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Impact of conservation agriculture production system on soil carbon dynamics

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Abstract

The research entitled "Effect of conservation production system on soil properties and carbon dynamics in rainfed condition" was conducted at AICRP for dryland agriculture, UAS, GKVK, Bangalore during *Kharif* 2020. With three main plot treatments, 'Tillage practices' (M_1-Conventional tillage, M_2-Reduced tillage, M_3-Zero tillage) and three sub plot treatments 'Cover crops' (C_1-Control, C_2-Field bean, C_3-Horse gram) replicated thrice and laid out in split plot design. Organic carbon content of soil differed significantly due to different tillage management with maximum (0.36%) in reduced tillage (M_2) and zero tillage (M_3). Among different carbon fractions zero tillage with horse gram as surface mulch (M_3C_3) increased the active carbon (0.89 g kg^{-1}) and water-soluble carbon (1.30 g kg^{-1}). Crop residue and tillage affects the soil environment directly or indirectly, incorporation of crop residue into soil or retention on the surface through the adaptation of conservation agriculture practice which increases the organic matter content of soil.

Keywords: Conventional tillage, reduced tillage, mulching

Introduction

Conservation agriculture (CA) system consists of no or minimal tillage and permanent soil cover, either with a live crop or with crop stubbles and diversified crop rotation that include legumes (FAO, 2019) [7]. An overall CA farming system is meant to ensure the sustainability of agriculture through conserving and protecting soil, water, and biological resources as much as possible with minimal external inputs, and it is associated with many benefits such as greater soil aggregation and water storage, improved soil quality, decreased erosion and in some instances higher yield and net farm income. This has led to the identification of conservation agriculture as a valuable tool to ensure future food production and to buffer agricultural productivity (FAO, 2019) [7].

Crop residue and tillage affects the soil environment directly or indirectly, incorporation of crop residue into soil or retention on the surface through the adaptation of conservation agriculture practice has positive influence on physical, chemical and biological properties of soil. Crop residues retained on the soil surface conserve soil and water and increase the subsequent crop yield. Adoption of proper crop residue management practices leads to improved soil quality and increase the production with the minimum adverse effect on environment. Residue management have greater influence on carbon sequestration, microbial activities, mineralization rate and replenish the annual carbon losses (Goyal *et al*., 1999) [9].

Soil organic matter (SOM) is an important determinant of soil fertility, productivity and sustainability, and is a useful indicator of soil quality in tropical agricultural systems where nutrient poor and highly weathered soils are managed with little external input. The dynamics of SOM are influenced by agricultural management practices such as tillage, mulching, removal of crop residues and application of organic and mineral fertilizers. The most important factor behind the improvements was observed under conservation agriculture is the greater soil organic matter (SOM), particularly at the surface, resulting in improvements in soil structural stability, fertility, and biological diversity relative to conventional agricultural systems. The soil organic matter is determined by the net difference between the organic matter inputs (biomass) and its losses (erosion, decomposition, leaching).

Thus, the degree and direction to which conservation agriculture influences SOM (measured typically by SOC) is a function of how it affects inputs and losses. Conservation agriculture practice modifies tillage practices, residue management, and crop/nutrient management in contrast to conventional agriculture system. All of these modifications have an impact on SOC.

Soil Organic Carbon (SOC) which is composed of labile and recalcitrant fraction, doesn't give sufficient information about mechanism of carbon accumulation and loss. Labile carbon fractions are sensitive to small changes in SOC (Xia *et al*., 2010) [24] and greatly influence microbial transformation process in soil (Haubensak *et al*., 2002) [11]. The relative proportion of the aforesaid fractions determines the quality of soil and forms the basis for study of carbon dynamics. Under CA practices carbon dynamics study is highly dependent on soil type and climate. Long-term experiment forms the basis of assessment of long-term changes in SOC and sustainability of agricultural production systems (Ladha *et al*., 2003) [15].

The study of SOC pools has been of increasing interest in classifying different types or fractions of soil organic carbon such as Active carbon (AC), labile carbon (LC), particulate organic carbon (POC), mineral associated carbon (Min-C), recalcitrant carbon and hot water extractable carbon (HWEC) with various residence or turnover times ascribed to the various fractions. These parameters also have been used as indicators for soil quality (Cambardella and Elliott 1992[5]; Blair *et al*., 1995) [2]. There have been a lot of investigations pointed out that KMnO4 extractable C, microbial biomass carbon, hot water extractable carbon, and Particulate Organic carbon were sensitive and rapid indicators for changes in soil organic carbon (Bolinder *et al*., 1999; Gregorich *et al*.,1997) [3, 10].

The dynamics of soil organic carbon (SOC) as affected by farming practices is imperative for maintaining soil productivity and mitigating global warming. The present study was undertaken to assess the effect of different management practices on carbon dynamics at AICRP on Dry Land Agriculture, UAS GKVK.

Material and Methods

Experimental site and treatment details

The field experiment was carried out during *Kharif*-2020 at AICRP for Dry Land Agriculture, UAS, GKVK**,** Bengaluru-65. It is located in the Eastern Dry zone of Karnataka at 13º 05' N latitude and 77^{0} 34' E longitude with an altitude of 924 meters above Mean Sea Level (MSL). The total rainfall during 2020 at AICRP for Dryland Agriculture, GKVK, Bengaluru was 1,182.2 mm with maximum rainfall during July (242.8 mm) and minimum during January and February (0.0 mm). The maximum and minimum temperature of 29.1 ºC and 18.2 ºC was observed during the cropping year. The soils of Gandhi Krishi Vignana Kendra (GKVK) belongs to Vijayapura series which is a dominant soil series of Bengaluru plateau. The soils of experimental site at AICRP on Dry Land Agriculture Project represents the typical lateritic area of Bengaluru plateau. These soils are classified as fine, kaolinitic, isohyperthermic, Typic Kandiustalf as per USDA classification. These soils are deep, yellowish red, lateritic, red sandy clay loam with good drainage and are derived from granite-gneiss under subtropical semi-arid climate.

Cropping history of the experimental plot

In the experimental plot Inter cropping of finger millet (*Eleusine coracana* (L.) Gaertn) + Pigeon pea (*Cajanus cajan*) was grown during *Kharif* 2019 and left fallow during rabi and summer. The experimental details was given in Table 1 and chemical properties of initial soil sample (1986) of the experiment site were given in Table 1.

Table 1: Experimental details

Location	**AICRP for Dryland agriculture**
Crop	Finger millet (*Eleusine coracana*), Pigeon pea (*Cajanus cajan*)
Cropping system	Inter cropping (8:2) Finger millet + Pigeonpea with conservation furrow
Variety	Finger millet-MR-1, Pigeon pea-BRG-5
Spacing	Finger millet (30cm × 10cm), Pigeon pea (60cm × 30cm)
Seed rate	Finger millet 12.5kg/ha Pigeon pea 12-15kg/ha
No of treatments	9
No of replication	3
Design	Split plot design
Plot size	9.0 x 9.9 m
NPK	Finger millet (50:40:37.5 kg/ha) Pigeonpea (25:50:25 kg/ha)
FYM	Finger millet, Pigeon pea (15 t/ha)

Table 2: Initial soil chemical properties of experimental site as influenced by conservation production system

Treatments	**pH**	**EC (dS m^{-1})**	**OC (%)**	**Nitrogen (kg ha^{-1})**	**Phosphorus (kg ha^{-1})**	**Potassium (kg ha^{-1})**	**Ca (meq/ 100g)**	**Mg (meq/ 100g)**	**Sulphur (mg kg^{-1})**	**Zinc (mg kg^{-1})**	**Manganese (mg kg^{-1})**	**Iron (mg kg^{-1})**	**Copper (mg kg^{-1})**
Tillage practice													
M_1: Conventional tillage	5.03	0.05	0.33	208.21	41.23	73.83	1.47	0.83	25.21	1.19	7.92	13.62	0.96
M_2: Reduced tillage	4.81	0.03	0.38	226.84	42.63	74.63	1.48	0.87	27.50	1.27	10.89	17.77	1.02
M_3:Zero tillage	4.58	0.03	0.36	236.48	48.64	76.27	1.53	0.84	24.14	1.00	9.42	16.25	0.77
S.E.M. ±	0.07	0.01	0.01	2.36	1.54	0.72	0.01	0.01	0.18	0.01	0.09	0.16	0.01
CD (P=0.05)	NS	NS	NS	7.29	NS	NS	NS	0.03	0.70	0.05	0.35	0.65	0.02
Cover crops													
C_1: Control	4.97	0.04	0.29	208.72	36.36	66.27	1.40	0.80	18.02	1.28	9.56	14.71	1.05

C_2: Field bean	4.99	0.04	0.36	212.45	48.63	80.27	1.59	0.86	33.46	1.13	9.65	16.73	0.87
C_3: Horsegram	4.93	0.03	0.42	234.86	40.29	78.20	1.49	0.88	25.37	1.05	9.01	16.21	0.83
S.E.M. ±	0.04	0.003	0.004	2.25	2.48	0.76	0.01	0.01	0.18	0.01	0.09	0.17	0.01
CD (P=0.05)	NS	NS	0.01	6.94	NS	2.33	0.03	0.02	0.54	0.03	0.28	0.52	0.02
Interaction													
M_1C_1	5.07	0.05	0.33	193.45	33.68	58.20	1.51	0.76	19.50	1.32	8.61	12.99	1.12
M_1C_2	5.14	0.05	0.33	199.26	41.23	74.20	1.29	0.91	18.36	1.21	7.93	14.32	0.90
M_1C_3	5.05	0.05	0.35	215.42	45.36	89.10	1.61	0.94	22.80	1.03	7.21	13.56	0.87
M_2C_1	5.00	0.03	0.32	198.36	34.12	67.80	1.68	0.76	16.20	1.62	11.23	19.18	1.31
M_2C_2	4.97	0.03	0.37	217.01	44.68	82.40	1.34	0.83	34.80	1.12	11.51	18.36	0.93
M_2C_3	4.90	0.03	0.44	251.26	36.89	73.70	1.42	0.90	40.20	1.08	9.92	15.78	0.81
M_3C_1	4.84	0.03	0.32	222.78	40.87	72.80	1.57	0.89	24.35	0.91	8.83	15.12	0.72
M_3C_2	4.87	0.04	0.39	228.90	53.56	84.20	1.58	0.83	25.38	1.07	9.52	18.26	0.79
M_3C_3	4.84	0.03	0.42	243.64	48.32	71.80	1.44	0.81	28.67	1.03	9.91	15.36	0.81
S.E.M. ±	0.07	0.005	0.01	3.90	4.30	1.31	0.02	0.01	0.31	0.02	0.16	0.29	0.01
CD (P=0.05)	NS	NS	0.02	12.02	NS	4.03	0.06	0.04	0.94	0.06	0.49	0.89	0.04

Treatment details

A. Main Plot Treatments

M_1	Conventional tillage (1 tractor drawn ploughing + 2 harrowing + 1 intercultural operations).
M_2	Reduced tillage (1 harrowing + 1 intercultural operation + pre-emergence herbicide).
M_3	Zero tillage (1 intercultural operation + pre-emergence herbicide).

B. Sub Plot Treatments

C1	Control (no cover crops)
C2	Field bean (HA-4) leaving the residue after harvesting the green pods for vegetable
C3	Horse gram in-situ and mulching

Soil sampling, processing and analysis: Soil samples from experimental area were collected from 0-15 cm, after the harvest of the crop. The collected soil samples were air dried, powdered with a wooden mallet, passed through 2 mm sieve, stored in polythene bags and analysed for various chemical properties adopting standard procedure. Organic carbon (OC) content of soil was estimated according to Walkley and Black's wet oxidation method (Jackson, 1973) [12] and expressed in gram per kg of soil. Soil inorganic carbon was estimated by acid neutralization method or rapid titration method of Piper (1944) [20]. Water-soluble Carbon (mg kg^{-1}) was determined as per the procedure outlined by Mc Gill *et al.* (1986) [18]. Potassium permanganate oxidizable carbon (PPOC) was determined as per the procedure described by Blair *et al.* (1995) [2]. Total Carbon (TC) in the soil was determined by the dry combustion method using carbon analyzer (Elementar) at 950 ºC temperature (Nelson and Sommers, 1996) [19]. Soil Organic Carbon Pools (Very Labile, Labile, Less Labile and Non-Labile) was determined by the method given by Kolar *et al*., 2011 [13].

Statistical analysis: The observations recorded in these studies were analyzed statistically for test of significance following the Fisher's method of analysis of variance (ANOVA) as outlined by Gomez and Gomez (1984) [8]. Whenever F-test was significant for comparison amongst the treatments means an appropriate value of critical differences (CD) was worked out. Otherwise against CD values, abbreviation NS (Non-Significant) was indicated. All the data were analysed and the results are presented and discussed at a probability level of 0.05 per cent and correlation and regression study was done as given by Gomez and Gomez (1984) [8].

Results and Discussion

Impact of conservation agriculture production system on Soil organic carbon pools

The effect of conservation agriculture practice in finger millet + pigeon pea intercropping system on soil carbon dynamics *viz.*, Very labile carbon, labile carbon, less labile carbon, non-labile carbon is given in Table 3.

Tillage practice *viz.*, conventional, reduced and zero tillage showed non-significant results with respect to very labile, labile and non-labile carbon pools except less labile carbon which varied significantly with tillage practices. Conventional tillage recorded statistically higher very labile carbon pools (2.75 g kg^{-1}) and Zero tillage recorded statistically higher less labile and non-labile carbon pools (1.15 g kg^{-1}) and (3.58 g kg^{-1}) respectively. Similarly, growing of cover crops also showed non-significant results with very labile, less labile and non-labile carbon pools, but growing of horse gram as cover crop recorded significantly higher labile carbon pools (1.90 g kg^{-1}).

Interaction effect between different tillage and cover crop was found to be non-significant with all carbon pools i.e very labile, labile, less labile and non-labile. Combination of conventional tillage with cover crops i.e Field bean and Horse gram recorded numerically higher very labile (3.20 & 2.75 g kg^{-1}) and labile carbon (1.95 & 2.25 g kg^{-1}).

Sharma *et al.* (2019) [23] studied the effects of tillage, crop establishment, and residue management practices on total as well as different pools of SOC in a sandy loam in RW system and reported that after six years very labile carbon concentration increased with the adoption of ZTDSR and CTDSR but the increase in concentration of labile C pool was not significant in all depths. In case of wheat, residue retention under CTW increased very labile carbon pool by 20.7 per cent in 7.5-15 cm soil depth only.

Bhattacharyya *et al.* (2012) [1] made an attempt to quantify labile and recalcitrant pools of SOC as affected by tillage systems in soybean-wheat crop rotation. Conventional tillage plots had significantly higher very labile carbon than no tillage plots. No tillage plots resulted in significantly higher concentrations of carbon in III and IV carbon pools as compared to conventional tillage in the upper layer.

Table 3: Soil organic carbon pools as influenced by conservation agriculture practices in finger millet+ pigeonpea intercropping (8:2)

Treatments	Very labile carbon (g kg^{-1})	Labile carbon (g kg^{-1})	Less labile carbon (g kg^{-1})	Non-labile carbon (g kg^{-1})
Tillage practice				
M_1: Conventional tillage	2.75	1.85	0.95	2.29
M_2: Reduced tillage	2.05	1.82	0.90	3.05
M_3: Zero tillage	1.70	1.18	1.15	3.58
S.E.M. ±	0.24	0.38	0.02	0.50
CD (P=0.05)	NS	NS	0.07	NS
Cover crops				
C_1: Control	1.85	1.24	0.85	2.45
C_2: Field bean	2.40	1.70	1.15	3.31
C_3: Horsegram	2.25	1.90	1.00	3.17
S.E.M. ±	0.23	0.15	0.12	0.50
CD (P=0.05)	NS	0.45	NS	NS
Interaction				
M_1C_1	2.30	1.35	0.90	0.90
M_1C_2	3.20	1.95	1.20	1.20
M_1C_3	2.75	2.25	0.75	0.75
M_2C_1	1.70	1.40	1.05	0.60
M_2C_2	2.30	2.10	1.05	1.20
M_2C_3	2.15	1.95	1.35	0.90
M_3C_1	1.55	0.98	0.60	1.05
M_3C_2	1.70	1.05	1.20	1.05
M_3C_3	1.85	1.50	0.90	1.35
S.E.M. ±	0.39	0.25	0.21	0.21
CD (P=0.05)	NS	NS	NS	NS

Note: M_1: Conventional tillage, M_2: Reduced tillage, M_3: Zero tillage, C_1: Control, C_2: Field bean, C_3: Horse gram

Impact of conservation agriculture production system on permanganate oxidizable carbon and water-soluble carbon

Effect of conservation agriculture practice in finger millet + pigeon pea intercropping system on soil permanganate oxidizable carbon and water-soluble carbon presented in Table 4.

Tillage practice *viz.*, conventional, reduced and zero tillage showed non-significant results with respect to permanganate oxidizable carbon and water-soluble carbon. Zero tillage recorded numerically higher permanganate oxidizable carbon (0.66 g kg^{-1}) and water-soluble carbon (1.10 g kg^{-1}) compared to the conventional and reduced tillage. Similarly, growing of cover crops also showed non-significant results with Permanganate oxidizable carbon and water-soluble carbon. But, growing of horse gram as cover crop recorded numerically higher permanganate oxidizable carbon and water-soluble carbon (0.68 g kg^{-1}) and (1.20 g kg^{-1}) respectively compared to control with lower permanganate oxidizable carbon and water-soluble carbon (0.42 g kg^{-1}) and (0.90 g kg^{-1}) respectively.

Interaction effect between different tillage and cover crop was found to be non-significant with permanganate oxidizable carbon and water-soluble carbon. However, Combination of zero tillage with horse gram as cover crop recorded higher permanganate oxidizable carbon and water-soluble carbon (0.89 g kg^{-1}) and (1.30 g kg^{-1}) respectively compared to all treatments.

A study conducted by Prasad *et al.* (2016) [21] for ten years revealed that the extent of improvement of KMnO4-C was 43.2 per cent, in NT over CT in surface soil (0-20 cm). Kubar *et al.* (2019) [14] studied the long-term effect of tillage and straw returning effects in rice-rape cropping system and reported that POC concentration was significantly higher under NT + R (4.76 g kg^{-1}) and CT+R (4.56 g kg^{-1}) as compared to NT-R (4.33 g kg^{-1}) and CT-R (3.68 g kg^{-1}) in surface layer. NT treatment significantly increased the KOC content by 17 per cent in comparison to the CT treatment at 0-20 cm, and 6 per cent higher under NT than CT treatment at 20-40 cm depth.

Similarly, higher values of active carbon (KMnO4) and water-soluble carbon was also recorded which was associated to the crop mulches under conservation tillage (NT) and also with the lower decomposition process. (Lopez-Garido *et al.*, 2012) [17]. In a study, Li *et al.* (2012) [16] reported that WSOC content in the double no tillage with residue incorporation (DNTR) increased significantly by 29.5 and 5.7 per cent in 0-5 cm and 5-15 cm layer, respectively over conventional till without residue retaining.

Impact of conservation agriculture production system on total organic carbon and total inorganic and total carbon content

Effect of conservation agriculture practice in finger millet + pigeon pea intercropping system on soil total organic and inorganic carbon and total carbon are presented in Table 5.

Tillage practice *viz.*, conventional, reduced and zero tillage showed significant results with respect to total carbon and total organic carbon. Among tillage practices, Zero tillage recorded significantly higher total organic carbon and total carbon (6.72 g kg^{-1}) and (6.83 g kg^{-1}) respectively. While the total inorganic carbon showed non-significant difference.

Similarly, growing of cover crops showed non-significant results with respect to total carbon and total organic & inorganic carbon. However, growing of horse gram as cover crop recorded numerically higher total organic carbon (6.75 g kg^{-1}), total inorganic carbon (0.15 g kg^{-1}) and total carbon (6.90 g kg^{-1}), compared to control lower total organic carbon (4.41 g kg^{-1}), total inorganic carbon (0.11 g kg^{-1}) and total carbon (4.53 g kg^{-1}) respectively.

Table 4: Permanganate oxidizable carbon Water-soluble carbon as influenced by conservation agriculture practices in finger millet + pigeonpea intercropping (8:2)

Treatments	Permanganate oxidizable carbon (g kg^{-1})	Water-soluble carbon (g kg^{-1})
Tillage practice		
M_1: Conventional tillage	0.45	0.97
M_2: Reduced tillage	0.55	1.07
M_3: Zero tillage	0.66	1.10
S.E.M. ±	0.11	0.04
CD (P=0.05)	NS	NS
Cover crops		
C_1: Control	0.42	0.90
C_2: Field bean	0.55	1.03
C_3: Horsegram	0.68	1.20
S.E.M. ±	0.09	0.12
CD (P=0.05)	NS	NS
Interaction		
M_1C_1	0.39	0.90
M_1C_2	0.42	0.90
M_1C_3	0.53	1.10
M_2C_1	0.48	0.80
M_2C_2	0.54	1.20
M_2C_3	0.63	1.20
M_3C_1	0.40	1.00
M_3C_2	0.69	1.00
M_3C_3	0.89	1.30
S.E.M. ±	0.16	0.21
CD (P=0.05)	NS	NS

Note: M_1: Conventional tillage, M_2: Reduced tillage, M_3: Zero tillage, C_1: Control, C_2: Field bean, C_3: Horse gram

Table 5: Total carbon and total organic and inorganic carbon as influenced by conservation agriculture practices in finger millet+ pigeonpea intercropping (8:2)

Treatments	Total organic carbon (g kg^{-1})	Total inorganic carbon (g kg^{-1})	Total carbon (g kg^{-1})
Tillage practice			
M_1: Conventional tillage	5.13	0.13	5.26
M_2: Reduced tillage	5.62	0.14	5.76
M_3:Zero tillage	6.72	0.11	6.83
S.E.M. ±	0.19	0.05	0.20
CD (P=0.05)	0.74	NS	0.78
Cover crops			
C_1: Control	4.41	0.11	4.53
C_2: Field bean	6.30	0.12	6.41
C_3: Horsegram	6.75	0.15	6.90
S.E.M. ±	0.95	0.04	0.94
CD (P=0.05)	NS	NS	NS
Interaction			
M_1C_1	4.13	0.05	4.18
M_1C_2	5.60	0.08	5.68
M_1C_3	5.65	0.25	5.90
M_2C_1	5.55	0.20	5.75
M_2C_2	5.75	0.15	5.90
M_2C_3	5.55	0.07	5.62
M_3C_1	3.55	0.10	3.65
M_3C_2	7.55	0.10	7.65
M_3C_3	9.05	0.13	9.18
S.E.M. ±	1.64	0.07	1.63
CD (P=0.05)	NS	NS	NS

Note: M_1: Conventional tillage, M_2: Reduced tillage, M_3: Zero tillage, C_1: Control, C_2: Field bean, C_3: Horse gram

No significant interaction was found between different tillage and cover crop with respect to total carbon and total organic & inorganic carbon. Combination of zero tillage with horse gram as cover crop recorded numerically higher total organic carbon (9.05 g kg^{-1}) and total carbon (9.18 g kg^{-1}) respectively compared to all treatments.

Chan *et al* (2002) [6] reported that significant differences in total soil organic carbon (TOC) amongst different soils were found to 0.20 m, however the magnitude of the differences decreased with depth. In the 0-0.05m layer both tillage and stubble effects were significant but not their interaction. TOC levels of different soils were found in the order ZT> RT> CT.

Correlation among different forms of carbon with water stable aggregates, mean weight diameter and soil water constants

The Correlation among different forms of carbon with water stable aggregates, mean weight diameter and soil water constants is given in Table 6.

Very labile carbon showed significant moderate negative correlation (r=-0.681) with water stable aggregates this might be due to the inability of the very labile carbon fraction to form stable aggregates. Non-labile carbon had non-significant but positive correlation with water stable aggregates (r = 0.319) and mean weight diameter (r = 0.445). KOC had highly positive correlation with water stable aggregates (r= 0.817) and mean weight diameter (r = 0.744). Soil carbon fractions except very labile carbon had negative correlation with permanent wilting point this might be due to the ability of soil organic carbon to improve soil porosity and water holding capacity.

Table 6: Correlation among different forms of carbon with soil physical properties *viz.*, (water stable aggregates, mean weight diameter and soil water constant)

	VLC	LC	LLC	NLC	KOC	WSC	TOC	TIC	TC	WSA	MWD	FC	PWP
VLC	1												
LC	0.762^{*}	1											
LLC	0.204^{NS}	0.248^{NS}	1										
NLC	0.095^{NS}	-0.018^{NS}	0.050^{NS}	1									
KOC	-0.308^{NS}	0.000^{NS}	0.236^{NS}	0.426^{NS}	1								
WSC	-0.051^{NS}	0.371^{NS}	0.016^{NS}	0.538^{NS}	0.719^{*}	1							
TOC	-0.120^{NS}	0.048^{NS}	0.316^{NS}	0.446^{NS}	0.925^{**}	0.515^{NS}	1						
TIC	0.040^{NS}	0.379^{NS}	-0.344^{NS}	-0.430^{NS}	0.087^{NS}	0.055^{NS}	0.161^{NS}	1					
TC	-0.118^{NS}	0.062^{NS}	0.300^{NS}	0.426^{NS}	0.922^{**}	0.513^{NS}	0.999^{**}	0.199^{NS}	1				
WSA	-0.681^{*}	-0.267^{NS}	0.212^{NS}	0.319^{NS}	0.817^{**}	0.627^{NS}	0.633^{NS}	-0.024^{NS}	0.628^{NS}	1			
MWD	-0.605^{NS}	-0.243^{NS}	0.335^{NS}	0.445^{NS}	0.744^{*}	0.601^{NS}	0.590^{NS}	-0.163^{NS}	0.579^{NS}	0.968^{**}	1		
FC	-0.388^{NS}	0.098^{NS}	0.549^{NS}	0.208^{NS}	0.605^{NS}	0.579^{NS}	0.428^{NS}	-0.104^{NS}	0.421^{NS}	0.823^{**}	0.861^{**}	1	
PWP	0.357^{NS}	-0.182^{NS}	-0.312^{NS}	-0.322^{NS}	-0.776^{*}	-0.747^{*}	-0.645^{NS}	-0.221^{NS}	-0.649^{NS}	-0.881^{**}	-0.878^{**}	-0.882^{**}	1

Correlation among different forms of carbon with bulk density, particle density, porosity, water holding capacity and porosity

Correlation between different forms of carbon with soil physical properties *viz.*, bulk density, particle density, porosity, water holding capacity and porosity (Table 7)

Very labile (r =-0.791) and labile carbon (r =-0.894) negatively correlated with bulk density and particle density (r =-0.788) & (r =-0.899) respectively. However, showed high positive correlation with porosity (r = 0.853) and (r = 0.863) respectively.

Other carbon fractions like less labile carbon, non-labile carbon, KOC, water-soluble carbon, total organic carbon was negatively correlated with bulk density and particle density while it is positively correlated with MWHC.

Results are in conformity with Sharma *et al.* (2014) [23] who reported that among different carbon fractions labile carbon fraction, KOC and WSOC had positive correlation with maximum water holding capacity (r = 0.658) and moderate negative correlation with BD (r=-0.481).

Correlation among different forms of carbon with pH, EC, OC and CEC

Table 8 represents the correlation among different forms of carbon with soil pH, EC, OC and CEC.

Very labile carbon had significant high positive correlation with pH (r = 0.827) and EC (r = 0.718). KOC (r = 0.880), TOC (r = 0.765) and TC (r = 0.759) had significant high positive correlation with cation exchange capacity, whereas NLC and WSOC showed non-significant correlation with cation exchange capacity.

Sharma *et al.* (2014) [23] revealed that among the different carbon pools KOC seemed to be strongly related to CEC. Correlations of KOC fraction with CEC suggests that soil organic matter contributes to increases in soil cation exchange capacity.

Table 7: Correlation among different forms of carbon with soil physical properties *viz.*, (Bulk density, particle density, porosity, water holding capacity and porosity)

	VLC	LC	LLC	NLC	KOC	WSC	TOC	TIC	TC	BD	PD	MWHC	POR
VLC	1												
LC	0.762^{*}	1											
LLC	0.204^{NS}	0.248^{NS}	1										
NLC	0.095^{NS}	-0.018^{NS}	0.050^{NS}	1									
KOC	-0.308^{NS}	0.000^{NS}	0.236^{NS}	0.426^{NS}	1								
WSC	-0.051^{NS}	0.371^{NS}	0.016^{NS}	0.538^{NS}	0.719^{*}	1							
TOC	-0.120^{NS}	0.048^{NS}	0.316^{NS}	0.446^{NS}	0.925^{**}	0.515^{NS}	1						
TIC	0.040^{NS}	0.379^{NS}	-0.344^{NS}	-0.430^{NS}	0.087^{NS}	0.055^{NS}	0.161^{NS}	1					
TC	-0.118^{NS}	0.062^{NS}	0.300^{NS}	0.426^{NS}	0.922^{**}	0.513^{NS}	0.999^{**}	0.199^{NS}	1				
BD	-0.791^{*}	-0.894^{**}	-0.435^{NS}	0.029^{NS}	-0.109^{NS}	-0.342^{NS}	-0.147^{NS}	-0.147^{NS}	-0.151^{NS}	1			
PD	-0.788^{*}	-0.899^{**}	-0.384^{NS}	0.013^{NS}	-0.114^{NS}	-0.375^{NS}	-0.138^{NS}	-0.163^{NS}	-0.143^{NS}	0.998^{**}	1		
MWHC	-0.418^{NS}	-0.272^{NS}	-0.371^{NS}	0.482^{NS}	0.563^{NS}	0.459^{NS}	0.554^{NS}	0.297^{NS}	0.562^{NS}	0.359^{NS}	0.331^{NS}	1	
POR	0.853^{**}	0.863^{**}	0.316^{NS}	0.134^{NS}	-0.095^{NS}	0.163^{NS}	0.092^{NS}	0.253^{NS}	0.101^{NS}	-0.794^{*}	-0.786^{*}	-0.145^{NS}	1

Table 8: Correlation among different forms of carbon with soil chemical properties *viz.*, (pH, EC, OC and CEC)

	VLC	LC	LLC	NLC	KOC	WSC	TOC	TIC	TC	pH	EC	OC	CEC
VLC	1												
LC	0.762^{*}	1											
LLC	0.204^{NS}	0.248^{NS}	1										
NLC	0.095^{NS}	-0.018^{NS}	0.050^{NS}	1									
KOC	-0.308^{NS}	0.000^{NS}	0.236^{NS}	0.426^{NS}	1								
WSC	-0.051^{NS}	0.371^{NS}	0.016^{NS}	0.538^{NS}	0.719^{*}	1							
TOC	-0.120^{NS}	0.048^{NS}	0.316^{NS}	0.446^{NS}	0.925^{**}	0.515^{NS}	1						
TIC	0.040^{NS}	0.379^{NS}	-0.344^{NS}	-0.430^{NS}	0.087^{NS}	0.055^{NS}	0.161^{NS}	1					
TC	-0.118^{NS}	0.062^{NS}	0.300^{NS}	0.426^{NS}	0.922^{**}	0.513^{NS}	0.999^{**}	0.199^{NS}	1				
pH	0.827^{**}	0.510^{NS}	0.126^{NS}	-0.281^{NS}	-0.607^{NS}	-0.523^{NS}	-0.354^{NS}	0.107^{NS}	-0.347^{NS}	1			
EC	0.718^{*}	0.236^{NS}	-0.054^{NS}	-0.136^{NS}	-0.392^{NS}	-0.394^{NS}	-0.190^{NS}	-0.037^{NS}	-0.190^{NS}	0.756^{*}	1		
OC	-0.157^{NS}	0.242^{NS}	0.254^{NS}	0.350^{NS}	0.801^{**}	0.894^{**}	0.561^{NS}	-0.098^{NS}	0.553^{NS}	-0.584^{NS}	-0.405^{NS}	1	
CEC	-0.560^{NS}	-0.308^{NS}	-0.044^{NS}	0.582^{NS}	0.880^{**}	0.662^{NS}	0.765^{*}	-0.020^{NS}	0.759^{*}	-0.822^{**}	-0.597^{NS}	0.657^{NS}	1

Correlation among different forms of carbon with soil major, secondary and micro nutrients

Correlation among different forms of carbon with soil available nutrients are given in Table 8 and 9.

KOC (r = 0.755) and WSOC (r = 0.844) had significant and high positive correlation with available nitrogen and other fractions except very labile carbon and TIC showed non-significant correlation with available nitrogen. All carbon fractions except very labile carbon had non-significant positive correlation with available phosphorous and potassium. The results are in line with Bongiorno (2020) [4] stating that increase in the soil carbon content had positive influence on the available major nutrient status of the soil. TOC and TC recorded non-significant positive correlation with exchangeable calcium and magnesium, NLC showed negative correlation with exchangeable calcium and magnesium (r =-0.683) and (r =-0.677) respectively.

Non-significant positive correlation between soil carbon fractions and DTPA extractable micronutrients might be due to the synergism between soil carbon and micronutrients, the results are in accordance with Ratnayake *et al*. (2020) [22] who revealed that there is a synergism between soil organic carbon fractions with micronutrients.

Correlation among different forms of carbon with soil biological properties

Correlation among different forms of carbon with soil biological properties are presented in Table 9.

This results revealed that soil carbon fractions improved the microbial activity in the soil. There was significant positive correlation (p = 0.01) found between microbial biomass carbon and NLC (r= 0.689), KOC (r= 0.747) and WSOC (r= 0.870). microbial biomass nitrogen showed significant correlation with WSOC (r= 0.676). The dehydrogenase activity showed significant high positive correlation with KOC (r= 0.755).

Bongiorno (2020) [4] reported significant positive correlation between soil carbon fractions and microbial biomass carbon, similarly Reatnayake *et al*. (2020) reported that improvement in the soil structure as indicated by increase in water stable aggregates and concluded that enhancing soil organic carbon fractions improves the availability of nutrient in the soil, Thus soil carbon has positive correlation with microbial activity.

Table 8: Correlation among different forms of carbon with available major and secondary nutrients

	VLC	LC	LLC	NLC	KOC	WSC	TOC	TIC	TC	N	P	K	Ca	Mg	S
VLC	1														
LC	0.762^{*}	1													
LLC	0.204^{NS}	0.248^{NS}	1												
NLC	0.095^{NS}	-0.018^{NS}	0.050^{NS}	1											
KOC	-0.308^{NS}	0.000^{NS}	0.236^{NS}	0.426^{NS}	1										
WSC	-0.051^{NS}	0.371^{NS}	0.016^{NS}	0.538^{NS}	0.719^{*}	1									
TOC	-0.120^{NS}	0.048^{NS}	0.316^{NS}	0.446^{NS}	0.925^{**}	0.515^{NS}	1								
TIC	0.040^{NS}	0.379^{NS}	-0.344^{NS}	-0.430^{NS}	0.087^{NS}	0.055^{NS}	0.161^{NS}	1							
TC	-0.118^{NS}	0.062^{NS}	0.300^{NS}	0.426^{NS}	0.922^{**}	0.513^{NS}	0.999^{**}	0.199^{NS}	1						
N	-0.342^{NS}	0.057^{NS}	0.200^{NS}	0.389^{NS}	0.755^{*}	0.844^{**}	0.494^{NS}	-0.122^{NS}	0.486^{NS}	1					
P	-0.079^{NS}	0.029^{NS}	0.043^{NS}	0.439^{NS}	0.524^{NS}	0.359^{NS}	0.631^{NS}	0.309^{NS}	0.638^{NS}	0.275^{NS}	1				
K	0.088^{NS}	0.361^{NS}	0.031^{NS}	0.079^{NS}	0.290^{NS}	0.428^{NS}	0.282^{NS}	0.500^{NS}	0.299^{NS}	0.400^{NS}	0.744^{*}	1			
Ca	-0.638^{NS}	-0.513^{NS}	-0.325^{NS}	-0.683^{*}	-0.002^{NS}	-0.312^{NS}	0.093^{NS}	0.404^{NS}	0.076^{NS}	-0.027^{NS}	0.063^{NS}	0.140^{NS}	1		
Mg	-0.641^{NS}	-0.520^{NS}	-0.316^{NS}	-0.677^{*}	0.010^{NS}	-0.311^{NS}	0.079^{NS}	0.396^{NS}	0.063^{NS}	-0.022^{NS}	0.066^{NS}	0.135^{NS}	1.000^{**}	1	
S	0.409^{NS}	0.373^{NS}	0.547^{NS}	0.650^{NS}	0.559^{NS}	0.498^{NS}	0.666^{NS}	0.167^{NS}	0.655^{NS}	0.436^{NS}	0.612^{NS}	0.489^{NS}	0.547^{NS}	0.539^{NS}	1

Table 9: Correlation among different forms of carbon with soil available micro nutrients

	VLC	LC	LLC	NLC	KOC	WSC	TOC	TIC	TC	Zn	Mn	Fe	Cu
VLC	1												
LC	0.762^{*}	1											
LLC	0.204^{NS}	0.248^{NS}	1										
NLC	0.095^{NS}	-0.018^{NS}	0.050^{NS}	1									
KOC	-0.308^{NS}	0.000^{NS}	0.236^{NS}	0.426^{NS}	1								
WSC	-0.051^{NS}	0.371^{NS}	0.016^{NS}	0.538^{NS}	0.719^{*}	1							

TOC	-0.120^{NS}	0.048^{NS}	0.316^{NS}	0.446^{NS}	0.925**	0.515^{NS}	1						
TIC	0.040^{NS}	0.379^{NS}	-0.344^{NS}	-0.430^{NS}	0.087^{NS}	0.055^{NS}	0.161^{NS}	1					
TC	-0.118^{NS}	0.062^{NS}	0.300^{NS}	0.426^{NS}	0.922**	0.513^{NS}	0.999**	0.199^{NS}	1				
Zn	0.118^{NS}	0.099^{NS}	0.152^{NS}	0.644^{NS}	0.273^{NS}	0.633^{NS}	0.129^{NS}	0.256^{NS}	0.118^{NS}	1			
Mn	0.543^{NS}	0.151^{NS}	0.377^{NS}	0.048^{NS}	0.296^{NS}	0.129^{NS}	0.257^{NS}	0.005^{NS}	0.256^{NS}	0.410^{NS}	1		
Fe	0.190^{NS}	0.289^{NS}	0.169^{NS}	0.321^{NS}	0.605^{NS}	0.432^{NS}	0.493^{NS}	0.222^{NS}	0.481^{NS}	0.479^{NS}	0.390^{NS}	1	
Cu	0.133^{NS}	0.103^{NS}	0.147^{NS}	0.645^{NS}	0.267^{NS}	0.621^{NS}	0.132^{NS}	0.253^{NS}	0.122^{NS}	1.000**	0.422^{NS}	0.478^{NS}	1

Table 10: Correlation among different forms of carbon with soil biological properties

	VLC	LC	LLC	NLC	KOC	WSC	TOC	TIC	TC	MBC	MBN	DEHY
VLC	1											
LC	0.762*	1										
LLC	0.204^{NS}	0.248^{NS}	1									
NLC	0.095^{NS}	-0.018^{NS}	0.050^{NS}	1								
KOC	-0.308^{NS}	0.000^{NS}	0.236^{NS}	0.426^{NS}	1							
WSC	-0.051^{NS}	0.371^{NS}	0.016^{NS}	0.538^{NS}	0.719*	1						
TOC	-0.120^{NS}	0.048^{NS}	0.316^{NS}	0.446^{NS}	0.925**	0.515^{NS}	1					
TIC	0.040^{NS}	0.379^{NS}	-0.344^{NS}	-0.430^{NS}	0.087^{NS}	0.055^{NS}	0.161^{NS}	1				
TC	-0.118^{NS}	0.062^{NS}	0.300^{NS}	0.426^{NS}	0.922**	0.513^{NS}	0.999**	0.199^{NS}	1			
MBC	0.064^{NS}	0.231^{NS}	0.133^{NS}	0.689*	0.747*	0.870**	0.632^{NS}	0.009^{NS}	0.628^{NS}	1		
MBN	0.482^{NS}	0.075^{NS}	0.055^{NS}	0.162^{NS}	0.576^{NS}	0.676*	0.381^{NS}	0.386^{NS}	0.394^{NS}	0.737*	1	
DEHY	0.599^{NS}	-0.155^{NS}	0.111^{NS}	0.204^{NS}	0.775*	0.611^{NS}	0.612^{NS}	0.222^{NS}	0.617^{NS}	0.740*	0.908**	1

Conclusion

Tillage practice showed non-significant results with respect to very labile, labile and non-labile carbon pools except less labile carbon which varied significantly with tillage practices. Conventional tillage recorded statistically higher very labile carbon pools (2.75 g kg^{-1}). Similarly, growing of cover crops also showed non-significant results with very labile, less labile and non-labile carbon pools, but growing of horse gram as cover crop recorded significantly higher labile carbon pools (1.90 g kg^{-1}). Zero tillage recorded statistically higher permanganate oxidizable carbon and water-soluble carbon (0.66 g kg^{-1}) and (1.10 g kg^{-1}) respectively compared to the conventional and reduced tillage. Among tillage practices, Zero tillage recorded significantly higher total organic carbon (6.72 g kg^{-1}) and total carbon (6.83 g kg^{-1}). Crop residue and tillage affects the soil environment directly or indirectly, incorporation of crop residue into soil or retention on the surface through the adaptation of conservation agriculture practice which increases the organic matter content of soil.

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