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RESEARCH PAPER

Buildup of soil organic carbon and stable aggregates under conservation tillage in loess dryland soil

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Abstract

The identification of sensitive soil organic carbon (SOC) fractions can be crucial for an understanding of SOC dynamics and stabilization in soil. This study was conducted during 2012-14 in fallow-wheat cropping system at loess dryland Pothwar, Pakistan to assess the effect of minimum tillage (MT), reduced tillage (RT), zero tillage (ZT) and conventional tillage (CT), with residue retuned (R^+) and removed (R^-) on SOC fractions and aggregate stability. The results showed that the ZT with residue returned provided the highest amount of SOC (7.80g kg^{-1}), microbial biomass carbon (MBC, 473 μg kg^{-1}), particulate organic carbon (POC, 2.27 g kg^{-1}) and water stable aggregates (WSA, 36%). On the other hand, CT with residue removed gave the least amounts of SOC (5.35 g kg^{-1}), MBC (130 μg kg^{-1}), POC (1.25 g kg^{-1}) and aggregate stability (24%). The trend among tillage treatments was ZT > RT > MT > CT for studied parameters. Among residue treatments, residue return (+R) had higher SOC content and aggregate stability than residue removed (-R). These results clearly demonstrate that ZT and RT with residue returned are potential alternatives to conventional tillage for enhancing soil organic carbon and structural stability in loess dryland soils.

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Introduction

Farming in the dryland areas is a high risk activity due to erratic rainfall and climatic patterns. Unfortunately, conventional system of excessive tillage and residue removal is further aggravating the situation by degrading soil quality via accelerated erosion and decomposition of soil organic carbon (SOC). The SOC is a key index of soil quality for sustainable crop production (Lal 2004), therefore decline in SOC poses serious agricultural and environmental drawbacks by reduced nutrient concentrations (Ashagrie *et al.* 2007), water storage (Resck *et al.* 2008) and emission of greenhouse gases (Lal 2006). Tillage also breaks soil aggregates that physically protect SOC from microbial decomposition (Beare *et al.* 1994; Tisdall and Oades 1982). Therefore, there is dire need to provide the farmers with alternative soil management options that minimize SOC degradation and improve soil aggregation in dryland areas.

Conservation tillage is a system that involves minimum disturbance of soil while leaving at least 30% of crop residue after planting on the soil surface. The term includes minimum tillage, direct drilling, zero tillage, no-till etc under its umbrella. Conservation tillage practice has shown great potential to increase SOC (Govaerts *et al.* 2009) and reduce wind and water erosion (López *et al.* 2001; García-Ruiz 2010). However, short-term effects of conservation tillage on SOC are complex and vary with soil conditions such as soil texture, climate, cropping system, kind of crop residue, as well as with the management itself (Paustian *et al.* 1997; Al-Kaisi *et al.* 2005; Mun˜oz *et al.* 2007).

Worldover, conservation tillage is practiced on about 125 million hector (Derpsch & Friedrich 2010) out of which 96% lies in Americas, Canada and Australia. In contrast Asia covers only 2.2% which indicates huge lag and missed opportunity. For instance, in dryland areas of Pakistan where soil receives about 8-10 ploughings during a short six-month fallow period, most of the studies on conservation tillage systems focused yield improvements but information on their effects on soil quality is scarce. Thus research for characterization of different SOC fractions and soil structural stability is needed to improve soil functioning and quality. With this aim a conservation tillage experiment was initiated with residue retention and removal compared with adjacent conventional moldboard system at northern Punjab, Pakistan to assess their effects on SOC content, its fractions and structural stability in loess dryland soils.

Materials and methods

Location of Experiment

Conservation tillage experiment was initiated in 2012 on a sandy clay loam soil at PMAS-Arid Agriculture University Research Farm Chakwal Road (latitude 33°36’0”N, longitude 73°02’0”E) in semi-arid dryland Pothwar, northern Punjab, Pakistan. The soil has sand 560 g kg^{-1}, silt 190 g kg^{-1} and clay 250 g kg^{-1}, pH around 7.85 and SOC 5.2 g kg^{-1}. The climate of the experimental site is semi-arid, very hot in summer and low temperature in winter with 70% of the rain received during monsoon in the form of heavy showers. The farmers of this area conventionally use fallow-wheat systems with intensive moldboard plow at the onset of monsoon, followed by 10 ploughings with tine cultivator for weed control and moisture conservation.

Treatment Details

The experiment was initiated on an area of 6000 m^2 with treatments arranged in a split plot design having four replications. The main plot treatments were tillage systems i.e. Conventional Tillage (CT), Minimum Tillage (MT), Reduced Tillage (RT) and Zero Tillage (ZT). The sub plot-treatments involved residues retained (R^+) and residues removed (R^-). One year earlier than installation of treatments, the field was left without tillage and crop to offset the residual effects of previous tillage practices. In CT plots, the soil was ploughed with moldboard plow at the start of monsoon followed by 8-10 time shallow cultivation with tine cultivator applied after each major rainfall for weed control and moisture conservation. Wheat sowing in these plots was done with seed-cum-fertilizer drill. In MT, the field was also ploughed with intensive moldboard on the onset of monsoon and four time cultivation with tine cultivator, while sowing was done with conventional seed-cum-fertilizer drill. In RT, one time chisel plough was applied at the start of monsoon and then during fallow period weeds were controlled with roundup herbicide (Glyphosate @ 1 L acre^{-1}) and wheat was sown through direct drilling with zero tillage drill. In ZT, field remained undisturbed for entire fallow period and weeds were controlled with roundup herbicide when needed. Winter wheat was directly sown with zero tillage drill. In sub-plot treatments +R involved just harvest of the previous crop spikes and retention of all the stubbles in field. In case of -R the crop was harvested with reaper and there was no crop residues left in field. The recommended doses of fertilizer NPK i.e. 100-60-30 in the form of urea, diamonium phosphate (DAP) and sulfate of potash (SOP) were used. Wheat was planted at seed rate of 100 kg ha^{-1}.

Soil Sampling and Analyses

Surface soil samples were collected at 0 - 20cm depth at sowing and harvest each year. Soil microbial biomass carbon (MBC) was measured by the chloroform fumigation and extraction method (Vance *et al.* 1987). The process of soil organic carbon fractionation was based on the methodology proposed by (Cambardella and Elliott 1992). Twenty five gram of soil sample was transferred into a 500 ml flask and added 200ml sodium hexametaphosphate solution, placed on mechanical shaker for 30 minutes. Soil suspension was then washed through a >53mm sieve and the coarse fraction was separated. The soil samples above the 53µm sieve were considered particulate soil organic matter (SOM) while, those that pass through the sieve for mineral associated organic carbon. The particulate (≥53µm) and mineral (<53µm) soil fractions were dried in an oven at 60C° and analyzed for organic carbon using the wet oxidation method. Total organic carbon (TOC) was determined in the bulk soil and also respectively for particulate organic carbon (POC) and mineral associated organic carbon (MOC) soil fractions using the wet oxidation method of (Walkley and Black 1934). One gram of soil sample was weighed into a 500ml conical flask, 10mls of 1N potassium dichromate added with the aid of a pipette, thereafter, 20mls of conc. Sulphuric acid added and allowed to cool to room temperature. 100mls of distilled water followed by 10ml of orthophosphoric acid was also added and 5drops of diphenylamine indicator were added. The sample was titrated against 0.5N ferrous sulphate.

Statistical Analyses

The data collected for various characteristics was subjected to Analysis of Variance (ANOVA) and means were compared at 5% level of significance by Least Significance Difference (Steel *et al.* 1997).

Results

The TOC was significantly affected by different tillage systems and residue management practices. By the end of first year, ZT and RT with crop residue retention showed more buildup of SOC than other treatments, while other tillage systems had equal TOC concentrations (Table 1). During second year ZT and RT with residue return also gave consistently highest TOC values both at sowing and harvest of wheat crop. When averaged over years (Fig. 1) it was important to note that all tillage systems without residue return showed similar TOC contents.

The soil MBC was significantly affected by different tillage systems and crop residue management (Table 2) Zero tillage gave the highest amount of MBC (474 µg kg^{-1}) followed by RT (425 µg kg^{-1}) both with retention of crop residue, whereas CT without return of crop residue, gave the lowest amount of MBC (130 µg kg^{-1}). Overall MBC contents improved with reduction in tillage in order of ZT > RT > MT > CT and crop residue retention (Fig. 2).

Table 1. Seasonal changes in soil organic carbon (g kg^{-1}) under conservation tillage systems compared with conventional tillage in loess dryland soils.

Treatments		2012-13		2013-14	
		Sowing	Harvest	Sowing	Harvest
Conventional tillage	With residue	5.30	5.56 b	5.98 c	6.19 bcd
	Without residue	5.25	5.30 b	5.41 c	5.35 d
Minimum tillage	With residue	5.35	5.61 b	6.03 bc	6.55 b
	Without residue	5.30	5.46 b	5.46 c	5.61 cd
Reduced tillage	With residue	5.51	6.65 a	6.86 ab	7.54 a
	Without residue	5.41	5.51 b	5.67 c	6.03 bcd
Zero tillage	With residue	5.77	6.76 a	7.07 a	7.80 a
	Without residue	5.46	5.56 b	5.93 c	6.29 bc

Means followed by different letters are significantly different at 5% level of probability.

Table 2. Seasonal changes in microbial biomass carbon (g kg^{-1}) under conservation tillage systems compared with conventional tillage in loess dryland soils**.**

Treatments		2012-13		2013-14	
		Sowing	Harvest	Sowing	Harvest
Conventional tillage	With residue	147.02c	212.36cd	196.02bcd	245.03bc
	Without residue	130.68bc	130.68e	130.68d	130.68d
Minimum tillage	With residue	163.35bc	245.03bc	228.69bc	277.69b
	Without residue	147.02bc	147.02de	179.69cd	179.69cd
Reduced tillage	With residue	212.36ab	310.37ab	392.04a	424.71a
	Without residue	163.35bc	212.36cd	228.69bc	277.69bc
Zero tillage	With residue	245.03a	359.37a	441.05a	473.72a
	Without residue	179.69bc	245.03bc	277.69b	294.03b

Means followed by different letters are significantly different at 5% level of probability.

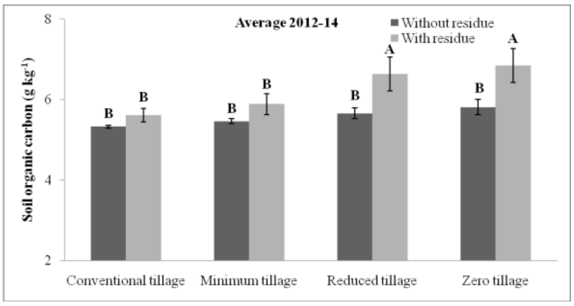

Fig.1. Average soil organic carbon concentration under conservation tillage systems compared with conventional tillage in loess dryland soils.

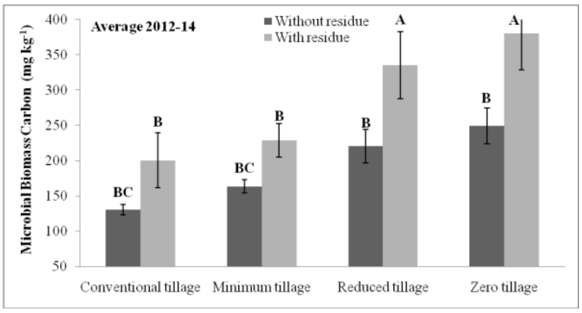

Fig.2. Average microbial biomass carbon concentration under conservation tillage systems compared with conventional tillage in loess dryland soils.

Particulate organic carbon was significantly improved by ZT and RT (Fig.3) when residue retained (2.27 g kg^{-1} and1.94 g kg^{-1}, respectively) while other treatments showed non-significant differences. The lowest amount of POC (1.25 g kg^{-1}) was observed under conventional tillage without retention of crop residues. The average of two year data also shows very pronounced effect of crop residue return in ZT and RT tillage systems (Table 3).

The mineral-associated SOC in the top soil layer did not change with tillage systems and residue management in both years (Fig.4). Although values did improve numerically with retention of crop residues and reduction of tillage operations but the change was not sufficient to produce statistically appreciable differences. The maximum amount of MOC (4.90 g kg^{-1}) was observed under RT in chisel plough followed by ZT with retention of crop residues. The least amount (4.05 g kg^{-1}) was observed under conventional tillage without retention of crop residues (Table 4).

Table 3. Seasonal changes in particulate organic carbon (g kg^{-1}) under conservation tillage systems compared with conventional tillage in loess dryland soils.

Treatments		2012-13		2013-14	
		Sowing	Harvest	Sowing	Harvest
Conventional tillage	With residue	1.20	1.29 b	1.32 c	1.39 c
	Without residue	1.16	1.21 b	1.22 c	1.25 c
Minimum tillage	With residue	1.19	1.38 ab	1.42 c	1.46 c
	Without residue	1.17	1.22 b	1.31 c	1.31 c
Reduced tillage	With residue	1.33	1.62 ab	1.82 ab	1.94 ab
	Without residue	1.26	1.37 ab	1.42 c	1.43 c
Zero tillage	With residue	1.39	1.80 a	1.92 a	2.27 a
	Without residue	1.21	1.41 ab	1.53 bc	1.55 bc

Means followed by different letters are significantly different at 5% level of probability.

Table 4. Seasonal changes in mineral associated organic carbon (g kg^{-1}) under conservation tillage systems compared with conventional tillage in loess dryland soils.

Treatments		2012-13		2013-14	
		Sowing	Harvest	Sowing	Harvest
Conventional tillage	With residue	4.15	4.25	4.10	4.70
	Without residue	3.90	4.00	3.95	4.05
Minimum tillage	With residue	4.20	4.25	4.25	4.65
	Without residue	4.05	4.25	4.20	4.20
Reduced tillage	With residue	4.25	4.30	4.30	4.90
	Without residue	4.05	4.15	4.25	4.30
Zero tillage	With residue	4.20	4.35	4.45	4.80
	Without residue	4.20	4.20	4.30	4.20

Means followed by different letters are not significantly different at 5% level of probability.

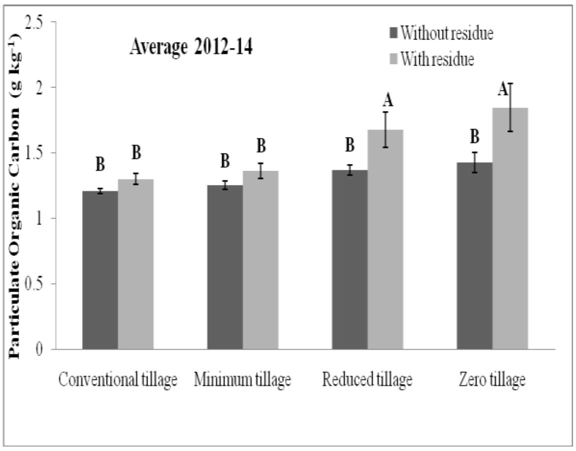

Fig.3. Average particulate organic carbon under conservation tillage systems compared with conventional tillage in loess dryland soils.

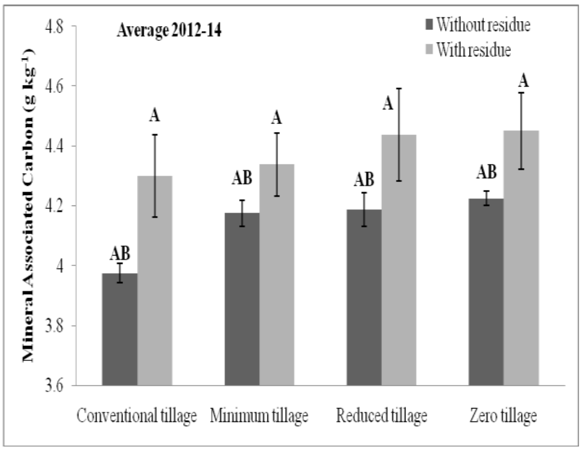

Fig.4. Average mineral associated organic carbon under conservation tillage systems compared with conventional tillage in loess dryland soils.

The data in each year at both sowing and harvesting times (Fig.5) shows that the highest percentage of water stable aggregates was observed under ZT and RT with retention of crop residues (35.7% and 33.8% respectively). The least amount of 23.12% was observed under CT without crop residue (Table 5).

Table 5. Seasonal changes in aggregate stability (%) under conservation tillage systems compared with conventional tillage in loess dryland soils.

		2012-13		2013-14	
	Treatments	**Sowing**	**Harvest**	**Sowing**	**Harvest**
Conventional tillage	With residue	24.75	24.38b	26.25bcd	28.68b
	Without residue	23.88	21.62c	23.75d	23.12c
Minimum tillage	With residue	25.25	25.25b	26.81bcd	28.87b
	Without residue	23.19	24.688c	24.37cd	24.06c
Reduced tillage	With residue	25.56	26.63a	31.56a	33.75a
	Without residue	25.38	24.81b	27.50bc	29.37b
Zero tillage	With residue	26.00	30.38a	32.37a	35.68a
	Without residue	25.50	25.68b	28.75ab	30.00b

Means followed by different letters are not significantly different at 5% level of probability.

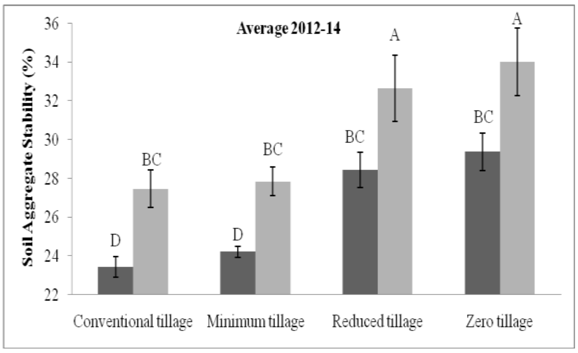

Fig.5. Average aggregate stability under conservation tillage systems compared with conventional tillage in loess dryland soils.

Discussion

The crop residues left under ZT and reduction of tillage operation enhanced SOC contents where under intensive tillage (*e.g.,* CT) crop residues become mixed and incorporated with the soil. Thus, slower residue decomposition rates under ZT may lead to a greater SOC accumulation in the topsoil (Alvaro-Fuentes *et al.* 2008). In semiarid areas, the greater accumulation of SOC under long term application of conservation tillage than conventional practices has been repeatedly reported (Alvaro-Fuentes *et al.* 2008; Hernanz *et al.* 2009; Lopez-Fando and Pardo 2011). However build up of SOC in this short term study is encouraging.

The pronounced increase in MBC concentration under ZT and RT tillage systems could be attributed to less physical disintegration of organic matter and organic matter addition as crop residues which resulted in accumulation of SOC. As the organic matter serves as a source of energy for soil microorganism, its availability led to accumulation of more microbial biomass in surface soil (Wright *et al.* 2005). Soil microbial biomass carbon respond quickly to changes in soil management (Biederbeck *et al.* 2005) and is proposed as more sensitive indicators of the changes in soil quality as affected by different soil management practices (Nannipieri *et al.* 2003; Filip *et al.* 2002).

In present study POC under ZT and RT was mainly improved when residue was retained. According to Yoo and Wander (2008) POC increases due to roots and crop residues left after the wheat harvest. The POC fraction in this experiment represented 9-30% of the total SOC that is in agreement with typical values of 10-30% as reported in the literature (Wander 2004; Alvaro-Fuentes *et al.* 2008; Martin-Lammerding *et al.* 2011). However, despite its small proportion, it has a large effect on structural stability and nutrient-supply ability of soils for which it is considered a key attribute of soil quality (Haynes 2005).

The higher proportion of carbon in mineral-associated fractions than in labile fractions is probably due to climatic conditions i.e. high temperature favorable to organic matter decomposition and transformation to MOC. In our study the non-significant effect of tillage on MOC was probably due to physical and chemical stability of SOM to biological decomposition. Parfitt *et al.* (1997) reported that variable charge mineral and soil organic matter interactions can promote a great soil organic matter protection against biological decomposition.

Compared with ZT and RT, the decrease of structural stability in CT could be attributed to two factors: i) continuous ploughing; ii) decreasing the concentrations of binding agents. Several studies reported that macroaggregates were more susceptible to breakdown by tillage practice (Mikha and Rice 2004; Ashagrie *et al.* 2007).

Conclusion

Our results confirm that reduction of tillage and retention of crop residues increases soil microbial biomass carbon, particulate organic carbon and total organic carbon as well as soil structural stability within two years of conservation tillage in loess dryland soils. Whereas, mouldboard plough especially with no residue return decreases soil organic carbon and soil aggregation. No-till and chisel plough with crop residue retention provides the best opportunity for accumulation of soil organic carbon which will improve soil quality and productivity of weakly structured loess dryland soils.

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