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Soil physical characteristics and yield of wheat and maize as affected by mulching materials and sowing methods

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Abstract

Soil physical degradation due to agriculture activity is a pressing issue in Pakistan causing reduction in crop yields. The study was conducted to assess the effects of two sowing methods and two mulching materials on soil physical characteristics and yields of wheat and maize during 2008-10 at Faisalabad, Pakistan. Results showed that Bed sowing method along with wheat straw mulch increased Leaf Area Index of wheat by 5 to 16%, and of maize by 4 to 14% compared with other treatments. This treatment also produced maximum 1000-grain weight (50.5 g) of wheat and maize (439.2g) as compared to flat sowing method where no mulch was applied. The highest grain yields of wheat (5017 kg ha^{-1}) and maize (10.6 Mg ha^{-1}) were recorded in Bed sowing + wheat straw mulch plots. Bed sowing alone decreased bulk density by 4% at 0-15 cm soil depth and 13.7% less soil penetration resistance (788.2 kPa) was noted. About 23.0% higher soil organic carbon contents (4.2 g kg^{-1}) at 0-15 cm soil depth, 39.1% higher field saturated hydraulic conductivity (24.3 mm hr^{-1}) and 14.2% higher infiltration rate (58.5 mm hr^{-1}) were recorded compared to flood irrigated flat sowing. Furrow irrigated raised bed technique was found to be environment friendly in combination with farm manure compared to wheat straw having enhanced soil organic carbon contents.

Key words: Bed and flat sowing, mulch, soil physical properties, grain yield

Introduction

Pakistan is an agricultural country with a good irrigation canal network. It plays a central role in the economy of Pakistan. Despite its critical importance, it has been suffering from slow decline in agricultural productivity. Khaliq-uz-Zaman (2011) estimated the Cobb Doughlas production function and calculated the coefficients for number of tubewells, tractors, improved seed, fertilizer use and area irrigated. This analysis showed that only increased cultivated area was significant and other factors were likely to play an insignificant role in the future and Sarwar *et al*. (2010) pointed out soil water stress to be the major yield reduction factor amongst others.

In addition to these factors, soil physical degradation is also an important aspect that affects crop yield adversely. The loss of soil aggregate stability, soil compaction, soil crust formation or sealing are examples of soil physical degradation (Dexter and Czyz, 2007; Khan, 2000). Aggregate breakdown by water is mainly related to slaking in organic matter deficient soils, and it influences seedling emergence and root growth (Annabi *et al*., 2007). Soil crusts and seals are formed due to low organic matter, high silt and/or exchangeable sodium percentage and it is a serious problem in Pakistan for causing reduction in food cropped output (Khan, 2000). As Nizami and Khan (1989 and 1991) reported reduction in seed germination, yield and plant population due to soil crusting. A linear decrease in seed germination with increasing soil compaction was noted by Sheikh (1976).

Rain drop and surface irrigation has immediate effect on unprotected surface soil because of their potential and kinetic energy. The mulches offer best protection against drop impact, water loss by evaporation and crust formation. Moreover, it enhances yield by improving soil physical conditions, including improved stability in the topsoil (De Silva and Cook, 2003; Tiwari *et al*., 2003), infiltration and storage of water in the rhizoshpere, and structure and macro-porosity of soil (Acharya and Kapur, 1993). It regulates the influence of environmental factors on soil by controlling diurnal seasonal fluctuations in soil temperature (Lalitha *et al*., 2001). Mulches also affect the soil organic carbon dynamics (Chantigny, 2003) and it is increased under crop residue mulch (Saroa and Lal, 2003). However, the maintenance of soil organic carbon is a problem under the intense climate that aggravates the decomposition process. Different organic materials evolve CO_2 in varying concentration owing to different C: N ratio (Gaur *et al*., 1971), hence, there is also a need to use such mulches which are environment friendly and cost effective.

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The objectives of the present study were i) to evaluate the effects of two sowing methods and two mulching materials on bulk density, field saturated hydraulic conductivity, infiltration rate, soil penetration resistance and soil organic carbon and ii) to quantify the effect on grain yields of wheat and maize crops.

Materials and Methods

The study was conducted at Research Farm of Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan. The experimental area is located at 73° East longitude, 31° North latitude and at an altitude of 184 m above sea level. Prior to experimentation, basic soil characteristics were determined (Table 1). Disturbed and undisturbed soil samples were taken from 0-15, 15-30 and 30-45 cm depths from five sampling points using the diagonal technique for the comprehensive representation of the research area (4048 m^2). Disturbed soil samples were taken using auger and were analyzed for particle size distribution using hydrometer method (Bouyoucos, 1962). Soil organic carbon (SOC) contents were estimated following the method described by Ryan *et al.* (2001). Undisturbed soil samples were collected for soil bulk density (BD) determination from each depth using stainless steel cylinders (Blake and Hartge, 1986).

pressed into the soil until soil surface was leveled with the base of the cone. The measurements of SPR, BD, k_{fs}, IR and SOC were carried out during April after wheat harvest and during November after maize harvest in each year. Data for grain yield of wheat and maize were recorded each year and were pooled for statistical analysis. The leaf area index (LAI) was measured by formula reported by Dwyer and Stewart (1986):

$$\text{Leaf area} = L \times W \times A \qquad [14]$$

Where ***L*** is leaf length, ***W*** is the greatest leaf width and ***A*** is factor having value of 0.75 for maize and 0.80 for wheat crop. Leaf area index of wheat and maize crop was measured at 15 days interval upto harvesting stage. Grain yield and 1000-grain weight of wheat and maize were recorded at crop maturity from sub plots. A strip of square meter was taken from each experimental unit and measurements were recorded.

Correlations were studied between SOC and BD; SOC and K_{fs}, and BD and K_{fs}. The data set for correlations consisted of 72 observations for each parameter. Soil physical data were also pooled and analyzed statistically by using Statistics 8.1 versions. Least Significance Difference (LSD) technique was used for comparing treatment means. The treatment combinations for the study are shown in Table 2. Temporal variations in temperature and rainfall during 2-Year study are shown in Figure 1.

Table 1: Soil physical characteristics of the experimental site before the start of study

Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural class	BD (Mg ha^{-1})	Θ_s (%)	f_e (%)	SOC (g kg^{-1})
0-15	41.80	34.71	23.49	Loam	1.41	46.8	39.5	2.50
15-30	45.21	31.34	23.45	Loam	1.45	45.3	40.3	1.90
30-45	46.37	30.19	23.44	Loam	1.49	43.8	39.0	1.80

BD: bulk density; Θ_s: saturated soil water contents; f_e: soil effective porosity; SOC: Soil organic carbon

The study was conducted using wheat-maize rotation for two years. The recommended dose of NPK was applied at 105 – 85 – 62 kg ha^{-1} for wheat, and 300 – 150 – 125 kg ha^{-1} for maize. The treatments were two sowing methods namely Bed sowing and Flat sowing with two mulching types (wheat straw and farm manure) applied at a rate of 8 Mg ha^{-1} on the surface at completion of germination and no mulch was applied in control plots. The design was randomized complete block with split arrangements. The plots were irrigated using cut throat flume for water quantification as and when required. After harvesting of each crop, three undisturbed samples using core method from 0-15, 15-30 and 30-45 cm soil depths were taken for determination of BD. The SOC contents were also measured by drawing soil sample at these depths. The infiltration rate (IR) and field saturated hydraulic conductivity (k_{fs}) were measured following procedures given in Klute (1986). Soil penetration resistance (SPR) was measured using cone penetrometer. The cone was

Table 2: Description of treatment combinations used in the study

Treatment	Description
BM_o	Bed sowing + no mulch
BM_{wst}	Bed sowing + mulch (wheat straw @ 8 Mg ha^{-1})
BM_{mn}	Bed sowing + mulch (farm manure @ 8 Mg ha^{-1})
FM_0	Flat sowing + no mulch
FM_{wst}	Flat sowing + mulch (wheat straw @ 8 Mg ha^{-1})
FM_{mn}	Flat sowing + mulch (farm manure @ 8 Mg ha^{-1})

Results

Effect of mulching and sowing methods on yield attributes of wheat and maize

Leaf area index (LAI)

Maximum LAI was recorded 75 days after sowing (DAS) of wheat (Figure 2) and 60 days after sowing of maize (Figure 3). The treatment of Bed sowing + wheat straw mulch produced maximum LAI (4.55) in wheat and 6.50 in maize. The LAI ranged from 3.91 to 4.55 in wheat and 5.69 to 6.50 in case of maize. The minimum LAI was recorded in plots where no mulch was applied under flat sowing for both crops. The LAI decreased in all treatments after 75 days of wheat sowing and 60 days of maize sowing. In maize, averaged over sowing methods, mulching materials showed 45.5 and 49.5% decrease under bed and flat sowing, respectively. In wheat, averaged over sowing methods, 50.8 and 55.3% decrease was noted in bed and flat sowing, respectively, under different mulching materials. At harvesting, only flat sowing without mulch depicted minimum LAI of 2.89 in maize and 1.68 in wheat.

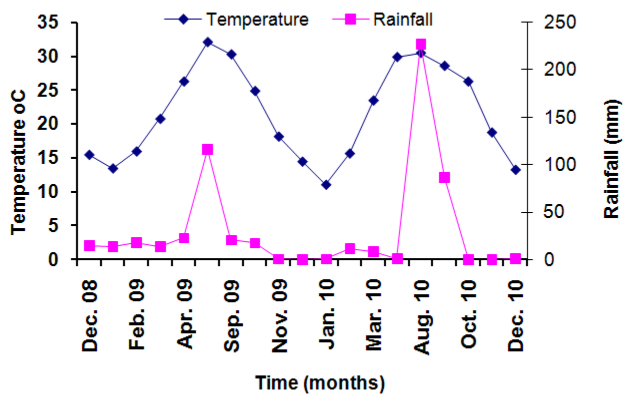

Figure 1: Temporal variations in temperature and rainfall during the 2-year study

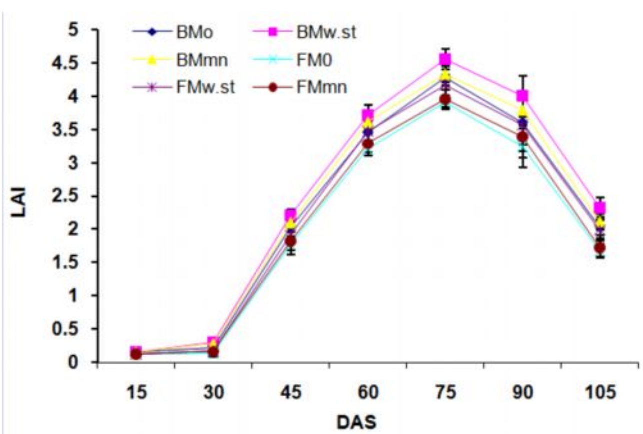

Figure 2: Effect of mulching and sowing methods on leaf area index of wheat

1000-grain weight (g)

Figure 4 (wheat) and 5 (maize) indicated that both mulching materials produced significant increase in 1000-grain weight (GW) under bed and flat sowing systems. Maximum GW, 50.5 (wheat) and 439.2 g (maize) was noted in treatment combination of wheat straw mulch and bed sowing system and minimum GW of 30.7 (wheat) and 263.1 g (maize) was noted in treatment of mulch control + flat sowing. This treatment showed 39.2 and 40.1% decrease in GW of wheat and maize, respectively, over BM_{wst} treatment. Wheat straw and farm manure mulches under bed sowing and flat sowing system showed similar effects on GW of wheat.

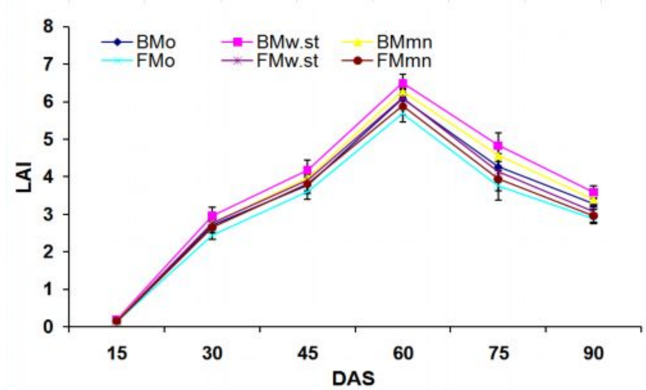

Figure 3: Effect of mulching and sowing methods on leaf area index of maize

The comparison of mulching materials indicated that wheat straw mulch showed 4.8 and 4.1% increase over farm manure mulch under bed sowing system; 9.9 and 14.5% increase over farm manure mulch under flat sowing system in GW of wheat and maize, respectively. Among the sowing methods alone, bed sowing gave more GW of wheat and maize by 31 and 25%, respectively, over flat sowing system. Regarding mulching levels, wheat straw mulch showed 26.6 and 23.5% increase over control in GW of wheat and maize, respectively.

Grain yield of wheat (kg ha^{-1}) and maize (Mg ha^{-1})

Bed sowing enhanced wheat yield by 33% (Figure 6) and maize yield by 47% (Figure 7) over flat sowing method. Regarding mulching materials, wheat straw and farm manure effect on wheat was similar but significant in case of maize. The wheat straw mulch produced higher yields of both crops compared with farm manure mulch and control. The mulching levels increased yield of wheat over control by 26%. Similarly maize yield was also increased by 39% in mulched treatments over non-mulched plots.

Interactive effect of mulching and sowing methods was significant on grain yields of wheat and maize. Wheat straw and farm manure mulching materials showed 26 and 20%, and 43 and 26% increase in grain yield of wheat and maize, respectively, on bed sowing system compared with no mulch treatment. Similarly, both mulching materials showed 25 and 23% and 34 and 19% increase in grain yield of wheat and maize, respectively, on flat sowing system compared with no mulch treatment. The Flat sowing + no mulch depicted less grain yield of wheat and maize by 40.9 and 50.0%, respectively, over Bed sowing + wheat straw mulch.

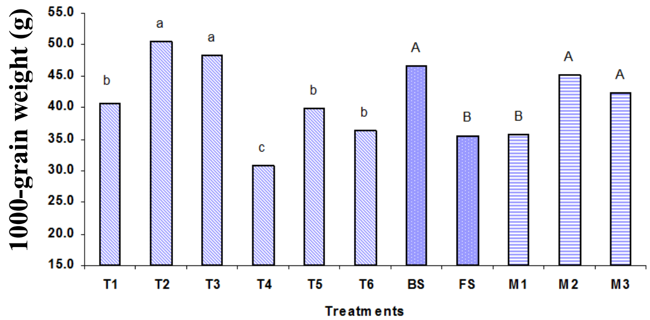

Figure 4: Effect of mulching and sowing methods on 1000-grain weight of wheat

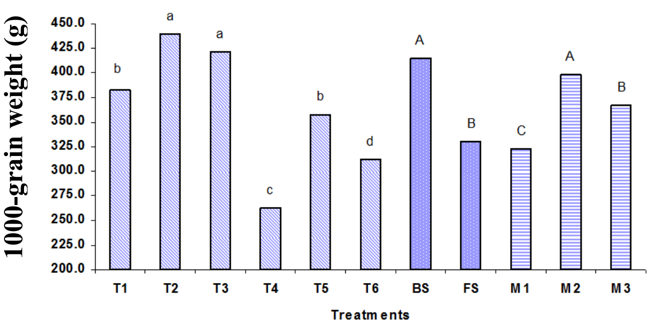

Figure 5: Effect of mulching and sowing methods on 1000-grain weight of maize

Note: T1 = Bed sowing + No mulch; T2 = Bed sowing + Wheat straw mulch; T3 = Bed sowing + Farm manure mulch; T4 = Flat sowing + No mulch; T5 = Flat sowing + Wheat straw mulch; T6 = Flat sowing + Farm manure mulch; BS = Bed sowing; FS = Flat sowing; M1 = No mulch; M2 = Wheat straw mulch; M3 = Farm manure mulch

Soil characteristics

Effect of mulching and sowing methods on Bulk density, Soil penetration resistance, Infiltration rate, Saturated hydraulic conductivity and Soil organic carbon after four cropping seasons

The effects of different treatment combinations on soil physical properties were significant. The treatment combination of wheat straw mulch + bed sowing system (BM_{wst}) showed the lowest BD (1.29 Mg m^{-3}) of 15 cm surface layer while the highest BD (1.41 Mg m^{-3}) was obtained with flat sowing without mulch. The BM_{wst} combination showed about 2 to 8% decrease in BD compared to all other treatment combinations (Figure 8). The SPR showed consistency with BD and ranged from 758 to 934 kPa. The BM_{wst} showed 2 to 17% decrease in SPR compared to all other treatment combinations (Figure 9).

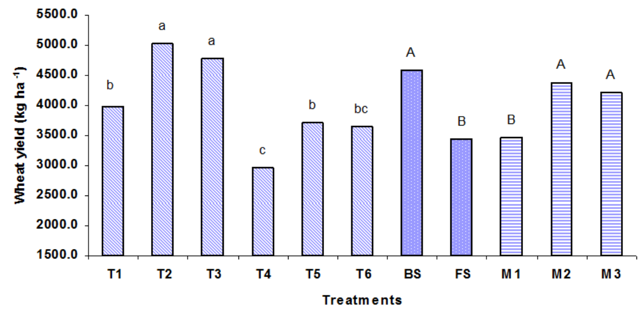

Figure 6: Effect of mulching and sowing methods on wheat grain yield

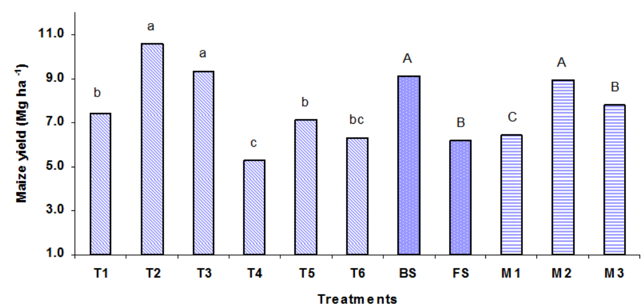

Figure 7: Effect of mulching and sowing methods on maize grain yield

Note: T1 = Bed sowing + No mulch; T2 = Bed sowing + Wheat straw mulch; T3 = Bed sowing + Farm manure mulch; T4 = Flat sowing + No mulch; T5 = Flat sowing + Wheat straw mulch; T6 = Flat sowing + Farm manure mulch; BS = Bed sowing; FS = Flat sowing; M1 = No mulch; M2 = Wheat straw mulch; M3 = Farm manure mulch

Minimum K_{fs} (12.4 mm hr^{-1}) was noted in plot where flat sowing in combination with no mulch was used and maximum (27.9 mm hr^{-1}) in plots where bed sowing in combination with wheat straw mulch was used. The BM_{wst} plots showed 17 to 125% increases in K_{fs} compared to all other treatments (Figure 10). Similarly, Figure 11 indicates that minimum IR (46.1 mm hr^{-1}) was observed in flat sowing plots without mulch and maximum (64.5 mm hr^{-1}) in BM_{wst} plots. The SOC contents in 15 cm layer were more in bed sowing than flat sowing (Figure 12). It ranged from 3.9 to 4.5 g kg^{-1} in bed sowing and 2.9 to 3.7 g kg^{-1} in flat sowing methods. The highest SOC contents were obtained in treatment where farm manure was applied under bed sowing method.

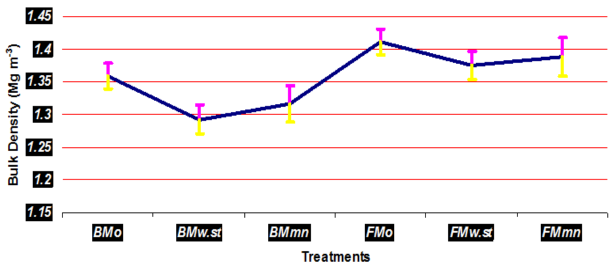

Figure 8: Effect of mulching and sowing methods on soil bulk density (0-15 cm)

Note: BM_0 = Bed sowing + No mulch; BM_{wst} = Bed sowing + Wheat straw mulch; BM_{mn} = Bed sowing + Farm manure mulch; FM_0 = Flat sowing + No mulch; FM_{wst} = Flat sowing + Wheat straw mulch; FM_{mn} = Flat sowing + Farm manure mulch

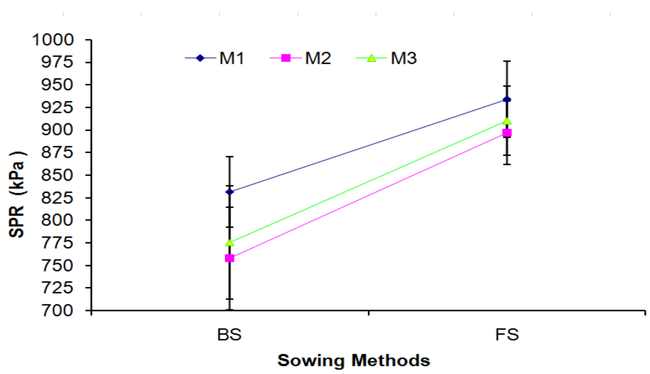

Figure 9: Effect of mulching and sowing methods on soil penetration resistance

Note: BS = Bed sowing; FS = Flat sowing; M1 = No mulch; M2 = Wheat straw mulch; M3 = Farm manure mulch

Pearson correlations between BD and K_{fs}, BD and SOC, and K_{fs} and SOC are shown in Figure 13 (a), (b) and (c), respectively. The negative correlation (r = 0.84) was found between BD and K_{fs}, SOC and BD (r = 0.72), whereas positive correlation (r = 0.60) of SOC was noted with K_{fs}.

Seasonal variations in soil physical parameters

Table 3 showed that during the 1st year, higher K_{fs} in summer season (April-09) compared to winter season (Nov-09) was recorded. Same trend was observed during the second year. Similar trend in case of IR was observed. However, higher SPR in summer compared to winter season was noted. The BD decreased from 1.37 to 1.34 in summer season and from 1.36 to 1.33 Mg m^{-3} in winter season in two years. The SOC contents showed increasing trend and 11% increase was noted in 2nd year for winter season.

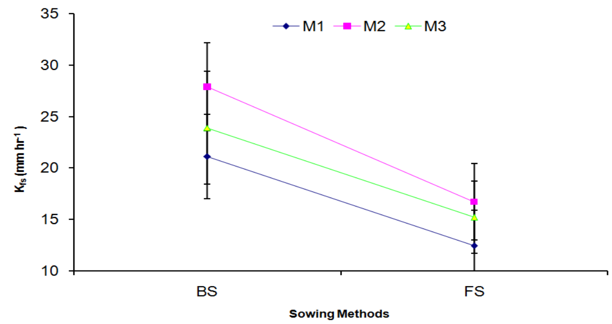

Figure 10: Effect of mulching and sowing methods on field saturated hydraulic conductivity

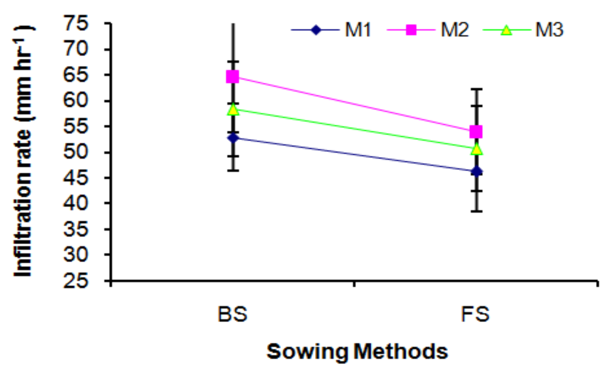

Figure 11: Effect of mulching and sowing methods on infiltration rate

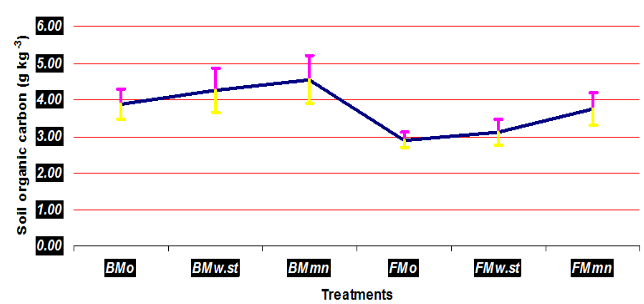

Figure 12: Effect of mulching and sowing methods on soil organic carbon (0-15 cm)

Note: BM_0 = Bed sowing + No mulch; BM_{wst} = Bed sowing + Wheat straw mulch; BM_{mn} = Bed sowing + Farm manure mulch; FM_0 = Flat sowing + No mulch; FM_{wst} = Flat sowing + Wheat straw mulch; FM_{mn} = Flat sowing + Farm manure mulch

Discussion

In month of April, the values of K_{fs}, IR and SPR were higher than in month of November (Table 3). The higher

Table 3: Seasonal variations in soil physical properties after the harvest of wheat and maize

Soil physical property	Seasonal variation			
	Year-1		Year-2	
	wheat	maize	wheat	maize
Field Saturated Hydraulic Conductivity (mm hr^{-1})	18.2	15.2	23.5	21.4
Infiltration Rate (mm hr^{-1})	50.5	46.2	63.0	57.8
Soil Penetration Resistance (kPa)	901.1	829.0	852.6	820.9
Bulk Density (Mg m^{-3})	1.368	1.357	1.338	1.330
Soil Organic Carbon (g kg^{-1})	3.29	3.81	3.61	4.23

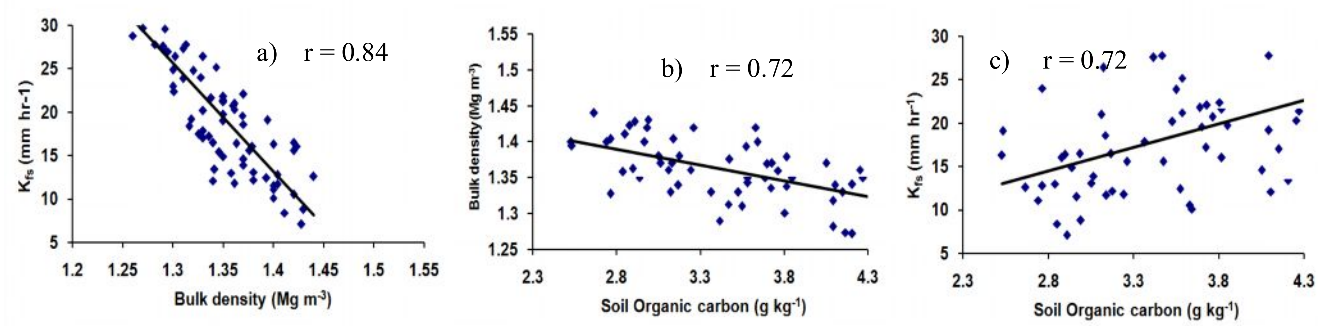

Figure 13: (a) Pearson correlation between K_{fs} and BD, (b) between BD and SOC, and (c) between K_{fs} and SOC

soil temperature in April caused reduction in viscosity of water (Darzi *et al*. 2008). The higher SPR values in warmer season than in winter season was due to more soil water storage and SOC in winter season (Halvorsona *et al*. 2003). After maize harvest, the SOC contents were more than after wheat harvest. The low SOC after wheat harvest may be due to higher temperature that accelerated the decomposition rate and caused reduction in organic carbon pool.

The higher SOC contents in bed sowing compared to flat sowing might be due to more root proliferation (Hassan *et al*. 2005). Improved soil physical health of raised beds compared to flat sowing could be because of less disruption of aggregates and settlement in the unsaturated conditions of the raised beds compared to the saturated conditions of the flat sowing method (Fahong *et al*. 2004; Hassan *et al*. 2005). Furthermore, the observations of less SPR and high K_{fs} supported the reduction in bulk density on beds. Therefore, soil physical health of beds was better compared to flat sowing. It was also noted that crop lodging was less in bed sowing than flat sowing which might be due to more drainage of water from beds into the furrows (Ahmad and Mahmood, 2005).

Among mulching materials, farm manure caused 22.55% more SOC contents compared to control (Figure 12). More SOC in farm manure amendment compared to wheat straw might be due to that wheat straw had wider C:N ratio and farm manure had narrow C:N ratio. Wheat straw is more susceptible towards global warming due to more loss of carbon dioxide into the atmosphere in comparison to farm manure (Jalali and Ranjbar, 2009). Increased soil organic carbon contents under crop residue mulch were also reported by Saroa and Lal (2003), and Canqui and Lal (2007).

Wheat straw and farm manure mulch showed better soil physical environment in term of lesser BD and SPR, and higher K_{fs} and IR compared with control where no mulch was applied. In this context, Pervaiz *et al*. (2009) investigated the mulching effect on soil physical characteristics and they observed decreased BD and soil strength under mulch compared to control. Sharma *et al*. (2009) also noted decreased BD under mulch levels of 6 t ha^{-1} (1.40 g cm^{-3}) compared with no mulch (1.44 g cm^{-3}). The IR increased from 0.65 cm hr^{-1}, (control) to 0.72 cm hr^{-1} under mulch level of 6 t ha^{-1}. Similarly, Lukman *et al*. (2008) also reported increased available water holding capacity by 18–35%, total porosity by 35–46% and soil moisture retention at low suctions from 29 to 70% under mulching. However, mulch rates showed non significant effects on soil BD. Similar results were reported by others (Jordan *et al*., 2010; Obalum and Obi, 2010)

The improvement in soil structure contributed to increased LAI and 1000-grain weight, resulting increased grain yield under wheat straw and farm manure mulches compared with control. Many other scientists also reported similarly like Zhang *et al*. (2008) who reported 13.9% more 1000-grain weight in wheat straw treatment with respect to control mulch level. Mulching has potential for increasing soil water storage (Shanging and Unger, 2001). Wheat straw mulch significantly affected the growth and yield of maize by increasing the LAI and water use efficiency (Iqbal *et al*., 2003). Similarly, Sharma *et al*. (1998) noticed higher wheat grain (3623 kg ha^{-1}) and straw yield (5560 kg ha^{-1}) in the plots where mulch level of 6 Mg ha^{-1} was applied and lower grain and straw yield in no mulch plots. Similar results were reported by Sarkar and Singh 2007; Glab and Kulig 2008). Wheat straw under bed sowing improved the soil physical condition. Although, the grain yields of wheat and maize were at par with farm manure under bed sowing. This might be due to better soil cover by wheat straw in relation to farm manure amendment that could not cover the soil surface completely.

Conclusion

Bed sowing provided good soil physical health and produced higher yield of wheat and maize in comparison to flat sowing. Both mulching materials also improved the soil physical health and consequently the yield of wheat and maize. Wheat straw mulch showed the highest yield of wheat and maize under bed sowing system. However, farm manure was found to be environment friendly compared to wheat straw having more soil organic carbon. Therefore, to overcome the problem of global warming due to agricultural activities and lower soil structural stability due to low organic matter, there is future need to explore the influences of farm manure as mulching material instead of incorporation in the soil.

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