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Research Article

Study on soil organic carbon dynamics and its different pools in maize crop (*Zea mays L.)* under different agricultural practices in semiarid region of Punjab, India

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Abstract

The soil organic carbon (SOC) is a vital resource whose presence or absence can determine the quality of soils. The sustainability potential of soils can be unlocked with the presence of SOC. The present study aimed to evaluate the implications of different agricultural field practices on the soil organic carbon, its various fractions, and the soil organic carbon stocks in the semi-arid region of Phagwara (Punjab) with a maize variety (Suvarna NMH-589). Soil samples were collected from all the treatments (T_0, T_1, T_2, T_3, …, T_9) at two soil depths, 'a' (0-15 cm) and 'b' (15-30 cm), during the experimental period of 2022-23 and 2023-24. Analyses were performed on the soils collected at 0 DAS (days after sowing), 45 DAS and 90 DAS. A pooled mean data of the analysis revealed that the total organic carbon (TOC) was maximum in the straw mulching treatment T_1 (7.87, 9.40, 11.50, along with increasing DAS). Values of TOC ranged from 5.48-11.05 g kg^{-1} and 4.16-7.93 g kg^{-1} at the surface and subsurface layers during the experimental periods. The oxidizable soil organic carbon (SOC) ranged from 3.67-6.07 g kg^{-1} and 2.62-4.63 g kg^{-1} at soil depths 'a' and 'b', respectively. There was the suggestive notion that the incorporation of organic matter and its decomposition has a positive effect towards increasing the organic carbon content in soils. The SOC stocks also fluctuated in a range of 7.26- 11.51 Mg ha^{-1} and 9.69-19.23 Mg ha^{-1} at the different soil depths 'a' and 'b'. Differential accumulation of biomass in the surface and subsurface layers was the driving factor for such a range in the values obtained. The carbon fractions also fluctuated during the experimental periods. It was concluded that different agricultural practices greatly influenced the organic carbon dynamics in soil. The agricultural practices that could boost SOC could improve crop productivity, improve nutrient transformation, and act as a sink for CO_2 in the soil.

Keywords: Carbon fractions, Soil health, Soil organic carbon, Soil organic carbon stocks, Total organic carbon

INTRODUCTION

Soil is a vital natural resource. It is a pivotal existence that controls the ecosystem's hydrological and biogeochemical processes. Sustainability approaches require active conservation of soil and its resources as they provide goods and services to mankind. The functioning of soil hydrology, biology, and chemistry largely depends on the carbon content of the soil system. Any change in agricultural land use practices rapidly accelerates the biogeochemical functioning of the Carbon fractions, soil health, soil organic carbon, soil organic carbon stocks, and total organic carbon which determines the fate of the soil (Pellegrini *et al*., 2018).The soil organic carbon (SOC) is an active determinant of a region's soil quality and soil health. The organic carbon is one of the largest pools and encompasses one-third of the terrestrial carbon pools. SOC reserves 1500 Pg carbon, two to three times larger than the total carbon in terrestrial vegetation and atmosphere. The soil properties are directly proportional to the SOC content. The different proportions of SOC differ in biological stability, turnover rates, and biochemical compositions (Abbas *et al*., 2020). To maintain sustainable productivity in agroecosystems, SOC and its different fractions are pivotal by influencing soil's physical, chemical, and biological properties (Meetei *et al*., 2020). The labile fraction is supposedly a sensitive indicator of soil quality. Due to its sensitive nature and fast turnover rates, it induces significant interactions with the soil system and supplies readily accessible substrates for the microbial biota.

Increasing the SOC storage in agricultural fields is necessary for improving soil health and other ecosystem services while providing optimum agronomic produce. Tillage practices are a major contributor of soil organic carbon dynamics and emissions, as they regulate the soil structure (Wang *et al*., 2020). In arid regions, mineralization of SOC induces soil carbon loss in the form of CO_2. In agricultural lands, soil disturbance from tillage operations is the major inducer of CO_2 emissions. Introduction of minimum tillage practices could potently increase the amount of SOC from the soil profile. This could result from soil structure not being disturbed, which induces a reduction in soil degradation and SOC mineralization rates. Adoption of no-till/ minimum tillage can sequester C @ 65-350 C $ha^{-1}y^{-1}$ (Wang *et al*., 2020). It could also be noted that the provision of tillage has been observed to increase the SOC in some cases (Page *et al*., 2020).

Other practices, such as straw mulching and plastic mulching could effectuate improvement in soil quality and crop-growing environments, often leading to increased production. Straw mulching in the field is also considered a conservation practice towards environmental pollution since most of the straw biomass in the field are burnt for subsequent cropping seasons. Straw mulching can effectively decrease air pollution and also provide a strata of soil organic matter in the mulched fields (Yang *et al*., 2018). Straw mulching has several benefits, including lowering soil surface evaporation loss, insulating the surface from raindrop impact, improving soil aggregation, and fostering biological activity (Demo *et al.* 2024). Plastic mulching is also a well-evolved technique for utilization in arid, semiarid and sub-humid agricultural zones. Plastic film mulching can increase the temperature of the topsoil and extend the time for reproductive growth, both of which improve the yield of grains (Yin *et al.* 2018). Yet, increases in soil temperature and water content have the potential to alter the biological properties of the soil and have a detrimental effect on soil sustainability and quality. Consequently, a comprehensive assessment of the impacts of mulching with straw and plastic film on soil organic matter is necessary to assess the alterations in soil quality. So, the present study aimed to generate insight on any agricultural practices that can help improve the soil organic carbon dynamics, a vital requirement in generating good soil health and productivity.

MATERIALS AND METHODS

Site description

The geographic location for the experimental site in Phagwara (Punjab) is at an altitude of 254 m above sea level. The coordinates of Phagwara are 31°14’48” N latitude and 75°41’45” E longitude. Out of the six agro-climatic regions of Punjab, Phagwara lies in the central plain region. The climate of Phagwara is humid subtropical and semiarid, with extremely high summer and winter temperatures. It has four distinct seasons in the geographical area: hot and dry summer (April to June), hot and humid summer (July to September), cold winter (November to January), and moderate winter (February to March). During the summer, the lowest temperature is 25°C and the warmest is 48°C. Its winter average temperature is 19°C, with a minimum of -1°C. The South-West monsoon brings about significant rainfall between July and September, with an average yearly total of 500–750 mm.

Treatment and crop description

A maize variety (Suvarna NMH- 589) was grown for two seasons during *Kharif* (June-Sep 2021-22)) and *Kharif* (June-Sep 2022-23) for conducting the experiment, which was laid out in Randomized Block Design with 10 treatments in 3 replications. The agricultural land use and treatments provided were: (i) T_0- Fallow; (ii) T_1-Organic mulching with straw; (iii) T_2- Plastic mulching; (iv) T_3- Minimum Tillage; (v) T_4- Earthing up; (vi) T_5-Paired row; (vii) T_6-Broadcasting; (viii) T_7-Ridge and Furrow; (ix)T_8-No weeding and (x) T_9-Weeding with weedicide. The experimental field was ploughed thoroughly twice, once with a cultivator and the other with a rotavator. However, the plot area for treatment T_3 was left undisturbed. The recommended dosage of fertilizers N: P_2O_5: K_2O @ 150:75:75 $kgha^{-1}$ and 10 tha-1 of vermicompost were applied to each treatment (Bhullar

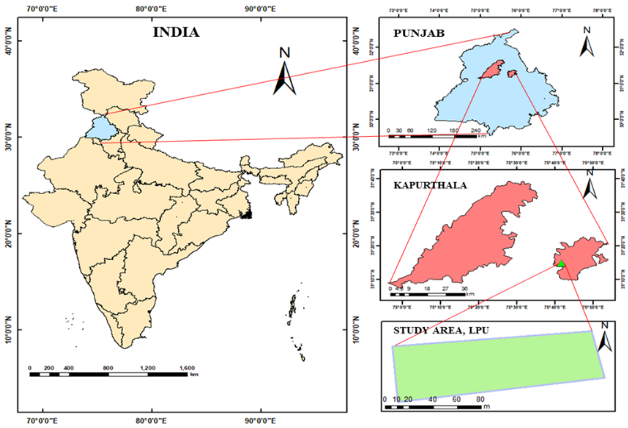

Fig. 1. *Study site : Phagwara (Punjab), for experimental study*

and Salaria, 2024). Nitrogen was applied in 3 equal split dosage: at land preparation, tillering stage, and crown root initiation stage. The entire dosage of phosphorus and potassium was integrated during land preparation. The vermicompost was applied during land preparation at equal proportions in all the treatment plots. Seeds were treated with fungicides and sown at the end of June 2022 for the first and June 2023 for the second seasons. All the other suggested packages of practices for *Kharif* maize cultivation, such as irrigation, weeding, plant protection, etc., were followed and performed by farmers whenever required.

Soil sampling and analysis

Four representative soil samples from 'a'(0-15 cm) and 'b' (15-30 cm) soil depths were taken from each plot. Utilizing a screw auger, samples were taken from a plot and mixed to create a composite sample for each depth. This procedure was then repeated in every other plot. The samples were air dried and passed through a 2.0 mm sieve to study soil's physical, chemical, and biological parameters.

The soil's bulk density (BD) was measured using a core method as indicated by Jalota *et al.* (1998) and presented in Table 1. Soil pH was measured in a soil with a water suspension ratio of 1:2.5 as given by Jackson (1973) and presented in Table 1. The available Nitrogen (Av. N) was measured in a Kjeldahl distillation unit, available Phosphorus (Av. P) using Bray's II method given by Bray and Kurtz (1945) and available Potassium (Av. K) carried out using hydrometer method given by Bouyoucos, (1962), presented in Table 2.

Carbon pools

The SOC was estimated with wet digestion method established by Walkley and Black, (1934). Different carbon pools, viz Cfrac1, Cfrac2, Cfrac3, and Cfrac4 pools, were determined using a modified system using the Walkley and Black method (Chan *et al*., 2001). It establishes the utilization of 5, 10 and 20 ml of conc. H_2SO_4 resulting in three acid-aqueous solution ratios of 0.5:1, 1:1 and 2:1 (parallels to 12.0 N H_2SO_4, 18.0 N H_2SO_4 and 24.0 N H_2SO_4, respectively). On comparison to the TOC, it allows the separation of TOC into the following four C fractions of decreasing oxidizability:

C_{frac1} (Very labile): Organic C oxidizable with 12.0 N H_2SO_4

C_{frac2} (Labile) : Remainder in oxidizable C extracted under 12.0 N H_2SO_4 and 18.0 N H_2SO_4

C_{frac3} (Less labile) : Remainder in oxidizable C extracted under 18.0 N H_2SO_4 and 24.0 N H_2SO_4

C_{frac4} (Recalcitrant): Remaining organic carbon following reaction with 24.0 N H_2SO_4 in comparison to TOC

Total organic carbon (TOC)

The TOC in soil was estimated using an altered method by Nelson and Sommers (1983), as outlined by Majumder (2006). In this approach, 0.5g of soil is to be digested using 5 ml of 2.0 N $K_2Cr_2O_7$ and 10 ml of H_2SO_4 in a hot air oven for 30 minutes at 150°C. After cooling the suspension, the digests will be titrated against standardised Ferrous Ammonium Sulphate (FAS).

Soil organic carbon stocks (SOCS)

The SOCS can be established with the formula given by Sharma *et al*., (2014) which is as follows:

$$\text{SOC stocks (Mg/ha)} = SOC \times \rho \times d \times 10{,}000 \quad \text{Eq. 1}$$

Such that, SOC is the soil organic carbon measured in $g\ g^{-1}$, ρ is the bulk density ($g\ cm^{-3}$) of the soil and d is the depth of the soil (m). The score of 10,000 represents the carbon stock for 1 ha of land area.

Statistical analysis

Using Microsoft Excel software, the soil analysis data was analysed using the Randomized block design (RBD) technique of "analysis of variance (ANOVA)" (Gomez and Gomez, 1984). When comparing the treatment means, the values of the least significant difference (LSD) and standard error of the mean (SE) will be computed at the 5% level of significance.

RESULTS AND DISCUSSION

Effect of different agricultural practices on Total organic carbon (TOC)

According to the experiment results, the total organic carbon varied significantly at each depth and on different days after sowing (DAS). Following Table 3, for soil depth 'a' (0-15 cm) and at 0 DAS, the TOC in organic mulching treatment T_1 (7.87) was significantly higher than the other treatments. It was statistically at par with minimum tillage T_3 (7.52). The lowest TOC (5.48) was observed in weeding with weedicide treatment T_9 at the initial phase. At 45 DAS and 90 DAS, the highest amount of TOC was observed at T_1, which were 9.40 and 11.05, respectively. An increase in TOC was ob-

Table 1. Pooled means of bulk density and soil pH of two years (2022-23 and 2023-24) for different treatments under varying soil depths ‘a’ (0-15 cm) and ‘b’ (15-30 cm)

Soil properties	**BD (g cm^{-3})**						**pH**					
	0 DAS		45 DAS		90 DAS		0 DAS		45 DAS		90 DAS	
Treatments	a	b	a	b	a	b	a	b	a	b	a	b
T_0 (Fallow)	1.32bc	1.38ab	1.34ab	1.39ab	1.38a	1.43a	7.37c	7.25de	7.49b	7.32c	7.45c	7.25de
T_1 (Organic Mulching)	1.27d	1.36ab	1.25cd	1.38ab	1.21c	1.38ab	7.30d	7.19f	7.43bcd	7.23d	7.28de	7.15f
T_2 (Plastic Mulching)	1.27d	1.37ab	1.26cd	1.37ab	1.27bc	1.39ab	7.49b	7.34b	7.63a	7.42b	7.65b	7.47b
T_3 (Minimum Tillage)	1.36a	1.39a	1.35a	1.42a	1.40a	1.46a	7.33cd	7.26de	7.40bcd	7.31c	7.21e	7.27cde
T_4 (Earthing up)	1.29cd	1.38a	1.27cd	1.40a	1.21abc	1.45a	7.35cd	7.28bcd	7.39cd	7.41b	7.37cd	7.38b
T_5 (Paired row)	1.32bc	1.38ab	1.30abc	1.35ab	1.28abc	1.39ab	7.37c	7.33bc	7.47b	7.43b	7.45c	7.39b
T_6 Broadcasting)	1.29cd	1.37ab	1.28bcd	1.39ab	1.31abc	1.38ab	7.33cd	7.25de	7.47bc	7.42b	7.44c	7.33bc
T_7 (Ridge and Furrow)	1.29d	1.32b	1.23d	1.32b	1.24bc	1.33b	7.30d	7.27cd	7.35d	7.39bc	7.34d	7.31cd
T_8 (No weeding)	1.33b	1.38ab	1.28bcd	1.37ab	1.28ab	1.41ab	7.59a	7.45a	7.63a	7.61a	7.85a	7.75a
T_9 (Weeding with weedicide)	1.32bc	1.35ab	1.30abc	1.35ab	1.36ab	1.39ab	7.29d	7.20ef	7.41bcd	7.21	7.32d	7.22e
C.D	0.11	0.13	0.20	0.08	0.16	0.06	0.06	0.02	0.07	0.03	0.06	0.01

Values in the same column and depths followed by different alphabets (a-f) are significantly different at 0.05% according to DMRT separation of means

served, along with an increase in the number of days after sowing. This could be due to the incorporation of required RDF and vermicompost in each treatment. A well-balanced application of NPK induces greater root biomass due to good crop growth, pivotal for the increase of TOC in soil (Rudrappa *et al.*, 2006). The similar result is also supported by Kanchikerimath and Singh (2001), who suggested that application of compost has a positive impact on the annual organic carbon input in soils. At soil depth ‘b’ (15-30 cm), the highest TOC accumulation was observed in minimum tillage treatment T_3 (5.71, 6.43 and 7.93, respectively), along increasing DAS (Table 3). It was statistically at par with T_1 (7.50) during the 90 DAS. The lowest was observed in treatment T_9 (4.16, 4.20 and 4.81) along with increasing DAS. Minimum tillage facilitates better stabilization of organic carbon for maize and wheat crops in semiarid northwest Indian soil (Jat *et al*., 2019). A higher accumulation of TOC was also observed in conservation agriculture-based scenarios in maize, wheat and soybean cropping systems due to decomposition of residues over time and the leaching of dissolved organic carbon at lower soil depths through irrigation in subhumid to arid climatic regions of Australian soils (Nachimuthu and Hulugalle, 2016), which coincides with the current findings. Minimal increases in TOC in other treatments T_0, T_4, T_6, T_7, T_8 and T_9 might be due to the agricultural practices and tillage operations involved during the experimental period. Six *et al*. (2000) also suggested similar findings whereby a good amount of TOC is lost whenever tillage practices are involved in temperate regions of Australian pasture soil. Tillage operations are largely disruptive in nature, and they cause an increase in soil microbial respiration, ultimately leading to loss of organic carbon from soil.

Effect of agricultural practices on Oxidizable organic carbon (SOC)

Similar to the results of TOC, upon the study of Table 3, the highest amount of oxidizable organic carbon was found in the organic mulching T_1 (4.95, 5.78 and 6.07, respectively, along the increasing DAS) at soil depth ‘a’. The paired row treatment T_5 was observed to induce the second highest SOC content (4.67, 4.85 and 5.53, respectively, along with increasing DAS) at soil depth ‘a’. Lowest SOC was observed in weeding with weedicide treatment. Accumulation of SOC in the upper soil depths of organic mulch treatment could be attributed to the continuous decomposition of straw, which further enhances the SOC content. The results could be justified by the study of Bhattacharyya et al. (2012), who suggested that adding straw and green manure, considered organic matter, increased SOC over time. Another study by Yang *et al*. (2018) demonstrated similar results: adding straw mulch increased SOC by 16.9% at 0-10 cm soil depth. Upon observing the soil depth ‘b’,

Table 2. Pooled means avalialble N, P and K of two years (2022-23 and 2023-24) for different treatments under varying soil depths ‘a’ (0-15 cm) and ‘b’ (15-30) cm

Soil property	**Av. N (kg ha^{-1})**						**Av. P (kg ha^{-1})**						**Av. K (kg ha^{-1})**					
	0 DAS		**45 DAS**		**90 DAS**		**0 DAS**		**45 DAS**		**90 DAS**		**0 DAS**		**45 DAS**		**90 DAS**	
Treatment	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**
T_0 (Fallow)	107.22a	37.63b	150.53a	52.27bc	131.71a	56.45a	11.02b	6.50 bc	11.54b	6.80 cd	12.36c	6.83e	212.04ab	147.25b	245.87cd	146.68c	229.20bcd	147.25b
T_1 (Organic Mulching)	92.57abc	41.81b	112.90b	58.54b	79.45bc	27.18de	12.05a	6.94a	13.81a	7.46b	14.32a	7.54b	204.14bc	154.19a	255.59b	148.68bc	240.27a	154.19a
T_2 (Plastic Mulching)	86.30cd	41.81b	79.45c	77.35a	58.54de	43.90ab	11.87a	6.76 ab	13.30a	7.74a	13.88a	7.86a	201.96bc	155.56a	272.94a	150.04bc	226.42bcd	155.56a
T_3 (Minimum Tillage)	103.02ab	50.18a	114.99b	81.54a	62.72cde	41.82bc	11.10b	6.77ab	12.08b	6.84c	12.70bc	6.91e	202.81bc	154.46a	234.11e	151.24ab	235.21ab	154.46a
T_4 (Earthing up)	67.48e	37.63bc	58.54d	54.36bc	43.91ef	23.00f	11.34b	6.50 bc	12.23b	6.71 cde	12.66bc	6.86e	217.43a	156.67a	257.18b	150.20bc	233.02ab	156.67a
T_5 (Paired row)	92.50abc	37.63bc	108.72b	64.81ab	87.81b	50.18ab	11.33b	6.69 abc	11.67b	7.26b	12.26c	7.24 bc	199.32c	153.11a	246.21cd	148.65bc	222.53cd	153.11a
T_6 (Broad casting)	90.48bcd	35.54bc	110.81b	56.45bc	83.63b	39.72bcd	11.29b	6.44 bc	12.17b	6.51e	13.00b	6.83e	193.67c	157.65a	222.93f	151.39ab	206.41e	157.65a
T_7 (Ridge and Furrow)	75.85de	35.54bc	87.81c	39.72c	54.36e	29.27cde	11.01b	6.86a	12.03b	7.23b	12.70bc	7.34b	193.92c	157.04a	247.77c	151.07ab	221.14d	157.04a
T_8 (No weeding)	69.57e	35.54bc	75.26c	52.27bc	27.18f	23.00f	11.29b	6.40c	11.80b	6.59 de	12.37c	6.88e	197.99c	154.45a	250.54c	147.63bc	230.89cd	154.45a
T_9 (Weeding with weedicide)	90.48bcd	26.94c	106.63b	52.27bc	77.36bcd	18.82f	10.99b	6.49 bc	11.85b	6.74cde	12.65bc	6.99 cd	193.72c	155.18a	241.82d	154.61a	205.85e	155.18a
C.D	10.01	4.34	7.00	3.77	4.95	6.62	0.43	0.32	0.84	0.28	0.46	0.42	6.13	2.90	3.51	2.08	10.80	2.57

Values in the same column and depths followed by different alphabets (a-e) are significantly different at 0.05% according to DMRT separation of means.

SOC in treatment, T_1 (3.86) was highest at 0 DAS. After 45 DAS, SOC was higher in treatment T_5 (3.88); however, it was statistically at par with treatment T_1 (3.55). At 90 DAS, treatment T_1 (4.63), was the highest at the certain soil depth 'b'. The lowest SOC at depth 'b' was recorded in treatment T_8 (2.62) at 0 DAS. At 45 DAS, SOC was lower in treatment T_9 (2.48) but was statistically at par with T_8 (2.58). At 90 DAS, treatment T_8 (2.93) was recorded to possess lowest SOC over the mean pool data along the DAS. Similar results were shown in a study by Begum *et al*. (2020), which indicated that leaching of decomposed organic matter positively affected the SOC content in the lower soil depths agricultural soils in Karakoram region, Pakistan.

Changes in carbon fractions

Certain variability was observed in the Carbon fractions (C_{frac1}, C_{frac2}, C_{frac3} and C_{frac4}) for every surface and subsurface soil treatment. However, the non-labile pools (C_{frac3} + C_{frac4}) were observed to be higher in the subsurface (15-30 cm) soil. Upon comparison with the control plot T_0 (fallow) treatment, treatments T_7 (33%) and T_6 (36%) were found to have the highest values in highly labile carbon pools (C_{frac1}) in the surface and subsurface soils, respectively (Fig. 2 and 3). Lowest observations were recorded in T_2 (14% and 16%) in soil depth 'a' and 'b', respectively. According to the land management practices involved, these labile fractions are highly susceptible to change. The labile fractions (C_{frac1} + C_{frac2}) in the surface soil layers were recorded to be higher than the subsurface layers. This could be due to the organic matter (leaf litter, crop residues, straw incorporation) inputs which promote high microbial activity than the subsurface soils. Tillage practices and high temperatures also contribute to the paradigm shift in labile carbon fractions (Pandher *et al*., 2020). Similar findings were observed in the findings of Meetei *et al*. (2020), which suggested that crop residues and root substrates in surface soils will provide higher microbial activity, thus increasing the labile carbon fractions in a rice-based hilly agro-ecosystem of north-east India. Another study by Fang et al. (2018) implied that the return of wheat crop residues in Luvisol of the Australian region increases the mineralization process due to higher microbial activity, thereby leading to higher labile fractions in the surface soils. Inversely, subsurface soils with lower microbial activity developed lower levels of labile fractions.

Effect of different agricultural practices on Soil organic carbon (SOC) stocks

The SOC in the upper soil depth 'a' at 0 DAS was maximum at the minimum tillage treatment T_3 (9.36) which was statistically at par with organic mulching treatment T_1 (9.33). At 45 DAS, stocks of SOC were maximized at T_2 (10.78) and at 90 DAS, T_3 (11.51) was recorded to accumulate higher SOC stocks, which was statistically at par with T_1 (10.95) (Table 3). Minimum findings were recorded in T_9 (7.26) at 0 DAS which was statistically at par with T_7 (7.31). Similar instances were found in 45 DAS and at 90 DAS, treatment T_8 (6.84) was found to be minimum which was statistically at par with T_7 (7.13). For lower soil depth 'b', the highest SOC was found at T_1 (13.78), which was statistically at par with T_3 (12.80) at 0 DAS. At 45 DAS, T_5 (15.86) was found to be maximum which was statistically at par with T_1 (14.74) and T_3 (14.44). At 90 DAS, T_1 (19.20) was recorded as the maximum SOC stock, statistically, in par with T_3 (18.80).

Minimum recordings were observed in T_9 (9.69, 7.81) at 0 and 45 DAS respectively, and T_8 (12.4) at 90 DAS. Each treatment was integrated with the same RDF and vermicompost. However, higher biomass accumulation in surface and subsurface soils due to organic mulching had greater impact in treatment T_1 and hence the higher SOC stocks. However, lesser biomass and litter accumulation in T_9 had a negative impact on the accumulation of SOC stocks. The findings are similar with

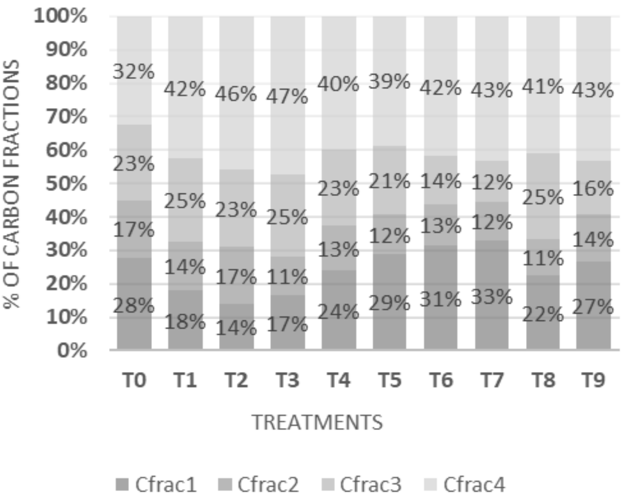

Fig. 2. *Carbon fractions (0-15 cm)*

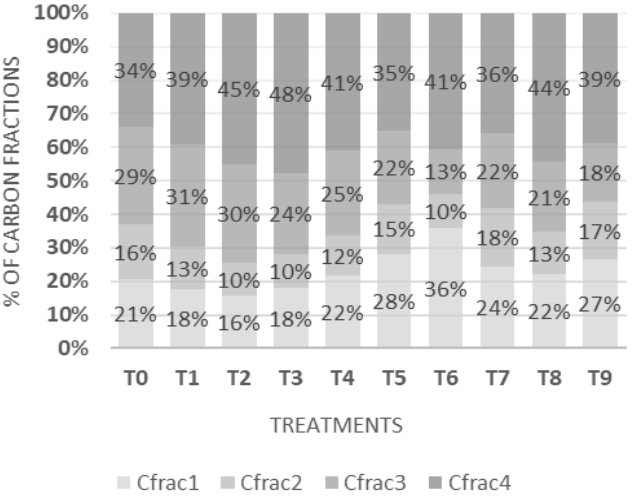

Fig. 3. *Carbon fractions (15-30 cm)*

Table 3. Variation in pooled means of TOC, Oxidizable OC and SOC stocks at different soil depths ‘a’ (0-15 cm) and ‘b’ (15-30 cm) for experimental years 2022 and 2023

Soil properties	**TOC (g kg^{-1})**						**Oxidizable OC (g kg^{-1})**						**SOC stocks (Mg ha^{-1})**					
	0 DAS		**45 DAS**		**90 DAS**		**0 DAS**		**45 DAS**		**90 DAS**		**0 DAS**		**45 DAS**		**90 DAS**	
Treatments	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**
T_0 (Fallow)	5.58 ef	4.51 efg	6.17e	4.90e	6.68d	5.80 cd	4.19 de	3.30 bcd	4.32 cd	3.10 cd	4.55 cd	3.97 bc	8.27c	12.52abc	8.68c	13.09 bc	9.46b	17.03bc
T_1 (Organic Mulching)	7.87a	5.50b	9.40a	5.93b	11.05a	7.50 ab	4.95a	3.86a	5.78a	3.55 ab	6.07a	4.63a	9.33a	13.73a	10.78a	14.74 ab	10.95a	19.23a
T_2 (Plastic Mulching)	6.44c	4.96 cd	7.90bc	5.70bc	8.38bc	6.58 bc	4.17 de	3.18 cde	4.55c	3.22 bcd	4.28 de	3.48 de	7.91d	11.98 bc	8.58c	13.36 bc	8.22c	14.58de
T_3 (Minimum Tillage)	7.52 ab	5.71a	8.22b	6.43a	10.57a	7.93a	4.57 bc	3.44 bc	4.42c	3.32 bc	5.43b	4.27 ab	9.36a	12.87ab	9.12 bc	14.44 ab	11.51a	18.88ab
T_4 (Earthing up)	5.79 def	4.84 cde	6.97d	5.40 cd	6.75d	6.00 bc	4.24d	3.22 cde	4.08d	3.17 bcd	4.04d	3.54 cde	8.17 cd	12.20bc	7.68d	13.50 bc	7.29 cd	15.60cd
T_5 (Paired row)	7.07b	5.18bc	7.88bc	5.79bc	8.82b	6.66 bc	4.67b	3.56 ab	4.85b	3.88a	5.53b	4.47a	9.20a	12.70ab	9.43b	15.86a	10.57a	18.62ab
T_6 (Broadcasting)	6.27 cd	4.58 def	7.33 cd	4.97 de	8.12c	5.83 cd	4.07e	2.98 de	4.53c	2.85 de	4.70c	3.67 cd	7.86d	11.14 cd	8.73 bc	11.90 cd	9.23b	15.20cde
T_7 (Ridge and Furrow)	5.80 def	4.42 fg	5.92e	4.54 ef	6.54d	5.77 cd	3.80f	3.14 cde	3.22e	3.06 cd	3.84 ef	3.73 cd	7.31e	10.55de	5.93e	12.20 cd	7.13 d	15.02cde
T_8 (No weeding)	6.15 cde	4.23 fg	6.78d	4.35f	7.09d	5.35 de	4.44c	2.62f	4.40c	2.58e	3.63f	2.93f	8.83b	9.70e	8.43c	10.72 de	6.84d	12.45f
T_9 (Weeding with weedicide)	5.48 f	4.16g	5.83e	4.20f	6.43d	4.81 e	3.67f	2.89 ef	3.12e	2.48e	3.82 ef	3.18 ef	7.26e	9.69e	6.17e	10.12 e	7.81 cd	13.28ef
C.D	0.55	0.13	0.64	0.19	0.46	0.28	0.13	0.22	0.14	0.16	0.19	0.09	0.24	0.57	0.34	0.87	0.44	0.79

Values in the same column and depths followed by different alphabets (a-g) are significantly different at 0.05% according to DMRT separation of means the studies of Meetei *et al*. (2020), which suggested that biomass accumulation in a rice-based ecosystem of Manipur, leads to higher SOC stocks in surface and subsurface soils. Another study by Benbi *et al*. (2015) indicated that a balance input of C through organic matter and root deposition had better efficiency for increasing the SOC stocks in a rice-wheat system of semiarid Punjab region.

Conclusion

The different treatments exhibited variations in the mineralization and accumulation of carbon and its different fractions under maize crop in typic heplustept soil of indo-gangetic plains in semiarid Punjab region. Upon closer examination, the organic mulching treatment T_2 had by far the exceptional properties with a better contribution to the oxidizable carbon, TOC, SOC stocks and both labile (C_{frac1} + C_{frac2}) and non-labile pools (C_{frac3} + C_{frac4}). The organic mulch biomass and other crop residues provide an ample environment for effective oxidization, increasing the soil's quality and productivity. Other treatments, such as minimum tillage and paired row treatments, offer similar benefits. However, organic mulching is a healthier approach for better sustainability and an effective increase of carbon reserves in the typic heplustept soil of Punjab region.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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