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Influence of tillage practices and weed control methods on organic carbon pools and physical properties of sandy clay loam soil in north central India

Manoj Kumar, Verma SK, Priyadarshani A Khambalkar, Asha Arora and Narendra Singh

Abstract
A four year field experiment (2014–2017) was conducted at Gwalior (*Typic Ustochrepts*), India with pearlmillet [*Pennisetum glaucum* (L.)]- mustard [Brassica juncea (L.) Czern. & Coss.] cropping sequence having five tillage practices; conventional tillage (CT), zero tillage (ZT) and their combinations with or without residue (R) management as the main plot, and three weed management practices as vertical plots in strip plot design. SOC concentration was significantly higher under ZT+R-ZT+R compared to CT-CT and CT-ZT and was at par to ZT-ZT +R at 0-15 cm. Contribution of non labile (C_{NL}) pool was more compared with very labile (C_{VL}), labile (C_{L}) and less labile (C_{LL}) pool of SOC under all treatments. Concentration of active (C_{ACT}) pool was higher in ZT-ZT+R with Oxyflourfen (0-30 cm); whereas passive (C_{PSV}) pool was higher in ZT+R-ZT+R with Pendimethalin. The C_{ACT} to C_{PSV} ratio was highest in CT-ZT with Pendimethalin (0-15 cm) and ZT-ZT with 1HW (15-30 cm). BD was increased in zero tillage treatments as compared with conventional tillage at (15-30 cm). Tillage practices and their interaction showed significant variation for MWD (>125μm) and total aggregates at 15-30 cm. Surface soil temperature was higher in conventional tillage compared with zero tillage and residue incorporation treatments at $2_{p.m.}$ (March 2017). Zero tillage with residue incorporation showed downside effect on increased BD in lower depths.

Keywords: conservation tillage; carbon sequestration; soil properties, organic carbon pool

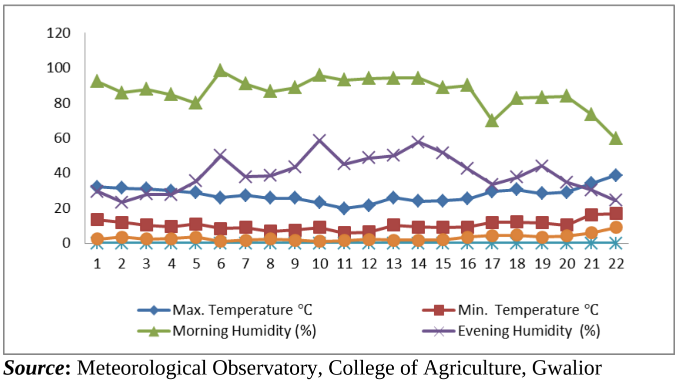
Introduction
Conservation agriculture is a major focus in the Indian agriculture in order to sustain the quality of natural resources and to meet the challenges of ever increasing demands for food, fodder and fuel of the country. One of the most important principles of conservation agriculture is minimal soil disturbance. Several workers (Gupta *et al*. 2002 [13], Gupta *et al*. 2005) [14] have reported positive effects on soil health and environmental quality of no-till system in India. Conventional tillage (CT) disturbs soil structure and may adversely affect long-term soil productivity due to erosion and loss of organic matter in soils. Sustainable soil management can be practiced through conservation tillage, high crop residue return and crop rotation (Hobbs, 2008) [17]. Soils under no-tillage and reduced tillage have significantly higher SOC concentration compared with conventionally tilled soils under a wide range of climatic conditions, soil types, and crop rotation systems (Alvarez, 2005) [2]. No-tillage (NT) has shown to improve soil properties, thereby enhancing water transmission, water retention and crop yield in many parts of the world (He *et al*., 2009) [16]. Soil organic carbon has profound effects on soil physical, chemical and biological properties (Haynes, 2005) [15] Maintenance of SOC in cropland is important, not only for improvement of agricultural productivity but also for reduction in C emission (Rajan *et al*., 2012) [27]. However, short- and medium-term changes of SOC concentration are difficult to detect because of its high temporal and spatial variability (Blayer 1995) [4]. Thus, carbon (C) sequestration is a major aim of adopting conservation tillage practices. Higher SOC concentration improves microbial activity and better physical environment in soil, thus ensures better health of soil. None the less, mustard-pearl millet cropping system is popular in north central zone of India improving land use efficiency and economic returns. In order to exploit these practices, there is a need to understand the influence of tillage and weed management on selected soil physical properties

in mustard-pearl millet growing area of semi-arid climate of Gwalior region of north central India. The hypothesis tested was that zero tillage in combination with residue incorporation will increase concentration of SOC, C_{VL}, C_{ACT}, C_{PSV} pools and improve MWD (>125µm), total aggregates and reduced soil temperature and also on account of less/no soil disturbance and retention of crop/weed biomass will increase SOC concentration in ZT except increased in BD at lower depth.

Materials and Methods

Site description

Information generated by monitoring a long-term field experiment AICRP project on Weed Management in pearlmillet-mustard cropping system at the research farm of College of Agriculture, RVSKVV Gwalior, India (latitude of 26° 13'N and longitude 76° 10'E with an altitude 197 meters). The experimental site is classified as *Typic Ustochrepts*, coarse loamy mixed hyper thermic with sandy clay loam (556 g kg^{-1} sand, 268 g kg^{-1} silt and 206 g kg^{-1}) texture (NBSS &LUP 1999)[26]. The field experiment was initiated in the *kharif* season of 2014 and soil samples were collected after harvest of mustard at the end of 4^{th} cropping year (2017). The climate of experimental site is semi arid and sub-tropical dominated with extreme weather conditions having hot and dry summer and cold winter. The research station falls in Grid zone of Madhya Pradesh, India. Maximum temperature goes up to 45 °C in summer and steeps down to a chilling temperature of as low as 2-5 °C during winter. The monsoon sets in last week of June. Most of which fall during last June to middle of September with mean annual rainfall of area is about 751 mm. The metrological data during study period (2017) is presented in Fig.1. The *kharif* crop pearlmillet was grown on the experimental land yearly and incorporates crop residues on the same site as according to treatments in *rabi* mustard. Soil initial chemical properties prior to the beginning of the experiment in *kharif* 2014 were soil organic carbon 3.83 g Kg^{-1}, available nitrogen 163 kg ha^{-1}, Olsen P 7.69 kg ha^{-1}, ammonium acetate-extractable K 169 kg ha^{-1}, soil BD 1.40 Mg m^{-3}, soil pH 7.69 and EC 0.41 dSm^{-1}.



Source: Meteorological Observatory, College of Agriculture, Gwalior

Fig. 1: Meteorological data of crop season (October 2016- April 2017)

Treatments description

The experimental trial was laid out under strip plot design and replicated three times with 15 treatments including 5 tillage practices viz. T_1- conventional tillage in *kharif* followed by conventional tillage in *rabi* (CT-CT), T_2 - conventional tillage in *kharif* followed by zero tillage in *rabi* (CT- ZT), T_3- zero tillage in *kharif* followed by zero tillage in *rabi* (ZT- ZT), T_4 - zero tillage in *kharif* followed by zero tillage and residue retained in *rabi* (ZT-ZT+R) (at least 30%) on the field and T_5 - zero tillage and residue retained in *kharif* followed by zero tillage and residue retained in *rabi* (ZT+R-ZT+R) as horizontal plots. Similarly, weed management practices through herbicides (pre and post emergence); W_1- Pendimethalin 30 EC @ 1.0 kg/ha as PE (pre-emergence), W_2 - Oxyflourfen 23.5 EC @ 0.230kg/ha as PE + 1 HW (hand weeding) at 25-30 days and W_3 - 1 HW alone as in vertical plots. All the treatments were randomized separately in each replication. The dimensions of individual sub plots were 7.0 × 6.0 m leaving 0.5 m in between two subplots and 1.0 m in between two main plots as borders.

Under CT, the residues of weeds and above ground crop biomass were removed manually from the field using a sickle. For field preparation in CT tillage, two manual spading followed by levelling were done to a depth of about 15 cm both before sowing of *kharif* and *rabbi* crops. Spading is done for manual turning of soil by a primary tillage farm impalements under CT. Weeds were removed manually by HW and use of weedicides as according to treatments. However under ZT–ZT+ R incorporation treatments, residues of *kharif* season crops were retained; similarly in ZT+R-ZT+R residues of *kharif* and *rabbi* season crops were retained on the soil surface as in-situ mulch in between the two rows of a crop. Sowing under ZT was done in narrow furrows made by National zero till ferti-seed drill (NZTD) machin (developed by G.B. Pant University of Agriculture & Technology, Pant Nagar) and primary tillage operations were completely avoided. Weeds were uprooted at HW operation and placed in between the crop rows as mulch under ZT. The sowing operation under CT was also performed using a manual furrow opener in well pulverized field. The Mustard (Rohini) was sown @ 5 kg/ha on 4^{th} November 2017. The fertilizer dose (N: P: K Kg/ha) 80: 40: 20 was used. 50% dose of the N form urea (46% N) was applied as basal and remaining 50% of nitrogen was top dressed after 35 days. The 100% dose of P and K were applied as single-super-phosphate (16%) and muriate of potash at the time of sowing. The fertilizers were applied in furrow opened by using a manual furrow opener in well pulverized plots under CT for both *kharif* and *rabbi* crops. Whereas, in case of ZT, furrows were opened using manual furrow opener in partially disturbed soil having partial incorporation of residues in ZT+R treatments. The fertilizers were mixed with the soil before sowing and covering of seeds. Gap filling (re-sowing) was done to maintain plant population. The crops were grown with recommended agronomic practices.

Soil sampling and analysis

Initial soil samples (about 500 g) were collected using a soil auger (screw head type, Tube auger) at the start of the experiment (2014) for analyzing some physico-chemical properties. Soil samples were also obtained from 0–15 cm and 15–30 cm depths after the harvest of *rabbi* mustard (across the rows) during 2017 using same auger. Immediately after sampling, one part of the soil samples were air dried under shade, gently ground, sieved through a 2 mm sieve, and stored in polyethylene bags for analysis of soil physico-chemical properties viz., organic carbon (Walkley and Black 1934) [31], oxidizable organic carbon pools by modified Walkely and Black as proposed by Chan *et al.*, (2001) [7]. The determination of oxidzable carbon was done by using 5 and 10 ml of concentrated sulphuric acid instead of the 20 ml specified by Walkey and Black (1934) [31]. The resulting three acid-aqueous solution ratio of 0.5:1, 1:1 and 2:1 (which corresponded respectively to 12 N, 18 N and 24 N of H_2SO_4)

allowed comparison of oxidizable organic carbon extracted under increasing oxidizing conditions. There are four pools of total organic carbon:

a) Very labile carbon (Pool: I) – (12 N H_2SO_4) – organic carbon oxidizable under 12 N H_2SO_4;
b) Labile carbon (Pool: II) – (18 N – 12 N H_2SO_4) – the difference in oxidizable organic carbon extracted between 18 N and 12 N H_2SO_4;
c) Less labile carbon (Pool: III) – (24 N – 18 N H_2SO_4) – the difference in oxidizable organic carbon extracted between 24 N and 18 NH_2SO_4. The 24 N H_2So_4 is equivalent to the standard Walkely-black method; and
d) Non-labile carbon (Pool: IV) – (TOC – 24 N H_2SO_4) – residual organic carbon after reaction with 24 N H_2SO_4 when compared with the total carbon determined by the TOC analyzer.

The pool I and II together represent the active pool [active pool = Σ (pool I + Pool II)] while pool III and pool IV together constitute the passive pool [Passive pool = Σ (pool III + Pool IV)] of organic C in soils (Chan *et al*., 2001) [7].

The physical properties including bulk density was recorded by using core sampler (Blake and Hartge 1986) [3] aggregate stability and mean weight diameter were determined by wet sieving method (Yoder, 1936 [33]; Kemper and Rosenau 1986 [19]). Soil temperature was measured on experimental field at weekly interval at surface, 15 cm and 30 cm depth by digital soil thermometer during 7.00 AM and 2.00 PM at periodic intervals as per standard time outlined by Indian Meteorological Department (IMD).The area truly represents the agro-climatic conditions of Indo-Gangetic and alluvial plains.

Statistical analysis

Data obtained were statistically analyzed with analysis of variance (ANOVA) in a strip plot design. The value was calculated only for those characters, which were found significant at 5 percent level of significance. Five tillage practices were assigned to the main plots and three weed management practices in vertical plots. The null hypotheses tested for tillage practices, weed management and their interactions effect with soil parameters equally. The difference between the treatments means were tested for statistical significance by the Least Significant Difference (LSD) at 5% probability (Gomez and Gomez, 1984 [12]). Interaction tables have been provided only when the effects were significant.

Results and Discussions

Tillage practices and weed management had variable effect on soil organic carbon, its pool and soil properties. The results obtained from the present study have been described in this section with possible cause and effects along with available literatures support.

Soil organic carbon

In general, SOC concentrations at 0–15 cm soil depth under all the tillage and weed management practices enhanced after four years of the study related to previous level (3.83 g/kg) (Table 1). The tillage practices recorded significant variation for soil organic carbon at 0-15 cm and 15-30 cm depth, respectively. After four years of the experimentation, the treatment combinations T_5W_1 and T_5W_2 had highest concentration of soil organic carbon 5.70 g kg^{-1} (0-15 cm) and 5.00 g kg^{-1} (15-30 cm) respectively. Treatment ZT+R-ZT+R was statistically significant over CT-CT and CT-ZT and was at par to ZT-ZT+R and ZT-ZT at both depths. Retention of crop and weed residues under ZT+R- ZT+R and ZT- ZT+R, was left undisturbed, reduced litter decomposition, less soil disturbance and thus was not subjected to accelerated decay which resulted in higher SOC (Al-Kaisi *et al*., 2005 [1]) especially in the top layer of soil i.e. 0–15 cm soil depth (Das et al., 2017 [9]). In present study, the increase in SOC concentration was largest near the surface (0–15 cm) than sub-surface (15–30 cm) soil across the treatments, obviously due to higher residue recycling enhanced the microbial activities at surface soil that fastened the decomposition of crop residues and acceleration of SOC (Singh *et al*. 2010 [30], Mandal *et al*. 2013 [24]). It is evident from the perusal of data that to bring significant changes in SOC under tillage system it requires a long term continuous residue addition coupled with minimum disturbances in soil. Similarly, zero tillage systems usually help to maintain soil organic matter (SOM) and aggregate stability (Rhoton, 2000 [28]).

Table 1: Effect of tillage practices and weed control methods on soil organic carbon (SOC) and bulk density (BD) of soil.

Weed control Method	SOC (g/kg of soil)					BD (Mg/m^3)				
	Tillage practices									
	(T_1)	(T_2)	(T_3)	(T_4)	(T_5)	(T_1)	(T_2)	(T_3)	(T_4)	(T_5)
	0-15 cm									
W_1	4.35	4.85	5.10	5.45	5.70	1.34	1.40	1.42	1.44	1.41
W_2	4.45	4.85	5.00	4.95	5.60	1.40	1.41	1.43	1.36	1.36
W_3	4.85	5.00	4.70	5.15	5.65	1.37	1.37	1.52	1.38	1.37
	T	W	T*W1	T*W2		T	W	T*W1	T*W2	
CD (*P* =0.05)	0.40	NS	NS	NS		0.05	NS	NS	NS	
	15- 30 cm									
W_1	3.96	3.76	4.21	4.50	4.41	1.45	1.47	1.51	1.55	1.52
W_2	3.66	3.51	4.31	4.21	5.00	1.47	1.41	1.47	1.41	1.39
W_3	3.51	3.86	4.16	4.65	4.60	1.49	1.42	1.45	1.54	1.50
	T	W	T*W1	T*W2		T	W	T*W1	T*W2	
CD (*P* =0.05)	0.63	NS	NS	NS		NS	NS	NS	NS	

T_1- conventional tillage followed by conventional tillage (CT-CT), T_2- conventional tillage followed by zero tillage (CT- ZT), T_3 -zero tillage followed by zero tillage (ZT- ZT), T_4 -zero tillage followed by zero tillage with residue retained (ZT-ZT+R), T_5 -zero tillage with residue retained followed by zero tillage with residue retained (ZT+R-ZT+R); W_1-Pendimethalin,W_2-Oxyflourfen+1HW (hand weeding),W_3-1HW, CD- critical difference, *P*= 0.05 -probability at 5%, NS – non significant

Oxidizable organic carbon pools

Ploughing disturbs the soil and promotes oxidation of organic C in soils. In zero tillage, carbon in crop residues was returned into the soil which helps to increase the soil carbon pools (Devi *et al*. 2015 [10], Singh *et al*. 2010) [30]. The organic carbon pools (very labile- $C_{VL,}$ labile- $C_{L,}$ less labile- $C_{LL,}$ and non labile- C_{NL}) and their distribution at 0-30 cm soil depth showed in Fig: 2. Study showed that there was maximum contribution of C_{NL} fallowed by C_{VL} compared with C_L and C_{LL} pool under all treatment combinations. The treatments mean value of C_{VL} (4.92g kg^{-1}), C_{LL} (3.83 g kg^{-1}) was higher in ZT+R-ZT+R fallowed by C_L (1.97 g kg^{-1}) in ZT-ZT+R compared to all fertility treatments. Crop residue, weed biomass having high content of polysaccharides (cellulose and hemicelluloses) and their continuous retention in soil could lead to the production of ample amounts pools of SOC (Majumder *et al*. 2008) [23] Increasing trend of C_{LL} was recorded in zero tillage (ZT+R-ZT+R, ZT-ZT+R, ZT-ZT) compared with conventional tillage (CT-CT) treatments after 4 years. In contrast, intense ploughing and removal of residues increased C_{NL} pool in CT-ZT (10.81g kg^{-1}) but ZT+R-ZT+R also showed increased value of C_{NL} (10.17 g kg^{-1}). From this it can be stated that ZT+R-ZT+R not only enhance C_{VL}, C_{LL} but also C_{NL} pool also. The weed management practices do not showed much variation for different pools of SOC except C_{NL} was higher in W_1. The distribution of C_{LL} and C_L pool was lowest in most of the treatment and weed management practices may be ascribed due to high temperature in the sub-tropical region (Khambalkar *et al*. 2013) [20] lower production of biomass, less residue retention (CT-ZT and CT-CT) into soil and influence of atmospheric temperature (Chivane and Bhattacharyya, 2010) [8].

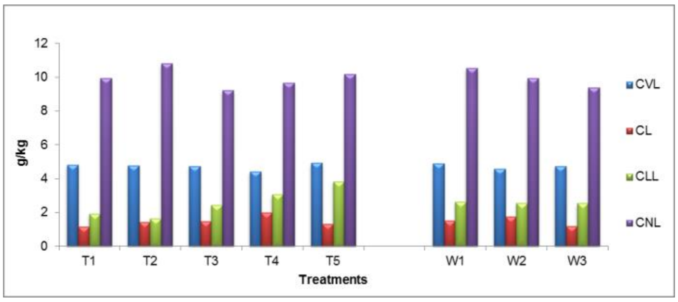


Fig 2: Effect of tillage Practices and weed control methods on oxidizable organic carbon pools at 0-30 cm soil depth

CVL- very lable pool, CL- labile pool, CLL- less labile pool, CNL-non lable pool; T_1- conventional tillage followed by conventional tillage (CT-CT), T_2- conventional tillage followed by zero tillage (CT- ZT), T_3 -zero tillage followed by zero tillage (ZT- ZT), T_4 -zero tillage followed by zero tillage with residue retained (ZT-ZT+R), T_5 -zero tillage with residue retained followed by zero tillage with residue retained (ZT+R-ZT+R); W_1- Pendimethalin, W_2 – Oxyflourfen +1 HW(hand weeding), W_3 -1HW

Active pool and passive pool

Results showed that under all treatment combinations passive pool remained dominant over active pool (Fig. 3). Fifteen treatment combinations showed contribution of active pool (28 to 40 %), and passive pool (60 to 72 %) of SOC, at 0-30 cm soil depth. The treatment combinations T_3W_2 (40%) and T_5W_1 (72%) were dominant contributor of active pool and passive pool, respectively of total soil organic carbon. The lowest contribution of active pool was recorded in treatment combinations T_1W_2 and T_1W_3 may be due to less residue retention in soil. The data presented in Fig: 4 showed that the ratio of active to passive pool of carbon was ranged between 0.44 to 0.69 and 0.35 to 0.82 at 0-15 cm and 15-30 cm depth, respectively after harvesting. The ratio of C_{ACT} to C_{PSV} was less than 1 across tillage practices indicating more recalcitrant form carbon exist in the soil than easily labile or oxidizable fractions (Kumar *et al*. 2018) [21]. This ratio was highest for treatment combinations T_3W_2 (0.82) fallowed by T_2W_1 (0.69) for 0-15 cm and 15-30 cm, respectively after harvesting. Different studies indicated that active pool of carbon gradually decreased in drier tracts (semi-arid moist and semi-arid dry) with corresponding increase in those of passive pool of carbon as compared to wetter areas (sub-humid moist and sub-humid dry) (Chivane and Bhattacharyya, 2010) [8]. The rate of C mineralization is high in the tropics because of high temperature and therefore humification efficiency is low (Ladha *et al*. 2003) [22].

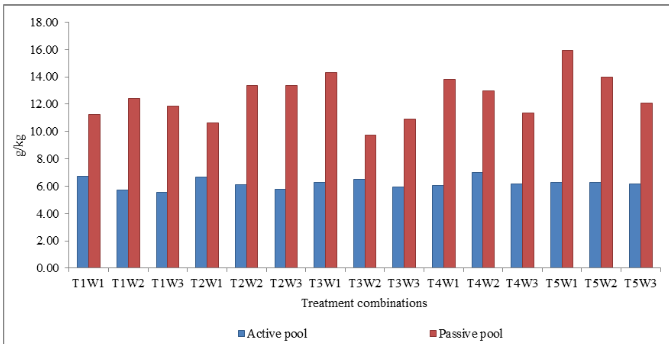


Fig 3: Effect of tillage practices and weed control methods on active and passive pool of soil organic carbon at 0-30 cm

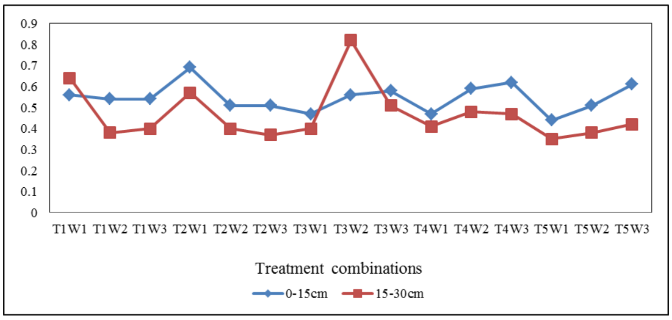


Fig. 4: Effect of tillage practices and weed control methods on active- passive pool ratio

T_1- conventional tillage followed by conventional tillage (CT-CT), T_2- conventional tillage followed by zero tillage (CT-ZT), T_3 - zero tillage followed by zero tillage (ZT- ZT), T_4 - zero tillage followed by zero tillage with residue retained (ZT-ZT+R), T_5 -zero tillage with residue retained followed by zero tillage with residue retained (ZT+R-ZT+R); W_1- Pendimethalin, W_2 – Oxyflourfen + 1HW (hand weeding), W_3 -1HW

Soil physical properties

Bulk density

Conventional tillage and residue incorporation in zero tillage significantly (P<0.05) lowered the bulk density in 0–15cm soil layer (Table. 1) over zero tillage treatment without residue incorporation. The weed management methods and their interactions showed non-significant effect on the soil bulk density at both soil depths. The highest value of bulk density was recorded in treatment combinations T_3W_3 (1.52 Mg m^{-3}) and T_4W_1 (1.55 Mg m^{-3}) at 0-15 cm and 15-30 cm, respectively after 4th cropping cycle. The maximum soil bulk density was recorded in ZT-ZT and CT-ZT at surface and sub surface soil; due to natural consolidation and minimum disturbance of soil tillage operation in zero tillage (John and Singh 2007) [18]. This was because the bulk density of the tilled soil was lower than that of the untilled soil. The tillage of the soil therefore created a better soil physical environment for root growth and development. This was evident in the higher values of root volume in the tilled soil than in the untilled soils, with the conventional tillage greater than the traditional and zero tillage (Bola *et al*.2013, Ghuman and Sur 2001) [11, 5].

Mean weight diameter (MWD >125 µm) and total aggregate percentage (>125 µm)

Different tillage practices, weed control methods and their interactions showed non- significant variation at 0-15 cm, similarly tillage practices and their interactions recorded significant variation and the weed control methods showed non-significant variation for MWD>125 µm, respectively at 15-30 cm depth (Table. 2). At the time of observation, the highest value of MWD recorded in treatment combinations T_2W_3 and T_5W_3 at both depths, respectively after harvesting of crop. Treatment ZT–ZT+R observed significantly higher value of MWD >125 µm; which was at par with ZT-ZT and the ZT+R-ZT+R and significantly superior over CT-CT. The interaction effect CT-ZT was at par with ZT–ZT+R. Similarly, the weed control treatment Pendimethalin @ 1.0 kg/ha as PE (W_2) was recorded higher value of MWD >125 µm; which was at par with all other weed control methods (W_1 and W_3) at 15-30 cm depth after harvesting. Boogar *et al*. (2014) [6] reported positive effects of conservation tillage (minimum or no-till) improved soil structure and by forming more aggregates. Physical destruction of soil structure occurs during tillage, which results in direct breakdown of the soil aggregates, while root pieces are considered as the main binding units contributing to the formation of macro-aggregates (> 250 µm) and the conventional or traditional tillage has the largest contribution in destruction of soil aggregates. On the other hand, keeping residue on the soil surface does not necessarily result in aggregates formation increase, but it can decrease aggregates breakdown by controlling erosion through keeping aggregates from rain water splash. The different tillage practices, weed control methods and their interactions reported non-significant variation in case of total aggregate (>125 µm) at both depths (table: 2). The total aggregate percentage was ranges between 68.77 to 74.73 % and 66.72 to 71.41 % at 0-15 cm and 15-30 cm depth, respectively. The highest value of total aggregate percentage (%) found in treatment combinations (T_5W_2) and (T_3W_2) at 0-15 cm and 15-30 cm, respectively after harvesting. The zero tillage system provides greater stability to soil aggregates compared to the fallow plus conventional tillage.

Table 2: Effect of tillage practices and weed control on Mean Weight Diameter (MWD >125 µm) and total aggregates (%) at 0-15 and 15-30 cm soil depth

Weed control Method	MWD >125 µm					Total Aggregates (%)				
	Tillage practices									
	(T_1)	(T_2)	(T_3)	(T_4)	(T_5)	(T_1)	(T_2)	(T_3)	(T_4)	(T_5)
	0-15 cm									
W_1	0.86	0.87	0.87	0.92	0.77	70.99	71.90	75.80	73.81	68.77
W_2	0.76	0.85	0.93	0.75	0.91	70.69	73.24	70.73	74.69	74.73
W_3	0.82	0.95	0.80	0.89	0.91	71.13	72.21	70.21	70.33	68.96
	T	W	T*W1	T*W2		T	W	T*W1	T*W2	
CD (*P* =0.05)	NS	NS	NS	NS		NS	NS	NS	NS	
	15- 30 cm									
W_1	0.78	0.99	0.89	0.94	0.96	67.98	70.52	69.33	68.26	68.05
W_2	0.85	0.84	0.94	1.03	0.94	66.72	70.25	71.41	70.45	70.72
W_3	0.75	0.78	0.90	1.03	1.04	69.11	68.59	68.55	68.81	70.88
	T	W	T*W1	T*W2		T	W	T*W1	T*W2	
CD (*P* =0.05)	0.11	NS	0.15	0.11		0.11	NS	0.15	0.11	

T_1- conventional tillage followed by conventional tillage (CT-CT), T_2- conventional tillage followed by zero tillage (CT- ZT), T_3 -zero tillage followed by zero tillage (ZT- ZT), T_4 -zero tillage followed by zero tillage with residue retained (ZT-ZT+R), T_5 -zero tillage with residue retained followed by zero tillage with residue retained (ZT+R-ZT+R); W_1-Pendimethalin,W_2-Oxyflourfen+1HW (hand weeding),W_3-1HW, CD-critical difference, *P*= 0.05 -probability at 5%, NS – non significant

Soil temperature (°C)

Soil temperature was recorded during the 4th cropping cycle from January to March at $7.00_{a.m.}$ and $2.00_{p.m.}$ for surface (0-5cm, Fig: 5) and at $2.00_{a.m.}$ for 15 and 30 cm soil depths (Fig :6). The surface soil temperature fluctuation between 7.00 am to 2.00 pm ranges between 4.8 to 13.5°C. Significant variations were recorded in different tillage practices at 30 cm, on 18th and 25th January, 2017. Similarly tillage practices and their interactions reported significant variation at 15 cm and 30 cm depth, respectively on 1st March 2017. The surface soil temperature showed much variation at $2_{p.m.}$ (March 2017) in residue management treatment i.e. ZT-ZT+R and ZT+R-ZT+R and their combinations with weed control practices. These treatments showed the lower soil temperature compared with CT-CT, CT-ZT and ZT-ZT in combinations with weed control methods. Continuous covers of crop residue and less soil disturbance by no tillage practices, prevents the soil surface from absorbing solar radiation directly (Al-Kaisi *et al*. 2005 [1]) this causes surface soil temperature reduction and could reduce soil moisture evaporation and improve soil moisture retention in the soil. Similar results reported by Wang *et al*. (2009) [32], in general, for every day of the year, the soil temperature was higher in the CT treatment than in the NT treatment. Moroizumi and Horino (2002) [25] found higher values of soil temperature under a CT treatment. The tillage depth under CT makes the soil more porous, and as a result, the soil likely has lower thermal conductivity (Sarkar and Singh, 2007 [29]). This change leads to greater heat retention under CT. In addition, the higher soil temperature under CT may be due to a surface difference under NT, the soil surface is partially covered by remnants of straw from the previous crop, causing the soil to absorb less solar radiation during the day (Wang *et al*., 2009) [32].

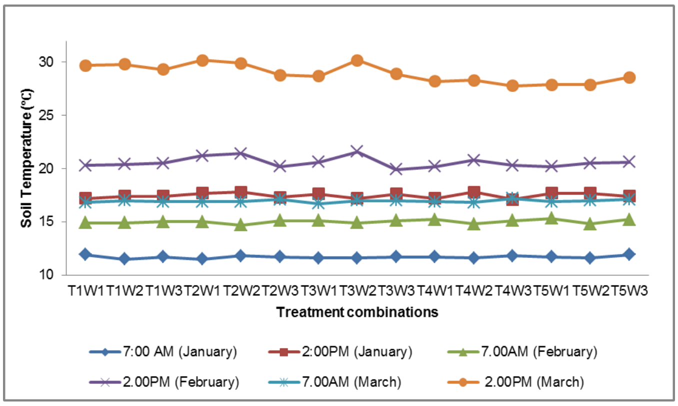


Fig 5: Effect of tillage practices and weed control methods on surface soil temperature (°C)

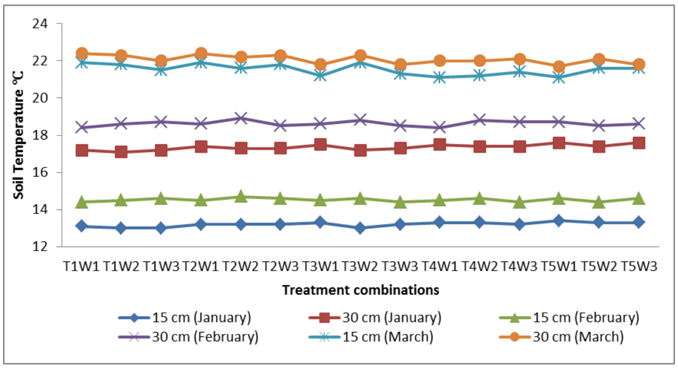


Fig 6: Effect of tillage practices and weed control methods on sub-surface soil temperature (°C)

T_1- conventional tillage followed by conventional tillage (CT-CT), T_2- conventional tillage followed by zero tillage (CT-ZT), T_3 - zero tillage followed by zero tillage (ZT- ZT), T_4 - zero tillage followed by zero tillage with residue retained (ZT-ZT+R), T_5 -zero tillage with residue retained followed by zero tillage with residue retained (ZT+R-ZT+R); W_1-Pendimethalin, W_2 – Oxyflourfen + 1HW (hand weeding), W_3 -1H.

Conclusion

The conservation tillage system is an ecological approach to soil surface management as it conserves soil organic matter, maintain physical properties, minimizes soil erosion risks but on other hand, increases surface bulk density. Thus, based on the results of present investigation, it can be concluded that adoption of zero tillage, residue incorporation (ZT-ZT+R, ZT+R-ZT+R) and integration of weed management optimize oxidizable organic carbon pool, active and passive pools, SOC, maintain the soil structure by provides greater stability to soil aggregates MWD>125 µm and increase total aggregates percentage and reduce surface soil temperature but increase BD (ZT-ZT) over conventional tillage and residue incorporation treatments compared to the CT-CT.

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