Original Research Article

Active Soil Organic Carbon Fractions and Aggregate Stability effected by Minimum Tillage and Crop Rotations on a Marginal Dryland Soil in Punjab, Pakistan

ABSTRACT

Conservation agriculture (CA) is an important technique for enhancing soil organic carbon (SOC) content in the surface layer and improving structural stability. CA is not widely practiced in dryland soils of developing countries where marginal farming practices are extensively used. Therefore, a field study was conducted in dryland region of Punjab, Pakistan to compare minimum tillage and intensified cropping systems effects on active SOC fractions and aggregate stability. The experiment was laid out in a split-plot design having moldboard plough (MP) and minimum tillage (MT) as main plots, and crop sequences as sub-plots. The latter comprised of fallow–wheat (*Triticum aestivum* L.), (FW, control), mungbean (*Vigna radiate* L.)–wheat (MW), sorghum (*Sorghum bicolor* L.)–wheat (SW), green manure–wheat (GW) and mungbean-chickpea (MC) (*Cicer arietinum* L.). Tillage systems had more pronounced effects than cropping sequences on microbial biomass carbon (MBC), potentially minerlizeable carbon (PMC) and particulate organic carbon (POC). The PMC in second year was significantly more in the soil under MT than that under MP especially with SW, GW and FW sequences (448, 442 and 419 µg g^{-1} soil day^{-1}, respectively). High MBC was also recorded under MT mainly with MW (361 µg g^{-1}). POC was the highest under MP with MC sequence and was 6.41% more than that under MT. More water stable aggregate (WSA) was recorded in soil under MT plots sown with MC and GW (48.62% and 46.25%, respectively) than that under MP. The results indicate that MT with legume based-cropping sequences reduced breakdown of soil aggregates than the current MP and fallow-based systems in Pothwar, Pakistan.

Keywords: Conservation agriculture; microbial biomass C; potentially mineralizable C; particulate organic C; Punjab; Mungbean; Photwar; Pakistan

1. INTRODUCTION

Soil organic carbon (SOC) is a complex mixture of organic compounds originating from plant residues, microbes and animals. Besides its multifarious role in soil quality and agronomic production, SOC plays a critical role in the global C cycle (1). It is the largest terrestrial C pool after fossil fuel deposits, and contains thrice as much C as that in the entire terrestrial vegetation (2). Thus, recent two decades since 1990 have witnessed a renaissance in SOC research, and it has emerged as a key indicator of soil quality for agricultural and environmental sustainability (3). The complex organic constituents of SOC vary in the age and ease of decomposability hence they have been conceptually divided into three pools: active, slow and passive. [4,5 and 6]. The active fractions [(e.g. microbial biomass C (MBC) and potentially mineralizable C (PMC) and particulate organic carbon (POC)], are labile and have turnover time of days to years [7]. These fractions play an important role in soil's moderating capacity for nutrient cycling and physical properties. The active fractions are fairly responsive to management changes and serve as an early indicator of long-term SOC turnover. The slow and passive fractions are relatively more resistant to decomposition and have turnover time of decades to centuries [8].

A Global review of 67 studies related to SOC affected by tillage and crop sequences showed that almost 50% of studies were carried out in Canda and USA (Weil and Magdoff 2004a). Another review of 59 studies [3] showed that 50% of research studies were reported from USA, Canada and Argentina where soil were Mollisols and Sopodosols, managed under highly mechanized practices. In the Mediterranean Basin numerous countries have been successful in establishing conservation agriculture (CA) but the areal extents are relatively uncertain. These include Spain, Portugal, France and Italy in Europe: Morocco and Tunisia in North Africa. Only Kazakhstan in central Asia has the areas exceeding one million hectare under CA. Countries in West Asia and Central Asia include Uzebekistan and Ukraine. Extensive research and development work has been conducted the West Asia and North Africa (WANA) in several countries since the early 1980s such as Morocco, [9], Tunisia [10,11] and in Turkey [12]. Similarly research, work on CA in Eurasia has been reported by [13], for Kazakhstan by Suleimenov, [14, 9] and 15], and 16 and 17]. Several international centers (e.g. International Center for Agricultural Research in the Dry Areas (ICARDA) and International Maize and Wheat Improvement Center (CIMMYT) have also been active in CA research in the WANA regions [18, 19 and 14). [21] estimated that the SOC loss from soil of five Central Asian Countries (Kazakkhstan, Kyrgystan, Tadjistan, Turkmenistan and Uzbekistan) of 1-2 Pg was due to agricultural mismanagement. In South Asia (e.g. Pakistan and Afghanistan) little information is available related to the SOC pools and its changes with land use and management. In Pakistan, most of research has been done on the importance of SOC in relation to fertility and magnitude of SOC. Less attention has thus far been given towards the effects of agricultural management on enhancing quality and quantity of SOC.

The SOC has a strong link with aggregate stability that is important to soil quality. Increased SOC concentration is often associated with improved soil physical condition [21]. The encapsulation of SOC into soil aggregates provides physical protection against rapid decomposition and is one of the key determinants of soil stability against erosion [22]. Although soil's structural stability is not considered as a direct plant growth factor, it exerts considerable influence on the air, water and nutrient supplies to the plant roots, as also on the movement of the soil macro-fauna [23]. Stable aggregates protect SOC by forming barriers between microbes and the substrate, thus inhibiting its microbial turnover [24]. The POC is an important agent in binding micro-aggregates which serve as precursor of macro-aggregates [25). However, there is no general agreement as to the type of organic matter that plays a key role in enhancing aggregation [26]. Improvements of SOC and aggregate stability are often associated with minimum tillage (MT) and intensified cropping. These proven approaches are now widely used in large scale commercial agriculture [27]. However, their use in drylands of developing countries, having small land holdings and marginal farming practices, is in its formative years. These dry areas are challenged by rapid population growth, frequent droughts, high climatic variability, land degradation and desertification, and widespread poverty. It is important to explore and demonstrate management options for improvement of SOC in these areas [28]. Therefore, a field experiment was conducted to assess the effects of different tillage systems and cropping sequences on labile SOC fractions, total organic carbon (TOC), bulk density and water stable aggregates in a subtropical dryland of Pakistan. The study was designed to test the hypothesis that tillage systems and crop sequences strongly affect SOC fractions under agroecolgical conditions of northern Punjab, Pakistan.

2. MATERIAL AND METHODS

2.1 Location and Experimental Layout

A two-year field experiment was conducted at the Research Farm of Pir Mehr Ali Shah-Arid Agriculture University Rawalpindi, Pakistan (33^{o} 38′ N, 73^{o} 05′ E) during 2010-11 and 2011-12. The experimental site is part of a wide rainfed track of northern Punjab called Pothwar plateau. The rainfall is of a bi-modal pattern with two maxima, the first in late summer (August and September) and the second during the winter-spring (February and March) (Fig. 1). The summer or monsoon rains constitute about 70 % of the total annual rainfall of 750-950 mm. These rains are highly torrential and result in severe soil erosion [29]. The mean maximum temperature during summer ranges from 36 ^{o}C to 42 ^{o}C with extremes sometimes as high as 48 ^{0}C [30]. Soil of experimental site is clay loam with pH of 8, ECe of 0.25 dSm^{-1}, bulk density of 1.4 Mg m^{-3}, and nutrient concentration (mg kg-1 soil) of 3.35, 6.50 and 130 for N, P and K, respectively. Predominant soil of the site (33° 38' N, 73" 05' E) is classified as Rawal series: Udic Haplustalf [31] (Table 2)

The experiment was laid out in a split-plot design. Main plots were comprised of two soil tillage systems: moldboard plough (MP, control), and minimum tillage (MT). Each main plot was divided into five sub plots with following crop sequences viz. fallow–wheat (*Triticum aestivum* L.) (FW) (control), mungbean (*Vigna radiate* L.) –wheat (MW), sorghum (Sorghum bicolor)–wheat (SW), green manure–wheat (GW) and mungbean-chickpea (MC) (*Cicer arietinum* L.). The green manure crop comprised of a mixture of mungbean and sorghum seeds, and ploughing under the biomass before the grain setting stage. Total six main-plots and thirty sub-plots were established. The main and sub plot sizes were 19×16 m and 2.5×16 m, respectively. At the end of each season from each sub-plot one sample was taken so, total thirty soil samples were collected with replication for analysis. The tractor used was Massey Ferguson (MF) 240 of 50 horse power at 2.250 rpm. Crops were seeded with a winter seed drill at row spacing of 15 cm. No crop was seeded in the FW system for the period from the previous harvest of wheat in April until the sowing of next wheat in November. Under MP tillage the FW rotation involved moldboard ploughing to 25 cm depth at the start of summer and subsequent repeated three cultivations with tine cultivator for weed control. The FW system under MT, involved no ploughing throughout the fallow period except at the time of seedbed preparation for wheat. Weeds in fallow plots under MT were controlled with two sprays of roundup (glyphosate [N- (phosphonomethyl) glycine)] @ 1.5 liter $ha.^{-1}$ In all treatments involving double cropping (i.e MW, SW, GW and MC), summer crops were sown at the onset of mosoon in July and harvested in mid-September. Winter crops were sown in early November and harvested in April. The MP ploughing was performed at depth of 25 cm on start of monsoon, followed by one tine cultivation and planting before sowing of summer crops. After the harvest of summer crop, soil was tilled by tine cultivator to 15 cm depth for 2-3 times before sowing of wheat. MT soil was kept free from any tillage except for the field preparation. The double cropping under MT involved only ploughing with tine cultivator at the time of sowing of summer and winter crops. Fertilization for mungbean, sorghum and wheat involved the application of 60 kg ha-1 urea 100-50 of kg ha^{-1} urea and DAP, 120-80 kg ha^{-1} urea and DAP respectively, applied at the time of seedbed preparation before the sowing of wheat. In MT plots, both summer and winter crop residues were returned back to the soil.

2.2 Soil Sampling and Analyses

Soil samples were obtained at one point in time without a priori baseline sampling. Soil samples were collected from 0-15 cm at the end of each cropping season. A bulk density sample was taken from 0-5 cm with core sampler. TOC was calculated on base of bulk density (Table. 4). MBC was estimated by chloroform fumigation extraction method [32]. One portion of soil was fumigated and samples were extracted with 50 ml 0.5 M K_2SO_4 by shaking at 200 rev min^{-1} and filtered through a (Whatman No. 40) filter paper. The non-fumigated portion of soil samples were extracted similarly. MBS associated TOC in the extracts were measured by using tube digestion method [32]. The PMC was measured by trapping CO_2 released during incubation in 20 cm^3 of 1 N NaOH solution and titrating it against standard 0.5 M HCl solution [33]. Measurement of POC involved dispersion of 5 g L^{-1} sodium hexametaphosphate, by passing the slurry through 50 µm sieve [34] and analyzing for C content [32]. Water stable aggregates (WSA) were measured using the wet aggregate sieving apparatus (Eijkelkamp, Netherlands) in which aggregates (1-2 mm) were placed in 0.25 mm sieve and immersed for three minutes in water. The material remaining in the sieve was immersed again in solution of 2 g L^{-1} sodium hexametaphosphate. All sediments in the container were dried at 60 ^{o}C for overnight and weighed [35]. TOC was determined by the wet oxidation method [36]. Bulk density was measured with core sampler using core 5cm in diameter and 5cm deep [37]. The SOC stock was computed on equal mass basis by using the procedure of [38].

2.3 Data Analysis

The data were subjected to analysis of variance (ANOVA) using the split-plot design, and means were compared at 1 % level of significance the by the Least Significant Difference (LSD) test [39]. The year effect was tested using a "Combine experiment" Model (11 MSTATC), with the block within year effect as the error term. The main plot effect (tillage × year interaction) was tested with appropriate error term for the split plot design. Cropping sequence and other effects were tested by using residual error. LSD value > 0.01.Year effect was tested using a 'Combine experiment" Model (11 MSTATC).

3. RESULTS AND DISCUSSION

3.1 Microbial Biomass Carbon

The response of MBC to tillage systems and crop sequences varied among the years (Fig. 3a), it was more pronounced in the second year than the first year when the highest MBC was measured under MT in combination with the MW sequence. The least MBC was recorded in soil under MP for three specific crop sequences: GW, SW and MC cropping sequences. Overall the soil under MT had 37 % higher MBC than that under MP. However, comparing the data of both experimental years, the soil under MP contained the highest MBC which was 46 % more in MW than that under FW and SW. Furthermore, the concentration of MBC under soil in GW was 20 % higher than that under MW, and 17 % more than that under SW cropping sequence. However, the MBC in soil under MT for MW was higher by 19 %, 22 %, 26 % and 20 % than that under FW, SW, GW and MC cropping sequences. In both experimental year with in tillage systems and cropping sequence, the trend in MBC differed under MP than that under MT system.

in the first year, the highest MBC was observed in soil under GW cropping sequence (247 µg g-1). In the second year, the highest concentration (160 µg g^{-1}) was observed under MW and it was similar to that for the first year. The highest concentration of MBC under MT (159 µg g^{-1}) was observed under MC. In the second year, the highest MBC of 360 µg g^{-1} was observed in the MW cropping sequence.

Tillage had prominent effect on labile SOC fractions (MBC and PMC) than did cropping sequences. On the other hand, MP had higher proportion of intermediate SOC (*i.e.* POC) fraction. These trends show that mineralization was relatively faster in soil than under MP than that under MT. Because the MT tillage involves return of crop residues to soil, this not only frequently recharges the active SOC pool but also reduces the surface soil temperature [40]. Further, less physical disintegration and oxidation of returned residues reduces the rate of decomposition under MT. In contrast, intensive ploughing with MP accelerates decomposition due to more soil disturbance, physical disintegration of aggregates [41].

3.2 Potentially Mineralizable Carbon

The response of PMC to tillage systems and crop sequences varied among the years (Fig. 3b), it was more noticeable in the second than in the first year when the highest PMC was measured in the soil under MT in combination with the MC sequence. The least PMC was recorded in soil under MP for GW and MC crop sequences. Overall the soil under MT had 10 % higher MBC than that under MP. However, comparing the data of both experimental years, the PMC concentration in soil under MP for FW was higher by 19 %, 0.74 %, 19 % and 56 % than that under MW, SW, GW and MC cropping sequences. Moreover, the PMC in soil under MT for MC was higher by 22 %, 17 %, 42 % and 18 % than that under FW, MW, SW, and GW cropping sequences. In both experimental year with in tillage systems and cropping sequence, the trend in PMC differed under MP than that under other tillage systems.

In the first year, the highest PMC was observed in soil under FW cropping sequence (388 µg g^{-1} soil day^{-1}). In the second year, the highest concentration (188 µg g^{-1} day^{-1}) was observed in the soil under SW. Differences among crops for SOC fractions could be attributed to amount of residue produced and returned to the soil. The fallowing-based sequences had lower proportion of active SOC because in a fallow period mineralization of SOC is higher due to more soil moisture [42]. Cropping sequence involving continuous cereal sequences that involved sorghum, had higher POC concentration than legume-based sequences because sorghum being a C4 plant has more lignin and phenol contents which are resistant to decomposition [43].

3.3 Particulate Organic Carbon

The response of POC was only significant in the second year (Fig. 3c), it was more evident in the second year than in the first year when the highest POC was measured under MT in combination with the SW cropping sequence. Overall, the soil under MP had 6.42 % higher POC than that under MT. The least POC was recorded in soil under MP for SW and MW cropping sequences. However, comparing the data of both experimental years, the POC concentration in soil under MP for GW was higher by 25 %, 23 %, 10 % and 3 % than that under FW, MW, SW and MC cropping sequences. Moreover, the POC in soil under MT for MC was higher by 16 %, 7.45 %, 1.27 % and 33% than that under FW, MW, SW, and GW cropping sequences. In both experimental years with in tillage systems and cropping sequence, the trend in PMC differed under MP than that under MT system.

In the first year, the highest POC pool was observed in soil under MC cropping sequence (2.0 Mg ha^{-1}). In the second year, the highest pool of POC (1.94 Mg ha^{-1}) was observed under GW, and that under MT (1.93 Mg ha-^{1}) was observed under MC sequence. In the second year, the highest POC of 1.76 Mg ha^{-1} was observed in the SW cropping sequence.

Differences among crops for SOC fractions could be attributed to amount of residue produced and returned to the soil. The fallowing-based sequences had lower proportion of active SOC because in a fallow period mineralization of SOC is higher due to more soil moisture [42]. Cropping sequence involving continuous cereal sequences that involved sorghum, had higher POC concentration than legume-based sequences because sorghum being a C_4 plant has more lignin and phenol contents which are resistant to decomposition (43).

3.4 Total Organic Carbon

The response of TOC to the tillage and cropping sequence were statistically non-significant both the years (Table 4). The average TOC pool under MP during the first year was 7.70 Mg ha^{-1} compared with 8.42 Mg ha^{-1} in second year. The average TOC pool in soil under MT was 7.63 Mg ha^{-1} in first year compared with 8.42 Mg ha^{-1} in second year. The average TOC pool was relatively high under GW cropping sequence.

The TOC concentration was neither affected by tillage nor crop sequences, possibly due to short duration of the experiment. Conversions to no tillage for < 5 years affect the SOC concentration only in the topsoil [44]. In general, however, no-tillage practices can increase TOC concentration in the surface layer, but this increase might take approximately 5–10 years due to site specificity of tillage systems and cropping sequences [45].

3.5 Bulk Density

The response of soil bulk density to tillage and cropping sequence treatments in both years were statistically non-significant (Table 5). Overall, the soil under MP had average bulk density of 1.61 Mg m^{-3} in first year compared with 1.28 Mg m^{-3} in the second year. The least bulk density was recorded in soil under MP for SW and MC cropping sequence in the first year, and under SW in the second year. In general, soil under MP cropping sequence had relatively high bulk density under GW sequence. The average bulk density of the soil under MT was relatively high in the first year than in the second year. Soil under GW cropping sequence had relatively high bulk density (Table 5).

3.6 Water Stable Aggregates

The response of water stable aggregates (WSA) to tillage systems and crop sequences differed among the years (Table 6), and the response of WSA in the second year than the first year when the highest WSA was measured under MT in combination with the MC sequence. The least WSA was observed in soil under MP for GW, SW, MW and MC cropping sequences. Overall, the soil under MT had 34% higher WSA than that under MP. However, comparing the data of both experimental years, the soil under MP contained the highest WSA which was 8 % more in soil under FW than that under MW. Furthermore, the proportion of WSA in the soil under FW was 7% higher than that under SW, 6 % higher than that under GW, and also 6 % more than that under MC cropping sequence. However, the WSA in soil under MT for MC was higher by 4 %, 11 %, 12 % and 2 % than that under FW, MW, SW, and GW cropping sequences. In both experimental year with in tillage systems and cropping sequence, the trend in WSA differed under MP than that under MT. For example, in the first year, the highest WSA was observed in soil under MC cropping sequence (21.4%). In the second year, the highest stability WSA of 36.5 % was observed under FW. The highest proportion of WSA under MT (27.4%) was observed under FW. In the second year, the highest WSA of 48.6 % was observed in the MC cropping sequence.

Higher WSA in soil under MT than MP may be attributed to less physical disruption and enhancement of active SOC. Addition of plant residues under MT stimulates more fungal hyphae which in combination with residue derived polysaccharide play a key role in increasing WSA [46]. [42] reported that standing stubbles of crop residue also increase aggregation because roots can produce exudates and physically exert lateral pressures that results in cohesion of soil particles around the roots. Decline of WSA under intensive tillage of MP could be attributed to mechanical disruption of macro aggregates.

Among crop sequences, the highest aggregate stability was observed under sorghum–wheat and green manure–wheat sequence. This trend could be due to polysaccharides and fungal hyphea promoted by cereal crops and more bacterial activities in legumes.

4. CONCLUSION

Tillage systems have pronounced effect on SOC fractions and aggregate stability than cropping sequences. Labile pool carbon fractions (as MBC and PMC) were higher in soil under MT as compared to that under MP. In particular, legume-based cropping sequenced, enhanced WSA as compared with intensive tillage and fallow-based cropping system. POC concentration was more in soil under MP than that under MT. However, TOC trend was similar under both treatments. TOC pools were below the critical value (1.2-1.5 Mg ha^{-1}) and depleted with passage of time so, need to adopt proper management practices such as addition of residues, green manure, mulching, cover crops, intensified cropping sequence and CA.

5. RECOMMENDATIONS

The results of the study provide encouraging evidence for the success of minimum tillage with legume based cropping sequences in dryland Pothwar. There is dire need of long term studies for corroboration of the results and promotion of conservation agriculture in dryland Pothwar, Pakistan and marginal dryland areas elsewhere in the developing world.

REFERENCES

1. Zhou Y, Pei Z, Su J, Zhang J, Zheng Y, Ni J, Xiao C, Wang R. Comparing soil organic carbon dynamics in perennial grasses and shrubs in a saline-alkaline arid region, northwestern China. 2012; PloS one 7, e42927.

2. Schmidt, MWI, Torn MSS, Abiven T, Dittmar G, Guggenberger IA, Janssens CMMS, Silva M, Fay EF. Effect of Salinity on Soil Microorganisms. In Soriano, MC. H. (ed.), Soil Health and Land Use Management. 2012; InTech. DOI: 10.5772/28613.

3. Weil RR, Magdoff F. Significance of soil organic matter to soil quality and health. Soil organic matter in sustainable agriculture. CRC Press, Boca Raton. 2004; FL, 1-43.

4. Stevenson FJ. Humus chemistry: genesis, composition, reactions: 2nd ed., John Wiley & Sons, New York. 1994.

5. Paul EA, Clark, Eds. FE Soil Microbiology and Biochemistry, 2nd ed., Academic Press, 1996; San Diego.

6. Paul EA, Collins HP, Eds. The characteristics of organic matter relative to nutrient cycling in advance study soil science. CRC Press Boca Raton, FL. 1997; Pp.181-197.

7. Brady NC, Weil RR. Soil organic matter. The Nature and Properties of Soils, Prentice Hall Inc, New Jersey. 2008; 518-519.

8. Dumale, WAJ, Miyazaki T, Nishimura T, Seki K. CO_2 evolution and short-term carbon turnover in stable soil organic carbon from soils applied with fresh organic matter Geo. Phys. Res. Lett. 2000; 36: L01301.

9. Mrabet R. Stratification of soil aggregation and organic matter under conservation tillage systems in Africa. Soil and Tillage Research. 2002; 66: 119-128.

10. M'Hedhbi K, Chouen S, Ben-Hammouda M. A recent Tunisian experience with direct drilling. Proceedings of the II World Congress on Conservation Agriculture, pp. 2003; 132-135.

11. Ben-Hammouda M, Hedhbi KM, Kammassi M, Gouili H. Direct drilling: An agro-environmental approach to prevent land degradation and sustain production. The Proceedings of the International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas, 2007; 2003; pp. 37-48.

12. Avci M, Mevveci, Akar K, T Ozdemir, Yururer B, Karakurt A, Surek E, Karacam DM. Turkish experience on dryland agronomy: lessons from the past and the recent experiments. J. Agric. Res. 2007; 45: 33-42.

13. Gan Y, Harker K.N, McConkey B. and Suleimanov M, Moving toword no till practices in Northern Eurasia. In: No till Farmoing Systems. Goddard T, Zoebisch MA, Gan, YT, Ellis, W, Waston A, Sombatpaint S. (eds). World Association of Soil and Water Conservation, Special Publication No. 3,WASWCA, Bangkok, 2008; pp 179-195

14. Suleimenov M. From conservation tillage to conservation agriculture. In From conservation tillage to conservation agriculture, Proceedings of the International Consultation Conference on "No-till with soil cover & crop rotation: a basis for policy support to conservation agriculture for sustainable production intensification, 2009; 56-68.

15. Fileccia T. Importance of zero-tillage with high stubble to trap snow and increase wheat yields in Northern Kazakhstan. 2009; Working paper.

16. Nurbekov A. Manual on Conservation Agriculture Practices in Uzbekistan. In Manual on Conservation Agriculture Practices in Uzbekistan: Ministry of Agriculture, FAO & ICARDA, Tashkent, Uzbekistan. 2008.

17. Ministry of Food and Agriculture, Lahore. 1974.

18. Pala M, Ryan J, Zhang H, Singh M, Harris H. Water-use efficiency of wheat-based rotation systems in a Mediterranean environment. Agricultural Water Management. 2007; 93: 136-144.

19. Karabayev M. Improvement of soil and water management in Kazakhstan: Conservation Agriculture for wheat production and crop diversification. Proceedings of an International Technical Workshop on Investing in Sustainable Crop Intensification: The case for improving soil health. 2008.

20. Lal R. Carbon sequestration in soils of central Asia. Land Degradation & Development. 2004; 15: 563-572.

21. Whitbread, A.M, Graeme JB, Rod DBL. Managing legume leys, residues and fertilizers to enhance the sustainability of wheat cropping systems in Australia 2. Soil physical fertility and carbon, Soil Till. Res. 2000; 5477-89

22. Wong VNL, Greene RSB,. Dalal RC, Murphy BW. Soil carbon dynamics in saline and sodic soils: a review, Soil Use Manage. 2010; 26: 2-11.

23. De Souza Silva CMM, Fay EF. Effect of salinity on soil microorganisms. Soil Health and Land Use Management. InTech Publisher, 2012; 1-22.

24. Six J, H Bossuyt, Degryze S, Denef K. A history of research on the link between (micro) aggregates, soil biota, and soil organic matter dynamics. Soil Till. Res. 2004; 79:7-31.

25. Jastrow J, Miller R, Lussenhop J. Contributions of interacting biological mechanisms to soil aggregate stabilization in restored prairie1. Soil Biol. Biochem. 1998; 30: 905-916.

26. Krull ES, Skjemstad JO, Baldock JA., Functions of soil organic matter and the effect on soil properties. CSIRO Land & Water, South Australia, Report, Project CSO 00029. 2004.

27. Alvarez R. A review of nitrogen fertilizer and conservation tillage effects on soil organic carbon storage, Soil Use. Manage. 2005; 21: 38−52.

28. ICARDA. Conservation Agriculture; opportunities for intensified farming environmental conservation in dry areas. Research to Action 2. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria. 2012.

29. Shaheen A, Naeem MA, Jilani G, Shafiq M. Integrated soil management in eroded land augments the crop yield and water-use efficiency. Acta Agri. Scan. Section B–Soil and Plant Sci. 2010; 60: 274-282.

30. Nizami MMI, Shafiq M, Rashid A, Aslam M. The soils and their agricultural development potential in Potwar, NARC, Islamabad. 2004

31. Govt. of Pakistan. Soil Series Key and Soil Classification. Soil Survey of Pakistan

32. Nelson DW, Sommers LE. Total carbon, organic carbon and organic matter. In Sparks, D.L. (eds.). Methods of Soil Analysis, Chemical Methods. SSA Book Series: 5 Soil Sci. Soc. Am. 2005; Wisconsin. USA.

33. Kassel A. Nannipieri P. Methods in Applied Soil Microbiology and Biochemistry, Academic Press, 1995; San Diego, USA.

34. Camberdella CA. Elliot ET. Particulate soil organic matter across grass land cultivation sequences. Am. J. Soil Sci. 1992; 76: 395-401.

35. Beare MH, Bruce R. A comparison of methods for measuring water-stable aggregates: implications for determining environmental effects on soil structure. Geoderma 1993; 56: 87-104.

36. Walkley A, Black IA. An examination of digestion method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 1934; 37: 29-37.

37. Blake GR, Hartge KH. Bulk Density by Core Method. In: Klute. A. (ed). Methods of Soil Analysis, Part I. Amer. Soc. Agron. No. 9. Madison, Wisconsin. 1986; Pp. 364-367.

38. Ellert BH, Janzen H, McConkey B. Measuring and comparing soil carbon storage. Soil processes and the carbon cycle. CRC Press, Boca Raton, FL, 2001;131-146.

39. Steel RGD, Torrie JH, Boston MA. Principles and Procedures of Statistics: A biometrical approach, Mc Graw Hill Inc. New York. 1997: 633.

40. Zibilske, LM., Makus DJ.. Black oat cover crop management affects on soil temperature and biological properties on a Mollisol in Texas, USA, Geoderma 2009; 149:179-185.

41. Paustian K, Six J, Elliot ET, Hunt HW. Management options for reducing CO_2 emission from agricultural soils, Biochem. 2000; 48: 147-163

.

42. Benbi DK, Nieder R. Handbook of processes and modeling in the soil-plant system. Routledge. 2003.

43. Six J, Frey SD, Thiet RK, and Batten KM. Bacterial and fungal contributions to carbon sequestration in agroecosystems, Soil Sci. Soc. Am. J. 2006; 70: 555-569.

44. McCarty G, Lyssenko N, Starr J. Short-term changes in soil carbon and nitrogen pools during tillage management transition. J. Soil Sci. Soc. Amer. 1998; 62: 1564-1571.

45. West TO, Post WM. Soil organic carbon sequestration rates by tillage and crop rotation. J. Soil Sci. Soc. Am. 2002; 66: 1930-1946.

46. Elmholt S, Schjønning P, Munkholm LJ, Debosz K. Soil management effects on aggregate stability and biological binding. Geoderma, 2008;144: 455-467.

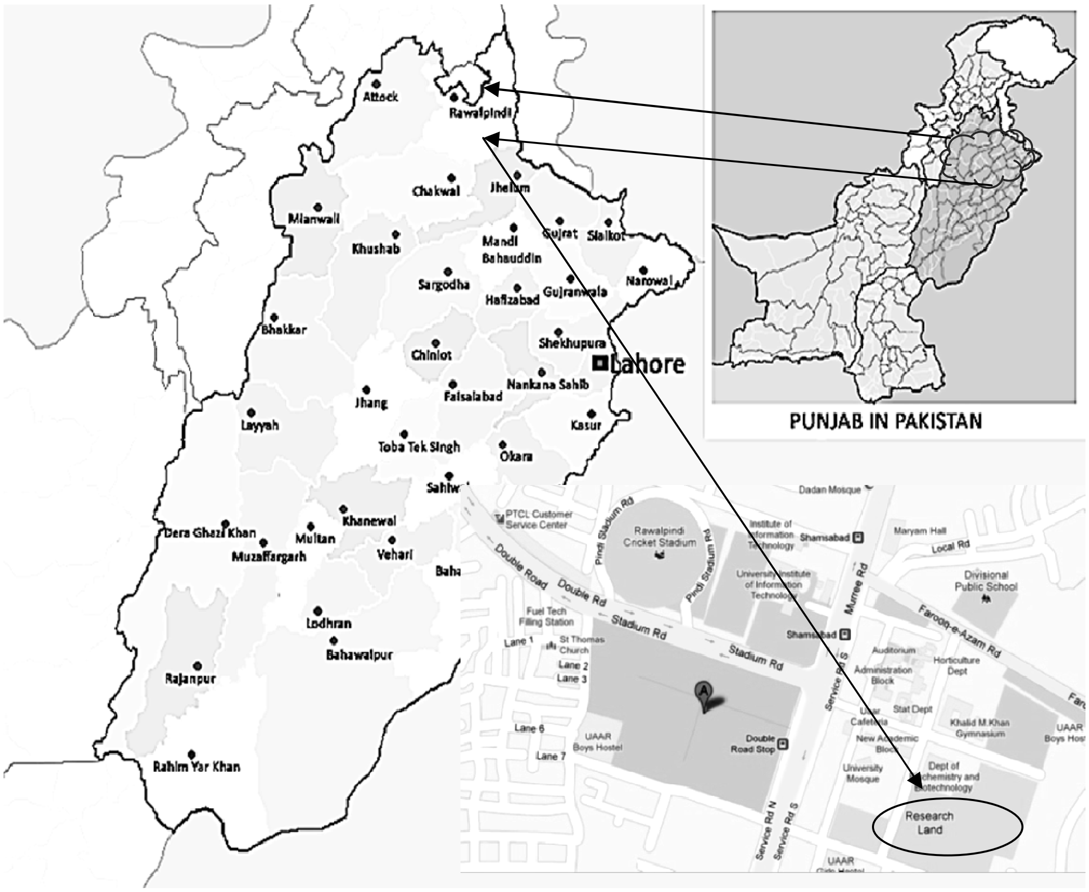

Fig.1. The map of the experimental location, the pothwar plateau, Punjab Province

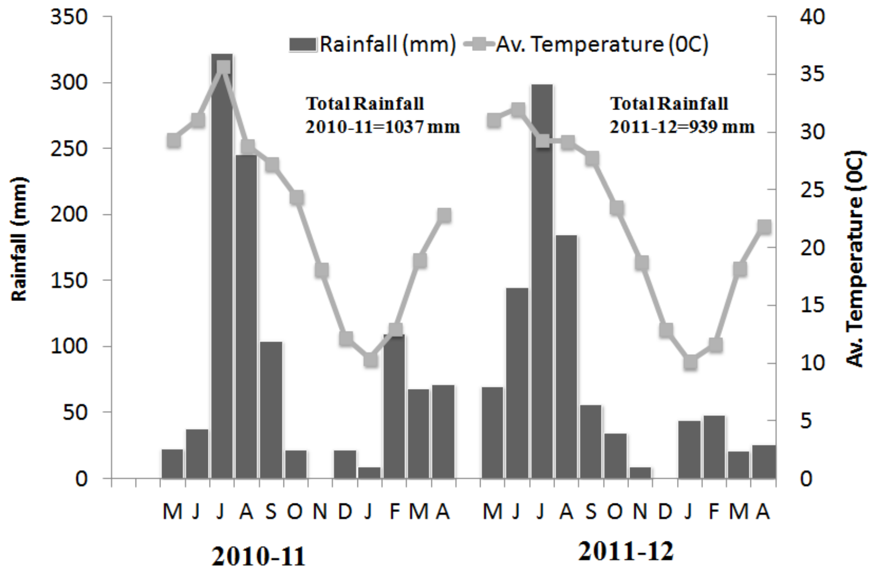

Fig.2. Monthly rainfall (mm) and mean monthly temperature (°C) during the experimental period

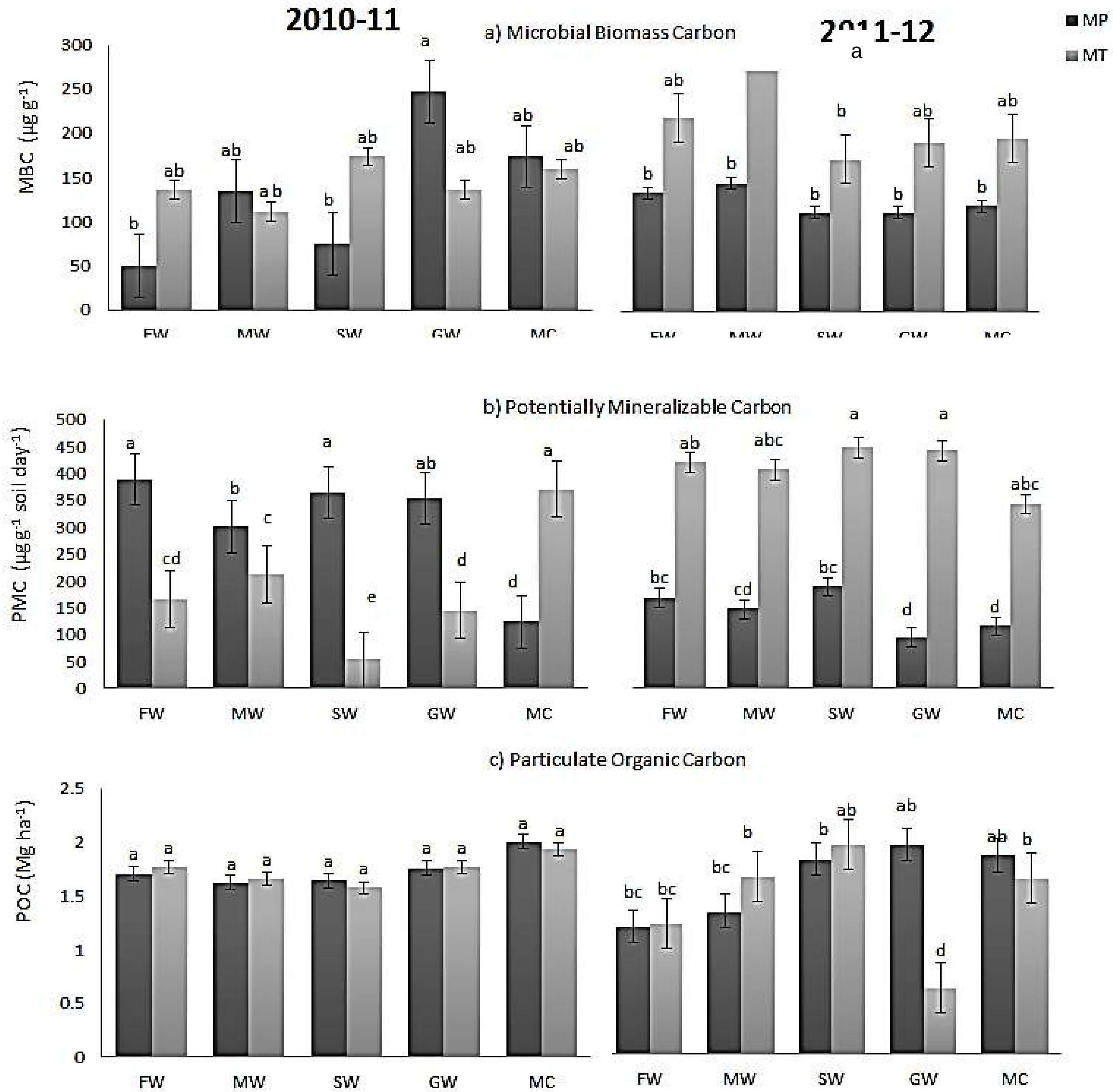

Fig. 3 The effect of tillage systems and crop sequences on labile SOC fractions a) microbial biomass carbon, b) potentially mineralizable carbon and c) particulate organic carbon

The error bars represent the standard error. Means with different letters are significanlty different according to LSD test at P =0.01

Table 1. The ANOVA table of variable assessed

Treatments	DF	MBC	CO_2	POC	TOC	WSA	Bulk density
		----P > 0.01----					
Year	1	*	*	ns	ns	ns	ns
Tillage	2	**	**	**	ns	*	ns
Crop	4	**	**	**	ns	ns	ns
Year × Tillage	2	**	**	**	ns	*	ns
Year × Crop	4	**	**	**	ns	ns	ns
Tillage × Crop	8	**	**	**	ns	ns	ns
Year × Tillage × Crop	8	**	**	**	ns	*	ns

Table 2. Physico-chemical properties of experimental soil

Soil Character	Unit	Mean Value
Soil texture		clay loam
Sand (2.0-0.2 mm)	%	38.1±0.41
Silt (0.2-0.02 mm)	%	32.2±0.94
Clay (0.02-0.002 mm)	%	29.6±0.24
Saturation	%	0.3±0.01
Soil pH		7.7±0.05
ECe	dS m^{-1}	0.2±0.02
Bulk Density	Mg m^{-3}	1.4±0.04
Available P	mg kg^{-1}	3.8±0.12
Extractable K	mg kg^{-1}	130±0.24
Nitrate-N	mg kg^{-1}	6.5±0.22
SOC	(Mg ha^{-1})	6.1±0.05
Moisture (Available)	cm m^{-1}	16.0±0.09
CEC	c mole $^{(+)}$ kg^{-1}	13.7±0.12
Water Stable Aggregates	%	20±0.05
$CaCO_3$	%	0.3±0.01
Soil Classification		Typic Ustochrepts Inceptisols Rawal series: Udic Haplustalf (Govt. of Pakistan, 1974)

Table 3. The effect of tillage systems and crop sequences on total organic carbon concentration (%) at 0-15cm soil.

	TOC (%)			
	2010-11	2011-12	2010-11	2011-12
Rotations	**MP**^{NS}	**MP**^{NS}	**MT**^{NS}	**MT**^{NS}
Fallow-Wheat	0.43	0.65	0.44	0.61
Mungbean-Wheat	0.41	0.62	0.41	0.59
Sorghum-wheat	0.45	0.60	0.51	0.62
Green Manure-wheat	0.55	0.71	0.64	0.65
Mungbean- chickpea	0.55	0.54	0.45	0.67

Tillage systems: MP, mouldboard plow and MT, minimum tillage.

Table 4. The effect of tillage systems and crop sequences on total organic carbon pool (Mg ha^{-1}) at 0-15cm Soil

	TOC (Mg ha^{-1})					
	2010-11	2011-12		2010-11	2011-12	
Rotations	**MP**^{NS}	**MP**^{NS}	**Mean**^{NS}	**MT**^{NS}	**MT**^{NS}	**Mean**^{NS}
Fallow-Wheat	7.19	8.72	7.95	7.00	8.24	7.62
Mungbean-wheat	6.67	8.31	7.49	6.50	7.97	7.23
Sorghum-wheat	7.26	8.12	7.69	7.51	8.44	7.97
Green Manure-wheat	9.90	10.9	10.0	10.1	9.95	10.0
Mungbean- chickpea	8.30	6.02	7.16	6.97	7.48	7.22
Mean	7.70	8.42		7.63	8.42	

Tillage systems: MP, mouldboard plow and MT, minimum tillage.

Table 5. The effect of tillage systems and crop sequences on bulk density (Mg m^{-3}) at 0-5cm depth

	Bulk density (Mg m^{-3})					
	2010-11	2011-12		2010-11	2011-12	
Rotations	**MP**^{NS}	**MP**^{NS}	**Mean**^{NS}	**MT**^{NS}	**MT**^{NS}	**Mean**^{NS}
Fallow-Wheat	1.67	1.25	1.45	1.60	1.34	1.47
Mungbean-wheat	1.62	1.36	1.49	1.60	1.35	1.46
Sorghum-wheat	1.61	1.14	1.37	1.46	1.50	1.40
Green Manure-wheat	1.66	1.53	1.59	1.59	1.53	1.56
Mungbean- chickpea	1.61	1.16	1.33	1.54	1.11	1.32
Mean	1.61	1.28		1.55	1.33	

Tillage systems: MP, mouldboard plow; TC, tine cultivator and MT, minimum tillage.

Table 6. The effect of tillage systems and crop sequences on aggregate stability.

Aggregate Stability (%)						
	2010-11			2011-12		
Rotations	MP	MT	Mean	MP	MT	Mean
Fallow-Wheat	19.8 c	27.5 a	23.7 A	36.5 a	38.1 d	33.0 AB
Mungbean-wheat	19.9 c	21.3 c	20.6 A	31.5 bc	39.5 c	32.7 AB
Sorghum-wheat	20.7 b	22.8 b	21.7 A	31.5 bc	37.5 e	31.7 B
Green Manure-wheat	21.2 a	20.9 d	21.1 A	31.6 b	46.3 b	36.5 A
Mungbean- chickpea	21.4 a	20.3 e	18.8 A	31.3 c	48.6 a	35.4 AB
Mean	20.6 C	22.6 C		32.5 B	42.0 A	

Tillage systems: MP, mouldboard plow and MT, minimum tillage.