1

2 ***Original Research Article***

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

7
8
9 **ABSTRACT**
10

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.

11
12 *Keywords: Conservation agriculture; microbial biomass C; potentially mineralizable C;*
13 *particulate organic C; Punjab; Mungbean; Photwar; Pakistan*
14
15
16 **1. INTRODUCTION**
17
18 Soil organic carbon (SOC) is a complex mixture of organic compounds originating from plant
19 residues, microbes and animals. Besides its multifarious role in soil quality and agronomic
20 production, SOC plays a critical role in the global C cycle (1). It is the largest terrestrial C
21 pool after fossil fuel deposits, and contains thrice as much C as that in the entire terrestrial
22 vegetation (2). Thus, recent two decades since 1990 have witnessed a renaissance in SOC
23 research, and it has emerged as a key indicator of soil quality for agricultural and
24 environmental sustainability (3). The complex organic constituents of SOC vary in the age
25 and ease of decomposability hence they have been conceptually divided into three pools:
26 active, slow and passive. [4,5 and 6]. The active fractions [[e.g. microbial biomass C (MBC)
27 and potentially mineralizable C (PMC) and particulate organic carbon (POC)], are labile and
28 have turnover time of days to years [7]. These fractions play an important role in soil's
29 moderating capacity for nutrient cycling and physical properties. The active fractions are

30   fairly responsive to management changes and serve as an early indicator of long-term SOC
31   turnover. The slow and passive fractions are relatively more resistant to decomposition and
32   have turnover time of decades to centuries [8].

33   A Global review of 67 studies related to SOC affected by tillage and crop sequences showed
34   that almost 50% of studies were carried out in Canda and USA (Weil and Magdoff 2004a).
35   Another review of 59 studies [3] showed that 50% of research studies were reported from
36   USA, Canada and Argentina where soil were Mollisols and Sopodosols, managed under
37   highly mechanized practices. In the Mediterranean Basin numerous countries have been
38   successful in establishing conservation agriculture (CA) but the areal extents are relatively
39   uncertain. These include Spain, Portugal, France and Italy in Europe: Morocco and Tunisia
40   in North Africa. Only Kazakhstan in central Asia has the areas exceeding one million hectare
41   under CA. Countries in West Asia and Central Asia include Uzebekistan and Ukraine.
42   Extensive research and development work has been conducted the West Asia and North
43   Africa (WANA) in several countries since the early 1980s such as Morocco, [9], Tunisia
44   [10,11] and in Turkey [12]. Similarly research, work on CA in Eurasia has been reported by
45   [13], for Kazakhstan by Suleimenov, [14, 9 and 15], and 16 and 17]. Several international
46   centers (e.g. International Center for Agricultural Research in the Dry Areas (ICARDA) and
47   International Maize and Wheat Improvement Center (CIMMYT) have also been active in CA
48   research in the WANA regions [18, 19 and 14). [21] estimated that the SOC loss from soil of
49   five Central Asian Countries (Kazakkhstan, Kyrgystan, Tadjistan, Turkmenistan and
50   Uzbekistan) of 1-2 Pg was due to agricultural mismanagement. In South Asia (e.g. Pakistan
51   and Afghanistan) little information is available related to the SOC pools and its changes with
52   land use and management. In Pakistan, most of research has been done on the importance
53   of SOC in relation to fertility and magnitude of SOC. Less attention has thus far been given
54   towards the effects of agricultural management on enhancing quality and quantity of SOC.

55   The SOC has a strong link with aggregate stability that is important to soil quality.
56   Increased SOC concentration is often associated with improved soil physical condition [21].
57   The encapsulation of SOC into soil aggregates provides physical protection against rapid
58   decomposition and is one of the key determinants of soil stability against erosion [22].
59   Although soil's structural stability is not considered as a direct plant growth factor, it exerts
60   considerable influence on the air, water and nutrient supplies to the plant roots, as also on
61   the movement of the soil macro-fauna [23]. Stable aggregates protect SOC by forming
62   barriers between microbes and the substrate, thus inhibiting its microbial turnover [24]. The
63   POC is an important agent in binding micro-aggregates which serve as precursor of macro-
64   aggregates [25]. However, there is no general agreement as to the type of organic matter
65   that plays a key role in enhancing aggregation [26]. Improvements of SOC and aggregate
66   stability are often associated with minimum tillage (MT) and intensified cropping. These
67   proven approaches are now widely used in large scale commercial agriculture [27].
68   However, their use in drylands of developing countries, having small land holdings and
69   marginal farming practices, is in its infancy. These dry areas are challenged by rapid
70   population growth, frequent droughts, high climatic variability, land degradation and
71   desertification, and widespread poverty. It is important to explore and demonstrate
72   management options for improvement of SOC in these areas [28]. Therefore, a field
73   experiment was conducted to assess the effects of different tillage systems and cropping
74   sequences on labile SOC fractions, total organic carbon (TOC), bulk density and water
75   stable aggregates in a subtropical dryland of Pakistan. The study was designed to test the
76   hypothesis that tillage systems and crop sequences strongly affect SOC fractions under
77   agroecolgical conditions of northern Punjab, Pakistan.
78

79   **2. MATERIAL AND METHODS**

80

81   **2.1 Location and Experimental Layout**

82   A two-year field experiment was conducted at the Research Farm of Pir Mehr Ali Shah-Arid
83   Agriculture University Rawalpindi, Pakistan (33° 38′ N, 73° 05′ E) during 2010-11 and 2011-
84   12. The experimental site is part of a wide rainfed track of northern Punjab called Pothwar
85   plateau. The rainfall is of a bi-modal pattern with two maxima, the first in late summer
86   (August and September) and the second during the winter-spring (February and March) (Fig.
87   1). The summer or monsoon rains constitute about 70 % of the total annual rainfall of 750-
88   950 mm. These rains are highly torrential and result in severe soil erosion [29]. The mean
89   maximum temperature during summer ranges from 36 ^{o}C to 42 ^{o}C with extremes sometimes
90   as high as 48 ^{o}C [30]. Soil of experimental site is clay loam with pH of 8, ECe of 0.25 dSm^{-1},
91   bulk density of 1.4 Mg m^{-3}, and nutrient concentration (mg kg-1 soil) of 3.35, 6.50 and 130
92   for N, P and K, respectively. Predominant soil of the site (33° 38' N, 73" 05' E) is classified
93   as Rawal series: Udic Haplustalf [31] (Table 2)

94   The experiment was laid out in a split-plot design. Main plots were comprised of two soil
95   tillage systems: moldboard plough (MP, control), and minimum tillage (MT). Each main plot
96   was divided into five sub plots with following crop sequences viz. fallow–wheat (*Triticum*
97   *aestivum* L.) (FW) (control), mungbean (*Vigna radiate* L.) –wheat (MW), sorghum (Sorghum
98   bicolor)–wheat (SW), green manure–wheat (GW) and mungbean-chickpea (MC) (*Cicer*
99   *arietinum* L.). The green manure crop comprised of a mixture of mungbean and sorghum
100   seeds, and ploughing under the biomass before the grain setting stage. Total six main-plots
101   and thirty sub-plots were established. The main and sub plot sizes were 19×16 m and
102   2.5×16 m, respectively. At the end of each season from each sub-plot one sample was taken
103   so, total thirty soil samples were collected with replication for analysis. The tractor used was
104   Massey Ferguson (MF) 240 of 50 horse power at 2.250 rpm. Crops were seeded with a
105   winter seed drill at row spacing of 15 cm. No crop was seeded in the FW system for the
106   period from the previous harvest of wheat in April until the sowing of next wheat in
107   November. Under MP tillage the FW rotation involved moldboard ploughing to 25 cm depth
108   at the start of summer and subsequent repeated three cultivations with tine cultivator for
109   weed control. The FW system under MT, involved no ploughing throughout the fallow period
110   except at the time of seedbed preparation for wheat. Weeds in fallow plots under MT were
111   controlled with two sprays of roundup (glyphosate [N- (phosphonomethyl) glycine)] @ 1.5
112   liter ha.$^{-1}$ In all treatments involving double cropping (i.e MW, SW, GW and MC), summer
113   crops were sown at the onset of mosoon in July and harvested in mid-September. Winter
114   crops were sown in early November and harvested in April. The MP ploughing was
115   performed at depth of 25 cm on start of monsoon, followed by one tine cultivation and
116   planting before sowing of summer crops. After the harvest of summer crop, soil was tilled by
117   tine cultivator to 15 cm depth for 2-3 times before sowing of wheat. MT soil was kept free
118   from any tillage except for the field preparation. The double cropping under MT involved only
119   ploughing with tine cultivator at the time of sowing of summer and winter crops. Fertilization
120   for mungbean, sorghum and wheat involved the application of 60 kg ha-1 urea 100-50 of kg
121   ha^{-1} urea, and DAP, 120-80 kg ha^{-1} urea and DAP respectively, applied at the time of
122   seedbed preparation before the sowing of wheat. In MT plots, both summer and winter crop
123   residues were returned back to the soil.

124

125   **2.2 Soil Sampling and Analyses**

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

143
144 **2.3 Statistical Analysis**

145
146 The data were subjected to analysis of variance (ANOVA) using the split-plot design, and
147 means were compared at 1 % level of significance the by the Least Significant Difference
148 (LSD) test [39]. The year effect was tested using a "Combine experiment" Model (11
149 MSTATC), with the block within year effect as the error term. The main plot effect (tillage ×
150 year interaction) was tested with appropriate error term for the split plot design. Cropping
151 sequence and other effects were tested by using residual error. LSD value > 0.01.Year
152 effect was tested using a 'Combine experiment" Model (11 MSTATC).

153
154
155 **3. RESULTS AND DISCUSSION**

156
157 **3.1 Microbial Biomass Carbon**

158 The response of MBC to tillage systems and crop sequences varied among the
159 years (Fig. 3a), it was more pronounced in the second year than the first year when the
160 highest MBC was measured under MT in combination with the MW sequence. The least
161 MBC was recorded in soil under MP for three specific crop sequences: GW, SW and MC
162 cropping sequences. Overall the soil under MT had 37 % higher MBC than that under MP.
163 However, comparing the data of both experimental years, the soil under MP contained the
164 highest MBC which was 46 % more in MW than that under FW and SW. Furthermore, the
165 concentration of MBC under soil in GW was 20 % higher than that under MW, and 17 %
166 more than that under SW cropping sequence. However, the MBC in soil under MT for MW
167 was higher by 19 %, 22 %, 26 % and 20 % than that under FW, SW, GW and MC cropping
168 sequences. In both experimental year with in tillage systems and cropping sequence, the
169 trend in MBC differed under MP than that under MT system. For example, in the first year,
170 the highest MBC was observed in soil under GW cropping sequence (247 µg g-1). In the
171 second year, the highest concentration (160 µg g^{-1}) was observed under MW and it was
172 similar to that for the first year. The highest concentration of MBC under MT (159 µg g^{-1}) was
173 observed under MC. In the second year, the highest MBC of 360 µg g^{-1} was observed in the
174 MW cropping sequence.

175 Tillage had prominent effect on labile SOC fractions (MBC and PMC) than did cropping
176 sequences. On the other hand, MP had higher proportion of intermediate SOC (*i.e.* POC)

177 fraction. These trends show that mineralization was relatively faster in soil than under MP
178 than that under MT. Because the MT tillage involves return of crop residues to soil, this not
179 only frequently recharges the active SOC pool but also reduces the surface soil temperature
180 [40]. Further, less physical disintegration and oxidation of returned residues reduces the rate
181 of decomposition under MT. In contrast, intensive ploughing with MP accelerates
182 decomposition due to more soil disturbance, physical disintegration of aggregates [41].

183 **3.2 Potentially Mineralizable Carbon**

184 The response of PMC to tillage systems and crop sequences varied among the years (Fig.
185 3b), it was more noticeable in the second than in the first year when the highest PMC was
186 measured in the soil under MT in combination with the MC sequence. The least PMC was
187 recorded in soil under MP for GW and MC crop sequences. Overall the soil under MT had 10
188 % higher MBC than that under MP. However, comparing the data of both experimental
189 years, the PMC concentration in soil under MP for FW was higher by 19 %, 0.74 %, 19 %
190 and 56 % than that under MW, SW, GW and MC cropping sequences. Moreover, the PMC in
191 soil under MT for MC was higher by 22 %, 17 %, 42 % and 18 % than that under FW, MW,
192 SW, and GW cropping sequences. In both experimental year with in tillage systems and
193 cropping sequence, the trend in PMC differed under MP than that under other tillage
194 systems. For example, in the first year, the highest PMC was observed in soil under FW
195 cropping sequence (388 µg g^{-1} soil day^{-1}). In the second year, the highest concentration (188
196 µg g^{-1} day^{-1}) was observed in the soil under SW. The highest concentration of PMC under
197 MT (371 µg g^{-1} soil day^{-1}) was observed in the soil under MC sequence. In the second year,
198 the highest PMC of 447 µg g^{-1} soil day^{-1} was observed in the SW cropping sequence.

199 Differences among crops for SOC fractions could be attributed to amount of residue
200 produced and returned to the soil. The fallowing-based sequences had lower proportion of
201 active SOC because in a fallow period mineralization of SOC is higher due to more soil
202 moisture [42]. Cropping sequence involving continuous cereal sequences that involved
203 sorghum, had higher POC concentration than legume-based sequences because sorghum
204 being a C4 plant has more lignin and phenol contents which are resistant to decomposition
205 [43].

206 **3.3 Particulate Organic Carbon**

207 The response of POC was only significant in the second year (Fig. 3c), it was more
208 evident in the second year than in the first year when the highest POC was measured under
209 MT in combination with the SW cropping sequence. Overall, the soil under MP had 6.42 %
210 higher POC than that under MT. The least POC was recorded in soil under MP for SW and
211 MW cropping sequences. However, comparing the data of both experimental years, the
212 POC concentration in soil under MP for GW was higher by 25 %, 23 %, 10 % and 3 % than
213 that under FW, MW, SW and MC cropping sequences. Moreover, the POC in soil under MT
214 for MC was higher by 16 %, 7.45 %, 1.27 % and 33% than that under FW, MW, SW, and
215 GW cropping sequences. In both experimental years with in tillage systems and cropping
216 sequence, the trend in PMC differed under MP than that under MT system. For example, in
217 the first year, the highest POC pool was observed in soil under MC cropping sequence (2.0
218 Mg ha^{-1}). In the second year, the highest pool of POC (1.94 Mg ha^{-1}) was observed under
219 GW, and that under MT (1.93 Mg ha^{-1}) was observed under MC sequence. In the second
220 year, the highest POC of 1.76 Mg ha^{-1} was observed in the SW cropping sequence.

221 Differences among crops for SOC fractions could be attributed to amount of residue
222 produced and returned to the soil. The fallowing-based sequences had lower proportion of
223 active SOC because in a fallow period mineralization of SOC is higher due to more soil

224   moisture (42). Cropping sequence involving continuous cereal sequences that involved
225   sorghum, had higher POC concentration than legume-based sequences because sorghum
226   being a C_4 plant has more lignin and phenol contents which are resistant to decomposition
227   (43).

228   3.4 Total Organic Carbon

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

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

239   3.5 Bulk Density

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

248   3.6 Water Stable Aggregates

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

265   Higher WSA in soil under MT than MP may be attributed to less physical disruption and
266   enhancement of active SOC. Addition of plant residues under MT stimulates more fungal
267   hyphae which in combination with residue derived polysaccharide play a key role in
268   increasing WSA [46]. [42] reported that standing stubbles of crop residue also increase

269 aggregation because roots can produce exudates and physically exert lateral pressures that
270 results in cohesion of soil particles around the roots. Decline of WSA under intensive tillage
271 of MP could be attributed to mechanical disruption of macro aggregates.

272   Among crop sequences, the highest aggregate stability was observed under
273 sorghum–wheat and green manure–wheat sequence. This trend could be due to
274 polysaccharides and fungal hyphea promoted by cereal crops and more bacterial activities in
275 legumes.
276
277 **4. CONCLUSION**
278
279 Tillage systems have pronounced effect on SOC fractions and aggregate stability than
280 cropping sequences. Labile pool carbon fractions (as MBC and PMC) were higher in soil
281 under MT as compared to that under MP. In particular, legume-based cropping sequenced,
282 enhanced WSA as compared with intensive tillage and fallow-based cropping system. POC
283 concentration was more in soil under MP than that under MT. However, TOC trend was
284 similar under both treatments. TOC pools were below the critical value (1.2-1.5 Mg ha-1) and
285 depleted with passage of time so, need to adopt proper management practices such as
286 addition of residues, green manure, mulching, cover crops, intensified cropping sequence
287 and CA. The results of the study provide encouraging evidence for the success of minimum
288 tillage with legume based cropping sequences in dryland Pothwar. There is dire need of long
289 term studies for corroboration of the results and promotion of conservation agriculture in
290 dryland Pothwar, Pakistan and marginal dryland areas elsewhere in the developing world.

291
292
293 **REFERENCES**

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

297 2. Schmidt, MWI, M.S.S. Torn, T. Abiven, G. Dittmar, I.A. Guggenberger, C.M.M.S.
298 Janssens, M.Silva, and E.F. Fay. 2012. Effect of Salinity on Soil Microorganisms. In
299 Soriano, M. C. H. (ed.), Soil Health and Land Use Management. InTech. DOI:
300 10.5772/28613.

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

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

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

308 6. Paul EA, Collins HP, Eds. The characteristics of organic matter relative to nutrient
309 cycling in advance study soil science. CRC Press Boca Raton, FL. 1997; Pp.181-
310 197.

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

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

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

318   10. M'Hedhbi K, Chouen S, Ben-Hammouda M. A recent Tunisian experience with direct
319   drilling. Proceedings of the II World Congress on Conservation Agriculture, pp. 2003;
320   132-135.

321   11. Ben-Hammouda M, Hedhbi KM, Kammassi M, Gouili H. 2007. Direct drilling: An
322   agro-environmental approach to prevent land degradation and sustain production.
323   The Proceedings of the International Workshop on Conservation Agriculture for
324   Sustainable Land Management to Improve the Livelihood of People in Dry Areas,
325   2003; pp. 37-48.

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

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

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

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

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

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

343   18. Pala M, Ryan J, Zhang H, Singh M, Harris H. Water-use efficiency of wheat-based
344   rotation systems in a Mediterranean environment. Agricultural Water Management.
345   2007; 93: 136-144.

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

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

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

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

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

359   24. Six J, H Bossuyt, Degryze S, Denef K.. A history of research on the link between
360   (micro) aggregates, soil biota, and soil organic matter dynamics. Soil Till. Res. 2004;
361   79:7-31.

362   25. Jastrow J, Miller R, Lussenhop J. Contributions of interacting biological mechanisms
363   to soil aggregate stabilization in restored prairie1. Soil Biol. Biochem. 1998; 30: 905-
364   916.

365   26. Krull ES, Skjemstad JO, Baldock JA., Functions of soil organic matter and the effect
366   on soil properties. CSIRO Land & Water, South Australia, Report, Project CSO
367   00029. 2004.

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

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

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

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

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

379   32. Nelson DW, Sommers LE. Total carbon, organic carbon and organic matter. In
380   Sparks, D.L. (eds.). Methods of Soil Analysis, Chemical Methods. SSA Book Series:
381   5 Soil Sci. Soc. Am. Wisconsin. USA. 2005.

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

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

386   35. Beare MH, Bruce R. A comparison of methods for measuring water-stable
387   aggregates: implications for determining environmental effects on soil structure.
388   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.

39. 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.

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

41.

42. 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.

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

.

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

45. 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.

46. 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.

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

48. Elmholt S, Schjønning P, Munkholm LJ, Debosz K. Soil management effects on aggregate stability and biological binding. Geoderma, 2008;144: 455-467.
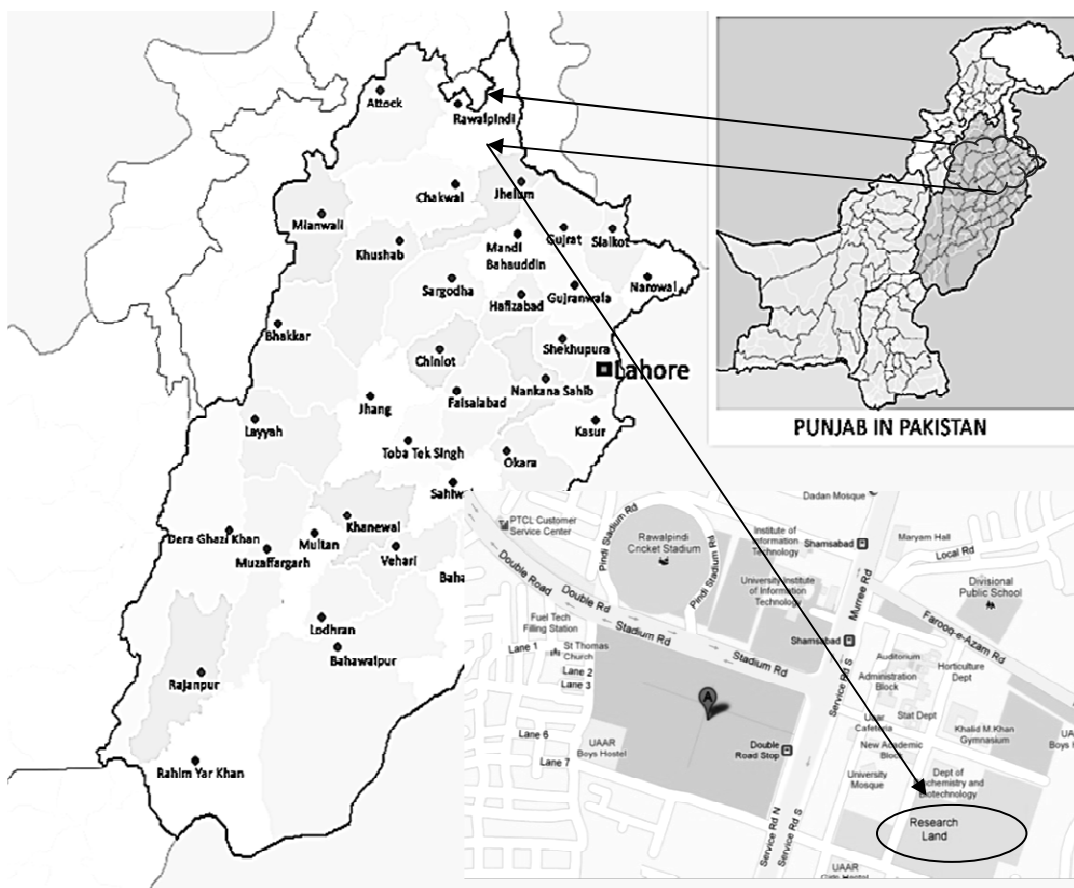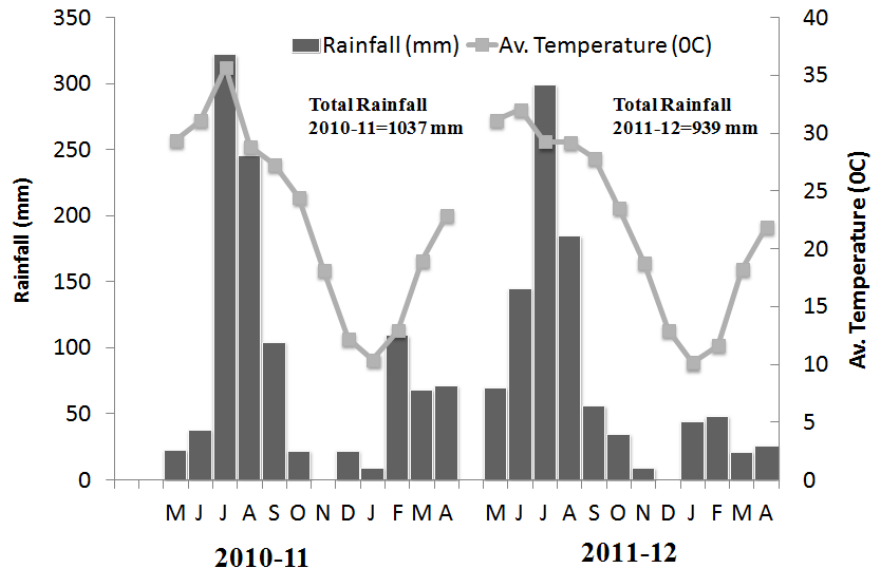
424

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

426

427

428

Fig.2 Monthly rainfall (mm) and mean monthly temperature (ºC) during the

experimental period
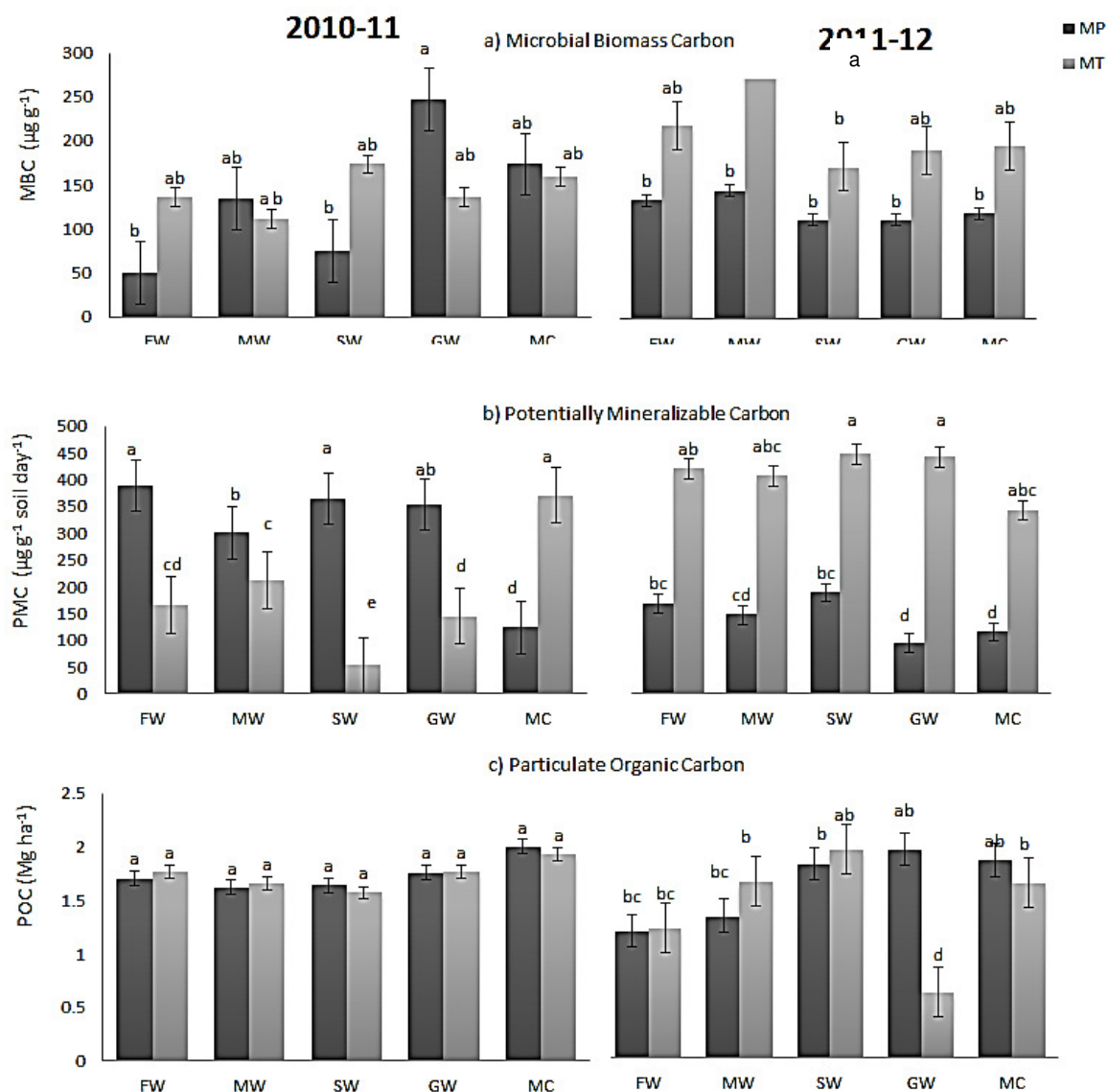
Fig. 3 The effect of tillage systems and crop sequences on labile SOC fractions

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

440   **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

441

442   **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$\pm$0.41
Silt (0.2-0.02 mm)	%	32.2$\pm$0.94
Clay (0.02-0.002 mm)	%	29.6$\pm$0.24
Saturation	%	0.3$\pm$0.01
Soil pH		7.7$\pm$0.05
ECe	dS m^{-1}	0.2$\pm$0.02
Bulk Density	Mg m^{-3}	1.4$\pm$0.04
Available P	mg kg^{-1}	3.8$\pm$0.12
Extractable K	mg kg^{-1}	130$\pm$0.24
Nitrate-N	mg kg^{-1}	6.5$\pm$0.22
SOC	(Mg ha^{-1})	6.1$\pm$0.05
Moisture (Available)	cm m^{-1}	16.0$\pm$0.09
CEC	c mole $^{(+)}$ kg^{-1}	13.7$\pm$0.12
Water Stable Aggregates	%	20$\pm$0.05
CaCO$_3$	%	0.3$\pm$0.01
		Typic Ustochrepts
		Inceptisols
Soil Classification		Rawal series: Udic Haplustalf (Govt. of Pakistan, 1974)

443
444
445
446
447
448
449
450
451

452 **Table 3: The effect of tillage systems and crop sequences on total organic**
453 **carbon concentration (%) at 0-15cm soil.**
454

	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

455 Tillage systems: MP, mouldboard plow and MT, minimum tillage.
456
457 **Table 4: The effect of tillage systems and crop sequences on total organic**
458 **carbon pool (Mg ha^{-1}) at 0-10cm Soil**
459

	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	

460 Tillage systems: MP, mouldboard plow and MT, minimum tillage.
461
462 **Table 5: The effect of tillage systems and crop sequences on bulk density (Mg m^{-3}) at 0-5cm depth**
463

	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	

464 Tillage systems: MP, mouldboard plow; TC, tine cultivator and MT, minimum
465 tillage.
466
467
468
469

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

Rotations	Aggregate Stability (%)					
	2010-11			2011-12		
	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	

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

472