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Effect of Plastic Mulch and Different Irrigation Practices on Soil Properties, Nutrient Contents and Their Availability in Maize

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Abstract: Mulching favors the plant growth by improving the soil physical practices, adding organic matter, by reducing the moisture losses and moderating the temperatures. Due to these associated benefits with mulching, a field study was carried out at Institute of soil and environmental sciences, University of Agriculture, Faisalabad, to evaluate, the suitability of mulching with different irrigation methods, in flat, ridge and raised bed planting methods. Results of this study revealed the significant effect of mulching on soil physical indices such as porosity, soil bulk density, soil strength and organic matter. Maximum soil organic carbon (0.49%) was observed in furrow irrigated ridge sowing with plastic mulch (FIFM). The observation of least soil bulk density (1.40 Mg m^{-3}) and soil strength (416.7 kPa) in furrow irrigated raised bed sowing with plastic mulch, indicates it a suitable management practice. However soil, maximum soil porosity (0.47 m^3 m^{-3}) was recorded in furrow irrigated raised bed sowing, with plastic mulch. Soil organic carbon contents were increased to 11.36%. Significant increase in nutrient uptake of nitrogen (15 kg ha^{-1}), phosphorus (3.7 kg ha^{-1}) and potassium (10.48 kg ha^{-1}) was observed in flood irrigated flat sowing with plastic mulch treatment.

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1. Introduction

With the increasing population of the world, it is essential to increase food production without affecting our natural resource of soil, water and air in future. The availability of water will be the major constraint in the sustainable agricultural production over the next few decades. Water table is going down gradually, and the agriculture is competing with urban and industrial water requirements. About one-third population of the developing countries will not have sufficient water resources to fulfill their agricultural and other needs in the year 2025 (Seckler et al., 1998). Pakistan is country with a population around 180 million, it will be hard to meet its needs of food, if sufficient water is not available for agriculture production (Kahlown et al., 2006). Water is of the most essential factor contributing to successful crop production through its movement from the soil to plant and ultimately to atmosphere (Boyer, 1982). Water is required for different physiological processes e.g. photosynthesis, enzyme activity, protein synthesis, and metabolic transpiration for the growing crops (Naceu et al., 1999). Many studies have been conducted to check the water loss through surface evaporation loss from soil and transpiration from leaves (Jin et al., 1999; Liu et al., 2002 and Zhang, 2007).

Evapo-transpiration, consisting of movement of water from soil surface and plant transpiration, is a main component of water balance. Grain yields may be described as a linear function of evapotranspiration for most crops. Water use efficiency and agriculture production can be improved by improving soil and water management practices, and growing drought-tolerant and high yielding cultivars. Efficient irrigation water application techniques and practices are means to realize potential water savings, thus moderating the negative impacts of higher water use on farm incomes and environmental impact on soils and groundwater systems (Khan and Abbas, 2007).

Mulching is one of the good management practices among all other to improve water use efficiency (Lin et al., 2015). Mulching material is divided into two types, i.e. organic and inorganic material. Most frequently used inorganic mulch is plastic mulch which is effective in order to cultivate earlier produce by controlling weeds and warming the soil (Katherine et al., 2006). Application of plastic mulch increases crop yield through improving solar energy, water and fertility status of soil (Shahid et al., 2014), reducing soil water loss and removing weeds (Bu et al., 2002), as weeds may pose inhibitory effect on the component crop through release of allelochemicals (Zohaib et al., 2014). The cost of plastic mulch is lower compared with that of gravel and sandy, and it is easily managed. Thus, it has been widely reported that both the grain yield and water use efficiency (WUE) are increased under mulches (Li et al., 2001; Li and Gong, 2002).

Land use and management response soil properties (Oku et al., 2015), such as soil texture, porosity, infiltration rate, organic matter and soil structure have frequently been reported for soil mulched with organic materials and plastic mulch (Saroa and Lal, 2003). In addition it increases the water use efficiency and microbial activity (Zhang et al., 2008), which increases the productivity of the crop (Murtaza et al., 2014). Mulching with plastic film enhanced water use efficiency by 14 % as compared to control treatment, grain yield by 17 % and biological yield by 19 %. The yield increases are generally due to increase in water content in the soil due to lesser evaporation. However, there is no detailed report comparing the effect of plastic mulch along with different irrigation practices on maize growth and water use efficiency (Tolk et al., 1999). So this study was aimed to evaluate the effect and irrigation mulches on physical properties of soil, water use efficiency (WUE), growth and yield of spring maize.

2. Material and Methods

2.1 Experimental site

The field experiment was conducted to study the effect of plastic mulch and different irrigation practices (Table 1) to enhance water use efficiency, soil physical indicators and maize yield at the Research Area, Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad. This area has typical semi-arid climate. The experiment was practiced during 2011.

Table 1: Treatment descriptions

T_1	Flood irrigated flat sowing without plastic mulch (FIF) (Control)
T_2	Flood irrigated flat sowing with plastic mulch (FIFM)
T_3	Furrow irrigated ridge sowing with plastic mulch (FIRM)
T_4	Furrow irrigated raised bed sowing with plastic mulch (FIRBM)

2.2 Design and treatments

There were four treatments replicated four times by following randomized complete block design (Table 1). The treatment (Flood irrigated flat sowing without plastic mulch) was made as control, as it is usual practice for cultivation of maize, in central irrigated zones of Punjab.

Before sowing the crop, composite soil samples were taken at random from the experimental field for the existing physical and chemical characteristics of soil. These soil samples were air-dried, ground, well mixed and passed through a 2 mm sieve and analyzed for different physico-chemical characteristics of soil (Table 2) before experiment. Soil texture was determined by hydrometer method (Gee and Bauder 1986). Moreover, pH of soil saturated paste was determined with a pH meter and electrical conductivity (EC) of soil saturated paste extract determined by EC meter. Field capacity of soil was determined by pressure membrane apparatus. Organic matter was determined by following Nelson and Sommers (1982).

2.3 Agronomic management practices

The recommended doses of NPK were applied as a basal dose to each treatment. Full dose of phosphorus, potassium, and 1/3 of nitrogen was applied at the time of sowing in the form of triple super phosphate (TSP), muriate of potash (MOP) and urea, respectively. The remaining 1/3rd of nitrogen was applied at knee height and 1/3 at tasseling stage. Soil Samples for organic carbon determination were collected with auger before sowing and at harvest from required depths for analysis from each treatment.

2.4 Procedures for sampling and analysis

After crop harvest density, porosity and organic matter were determined in the following way. Soil bulk density (Mg m^{-3}) and total porosity (m^3 m^{-3}) were measured from 0-10 cm depth, and 0-10 cm depth respectively. Soil organic carbon concentration was determined from 0-20 cm depth. Moreover, soil strength (kPa) and soil N, P and K concentrations were also evaluated from the plough layer. Soil and plant samples analysis were carried out according to analytical methods devised by U. S. Salinity Lab. Staff (1954).

Table 2. Physical and chemical characteristics of soil

Characteristics	*Unit*	*Value*
Particle Size Analysis		
Sand	%	52.80
Silt	%	19.75
Clay	%	27.45
Textural Class		Sandy clay loam
Chemical Analysis		
SOC concentration (0-5 cm depth)	%	0.4
SOC concentration (5-10 cm depth)		0.3
SOC concentration (10-20 cm depth)		0.2
Saturation Percentage	%	36.1
EC	dSm^{-1}	2.82
pH		7.7
Total Nitrogen	$g\ kg^{-1}$	0.42
Available Phosphorus	$mg\ kg^{-1}$	13
Extractable potassium	$mg\ kg^{-1}$	160
Soil NO^{-}_{3}-Nconcentration (0-10 cm depth)	$mg\ kg^{-1}$	2.82
Soil NO^{-}_{3}-Nconcentration(10-25 cm depth)	$mg\ kg^{-1}$	4.83
Soil NO^{-}_{3}-Nconcentration(25-40 cm depth)	$mg\ kg^{-1}$	7.33
Soil $NO\text{-}_{3}$-Nconcentration (25-40 cm depth)	$mg\ kg^{-1}$	2.34

SOC: soil organic carbon, EC: electrical conductivity, NO^{-}_{3}: Nitrate

Soil pH was measured by HM 12 pH meter and electrical conductivity was measured by Jenway Conductivity Meter Model 4070. Moisture content was determined by using the following equation.

$$H_2O(\%) = \frac{\Delta M}{M_2} \quad (1)$$

Where H_2O (%) is moisture content in percentage, ΔM is loss in mass of soil after drying and M_2 is mass of oven dry soil.

$$Water\ content\ (\%) = \frac{Loss\ in\ mass\ on\ drying}{Mass\ of\ oven\ dry\ soil} \times 100$$

(2)

Soil organic carbon was determined following the methods described by Ryan et al. (2001).

$$Oxidizable\ organic\ carbon = \{(Vblank - Vsample) \times 0.3 \times M\} / (weight\ of\ soil\ (g))$$

(3)

Percentage of total organic carbon (w/w) = 1.33 × percentage of oxidizable organic carbon

SOC concentration ($g\ kg^{-1}$) = percentage of total organic carbon × 10, Where, M = Molarity of ferrous sulphate solution, V blank = Volume of ferrous ammonium sulphate solution used for blank (mL), Vsample = Volume of ferrous ammonium sulphate solution with soil sample (mL).

Nitrate-N in soil was measured by a Spectrophotometer method, using chromotropic acid. Soil bulk density from 0-10 depth was determined by using the following formula.

$$Bulk\ density\ (Mg/m^3) = \frac{(Mass\ of\ oven-dry\ soil)}{(Volume\ of\ soil\ including\ pore\ spaces)}$$

(4)

The total porosity of the soil (f) was obtained from its bulk density (ρb) and particle density (ρp) by the following formula, f = 1- (ρb /ρp)

N was calculated by the formula: $\%\ N = \frac{(V-B) \times N \times R \times 14.01 \times 100}{Wt \times 1000}$

Where, V = Volume of 0.01 N H_2SO_4 used for titration of the sample (mL), B = Digested blank titration volume (mL), i.e. without soil, N = Normality of H_2SO_4 solution, 14.01 = Atomic weight of nitrogen, R = Ratio between total volume of the digested and sample volume used for distillation and Wt. = Weight of air-dry soil (g).

Sodium extraction was made with the ammonium acetate and extractable K was determined by Corning Flame Photometer-410 after calibrating with K standard solution and soil penetration resistance was measured with Cone Penetrometer.

3. Results and discussion

3.1 Soil Properties

3.1.1 Soil Organic Carbon (%)

The effect of plastic mulch with different irrigation practices was significant on SOC at 0-5 and 10-20 cm. Data regarding the effect of different irrigation practices with plastic mulch on SOC is given in Table-3. Maximum SOC was observed in flood irrigated flat sowing with plastic mulch (FIFM) (0.49 %), followed by furrow irrigated raised bed sowing with plastic mulch (FIRBM) and furrow irrigated ridge sowing with plastic mulch (0.48 %) and minimum in flood irrigated flat sowing without mulch (0.44 %). So mulching significantly increased SOC 11.36 % in FIFM and 9.09 % in FIRBM and FIRM treatments. Enhancements in soil physical indices such as porosity, infiltration rate, organic matter and soil structure have also frequently been reported for soil mulched with organic materials (Saroa and Lal, 2003).These increases might be due to Carbon addition through the roots and crop residues. Polythene sheet also prevent fast decomposition of OM due to more moisture conservation and moderating temperature, so more SOC was found in case of polythene.

3.1.2. Soil bulk Density (Mg m^{-3})

The soil on the top of plastic mulch with different irrigation practices retained structural stability and lower bulk density than that in un-mulched. The differences arose presumably because there was less structural disruption of aggregates and settlement in the unsaturated condition of the polythene in furrow irrigation raised bed sowing compared to the saturated condition of the flood irrigation. There was lesser bulk density 1.40 Mg m^{-3} in furrow irrigated raised bed sowing with plastic mulch and higher 1.45 Mg m^{-3}in flood irrigation. So FIRBM treatment significantly decreased the bulk density as compared to control and other treatments. These results are similar to Mbah et al. (2010) who found that plastic film mulching resulted in significantly higher water retention than the control. Plastic film mulching also resulted in decrease bulk density 9 % (BWM), 4 % (WM) and 17 % (BM) than the control. Increase in yield observed was 55-78 % than the control.

3.1.3. Soil porosity (m^3 m^{-3})

The effect of plastic mulch with different irrigation practices was significant on soil porosity at different depths Table-3. Application of plastic mulch with different irrigation practices significantly enhanced soil porosity.

Table 3: Effect of plastic mulch and different irrigation practices on soil organic carbon and soil bulk density

Treatment	Soil Organic Carbon (SOC %)	Soil Bulk Density (Mg m^{-3})	Soil porosity ($m^3 m^{-3}$)	Soil strength (kPa)
FIF	0.44c	1.45a	0.43c	480.0b
FIFM	0.49a	1.45a	0.43c	486.7a
FIRM	0.48ab	1.43b	0.45b	466.7c
FIRBM	0.48ab	1.40c	0.47a	416.7d

Flood irrigated flat sowing without plastic mulch (FIF), Flood irrigated flat sowing with plastic mulch (FIFM), Furrow irrigated ridge sowing with plastic mulch (FIRM), and Furrow irrigated raised bed sowing with plastic mulch (FIRBM).

Maximum soil porosity(0.47m^3 m^{-3}) was recorded in furrow irrigated raised bed sowing, with plastic mulch, followed by (0.45m^3 m^{-3}) furrow irrigated ridge sowing with plastic mulch whereas, minimum (0.43m^3 m^{-3}) was observed in flood irrigated flat sowing. This may be attributed to lesser soil compaction and better soil aeration especially in early growth period and more uniform distribution of nutrients in soil profile.

3.1.4. Soil Strength (kPa)

The data regarding soil strength (kPa) as affected by plastic mulch with different irrigation practices is represented in given Table-3, which depicts that plastic mulch with different irrigation practices have significant effect on soil strength. Application of plastic mulch along with different irrigation practices reduced soil strength. There was lesser soil strength (416.7 kPa) in furrow irrigated raised bed sowing with plastic mulch, followed by (466.7 kPa) in furrow irrigated ridge sowing with plastic mulch, higher (416.80 kPa) in flood irrigated flat sowing without plastic mulch and highest (486.0 kPa) was measured in flood irrigated flat sowing with plastic mulch. Soil moisture content was also enhanced with increasing mulch rate but mulch has no effect in case of low rate. Mulch application also resulted in increased infiltration rate and reduced soil strength (Jordan et al. 2010). Pervaiz et al. (2009) also concluded that mulch increased soil organic matter (1.32 g kg^{-1}) and soil moisture contents (17 %), but decreased bulk density (1.35 Mg m^{-3}) and soil strength (464 kPa) compared to control.

3.2. Nutrients status of plant and soil

3.2.1. Nitrogen uptake (kg ha^{-1}) by maize

Data in Table-4 depicts the statistical behavior of different treatments on nitrogen uptake by maize crop. The N uptake was higher under FIRBM (148.7 kg ha^{-1}), followed by FIRM (142.2kg ha^{-1}), and FIFM

(135.7 kg ha^{-1}), while lowest yield i.e., 129.3 kg ha^{-1} was produced by FIF (control). In conclusion, maize plant furrow irrigated raised bed with plastic mulch exhibited 15 % more N uptake than flood irrigated flat sowing without mulch. Similarly furrow irrigated ridge sowing maize showed 9.98 % N uptake. There was 4.5 % more N uptake where polythene mulch was applied in flood irrigation over control. Singh et al. (2002) also reported that total nutrient uptake of nitrogen, phosphorus; potassium was significantly higher under mulch than no mulch treatment.

3.2.2. Phosphorous uptake (kg ha^{-1}) by maize

Data in Table-4 depicts the statistical behavior of different treatments on nitrogen uptake by maize crop. The P uptake was higher under FIRBM (38.7 kg ha^{-1}), followed by (35.7 kg ha^{-1}) FIRM, followed by (31 kg ha^{-1}) FIFM and lowest (29.9 kg ha^{-1}) by FIF (control).Resultantly, maize plant furrow irrigated raised bed with plastic mulch exhibited 29 % more P uptake than flood irrigated flat sowing without mulch. Similarly furrow irrigated ridge sowing maize showed 19 % more P uptake. There was 3.7 % more P uptake where polythene mulch was applied in flood irrigation over control. These results attributed to that account of the corresponding higher amount of the available N&P due to mulch, which substantially increased utilization and the productivity.

Table 4: Effect of plastic mulch and irrigation practices on N, P and K uptake (kg ha^{-1}) by maize

Treatment	N uptake (*kg ha^{-1}*)	P uptake (*kg ha^{-1}*)	K uptake (*kg ha^{-1}*)
FIF	129.3 d	29.9 c	132.6 c
FIFM	135.7 c	31.0 c	137.3 b
FIRM	142.2 b	35.7 b	140.6 b
FIRBM	148.7 a	38.7 a	146.5 a
LSD value	4.6	2.814	4.6894

Flood irrigated flat sowing without plastic mulch (FIF), Flood irrigated flat sowing with plastic mulch (FIFM), Furrow irrigated ridge sowing with plastic mulch (FIRM), and Furrow irrigated raised bed sowing with plastic mulch (FIRBM).

3.2.3. Potassium uptake (kg ha^{-1}) by maize

Data in Table-4 depicts the statistical behavior of different treatments on K uptake by maize crop. The P uptake was higher under FIRBM (146.5 kg ha^{-1}), followed by FIRM (140.6 kg ha^{-1}), and FIFM (137.3 kg ha^{-1}), while lowest K uptake i.e., 132.6 kg ha^{-1} was observed under FIF (control). Maize plant furrow irrigated raised bed with plastic mulch exhibited 10.48 % more K uptake than flood irrigated flat sowing without mulch. Similarly furrow irrigated ridge sowing maize showed 6.04 % more P uptake. There was 3.54 % more P uptake where polythene mulch was applied in flood irrigation over control. Pinjari (2007) also reported that nitrogen, phosphorus and potassium uptake in the leaves, stem, cob sheath, cob axis, kernels were significantly higher under polythene mulch than no mulch.

3.2.4. Soil Nitrogen contents (g kg^{-1})

The results obtained from statistical interpretation of N concentration in soil (Table 4) showed that N concentration was significantly affected by plastic mulch with different irrigation practices at 0-20 cm depth .Treatment FIRBM gave maximum N content (0.65 g kg^{-1}) in soil, followed by FIRM treatment which gave (0.62 g kg^{-1}) N in soil ,followed by FIFM treatment which gave (0.6 g kg^{-1}) N in soil, while FIF showed the lowest value of N content(0.58 g kg^{-1}) in soil. About 12 % more soil N was noted with FIRBM, 6.9 % in FIRM and 3.45 % in FIFM as compared to control.

3.2.5. Soil Phosphorous contents (mg kg^{-1})

The results obtained from statistical interpretation of P concentration in soil (Table 4) showed that phosphorus concentration was significantly affected by plastic mulch with different irrigation practices at 0-20 cm depth .Treatment FIRBM gave maximum p content (20.9 mg kg^{-1}) in soil, followed by FIRM treatment which gave (20.4 mg kg^{-1}) p in soil ,followed by FIFM treatment which gave (19.9 mg kg^{-1}) P in soil, while FIF showed the lowest value of P content (18.1 mg kg^{-1}) in soil. About 15.5 % more soil P was noted with FIRBM, 10.5 % in FIRM and 9.9 % in FIFM as compared to control. Weeraratna and Asghar (1992) also found that straw mulch application resulted in more soil N availability. Increase in soil N under mulch might be due to addition of organic material.

Table 5: Effect of plastic mulch and irrigation practices on soil N, P and K contents

Treatment	N status (g kg^{-1})	P status (mg kg^{-1})	K status (mg kg^{-1})
FIF	0.58 d	18.1 b	146.5 c
FIFM	0.60 c	19.9 ab	159.5 b
FIRM	0.62 b	20.4 a	162.6 b
FIRBM	0.65 a	20.9 a	170.2 a
LSD value	0.01	1.85	6.64

Flood irrigated flat sowing without plastic mulch (FIF), Flood irrigated flat sowing with plastic mulch (FIFM), Furrow irrigated ridge sowing with plastic mulch (FIRM), and Furrow irrigated raised bed sowing with plastic mulch (FIRBM).

3.2.6. Soil K (mg kg^{-1})

The results obtained from statistical interpretation of K concentration in soil (Table-5) showed that potassium concentration was significantly affected by plastic mulch with different irrigation practices at 0-

20 cm depth .Treatment FIRBM gave maximum K content (170.21 mg kg^{-1}) in soil, followed by FIRM treatment which gave (162.6 mg kg^{-1}) K in soil ,followed by FIFM treatment which gave (159.5 mg kg^{-1}) P in soil, while FIF showed the lowest value of K content (146.53 mg kg^{-1}) in soil. About 16 % more soil K was noted with FIRBM, 11 % in FIRM and 8.9 % in FIFM as compared to control. Weerararna and Asghar (1992) also found that straw mulch application resulted in more soil N availability. Increase in soil N under mulch might be due to addition of organic material.

4. Conclusion

Results of this study revealed the significant effect of mulching on soil physical indices such as porosity, soil bulk density, soil strength and organic matter. The study has shown the beneficial effects of mulch application under different irrigation regimes. Promising results were obtained in furrow irrigated raised bed condition along with mulch application (FIRBM) that improved soil properties and nutrient uptake. However, flood irrigation with flat sowing with mulch (FIFM) had maximum soil organic carbon.

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Competing Interests

The Authors declare that they have no conflict of interests regarding contents of this paper. First two authors. Commercial names or details of equipment's are just for guidelines only.

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