and straw mulch was not significant in 2015-16 in both soil layers. Straw mulch significantly increased soil organic matter (SOM) and active carbon in both soil layers

(Figure 3a and 3b). In 2014-15, difference between plastic film and straw mulch was non-significant in 15-30 cm soil layer in both seasons. The soil water contents after harvesting varied significantly under different mulches during both seasons in each soil layer (Figure 4). In both seasons growing seasons, soil water contents were increased significantly under straw mulch in all soil layers. In deeper soil layers (80, 140-160 cm) soil water contents did not vary significantly in 2014-15. In 2015-16 growing season soil water contents were not significant in 140 and 160 cm soil layers. During both growing seasons effect of mulches on soil water storage (SWS) was different (Figure 4). In 2014-15 growing season, SWS under straw mulch was lower in the start but was higher during rest of season except for one sampling date in late of season. In 2015-16, SWS was more under straw mulch throughout the season.

## DISCUSSION

Beneficial effects of mulching have been recognized and harnessed for water conservation in drylands (Li et al., 2013a). However, depletion of agricultural water resources in Pakistan (Ahmed et al., 2007) and elsewhere in the Indo-Gangetic Plains (MacDonald et al., 2016) has drawn more attention to the use of mulches in recent years (Sarwar et al., 2010). Straw mulch acts as a protective cover on soil surface reducing the rainfall impact on soil surface and in result reduces soil dispersion. Water infiltration and water storage is increased in soil profile. Straw mulch also conserves the water efficiently infiltrated in to the soil (Li et al., 2013b).

Through a straw mulched surface rate of water loss is lower than that of a bare moist surface. This reduction in water losses is due to three reasons. First, water must convert from liquid to vapor phase if it is lost and diffuses through mulch which is greatly lower as compared to unmulched soil surface. Amount of energy required by

water to change its phase is greatly reduced by presence of mulch which acts as a barrier and prevents direct solar radiation. Third, mulch prevents the downward conduction of heat in to the soil and thereby reducing the conversion of liquid into vapors and their escape (Unger et al., 2006). The data presented herein provide a analysis on the effects of two mulching techniques (plastic film and straw mulch) on yields and WUE of wheat. The more pronounced effect of plastic film was observed as compared to that under straw mulch for maize. Changes in soil temperature and reduction in evaporation might be the positive effects of soil mulching which increased the yield. Thus favorable moisture and temperature conditions can enhance plant nutrient uptake from the topsoil and increase grain yield.

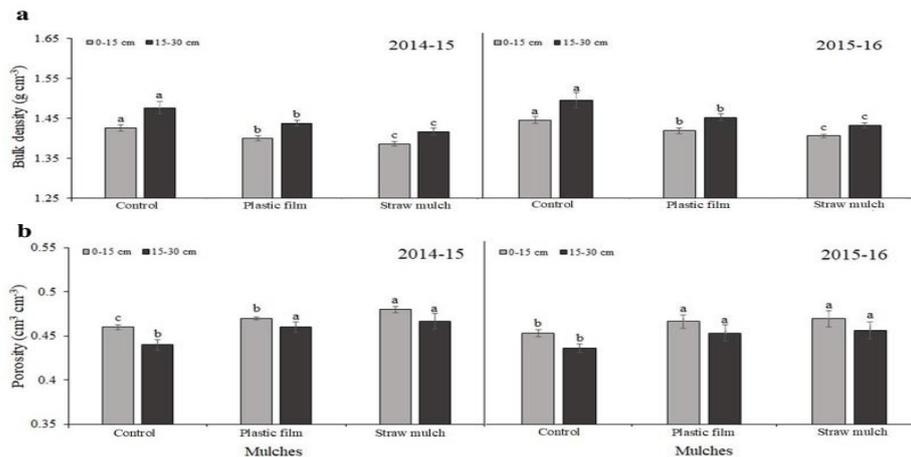
The results showed that by using straw mulch the wheat yield and WUE was more as compared to control. Mulching affects soil water availability and fertility of soil which in turn significantly influence crop yield (Peng et al., 2014). Thus, the mulching the soil with crop straw can affect crop yield positively (Karami et al., 2012). Increased crop yield and WUE with decrease in water use has also been reported by Tao et al. (2015). The surface application of straw mulch increases soil water content, reduces water evaporation, and conserves water without decreasing grain yield and leads to enhanced WUE (Jin et al., 2009).

Organic matter is the main factor that improved the soil properties (Akhtar et al., 2018). The results revealed that an increase in the soil organic matter and active carbon content was observed under straw mulch as compared with that of unmulched (control). Straw being a good source of carbon becomes constituent of SOM after decomposition (Ram et al., 2013). This SOM improvement increases aggregate stability and porosity with a decrease in bulk density. Positive effects are also observed in soil aggregates

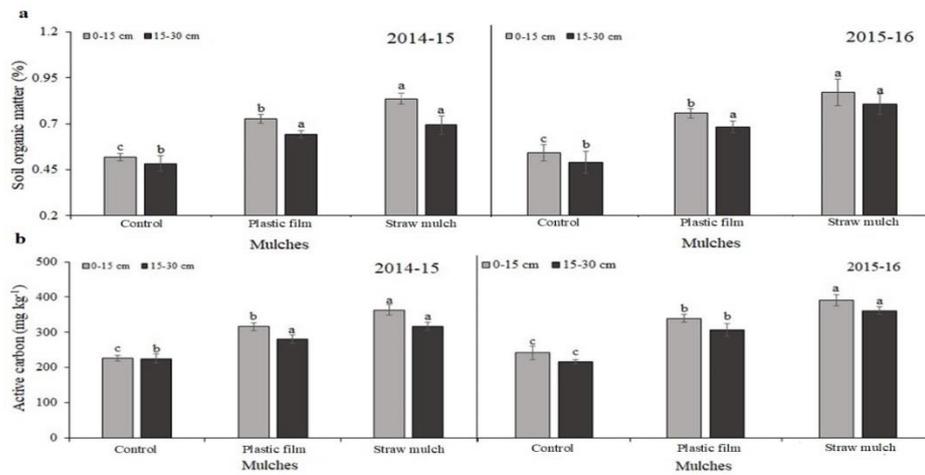
**Table 1: Grain yield, total water use and water use efficiency of wheat under different mulching materials.**

Mulches	Grain yield (kg ha <sup>-1</sup> )		Total water use (mm)		Water use efficiency (kg ha <sup>-1</sup> mm <sup>-1</sup> )	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
	Control	2.78 b	2.87 c	356.64 a	333.22a	7.81 b
Plastic film	3.32 a	3.47 b	333.47 b	309.30b	9.97 a	11.22 b
Straw mulch	3.61 a	3.89 a	327.16 b	317.55 ab	11.09 a	12.39 a
<b>HSD<sub>(0.05)</sub></b>	<b>0.51</b>	<b>0.23</b>	<b>20.08</b>	<b>19.36</b>	<b>1.55</b>	<b>0.89</b>

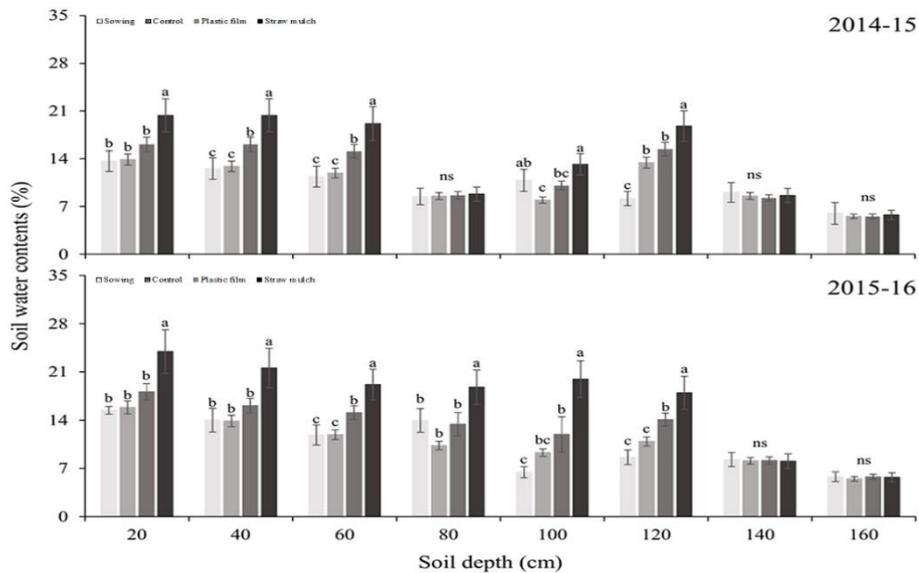
Within a column, same letters are non-significant at  $P = 0.05$ .



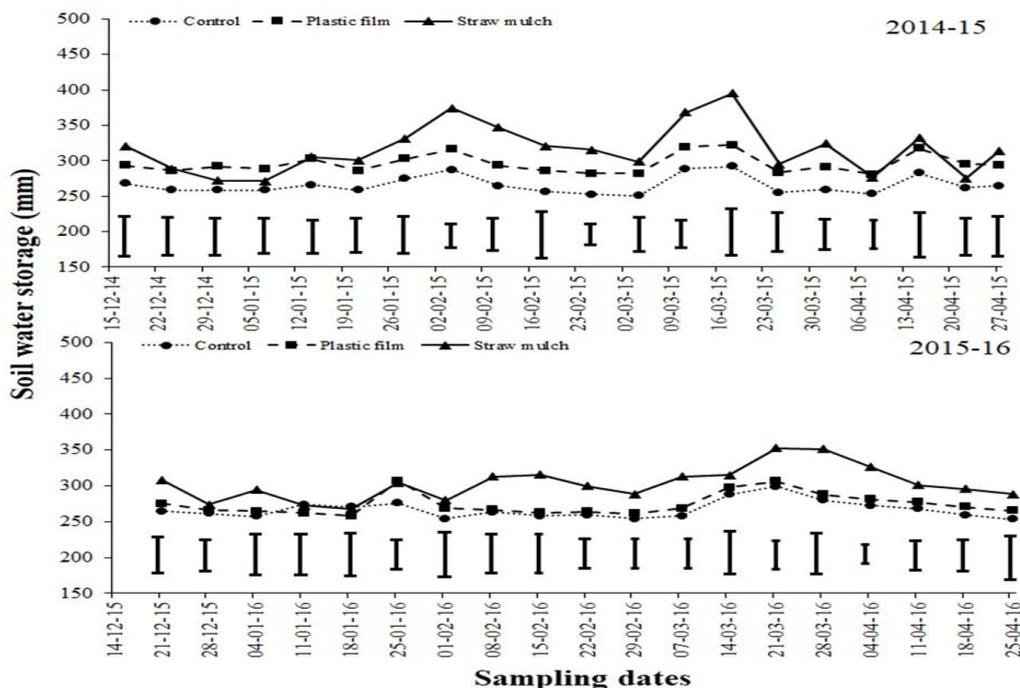
**Figure 2: Soil bulk density (a) and porosity (b) after wheat harvest under different mulches. Bars within same depth and year with same letters are non-significant at  $P = 0.05$ .**



**Figure 3: Soil organic matter (a) and active carbon (b) after wheat harvest under different mulches. Bars within same depth and year with same letters are non-significant at  $P = 0.05$ .**



**Fig. 4: Soil water contents under different mulches in 2014-15 and 2015-16. Bars within same depth and year with same letters are non-significant at  $P = 0.05$ .**



**Fig 5: Soil water storage under different mulches in 2014-15 and 2015-16**

stability and SOM improvement due to straw mulching (Wagner et al., 2007). According to Nzeyimana et al. (2017) straw mulching soil carbon, improved aggregate stability and decreased the bulk density significantly.

Rice straw mulch significantly increased the water contents and SWS which might be due to the reason that straw acts as a protective cover on soil surface reducing the water loss from soil surface. Uniform application of straw mulch on soil surface conserves soil moisture (Tao et al., 2015) and decreases soil evaporation (Zhu et al., 2010). Liu et al. (2016) also reported that mulches significantly improved the soil water contents and water storage.

The data presented suggest that soil mulching may increase WUE and narrow the gap between actual and attainable 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 to improve nutrient and water management to

narrow the yield gaps. These findings clearly demonstrate the significance of site-specific management and knowledge of mulching.

## CONCLUSION

Applying rice straw mulch had significant effect in improving yield and WUE of wheat as compared to plastic film mulching. SOM and act. C increased under straw mulch which decreased bulk density and improved porosity. Soil water contents and SWS were improved in upper and deeper soil layers. Straw mulching proved to be a good optimization to improve yield, water use efficiency and soil properties.

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## CONFLICT OF INTERESTS

We have no conflicts of interest to disclose among authors.

## REFERENCES

- Ahmed A, Iftikhar H, Chaudhry GM (2007). Water resources and conservation strategy of Pakistan. *The Pakistan Development Review*. 46: 4 Part II. pp 997-1009.
- Akhtar K, Wang W, Ren G, Khan A, Feng Y, Yang G (2018). Changes in soil enzymes, soil properties, and maize crop productivity under wheat straw mulching in Guanzhong, China. *Soil Till Res.*, 182: 94-102.
- Almeida WFD, Lima LA, Pereira GM (2015). Drip pulses and soil mulching effect on American crisphead lettuce yield. *Engenh Agrícola.*, 35: 1009-1018.
- Atreya K, Sharma S, Bajracharya RM, Rajbhandari NP (2008). Developing a sustainable agro-system for central Nepal using reduced tillage and straw mulching. *J Environ Manag.*, 88:547-555.
- Begum SA, Ito K, Senge M, Hashimoto I (2001). Assessment of selected mulches for reducing evaporation from soil columns and dynamics of soil moisture and temperature. *Sand Dune Res.*, 48:1-8.
- Blake GR, Hartge KH (1986). Bulk density, in: Klute, A. (Ed.), *Methods of Soil Analysis Part I. Agron.* 9. ASA, Madison, WI, USA: pp 3633-375.
- Dong H, Li V, Tang W, Zhang D (2009). Early plastic mulching increases stand establishment and lint yield of cotton in saline fields. *Field Crops Res.*, 111: 269-275.
- Filipović V, Romić D, Romić M, Borošić J, Filipović L, Mallmann FJK, Robinson DA (2016). Plastic mulch and nitrogen fertigation in growing vegetables modify soil temperature, water and nitrate dynamics: Experimental results and a modeling study. *Agric Water Manag.*, 176: 100-110.
- Gyssels G, Poesen J, Bochet E, Li Y, (2005). Impact of plant roots on the resistance of soils to erosion by water: A review. *Prog Phys Geogr.*, 29: 189-217.
- Jabran K, Hussain M, Fahad S, Farooq M, Bajwa AA, Alharrby H, Nasim W (2016). Economic assessment of different mulches in conventional and water-saving rice production systems. *Environ Sci Pollut Res.*, 23: 9156-9163.
- Jaleta M, Kassie M, Erenstein O, (2015). Determinants of maize stover utilization as feed, fuel and soil amendment in mixed crop-livestock systems, Ethiopia *Agric Syst.*, 134: 17-23.
- Javed A, Iqbal M, Farooq M, Lal R, Shehzadi R (2019). Plastic film and straw mulch effects on maize yield and water use efficiency under different irrigation levels in Punjab, Pakistan. *Int J Agric Biol.*, 21(4): 767-774.
- Jin H, Wang QJ, Li HW, Liu LJ, Gao HW, Hoogmoed WB (2009). Effect of alternative tillage and residue cover on yield and water use efficiency in annual double cropping system in North China Plain. *Soil Till Res.*, 104: 198–205.
- Jordan A, Zavala LM, Gil G (2017). Effects of mulching on soil physical properties and runoff under semi-arid conditions in southern Spain. *Catena*, 81: 77-85.
- Kader MA, Sengeb M, Mojid MA, Ito K (2017). Recent advances in mulching materials and methods for modifying soil environment. *Soil Till Res.*, 168: 155-166.
- Karami Z, Homae M, Afzalinia S, Ruhipour H, Basirat S (2012). Organic resource management:

- impacts on soil aggregate stability and other soil physico-chemical properties. *Agric. Ecosyst. Environ.* 148: 22-28.
- Kasirajan S, Ngouajio M (2012). Polyethylene and biodegradable mulches for agricultural applications: A review. *Agron. Sustain. Dev.* 32:501-529.
- Lal R (2015). A system approach to conservation agriculture. *J. Soil Water Conserv.* 70(4):82A-88A.
- Li S, Kang S, Zhang L, Ortega-Farias S, Li F, Du T, Tong L, Wang S, Ingman M, Guo W (2013a). Measuring and modeling maize evapotranspiration under plastic film-mulching condition. *J. Hydrol.* 503:153-168.
- Li SX, Wang ZH, Li SQ, Gao Y, Tian XH (2013b). Effect of plastic sheet mulch, wheat straw mulch, and maize growth on water loss by evaporation in dryland areas of China. *Agric. Water Manage.* 116:39-49.
- Liu Q, Chen Y, Liu Y, Wen X, Liao Y (2016). Coupling effects of plastic film mulching and urea types on water use efficiency and grain yield of maize in the Loess plateau, China. *Soil Till Res.*, 157: 1-10.
- López-López R, Inzunza-Ibarra AM, Sánchez-Cohen I, Fierro-Álvarez AE, Sifuentes-Ibarra E (2015). Water use efficiency and productivity of habanero pepper (*Capsicum chinense* Jacq.) based on two transplanting dates. *Water Sci Tech.*, 71: 885-891.
- MacDonald AM, Bonsor HC, Ahmed KM, Burgess WG, Basharat M, Calow RC, Dixit A, Foster SSD, Gopal K, Lapworth DJ, Lark RM, Moench M, Mukherjee A, Rao MS, Shamsudduha M, Smith L, Taylor RG, Tucker J, van Steenberg F, Yadav SK (2016). Groundwater quality and depletion in the Indo-Gangetic Basin mapped from in situ observations. *Nature Geosci.*, 9: 762-766.
- Moebius BN, van Es HM, Schindelbeck RR, Idowu OJ, Clune DJ, Thiesand JE (2007). Evaluation of laboratory-measured soil properties as indicators of soil physical quality. *Soil Sci.*, 172: 895-912.
- Mueller ND, Gerber JS, Johnston M, Ray DK, Ramankutty N, Foley JA (2012). Closing yield gaps through nutrient and water management. *Nature*, 490: 254-257.
- Mutetwa M, Mtaita T (2014). Effects of mulching and fertilizer sources on growth and yield of onion. *J Global Inno Agric Social Sci.*, 2: 102-106.
- Nzeyimana I, Hartemink AE, Ritsema C, Stroosnijder L, Lwanga H, Geissen V (2017). Mulching as a strategy to improve soil properties and reduce soil erodibility in coffee farming systems of Rwanda. *Catena*, 149: 43-51.
- Pannell DJ, Llewellyn RS, Corbeels M, (2013). The farm-level economics of conservation agriculture for resource-poor farmers. *Agric Ecosyst Environ.*, 187: 52-64.
- Peng Z, Wei T, Jia Z, Han Q, Ren X, LiY (2014). Effects of straw incorporation on soil organic matter and soil water-stable aggregates content in semiarid regions of northwest China. *Plos One.*, 9: e92839.
- Ram H, Dadhwal V, Vashist KK, Kaur H (2013). Grain yield and water use efficiency of wheat (*Triticum aestivum* L.) in relation to irrigation levels and rice straw mulching in North West India. *Agric Water Manag.*, 128: 92-101.
- Ryan J, Estefan G, Rashid A (2001). Soil and plant analysis laboratory manual, 2nd edition. International Center for Agricultural Research in the Dry Areas (ICARDA). Aleppo, Syria,

- Sarwar N, Maqsood M, Mubeen K, Shehzad M, Bhullar MS, Qamar R, Akbar N (2010). Effect of different levels of irrigation on yield and yield components of wheat cultivars. *Pak J Agric Sci.*, 47: 371-374.
- Smets T, Poesen J, Knapen A (2008). Spatial scale effects on the effectiveness of organic mulches in reducing soil erosion by water. *Earth Sci Rev.*, 89:1-12.
- Steinmetz Z, Wollmann C, Schaefer M, Buchmann C, David J, Tröger J, Muñoz K, Frör, Schaumann GE (2016). Plastic mulching in agriculture. Trading short-term agronomic benefits for long-term soil degradation. *Sci Total Environ.*, 550: 690-705.
- Su ZY, Zhang JS, Wu WL, Cai DX, Lu JJ, Jiang GH, Huang J, Gao J, Harmann R, Gabriels D (2007). Effects of conservation tillage practices on winter wheat water-use efficiency and crop yield on the Loess Plateau, China. *Agric Water Manag.*, 87: 307-314.
- Tao Z, Li C, Li J, Ding Z, Xu J, Sun X, Zhou P, Zhao M (2015). Tillage and straw mulching impacts on grain yield and water use efficiency of spring maize in Northern Huang-Huai-Hai Valley. *The Crop J.* 3: 445-450.
- Unger PW, Payne WA, Peterso GA (2006). Water conservation and efficient use. In: G.A. Peterson, P.W. Unger and W.A. Payne (Eds.). *Dryland Agriculture*. ASACSSA-SSSA, Madison, WI, USA. pp 39-85.
- Wagner S, Cattle SR, Scholten T (2007). Soil-aggregate formation as influenced by clay content and organic-matter amendment. *J Plant Nutri Soil Sci.*, 170: 173-180.
- Weil RR, Islam KR, Stin MA, Gruver JB, Samson-Liebig SE (2003). Estimating active carbon for soil quality assessment: A simplified method for laboratory and field use. *Americ J Alter Agric.*, 18: 3-17.
- Zhao H, Wang RY, Ma BL, Xiong YC, Qiang SC, Wang CL, Liu CA, Li FM (2014). Ridge-furrow with full plastic film mulching improves water use efficiency and tuber yields of potato in a semiarid rainfed ecosystem. *Field Crops Res.*, 161: 137-148.
- Zhu H, Wu J, Huang D, Zhu Q, Liu S, Su Y, Wei W, Syers JK, Li Y (2010). Improving fertility and productivity of a highly-weathered upland soil in subtropical China by incorporating rice straw. *Plant Soil.*, 331: 427-437.