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# Carbon and nitrogen dynamics, carbon sequestration and energy saving in soils under different tillage, stubble mulching and fertilizer management in rice–wheat cropping system

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## Abstract

Soil organic carbon plays the crucial role in maintaining soil quality. The impact carbon and nitrogen dynamics and rate of SOC sequestration in tillage and crop residue application is still in investigation in this environment. A field experiment was initiated in 2009-10 and continued up to 2015-16 to compare the organic carbon build up in the soil due to tillage and crop residue application. The soil organic carbon data represents the cumulative after five crop cycle. About 5 t ha$^{-1}$ of standing rice and wheat crop was retained for succeeding crop in retained treatments. Result showed that, soil organic carbon build up was affected significantly by tillage and residue level in upper depth of 0-15 cm but not in lower depth of 15-30 cm. Higher SOC content of 19.44 g kg$^{-1}$ of soil was found in zero tilled residue retained plots followed by 18.53 g kg$^{-1}$ in permanently raised bed with residue retained plots. Whereas, the lowest level of SOC content of 15.86 g kg$^{-1}$ of soil were found in puddled transplanted rice followed by wheat planted under conventionally tilled plots. Zero tilled residue retained plots sequestrated 0.91gkg$^{-1}$yr$^{-1}$ SOC in the year 2015-16 which was 22.63% higher over the conventionally tilled residue removed plots after seven seasons of experimentation.

The zero tilled soil had values of dehydrogenase, urease, phosphatase and β-glucosidase activities, and water aggregate stability higher than conventional tilled soils but lowers than the soil under permanent raised beds with residue retention. The enzyme activities and water aggregate stability reflected early changes in soil the profile to a greater extent than did physical-chemical and chemical properties. Similarly, treatments that included organic manure had significantly higher SOC concentrations and stocks than mineral or unfertilized treatments. The organic manure treatments also had higher concentrations of non-labile but at the same time a higher proportion of labile C than the mineral or unfertilized treatments. This was confirmed by the carbon management index (CMI) which was significantly increased by organic manure addition. This study demonstrates that fertilization strategies that include organic manure can increase the pool of stable C in the surface soil layer, while at the same time increasing concentrations and proportions of labile C.Therefore, CA in rice-wheat system can help directly in building–up of soil organic carbon and improve the fertility status of soil.

**Keywords:** soil organic carbon; residue retention; carbon sequestration, microbial biomass carbon, soil enzymes, energy use pattern

## 1. Introduction

Soil organic matter, as indicated by C and N levels, is an important component of soil quality and productivity. Increasing soil organic matter through enhanced C and N sequestration can also reduce the potentials for global warming by mitigating greenhouse gas emissions and N leaching by increasing N storage in the soil (Lal *et al*., 1995) [33]. Carbon and N sequestration usually occur when non-harvested crop residues, such as stems, leaves, and roots, are placed at the soil surface due to no-tillage (Sainju *et al*., 2007) [66]. Carbon and N sequestration rates, however, depend on the balance between the amounts of plant residue C and N inputs and rates of C and N mineralized in the non- manured soil (Peterson *et al*., 1998). Other benefits of increasing C and N storage include enhancement of soil structure and soil water-nutrient-crop productivity relationships (Bauer A, Black, 1994) [1]. Soil and crop management practices can alter the quantity, quality, and placement of crop residues in the soil, thereby influencing soil C and N storage, microbial biomass and activity, and N mineralization–immobilization (Sainju *et al*., 2006b) [67]. Residue placement in the soil under different tillage systems can influence C and N levels by affecting soil aggregation, aeration, and C and N mineralization (Halvorson *et al*., 2002b) [21].

Plant residues have an important role as soil and water-protecting factors.

In Iran, in recent decades, there has been an increasing interest in managing crop residues using practices other than burning or removing them from the field (Kumar and Goh, 1999) [31]. Burning and removal of residues not only causes a direct loss of nutrients in soils but also deprives the soil of carbon or organic matter, which is important for improving soil structure and providing life to the soil by acting as a substrate for various microbes and biota (Blanco-Canqui and Lal, 2009) [2]. Also, the removal of crop residues from an agricultural system will increase the potential for increased soil erosion and/or negative effects on environmental quality (Johnson *et al*., 2010) [28]. Therefore, management of a crop residue can contribute to increased nutrient cycling and greater crop yields (Cruse and Herndl, 2009) [7] and also has an important role in reducing soil erosion and maintaining yield (Lal, 2000) [36]. By management practices such as zero tillage to reduce soil disturbance and/or increase the amount of residue returned to the soil, soil organic carbon and nitrogen can be increased in the system (Ghimire *et al*., 2012) [15]. The rate of decomposition and N mineralization increases by increasing the quality of a plant residue (Jensen *et al*., 2005) [25]. Although the quality of a residue is an important factor to determine the C and N mineralization rate, residue management is a factor affecting this process (Smith and Sharpley, 1990) [78]. The amount of nutrients released during the decomposition of a crop residue is very important in both organic and conventional farming systems; in the former, it has a decisive influence on crop yield and in the latter, it could lead to a reduction in mineral fertilizer application (Kwabiah *et al*., 2003) [34].

The conventional or plow tillage (CT) may have some beneficial impacts including temporary reduction in soil compaction, plowing under of crop residues, and control of weeds. However, CT also aggravates soil erosion, off-site transport of nutrients, loss of soil organic matter (SOM) and decline of soil quality (Lal, 2007; Naresh *et al*., 2016) [86, 55]. Thus, use of conservation agriculture systems (CA) with less soil disturbance are beneficial to saving energy, improving soil quality, maintaining soil fertility, reducing risks of soil degradation and decreasing soil erosion (Seta *et al*., 1993) [72]. Indeed, the amount of SOC storage depends on the balance between quantity and quality of SOM inputs–outputs, which is largely determined by the combined interaction of climate, soil properties and land use management (Paustian *et al*., 1997) [60]. Thus, retaining crop residues is important for SOM maintenance, long term soil health and the attendant increase in SOC and N storage (Salinas-Garcıa *et al*., 2002) [70].

Organic matter and nutrient deficiency also appeared as a great concern in the intensively cultivated areas due to lack of proper soil management by incorporating organic manures (Bhattacharya *et al*., 2010). Because hyperthermic temperature regime, the rate of organic matter mineralization in soils of western Uttar Pradesh is usually very high, which is a basic problem in soil of Uttar Pradesh (Naresh *et al*., 2015) [54]. The present carbon status in soil is alarming and, therefore, proper and deliberate management of soil organic carbon is essential for the sustainability of agricultural production systems.

SOM is not sensitive to short-term changes of soil quality with different soil or crop management practices due to high background levels and natural soil variability (Haynes, 2005) [22]. Labile soil rganic carbon pools like dissolved organic C (DOC), microbial biomass C (MBC), and particulate organic matter C (POC) are the fine indicators of soil quality which influence soil function in specific ways (e.g., immobilization–mineralization) and are much more sensitive to change in soil management practices (Xu *et al*., 2011) [89]. Because these components can respond rapidly to changes in Supply, they have been suggested as early indicators of the effects of land use on SOM quality (Naresh *et al*., 2017) [56]. Recently, many studies have reported responses of labile SOC pools to management practices (Liang *et al*., 2011 and Nayak *et al*., 2012) [41, 58], though limited to tillage practices or cropping intensity and rotations management (Dou *et al*., 2008) [13]. Available N fractions that influence plant growth and N losses due to leaching, DE nitrification, or volatilization are $NH_4$-N and $NO_3$-N (Sainju *et al*., 2006b) [67]. Although active C and N fractions in the soil can change more rapidly than the other fractions, these fractions sometime may not be readily changed within a crop growing season due to high variability in soil properties within a short distance in the field or in regions with limited precipitation, cold weather, and a short growing season (Sainju *et al*., 2009) [67]. Our objectives were to: (1) evaluate the effects of residue placement and tillage on crop yields, residue C and N dynamics, and carbon sequestration within a growing season and (2) to identify the suitable sustainable tillage-residue management systems based on their effects on SOC and N storage in the *Typic Ustochrept* soil.

## 2. Materials and methods

### 2.1. Experimental site

A long-term field experiment was established in the year 2009 at Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, (28°40′ 07″N to 29° 28′ 11″N, 77° 28′ 14″E to 77° 44 18″E, 237 m above mean sea level) Uttar Pradesh, India with rice (*Oryza sativa* L.)–Wheat (*Triticum aestivum* L.) cropping system. The region has a semi-arid sub-tropical climate with an average annual temperature of 16.8 $^0$C. The highest mean monthly temperature (38.9 $^0$C) is recorded in May, and the lowest mean monthly temperature (4.5 $^0$C) is recorded in January. The average annual rainfall is about 665 to 726 mm (constituting 44% of pan evaporation) of which around 80% is acknowledged for the duration of monsoon period. Remaining 20% rainfall is received during the non-monsoon period in the wake of western disturbances and thunder storms. The predominant soil at the experimental site is classified as *Typic Ustochrept*. Soil samples for 0–20 cm depth were collected at the site and tested previous to put on treatments and basic possessions were non-saline (EC 0.42 dS $m^{-1}$) but mild alkaline in reaction (pH 7.98). General soil properties were elaborated in Table 1.

**Table 1:** General soil properties (0–20 cm) before the experiment started in 2009.

| Parameter | Mean | C.V. $^b$ (%) |
|---|---|---|
| TOC (g $kg^{-1}$) | 7.44 | 6.02 |
| Total N (g $kg^{-1}$) | 0.93 | 3.02 |
| Olsen-P (mg $kg^{-1}$) | 9.57 | 15.66 |
| Available $K^a$(mg $kg^{-1}$) | 191 | 3.30 |
| Total porosity (%) | 49.6 | 5.8 |
| Bulk density (g $cm^{-3}$) | 1.35 | 3.70 |

**Note:** mean values of parameters in the table were calculated from data for all experimental plots. $^a$ Available K was extracted with 1 M $NH_4AC$; $^b$C.V: is coefficient of variation.

### 2.2. Experimental design and management

A comprehensive description of unlike tillage systems is essential to compare effect of tillage on environmental concert (Derpsch *et al*., 2014) [12]. The experiment was laid out in a split plot design keeping seven tillage crop residue practices$T_1$- ZT without residue, $T_2$-, ZT with 4 tha$^{-1}$ residue retained, $T_3$- ZT with 6tha$^{-1}$ residue retained, $T_4$- FIRB without residue,$T_5$- FIRB with 4 tha$^{-1}$residue retained, $T_6$- FIRB with 6 tha$^{-1}$residue retained, $T_7$- Conventional tillage in main plots and six nitrogen management practices were $F_1$- Control; $F_2$- 100% RDF; $F_3$-50%RDF +VC @ 5 t ha$^{-1}$; $F_4$- 75%RDF +VC @ 5 t ha$^{-}$; $F_5$-100%RDF +VC @ 5 t ha$^{-1}$; $F_6$- VC @ 5 t ha$^{-1}$allotted to sub-plots replicated thrice. The net and gross plot sizes were 8.0 m×2.8 m and 10 m×4.2 m, respectively and treatments were superimposed in the same plot every year to study the cumulative effect of treatments.

The tillage and crop establishment methods comprised of (i) conventional tillage (CT): In conventional tillage there were four tillage operations. The first tillage was performed in the pre-monsoon season (April/May) and the second one was performed in May/June, some 20–25 days after the first tillage. The third tillage was conducted during June and the fourth rice harvest (October/November) at deeper depth (>15 cm) using a tractor drawn cultivator. Similar tillage operations were followed for the wheat crop.; (ii) Permanent Raised Beds (FIRB): seeds were drilled, 5 cm deep, over rice harvested bed tops, in six rows, after superficial reshaping using plots using inclined plate zero-till cum raised bed planter (FIRB); and (iii) zero tillage (ZT): seeds were drilled, 5cm deep, on untilled rice harvested plots using inclined plate zero-till seed drill. The residue management consisted of (i) residue retention (RR): The40 cm stubbles of preceding crop were left at harvest and chopped rice straw of size 15–20 cm was applied in 4 tha$^{-1}$and 6 t ha$^{-1}$as mulch manually on the same day after sowing of wheat in each year. (ii) Residue removal (RO): preceding crop was harvested from ground level leaving about 5 cm stubbles. The nutrient management practices one-third of N and entire P, K were applied at the time of transplanting/sowing and remaining N was top dressed in 2 equal splits at maximum tillering and panicle/ear emergence. Both crops were grown under assured irrigated conditions with recommended agronomic practices.

### 2.3. Soil sampling and processing

Soil samples were collected arbitrarily from three spots with the assistance of a core sampler from each replicated plot (10 cm internal diameter and 15 cm height) after harvest of crop in the year 2015-16. The soil cores were collected from a soil depth of 0-5; 5-10; 10-15 and 15 to 30 cm. One merged sample on behalf of each replication was set by mixing two cores of own depth of soil. Instantly after the collection, soil samples were brought to the laboratory and stored in a refrigerator for measurement of microbial biomass carbon (MBC). A subset of samples was air dried and passed over a 2 mm sieve for determination of pH, SOC and particulate organic carbon (POC). The third core sample was used to appraisal of bulk density. The soil porosity was calculated from the relationship between particle density and bulk density using (1). Permanent wilting point and Soil field capacity were measured using pressure plate apparatus, while available water content was calculated using (2). Consider

$$\text{Porosity (\%)} = 1 - \mathrm{BD}PDx100 \quad (1)$$

Where BD is bulk density (g cm$^{-3}$), PD is particle density (g cm$^{-3}$), and

$$\mathrm{d} = FC - PWP100\text{x BD x Soil depth} \quad (2)$$

Where d is an available water content (cm) at 60 cm depth, FC is field capacity (%), and PWP is permanent wilting point (%)

To determine the water infiltration the double ring in filter meter method was used and computed as rate of infiltration in mm h$^{-1}$ and cumulative infiltration.

### 2.4. Soil analysis

The electrical conductivity (ECe) of soil was resolute in soil saturation extract. The pH of soil was measured in soil: water suspension (1:2). The soil bulk density was measured using core sampler method as suggested by Veihmeyer and Hendrickson, (1984) [86].

### 2.4.1. Carbon management index and carbon pool calculations

The carbon management index (CMI) provides a sensitive measure of the rate of change in soil C dynamics of a given system relative to a more stable reference soil (Blair *et al*., 1995). This index was calculated for each of the treatments using a reference sample value, obtained from the control plot under the cropping system without any fertilizers, as follows:

Firstly, a C pool index (CPI) was calculated from:

$$\mathrm{CPI} = \frac{\text{sample total organic C (g/kg)}}{\text{reference sample total C (g/kg)}}$$

Then, a lability index (LI) from:

$$\mathrm{LI} = \frac{\text{lability of C in each sampled soil}}{\text{lability of C in the reference soil}}$$

Where

$$\text{lability of C} = \frac{\text{KMnO4 C}}{\text{TOC} - \text{KMnO4 C}}$$

The CMI was then estimated from: CMI = CPI x LI x100

### 2.4.2. Total organic carbon

The TOC content was determined by using Walkley and Black’s (1934) rapid titration method and computed using Eq. (3):

TOC stock (Mg C ha$^{-1}$) = TOC content (g C kg$^{-1}$) × Db (Mg m$^{-3}$) × Soil layer (m) × 10**(3)**

Where,

Db is bulk density of the particular soil layer (Db values for 0-5 cm and 5-15 cm soil layer were 1.32and 1.34 Mg m$^{-3}$, respectively).

### 2.4.3. Soil organic carbon

Wet digestion with potassium dichromate accompanied by 3:2 $H_2SO_4$: 85% $H_3PO_4$ digestion mixture in a digestion block set at 120 °C for 2h was used to determined soil organic carbon (Snyder and Trofymow, 1984) [79]. Removal of carbonate and bicarbonate was finished by apre-treatment with 3 ml of 1 $NH_4Cl$ g$^{-1}$ of soil. By using bulk density value the SOC for every soil layer was calculated and expressed as Mg ha$^{-1}$.

### 2.4.4. Particulate organic carbon

Particulate organic matter (POM) was detached from 2 mm soil following method described by Camberdella and Elliott, (1992). Briefly a 10 g sub-sample of soil was disseminated in

100 ml 0.5% sodium hexa-metaphosphate solution by shaking for 15h on a reciprocal shaker. The soil suspension was decanted over a 0.05 mm screen. All material left over on the screen, definite as the POM fraction within a sand matrix, was transported to a glass beaker and weighed after oven-drying at 60°C for 24 h. Snyder and Trofymow (1984) [79] was used to determine particulate organic carbon in POM.

### 2.4.5. Water soluble organic carbon

The water soluble carbon (WSC) was consecutively analyzed conferring to the method defined by Zhang *et al*. (2009). Briefly, the soil samples were first suspended in distilled water at 70±1 °C for 60 min. The supernatant was mentioned to as the water soluble fraction (WSF)

### 2.4.6. Labile carbon pools

$KMnO_4$oxidizable carbon (KOC) in soil was determined by following the procedure of Blair *et al*. (1995). Moist sample of soil (2.0 g) was taken in centrifuge tube and oxidized with 25 ml of 333 mM $KMnO_4$ by shaking on a mechanical shaker for 1 h. The tubes were then centrifuged for 5 min at 4000 rpm and 1.0 ml of supernatant solution was diluted to 250 ml with double distilled water. The concentration of $KMnO_4$ was measured at 565 nm wavelength using a spectrophotometer. The change in concentration of $KMnO_4$ is used to estimate the amount of carbon oxidized assuming that 1.0 mM of $MnO_4^-$ was consumed ($Mn^{7+} \rightarrow Mn^{2+}$) in the oxidation of 0.75 mM (9.0 mg) of carbon.

### 2.4.7. Soil microbial biomass carbon

Microbial biomass carbon was determined according to the $CHCl_3$ fumigation–extraction method in field-moist samples (Vance *et al*., 1987). Fumigated and non-fumigated samples were incubated during 24 h at 25˚C at constant moisture content. Microbial C was extracted from both fumigated and non-fumigated samples with 0.5 M $K_2SO_4$ and digested in the presence of potassium persulphate ($K_2S_2O_8$) and 0.025 M $H_2SO_4$in a digestion block at 120˚C for 2 h. The amount of $CO_2$–C thus evolved was estimated by following the method of Snyder and Trofymow (1984) [79]. Microbial C was calculated by subtracting the extracted C in un fumigated samples from that measured in fumigated samples and dividing it by a $K_c$ value of 0.45 (Joergensen, 1996) [79]. The values of MBC were represented in mg $kg^{-1}$ dry soil.

### 2.4.8. Carbon mineralization

Aerobic incubation in the laboratory was used to estimate potential C mineralization. Samples of 100 g fresh soil at 60% water holding capacity (WHC) were placed in a 1 L air tight jar along with a vial containing 0.1 N NaOH to trap evolved $CO_2$ (Zibilski, 1994) [93] and incubated for 30 days at 28 ◦C. The alkali was replaced twice a week during the first two weeks, followed by once a week for the rest of the incubation period. The unspent alkali was titrated back with standard HCl to estimate the $CO_2$–C evolved from soil.

### 2.5. Sustainable Yield Index

Total crop productivity of rice and wheat was calculated through a SYI using yield-data of 5 yr. This was done to adjust any annual variations in the yield and to highlight the relative productivity of the treatments for the entire experimental period. The SYI is defined according to Eq. [4]:

$$SYI = \frac{y - \text{ø}}{Ymax}(4)$$

Where

Y is the estimated average yield of a practice across the years,
ó is its estimated standard deviation, and
$Y_{max}$ is the observed maximum yield in the experiment during the years of cultivation (Singh *et al*., 1990) [76].

### 2.6. Measurement of Soil Enzyme Activity

Nitrifying and denitrifying bacteria are determined using the MPN counting method (Li, Luo, and Teng 2008). Four soil enzyme activities (phosphatase, β-glucosidase, urease, and dehydrogenase) were measured. The detailed methods forthe enzyme analyses are as follows:

Assay of soil phosphatase activity: 100.0 mg of soil sample was taken in a micro centrifuge tube and 0.5ml of 100.0mM phosphate buffer was included. 10.0mM of P nitro phenyl phosphate (p-NPP) in 100.0µl solution was used as substrate. The final volume of the reaction mixture was adjusted to 1.0ml with the addition of requisite amount of distilled water. The tube was vortexed (2.0min.) at room temperature. It was then incubated at 37.0$^0$C for 60min in shake condition (100 rpm). After the incubation period, the sample was centrifuged at 10000 rpm (5.0min). The clear supernatant was taken in a clean test tube and 2.0ml of 1.0M NaOH was added. The yellow colored filtrate was analyzed using a colorimeter (Klett colorimeter, Clinical model, 800-3, 115 VAC) at λ=430nm.

*Β-glucosidase* (EC 3.2 pH 6,37ºC) activity was determined using *p*-nitrophenyl *β*-glucopyranoside as substrate by incubating in a pH 6 modified buffer at 37 ºC. After 1h,0.5 mol $L^{-1}CaCl_2$ and 0.5mol $L^{-1}$ Tris solution (pH 12) were added to precipitate humic molecules responsible for brown coloration and to extract *p*-nitrophenol. The *p*-nitrophenol produced was measured colorimetrically (Tabatabai, 1994) [8]. The enzyme activity of the controls was measured by the same procedures, but the substrates were added to the soil samples after incubation and prior to the analysis of the reaction product.

Urease activity was determined using urea as the substrate. Five grams of soil, 10 ml of 10%ureasolution, and 20 ml of citrate buffer (pH 6.7) were added to a 50-ml flask and incubated at 37°C for 2 h. After filtration, an aliquot of 3 ml of the filtrate was added to a 50-ml flask, and then 4 ml of sodium phenol late and 3 ml of sodium hypochlorite were added. The color developed at room temperature was measured at 578 nm (Guan, 1986). The unit of urease activity was reported as µg $NH_4^+$-N released · $g^{-1}$ dry soil · $h^{-1}$.

Dehydrogenase activity was determined according to García *et al*. (1997) [14]. For this, 1 g of soil at 60% of its field capacity was exposed to 0.2 ml of 0.4% INT (2-p-iodophenyl-3-pnitrophenyl-5-phenyl- tetrazolium chloride) in distilled water for 20 h at 22ºC in darkness. The INTF (iodonitrotetra-zoliumformazan) formed was extracted with 10 ml of methanol by shaking vigorously for 1 min and filtration through a what man no. 5 filter paper. INTF was measured spectrophotometrically at 490 nm.All determinations of enzymatic activity were performed in triplicate, and all values reported are averages of the three trials performed on oven-dried soil (105°C).

### 2.7. Energy saving

Total system energy input and output was measured based on energy input/output of each treatments in respective parameters. Physical energy of each input and output was converted into energy equivalents viz. Mega Joules (MJ) and Giga Joules (GJ) by using conversion coefficient values given by Gopalan *et al. (*1978) [17]. Energy input–output relationship with respect to energy efficiency, energy productivity and net energy in different treatments vary with the component knitted in a soil type, agronomic operations and fertilizers used, plant protection measures and economic produce levels Mandal *et al*.2005 [47].

### 2.8. Statistical analysis

Statistical analysis was performed by the Windows-based SPSS program (Version 10.0, SPSS, 1996, Chicago, IL).The SPSS procedure was used for analysis of variance to determine the statistical significance of treatment effects. Duncan's Multiple Range Test (DMRT) was used to compare means through least significant difference (LSD).The 5.0% probability level is regarded as statistically significant.

## Results and Discussion

### Changes of Soil Physical Properties

**Bulk Density (BD) and Porosity:** Among tillage crop residue practices, plots under ZT without residue (ZT-WR) $T_1$had about 4% higher BD (1.62gm$^{-3}$) than $T_7$ plots. Unlike residue management, tillage had greater impacts on soil BD. Plots under $T_3$ ~ 7.7% and $T_6$ had ~ 10.6% less soil BD as compared with $T_7$ plots(Figure 1).The BD did varied significantly due to seeding techniques and it was significantly reduced under conventional and FIRB with residue retention compared to ZT without residue retention. This was attributed mainly due to more pore spaces created in these techniques through modified land configuration by accumulations the topsoil. The decrease in BD under conservation agriculture (CA) could be due to higher SOC content, better aggregation and biomass (Unger and Jones, 1998).Elsewhere, the similar findings of lower BD values under ZT with residue retention were also reported by Verhulst *et al*., (2011); Naresh *et al*., (2015) [54]; Salem *et al*., (2015)and Singh *et al*., (2016).

Soil porosity results showed that the residue retention treatments ($T_2$, $T_3$, $T_5$ and $T_6$) could increase the total porosity of soil, while zero till residue removal (ZT-WR) ($T_1$) would decrease the soil porosity for aeration as a result; it enhances the water holding capacity of soil along with bad aeration of soil. However, the effects of tillage and residue retention treatments ($T_3$ and $T_6$) on the total porosity and porosity size distribution were not significant and ZT-WR ($T_1$) could increase the quantity of big porosity. Residue retention treatments shown an improvement in the soil porosity and was most probably related to the beneficial effects of soil organic matter caused by ZT with residue cover (Figure 1).

**Cation Exchange Capacity (CEC):** Other notable changes in soil quality due to the legacy of residue harvesting are evident in (Figure 1).CEC was also increased due to tillage and crop residue management. The highest CEC increase (10.3%) was found in $T_6$followed by $T_3$ (5.0%) and $T_5$ (2.4%) as compared to $T_7$ which obtained the lowest CEC from the experimentation (Figure 1).

**Infiltration rate (IR):** Among tillage crop residue practices treatment $T_6$ was found to be significantly superior to all the treatments, except $T_1$ and $T_3$ also recorded highest IR (16.9 hr cm$^{-1}$) during the year of study. The difference in IR due to tillage crop residue practices treatments proved significant. Treatments$T_3$ and $T_6$ were significantly superior to the remaining treatments. $T_5$ was also significant over $T_1$ treatment which recorded lowest IR (10.3hrcm$^{-1}$), during the year of study. However, the highest increase (38.4%) was found in $T_6$ followed by $T_3$ (34.3%) and $T_5$ (31%), whereas $T_1$ and $T_7$ showed decreasing trend (Figure 1). Tillage plays a vital role in improve the soil condition by altering the mechanical impedance to root penetration, hydraulic conductivity and water holding capacity. Increases in the BD usually result in large decreases in water flow through the soil and retaining crop residues on the soil surface with CA would reduce evapo-transpiration and increase infiltration rate (Naresh *et al*., 2015) [54].

**Basal respiration (BR):** The tillage treatments had significant effect on BR. The CA treatments increased BR values compared to those of the CT. The highest values were obtained in ZT and FIRB with residue retention practices during experimentation although the lowest values were reported in$T_1$, ZT without residue; $T_4$ FIRB without residue and ($T_7$)CT practice, in which crop residues were, removed (Figure 1).The increase in BR activity following the addition of crop residue (CR) may be attributed to the enhanced availability of C as an energy source for micro-organisms native to the soil leading to enhanced mineralization and consequent release of $CO_2$, though in RWCS, BRdecreased slightly in ZT and FIRB without residue retention than residue retention plots. CR supplies C as an energy source for micro-organisms and increases the microbial activity (Rousk& Baath 2007) [65].

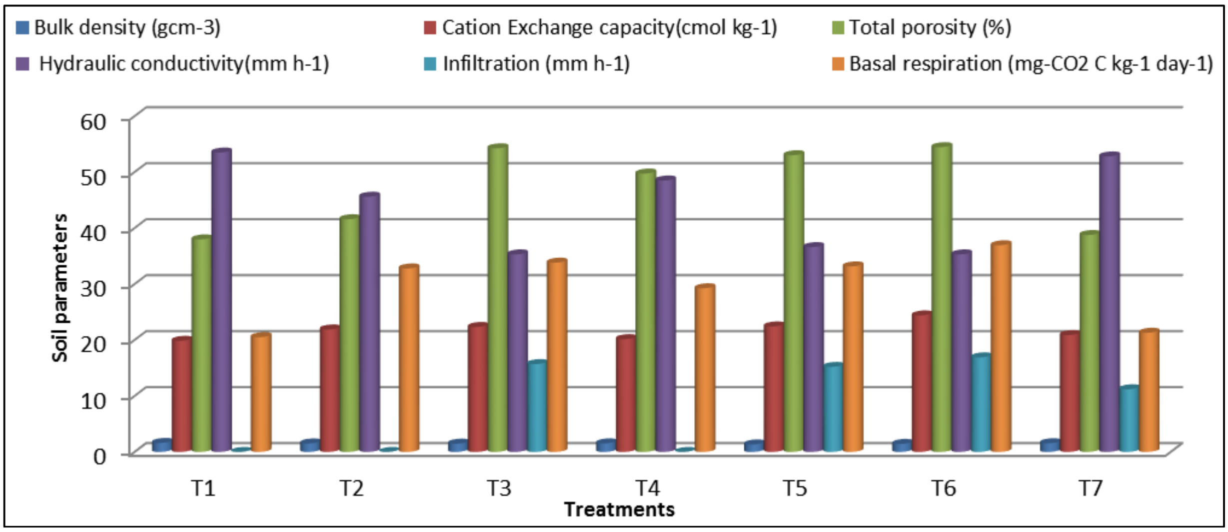

**Fig 1:** Effect of tillage crop residue practices on physical properties of soil and basal respiration

**Yield and Sustainable yield index (SYI):** Grain yield of rice and wheat differed among tillage crop residue practices and fertilizer treatments. Yield trends over 7yr of cropping indicated similar initial yields (2–3 yr) among tillage crop establishment, mineral fertilization and INM with organic manure, but significant differences occurred during the later periods. Significantly higher SYI was observed with the application of vermi-compost (VC) either alone or in combination with mineral fertilizers compared to control ($F_1$).The highest SYI (%) for rice and wheat was observed in $F_5$ with $T_6$(5.8;5.4) followed by $F_4$ (5.4; 5.3) with $T_3$, and the lowest was in $F_1$(3.2;4.1) with $T_1$(Figure 2&3). This trend is mainly due to a high moisture retention capacity inVC-treated plots with ZT and wide FIRB practices with those receiving mineral fertilizers with ZT drill seeding rice and dry CT drill seeding wheat and also due to a slow N-releasing capacity of VC (Bossche *et al.*, 2009) [3].

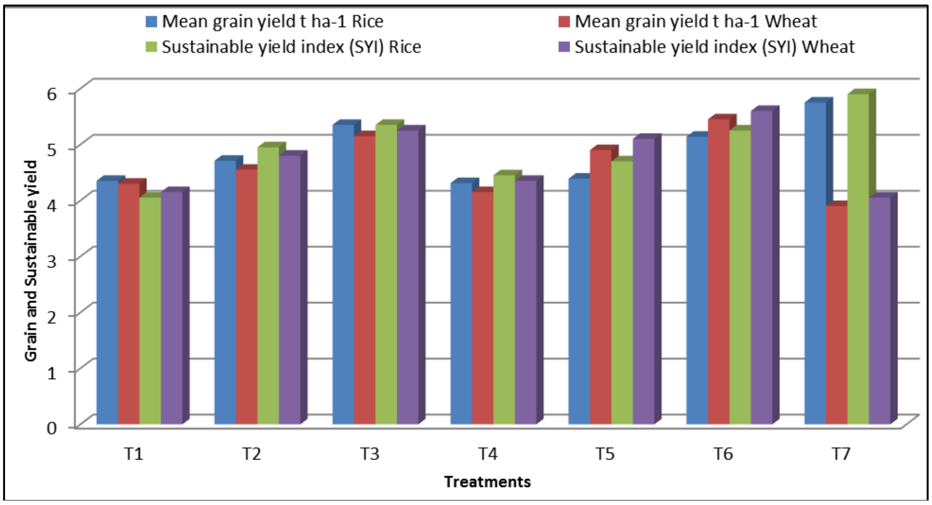

**Fig 2:** Effect of tillage crop residue practices on mean grain yield and sustainable yield index in rice and wheat crop

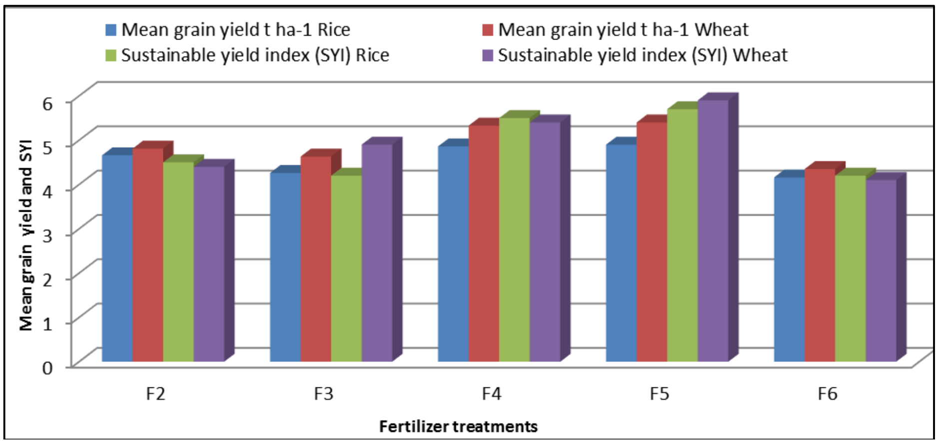

**Fig 3:** Effect of nutrient management practices on mean grain yield and sustainable yield index in rice and wheat crop

## Soil organic carbon pool

Total SOC storage (on an equivalent-depth basis) in the ZT plots was about 20.8% higher than in ($T_7$) CT plots (30.60 Mg $ha^{-1}$) in the 0- to 30-cm soil layer and nearly 15.9% higher in the FIRB plots than in ($T_7$) CT (24.23Mg $ha^{-1}$) in the 0- to 30-cm soil layer(Figure 4). Tillage had significant impact on SOC storage in the 0- to 30-cm soil layer. On an equivalent-mass basis, plots under ZT and FIRB with residue retained had significantly higher SOC stock than CT plots up to 0-30 cm soil layer after 7 yr of rice-wheat cropping system (Figure 4).Change in SOC pool is a process of soil establishing a new balance between inputs and outputs under different treatments (Lal *et al.*, 1998) [37]. Generally, ZT with residue left in placehas the potential for sequestering more SOC than CT in the upper soil depths for two reasons: (i) tillage destroys the protection provided by crop residue on the surface; and (ii) increases the oxidization of SOM which could be avoided by no-tillage treatment.

In the ZT and FIRB systems, stubble was left on the soil surface, implying much slower stubble decomposition and protection of the soil surface from raindrop impact and wind erosion (Chivenge *et al.*, 2007) [6]. These factors were probably very helpful in attaining higher SOC content in the ZT and FIRB plots. Higher SOC content in the 0-30 cm soil layer of a ZT and FIRB systems might have led to more large macro-aggregates, which were more stable (Singh and Malhi, 2006) [75]. All these factors led to the accumulation (and prevention of loss) of SOC in the ZT plots in the upper soil layer. Similar results was by Chen *et al*. (2009) [5] observed that shallow tillage (with residue retention) and ZT (with residue retention) treatments had 14.2 and 13.7% higher total SOC than CT (without residue retention) in the upper 15-cm soil layer after 11 yr of maize (*Zea mays* L.) mono-cropping in the Loess Plateau of China. Nutrient management practices had a significant impact on SOC storage in the 0- to 30-cm soil layers (Figure 5). Plots under $F_4$ and $F_6$ had similar SOC stocks, but had significantly higher SOC stocks than $F_1$ and $F_2$ plots in the 0- to 30-cm depth layer and higher SOC stocks compared with $F_6$ plots only in the $F_3$ plots (Figure 5).

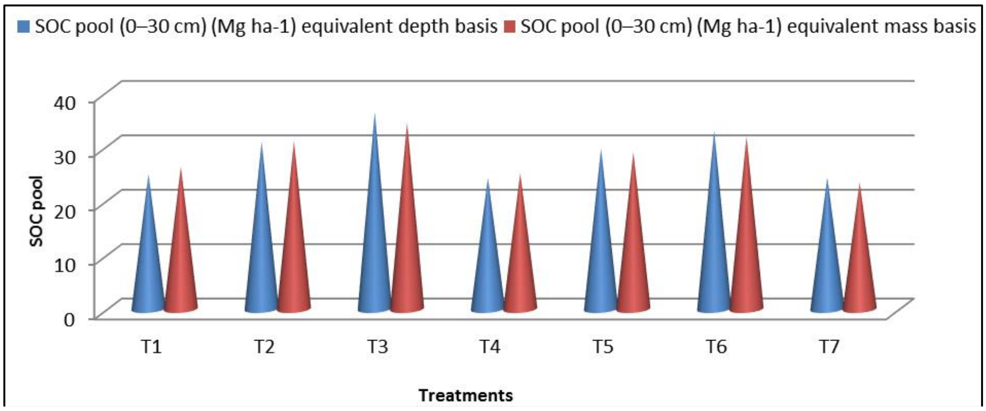

**Fig. 4:** Effect of tillage crop residue practices on SOC pool on depth and mass basis

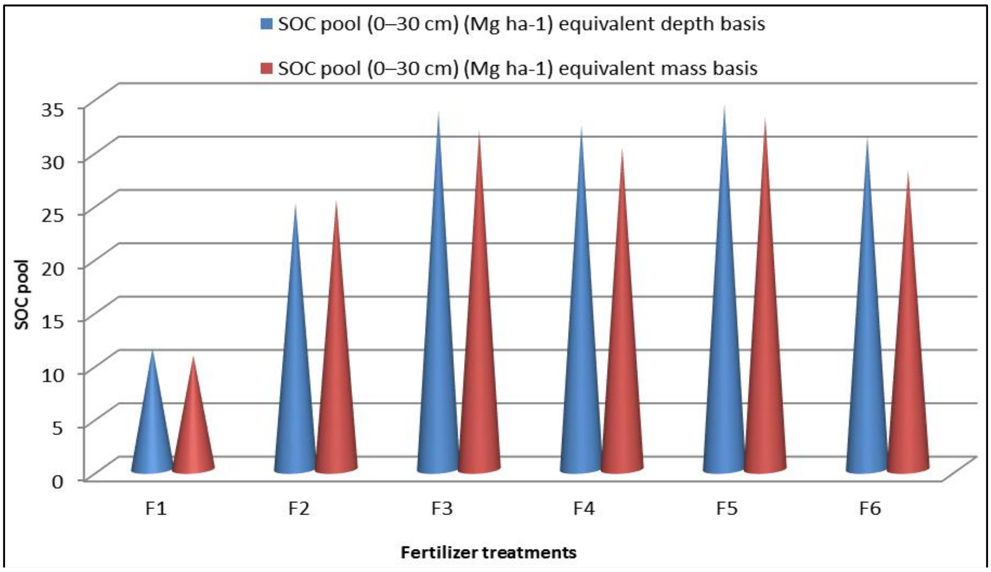

**Fig 5:** Effect of fertilizer treatments on SOC pool on depth and mass basis

### Profile SOC, C buildup, stabilization and sequestration

There were significant differences in the profile SOC pool among treatments (Table 2). The SOC pool was the highest in the100 per cent RDF + VC (56.8 Mg C ha$^{-1}$), and it was on par with 50 per cent RDF +VC (52.8 Mg C ha$^{-1}$)>75 per cent RDF +VC (51.4 Mg C ha$^{-1}$)>VC (49.4Mg C ha$^{-1}$) >RDF (39.3 Mg C ha$^{-1}$)> control (35.9 Mg C ha$^{-1}$) treatments. A higher percentage of C buildup was observed in 100 per cent RDF + VC treatment (43.6 per cent) followed by 50 per cent RDF+VC treatment (40.7 per cent), which was reflected in the profile SOC concentration of respective treatments. The SOC buildup rate also followed a similar trend as C buildup. The C budgeting shows that 36.8 per cent of the C applied as VC was stabilized. With the exception of the control and sole application of RDF through chemical fertilizer, the magnitude of SOC sequestration in other treatments was 7.9–9.6 Mg ha$^{-1}$. Higher SOC sequestration was observed with the application of vermicompost along with 100, 75 and 50 per cent recommended rate of RDF. Cultivation of a crop without using any organic and/or inorganic fertilizer inputs (control) caused a net depletion of SOC pool by 12.0 Mg C ha$^{-1}$. Though application of VC decreasedthe bulk density of the soil particularly at surface and subsurface layer due to higher SOC and increased root biomass it improves the SOC concentration significantly and ultimately increased SOC stock of the profile. SOC concentrations and stocks increased considerably with organic manure incorporation rates, which is possibly attributed to a larger proportion of recalcitrant organic compounds in manure (Liu *et al*., 2014) [44]. Vermicompost manure application can result in an increase in lignin and lignin-like products, which are major components of the resistant C pool in the soil (Lima *et al*., 2009) [9]. Crop production was also enhanced by the manure inputs, which lead to higher total C inputs from rhizodeposition, root biomass and stubble return (Table 2)

Maintaining the SOC pool above the critical level is necessary to sustain agronomic productivity and to minimize environmental degradation (Lal2010c). However, maintaining or improving the SOC pool in light-textured soils of arid and semi-arid regions is a major challenge(Lal 2011, Srinivasarao *et al*. 2012).The prevailing low levels of SOC concentrations are attributed to soil-mining practices – alittle or no crop residues returned to the soil, excessive tillage, unbalanced fertilizer use and severe soil degradation. Ploughing for seedbed preparation disturbs the soil, adversely affects the distribution and stability of aggregates, exacerbates the oxidation of SOM and depletes the SOC pool (Kong *et al*. 2005). Although ploughing-induced depletion of SOC pool is widely observed (Lal 2010a, Dalal *et al*. 2011) [11, 38] the magnitude of depletion depends upon the geographical location, crops/cropping systems, inherent soil properties, cropping history and the duration of the fallow period (Mandal *et al*. 2008) [48]. The higher biomass and C input in [$T_2$], ZT with 4 t residue retained, [$T_3$] ZT with 6 t residue retained, [$T_5$] FIRB with 4 t residue retained and[$T_6$] FIRB with 6 t residue retained may be due to the increased availability of deficient nutrients (i.e. N, K, Ca, Mg, S, Zn and B) with organic manure.

### C: N Ratio

There was an overall effect of tillage on the C: N ratio at the residue management under rice-wheat system with a higher C: N ratio in CT than in ZT and FIRB. The 7-yrrotation increased the C: N ratio by 8.5 27.6and 29.9% as compared to ZT, FIRB with and without residue retention plots. Treatment CT with rice-wheat rotation has higher C: N ratio as compared to different ZT and FIRB management systems are likely due to the contribution of residue and root inputs system (Table 2). The non-significant increase of C: N ratio under ZT compare to FIRB probably is related tome chanical redistribution when residues and roots in soil homogenized and distributed in soil profile (Wright *et al*., 2007) [13]. The lower C: N ration C in [$T_2$], ZT with 4 t residue retained, [$T_3$] ZT with 6 t residue retained, [$T_5$] FIRB with 4 t residue retained and [$T_6$] FIRB with 6 t residue retained may be due to the residues and roots in soil homogenized and distributed in soil profile.It is conceivable that differences in C: N ratio among treatments may become significant if the study were performed longer.

Application of high fertilizer N rate in high C:N residue amended soils lowers the C: N ratio of the residue which avoids net immobilization but enhances the mineralization process (Pathak *et al*. 2006) [59]. This N remained in the soil after harvest and helped to maintain inorganic N concentrations in soil

### Water Aggregate Stability (WSA)

Soil aggregates are a reflection of soil structure and texture. The combined group of soil particles is stronger rather than a single one. Aggregate stability is prominently a multi-parameter effect on the soil properties.Tillage practicessignificantly impacted water aggregate stability (WAS; %) in different residue retention management under rice -wheat system at 4 to 6tha$^{-1}$. The zero till without residue retention tended to increase the WAS compared to that under CT. The WAS under ZT without residue retention (93.4%) significantly increased by 4%compared to CT system (89.7%). A similar trend was observed under fertilizer management practices where control (91.7%) significantly increased WAS by 2.3% compare to 100% VC (93.9%). The 50%RDF +50%VC and 75%RDF +25%VC decreased WAS by 4% compared to under 100% RDF system. The study reported that mechanical tillage increased the breakdown of soil macro-aggregates and that CT disrupted soil macro-aggregates into micro-aggregates or individual particles. In addition, soil under CT system distributed aggregates during the plowing event by bringing protected aggregates to the soil surface.The degree of macro-aggregation in this soil was much lower than in most other agricultural systems, due primarily to the puddling of soil which tends to destroy aggregates.

Tillage and fertilizer management practices had a strong influence on the stabilization mechanisms and dynamics of organic carbon in arable soils (von Lützow *et al*., 2008) [88]. In the present study, fertilizer management practices and tillage crop residue significantly impacted the water stable aggregates. The ZT without residue retention had greater stable aggregates associated with higher SOC (Table2). The ZT system likely improved the physical protection of organic carbon from decomposition and therefore, generally had higher SOC. In contrast, CT disrupts aggregates and exposing them to microbial decomposition (Tan *et al*., 2007; Zotarelli *et al*., 2007) [82, 94]. Our results are in accordance with the available literature (Mamedov *et al*., 2016; Saygn *et al*., 2017) [46, 76] which revealed that the WSA of cropland could be affected by the use of heavy farm machinery, animals, and human activity.

**Table 2**: Profile organic C (OC), C build-up, C build-up rate, C sequestered, C: N ratio and wet aggregate stability (WAS)in the soil profile as affected by 7 yr of tillage crop residue and nutrient management practices

| **Treatments** | **Profile OC** Mg ha$^{-1}$ | **C build-up** % | **C build-up rate** Mg C ha$^{-1}$ y$^{-1}$ | **C Sequestrated** Mg C ha$^{-1}$ | **C:N** Ratio | **WAS** (%) |
|---|---|---|---|---|---|---|
| **Tillage crop residue practices** | | | | | | |
| $T_1$ | $43.5\pm3.1^{d}$ | $27.9\pm0.7^{c}$ | $1.06\pm0.08^{e}$ | $6.7\pm0.2^{d}$ | $14.5^{ab}$ | $93.4^{c}$ |
| $T_2$ | $51.7\pm2.5^{c}$ | $34.2\pm1.8^{b}$ | $1.36\pm0.07^{cd}$ | $8.2\pm0.1^{c}$ | $12.7^{b}$ | $92.9^{c}$ |
| $T_3$ | $69.4\pm3.3^{a}$ | $36.6\pm0.6^{b}$ | $1.46\pm0.09^{b}$ | $8.6\pm0.8^{bc}$ | $9.43^{c}$ | $95.7^{ab}$ |
| $T_4$ | $63.3\pm2.8^{b}$ | $31.8\pm0.6^{bc}$ | $1.33\pm0.04^{d}$ | $7.6\pm0.8^{b}$ | $13.5^{ab}$ | $94.5^{bc}$ |
| $T_5$ | $72.9\pm3.7^{a}$ | $41.0\pm2.2^{a}$ | $1.63\pm0.09^{a}$ | $9.2\pm0.2^{ab}$ | $12.3^{b}$ | $96.9^{a}$ |
| $T_6$ | $73.0\pm3.6^{a}$ | $41.2\pm2.3^{a}$ | $1.64\pm0.10^{a}$ | $9.6\pm0.2^{a}$ | $9.28^{c}$ | $97.6^{a}$ |
| $T_7$ | $41.5\pm2.9^{d}$ | $22.4\pm1.2^{c}$ | $0.89\pm0.06^{f}$ | $5.3\pm0.5^{e}$ | $15.3^{a}$ | $89.7^{d}$ |
| Fertilizer Management Practices | | | | | | |
| $F_1$ | $35.9\pm1.6^{c}$ | - | - | $-12.0\pm0.7^{d}$ | $16.2^{a}$ | $93.7^{d}$ |
| $F_2$ | $39.3\pm1.8^{c}$ | $29.8\pm0.06^{d}$ | $1.28\pm0.007^{d}$ | $-0.61\pm0.8^{c}$ | $15.3^{ab}$ | $92.3^{bc}$ |
| $F_3$ | $52.8\pm0.02^{ab}$ | $40.7\pm2.4^{a}$ | $1.82\pm0.006^{a}$ | $9.3\pm0.8^{a}$ | $14.5^{bc}$ | $90.1^{b}$ |
| $F_4$ | $51.4\pm2.1^{ab}$ | $37.3\pm0.06^{b}$ | $1.73\pm0.021^{b}$ | $8.5\pm0.5^{b}$ | $13.7^{c}$ | $89.9^{b}$ |
| $F_5$ | $56.8\pm1.9^{c}$ | $43.6\pm0.09^{a}$ | $1.88\pm0.001^{a}$ | $9.6\pm0.7^{a}$ | $8.99^{e}$ | $87.4^{a}$ |
| $F_6$ | $49.4\pm2.3^{b}$ | $34.2\pm1.8^{c}$ | $1.46\pm0.07^{c}$ | $7.9\pm0.3^{c}$ | $10.8^{d}$ | $91.1^{bc}$ |

### Soil total organic carbon (TOC)

Tillage treatments generally did statistically affect TOC, although more significant differences were found at the depth of 0-10 cm in 7 year of crop cycle (Table 3) for FIRB and ZT practices. The highest TOC values at 0-10 cm were 23.87 and 25.68 g kg$^{-1}$ under FIRB and ZT with 6 tha$^{-1}$ residue retention and the lowest values were 9.28, 18.50 and 19.30 g kg$^{-1}$ under CT, FIRB and ZT with residue removal, respectively. TOC values were lower under both CT practices and residue removal that accelerated the loss of organic carbon content. The results also obtained during the study indicated an organic carbon increase at 0-10 soil depth under ZT and FIRB practices. The rates of increase in organic carbon obtained in ZT and FIRB with 6 and 4 tha$^{-1}$ residue retention were 64%, 61%, 60% and 50% as compared to CT, respectively. On the other hand, ZT decreases the organic carbon 21%and 19%, respectively, within the same period. At the end of the experiment, TOC values under ZT and FIRBapplication were 59% and 57% higher than those under CT, respectively (Table 3). Resck *et al*. (1999) [63] revealed that the loss of organic carbon under CT might be the breakdown of soil structure and of macro aggregates by relatively frequent and deep plowing of the soil. It is of prime importance to increase or preserve the soil organic matter content for the physical, chemical and biological qualities of the soil (Bradford and Peterson, 2000).

### Total N

The effects of tillage practices on the total N (TN) content were significantly different at0-10 & 10-20 cm depth (Table 3). The highest TN at 0-10 cm was obtained under ZT (696mg $kg^{-1}$) and FIRB (845mg $kg^{-1}$) in 6 $tha^{-1}$ residue retention, respectively. However, the lowest TN was recorded under CT, ZT and FIRB without residue retention (422, 516 and 539mg $kg^{-1}$). ZT and FIRB with 4 $tha^{-1}$ residue retention had similar effects on total N at 0-10 cm depth. Similar trend were recorded on TN at 10-20 cmduring 7 yr of crop cycle but lower values. When the initial and final values were considered, statistically significant differences occurred between tillage treatments. The TN contents were 52%, 43%, 41%and 27% higher compared to those found in 2009, respectively. The higher TOC content caused high TN content in FIRB and ZT plots compared to CT at the surface soil (Table 3). Our results are in agreement with those of (Heenan *et al*., 2004,Naresh *et al*., 2015) [54], who reported that NT and RT practices increased the TN content of the soil when compared to CT. Dalal (1992) [9] also found greater amount of TN under NT than CT in a vertisol. The effects of tillage practices on TOC and TN in the surface layer were probably resulted lowering the TOC and total N contents (Madejon *et al*., 2007) [45].

**Table 3:** Effect of 7 years of application of treatment son total organic C (TOC), total N (TN), and soil organic carbon (SOC)

| **Treatments** | **0-10 cm layer** | | | | **10-20 cm layer** | | | |
|---|---|---|---|---|---|---|---|---|
| | **TOC ($g\ kg^{-1}$)** | **TN ($mg\ kg^{-1}$)** | **SOC ($g\ kg^{-1}$)** | **SOC stock ($Mg\ ha^{-1}$)** | **TOC ($g\ kg^{-1}$)** | **TN ($mg\ kg^{-1}$)** | **SOC ($g\ kg^{-1}$)** | **SOC stock ($Mg\ ha^{-1}$)** |
| **Tillage crop residue practices** | | | | | | | | |
| $T_1$ | $19.30^{c}$ | $539^{c}$ | $5.9^{c}$ | $19.79^{e}$ | $14.37^{d}$ | $489^{c}$ | 4.5d | $14.91^{c}$ |
| $T_2$ | $23.00^{b}$ | $590^{b}$ | $6.5^{b}$ | $30.05^{c}$ | $17.98^{c}$ | $561^{bc}$ | $5.8^{bc}$ | $27.70^{b}$ |
| $T_3$ | $25.68^{a}$ | $696^{ab}$ | $7.2^{a}$ | $35.40^{a}$ | $21.63^{a}$ | $643^{ab}$ | $6.6^{a}$ | $30.97^{a}$ |
| $T_4$ | $18.50^{c}$ | $516^{c}$ | $4.5^{d}$ | $22.18^{d}$ | $14.32^{d}$ | $483^{c}$ | $4.6^{d}$ | $16.79^{c}$ |
| $T_5$ | $23.01^{b}$ | $584^{bc}$ | $6.1^{bc}$ | $31.63^{bc}$ | $18.89^{bc}$ | $546^{bc}$ | $5.4^{c}$ | $25.99^{b}$ |
| $T_6$ | $23.87^{ab}$ | $845^{a}$ | $6.8^{ab}$ | $33.52^{ab}$ | $19.98^{ab}$ | $765^{a}$ | $6.1^{ab}$ | $29.26^{ab}$ |
| $T_7$ | $9.28^{d}$ | $422^{c}$ | $3.6^{e}$ | $14.91^{f}$ | $7.36^{e}$ | $328^{d}$ | $3.2^{e}$ | $9.46^{d}$ |
| Fertilizer Management Practices | | | | | | | | |
| $F_1$ | $10.99^{d}$ | $406^{cd}$ | $6.9^{c}$ | $23.16^{c}$ | $9.01^{d}$ | $349^{d}$ | $6.1^{c}$ | $21.74^{c}$ |
| $F_2$ | $13.56^{c}$ | $544^{cd}$ | 7.8 | $29.67^{c}$ | $12.37^{c}$ | $514^{bc}$ | $7.0^{bc}$ | $24.15^{c}$ |
| $F_3$ | $19.64^{b}$ | $621^{bc}$ | $8.5^{b}$ | $32.97^{bc}$ | $15.64^{bc}$ | $548^{bc}$ | $7.5^{bc}$ | $27.75^{bc}$ |
| $F_4$ | $17.78^{b}$ | $577^{c}$ | $8.4^{bc}$ | $31.70^{c}$ | $15.13^{c}$ | $564^{c}$ | $7.3^{bc}$ | $29.55^{c}$ |
| $F_5$ | $23.65^{a}$ | $896^{a}$ | $9.6^{a}$ | $36.14^{a}$ | $19.08^{a}$ | $783^{a}$ | $8.3^{a}$ | $34.19^{a}$ |
| $F_6$ | $16.63^{c}$ | $568^{cd}$ | $8.1^{c}$ | $30.80^{c}$ | $14.89^{c}$ | $529^{c}$ | $7.2^{b}$ | $28.45^{b}$ |

Different small letters within the same column show the significant difference at $P = 0.05$ according to Duncan Multiple Range Test for separation of mean.

### Water Soluble Carbon (WSC)

The distribution of soil mass among the size classes of WSC was strongly influenced by tillage crop residue practices in both the soil depths (0–15 cm and 15-30 cm). WSC was found to be 5.48% higher in surface soil than in sub-surface soil (Table 4). In both the depths, $T_6$ treatment had the highest WSC as compared to the other treatments studied. Compared to CT, FIRB and ZT coupled with 6$tha^{-1}$ CR increased 35.6% WSC in surface soil and 33.1% in sub surface soil. Among all the treatments, $T_6$ had significantly higher (19.73%) proportion of WSC than the other treatments compared. Irrespective of tillage practices, residue retention resulted in 22.56% and 25.61% higher WSC as compared to the non-residue treatments in surface and sub-surface soil, respectively. The WSC content in surface soil (0–15 cm) was significantly higher in 100% RDN as CF+ VC@ 5$tha^{-1}$($F_5$)treatment (32.5 mg $kg^{-1}$) followed by 75% RDN as CF+ VC@ 5$tha^{-1}$ ($F_4$) (29.8 mg$kg^{-1}$) and least in unfertilized control plot [($F_1$) (21.9 mg$kg^{-1}$) (Table 4)]. However, similar significant effect was observed in sub-surface soil (15-30 cm) and the magnitude was relatively lower. The increase in WSC in 0–15 cm soil depth was 37.2 and 28.4% in 100% RDN as CF+ VC@ 5$tha^{-1}$ ($F_5$) and 75% RDN as CF+ VC@ 5$tha^{-1}$($F_4$) treated plots over control. WSC, an active pool of organic C, serves as both source and sink for mineral nutrients and organic substrates in ashort-term, and as a catalyst for conversion of plant nutrients from stable organic form over a longer period there by influencing crop productivity and nutrient cycling.

### Soil microbial biomass carbon

The level of MBC was indistinguishable between the CT and ZT without residue retention regimes and was markedly lower under these regimes than under ZT and FIRB with residue retention (Table 4).Changes in MBC can indicate the effects of management practices on soil biological and biochemical properties. The higher MBC was observed in the ZT and FIRB with residue retention plots than the CT plot under the RWCS suggests that abandonment of the cropland had substantial beneficial effects on the activity of microbial organisms probably caused by the accumulation of organic C compounds att he soil surface. A possible reason for this difference is that in the absence of growing plants other labile Cfractionsmay provide food for microbes, and thus maintain MBC. Another possible reason could be related to the soil moisture status. Under the CT treatment, in which biomass production would inevitably deplete much more soil moisture, the microbes in the plot would be stressed at the time of sampling (wheat maturity).

The microbial biomass carbon (MBC) is an important component of the SOM that regulates the transformation and storage of nutrients. The soil MBC regulates all SOM transformations and is considered to be the chief component of the active SOM pool. It is evident that the MBC contents in both surface and sub-surface soil were significantly higher in plots receiving 100% RDN as CF+ VC@ 5$tha^{-1}$($F_5$) and 75% RDN as CF+ VC@ 5$tha^{-1}$($F_4$) treated plots compared to 100% RDN as CF ($F_2$) fertilizer and unfertilized control plots (Table

4). The values of MBC in surface soil varied from 116.8 mgkg$^{-1}$ in unfertilized control plot to 424.1 mgkg$^{-1}$ in integrated nutrient use of 100% RDN as CF+ VC@ 5tha$^{-1}$ plots, respectively; while it varied from 106.6 mgkg$^{-1}$ (control) to 324.9 mgkg$^{-1}$ (100% RDN as CF+ VC@ 5tha$^{-1}$F$_5$) in sub-surface (15-30 cm) soil layer. The values of MBC increased by 72.5 and 58.4% under 100% RDN as CF+ VC@ 5tha$^{-1}$ (F$_5$) and 75% RDN as CF+ VC@ 5tha$^{-1}$(F$_4$) treatment in surface soil over control. While, there were 34.4% increase of MBC over 100% RDF as CF (F$_2$) fertilizer, respectively. The highest value of MBC due to integrated use of FYM and RDN fertilizer might be due to higher turn-over of root biomass produced fewer than100% RDN as CF+ VC@ 5tha$^{-1}$ treatment. Application of 100% RDN as CF fertilizer is not only required for better growth of the crop but also required for synthesis of cellular components of microorganisms. Therefore, higher root biomass under 100% RDN as CF+ VC@ 5tha$^{-1}$ fertilizer treatment helped in increasing MBC over other treatments. Although MBC content in soil represent a small fraction i.e. about 2-4% of TOC, however, variation in this pool due to management and cropping systems indicate about the quality of soil, because the turn-over of SOM is controlled by this pool of SOC which can provide an effective early warning of the improvement or deterioration of soil quality as a result of different management practices. In our study, MBC was highest in the 100% RDN as CF+ VC@ 5tha$^{-1}$ treatment. The increase of MBC under vermi-compost (VC) amended soils could be attributed to several factors, such as higher moisture content, greater soil aggregation and higher SOC content. The VC amended plots provided a steady source of organic C to support the microbial community compared to inorganic fertilizer treated plots. Generally, VC applied to soil has long been employed to enhance favourable soil conditions. This view is consistent with the observation of Hao *et al.* (2008) who observed that the microbial biomass was considerably greater in soils receiving FYM along with NPK fertilizer than in plots receiving merely NPK fertilizer in three subtropical paddy soils. Mandal *et al.* (2007) [7] also reported that the microbial biomass was greater in soils due to addition of straw plus inorganic NPK for 34 years than that of inorganic NPK fertilizers. Similarly, Kaur *et al.* (2005) also observed that in general, MBC tends to be smaller in unfertilized soils or those fertilized with chemical fertilizers compared to soil amended with organic manures. The readily metabolizable carbon and N in FYM in addition to increasing root biomass and root exudates due to greater crop growth are the most influential factors contributing to the increase in soil MBC. MBC is an active component of SOM and constitutes an important soil health parameter as carbon contained within microbial biomass is a stored energy for microbial process. Thus MBC measure of potential microbial activity, are strongly related to soil aggregate stability.

### Light fraction of carbon (LFC)

LFC is considered as a useful approach for the characterization of SOC resulting from different soil management practices including cropping systems and application of organic and inorganic sources of nutrients. The values of LFC in surface soil (0-15 cm) were 81.3, 95.7, 107.8, 128.8, 155.2, 177.8 and 52.7 mgkg$^{-1}$ in ZT and FIRB without residue retention, ZT and FIRB with 4 & 6 tha$^{-1}$residue retention and C Ttreatments, respectively (Table 4). In 15-30 cm layer, the increasing trends in LFC content due to use of tillage practices and residue retention were similar to those observed in 0-15cm layer; however, the magnitude was relatively lower (Table 4).The LFC content of the soil increased with theapplication of fertilizers and/or VC (Table 4). In the surface layer, the organic treatment accumulated 51.5% greater LFC (183.9 mg kg$^{-1}$) followed by 44.4% greater in integrated (160.5 mgkg$^{-1}$) and 27.7% greater in RDN (123.5 mg kg$^{-1}$) as compared to the control treatment. In general, the management practices which accumulate greater amounts of SOC, such as organic residue additions (Janzen *et al.* 1992) and nutrient applications (Nyborg *et al.* 1999), are considered to increase the proportion of LFC in soil. Other studies suggest that the microbial population and enzyme activity (Kanazawa and Filip 1986) and soil respiration rate (Janzen *et al.* 1992) are associated with the LFC. Therefore, the LFC can be considered as an important indicator of soil organic matter turnover.

**Table 4:** Concentrations of different soil organic matter carbon fractions $_f$POM and $_c$POM at different soil depths as affected by tillage and nutrient management to the continuous RW cropping system.

| **Treatments** | **0-15 cm layer** | | | | | **15-30 cm layer** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **WSC (mgkg$^{-1}$)** | **MBC (mgkg$^{-1}$)** | **LFC (mgkg$^{-1}$)** | **$_f$POM (g Ckg$^{-1}$)** | **$_c$POM (g Ckg$^{-1}$)** | **WSC (mgkg$^{-1}$)** | **MBC (mgkg$^{-1}$)** | **LFC (mgkg$^{-1}$)** | **$_f$POM (g Ckg$^{-1}$)** | **$_c$POM (g Ckg$^{-1}$)** |
| **Tillage crop residue practices** | | | | | | | | | | |
| T$_1$ | $16.9^{d}$ | $311.4^{c}$ | $81.3^{d}$ | $0.44^{d}$ | $0.92^{cd}$ | $15.7^{d}$ | $193.9^{cd}$ | $65.1^{d}$ | $0.32^{cd}$ | $0.58^{bc}$ |
| T$_2$ | $18.9^{c}$ | $345.2^{bc}$ | $107.8^{bc}$ | $0.62^{bcd}$ | $1.82^{bc}$ | $17.8^{cd}$ | $219.8^{c}$ | $94.1^{bc}$ | $0.55^{de}$ | $1.31^{bcd}$ |
| T$_3$ | $20.8^{ab}$ | $481.7^{a}$ | $155.2^{a}$ | $0.88^{ab}$ | $2.54^{a}$ | $19.6^{bc}$ | $294.8^{ab}$ | $132.6^{a}$ | $0.83^{c}$ | $1.93^{a}$ |
| T$_4$ | $18.7^{d}$ | $306.5^{c}$ | $95.7^{c}$ | $0.53^{cd}$ | $1.03^{d}$ | $17.6^{cd}$ | $187.5^{cd}$ | $87.6^{c}$ | $0.35^{bc}$ | $0.94^{ab}$ |
| T$_5$ | $21.4^{bc}$ | $398.6^{b}$ | $128.8^{b}$ | $0.86^{bc}$ | $2.21^{ab}$ | $20.3^{ab}$ | $240.9^{bc}$ | $102.9^{b}$ | 0.72a | $1.64^{a}$ |
| T$_6$ | $23.2^{a}$ | $535.8^{a}$ | $177.8^{a}$ | $1.30^{a}$ | $2.38^{ab}$ | $21.6^{a}$ | $361.8^{a}$ | $141.2^{a}$ | $1.19^{e}$ | $1.89^{cd}$ |
| T$_7$ | $14.2^{e}$ | $266.7^{c}$ | $52.7^{e}$ | $0.38^{d}$ | $0.94^{d}$ | $13.8^{e}$ | $145.9^{d}$ | $49.8^{e}$ | $0.26^{f}$ | $0.61^{d}$ |
| Fertilizer Management Practices | | | | | | | | | | |
| F$_1$ | $21.9^{e}$ | $116.8^{c}$ | $89.2^{c}$ | $0.41^{d}$ | $0.\ 64^{d}$ | $15.1^{e}$ | $106.6^{d}$ | $47.9^{f}$ | 0.28 | $0.48^{d}$ |
| F$_2$ | $28.4^{d}$ | $189.2^{c}$ | $123.5^{bc}$ | $0.60^{cd}$ | $0.93^{d}$ | $18.8^{d}$ | $166.8^{cd}$ | $66.7^{e}$ | 0.45 | 0.59 |
| F$_3$ | $29.2^{cd}$ | $239.9^{bc}$ | $146.4^{c}$ | $0.71^{cd}$ | $1.52^{cd}$ | $20.2^{cd}$ | $196.8^{bc}$ | $85.9^{d}$ | 0.52 | $0.74^{cd}$ |
| F$_4$ | $29.8^{c}$ | 280.7b | $160.5^{b}$ | $1.33^{ab}$ | $2.81^{ab}$ | $21.9^{bc}$ | $219.9^{bc}$ | $103.2^{bc}$ | 0.72 | $1.64^{ab}$ |
| F$_5$ | $32.5^{a}$ | $424.1^{a}$ | $183.9^{a}$ | $1.89^{a}$ | $3.78^{a}$ | $26.4^{a}$ | $324.9^{a}$ | $152.9^{a}$ | 0.92 | $2.34^{a}$ |
| F$_6$ | 28.9 | 210.3 | $133.2^{c}$ | 0.66 | 1.19 | 19.8 | 178.2 | 76.4 | 0.51 | 0.63 |

****** Different letters within columns are significantly different at P=0.05 according to Duncan Multiple Range Test (DMRT) for separation of means. WSC = water soluble carbon, MBC = microbial biomass carbon, LFC = labile fraction carbon, $_c$POM= coarse particulate organic carbon,$_f$ POM= fine particulate organic carbon

### Particulate organic matter fractions

The largest differences among tillage systems were found at the soil surface (Table 4). In the upper 15 cm depth, the $_f$POM content was between 1.9 and 2.8 times higher under ZT and FIRB with residue retained than under CT. The lower $_c$POM content under ZT with residue removal than under CT in the two soil layers (2–2.6 times less) can be explained by the farmer's practice of removing crop residues from the ZT field (Table 4). These values represent between 50.7 and 64.8% more $_f$POM with residue retained ZT and FIRB, averaging about 76.5% more. For $_c$POM, this range varied from 56.9% and 59.1% more, with an average value of 58% more. For both $_c$POM and $_f$POM fractions, the decreasing pattern in OC concentration with depth was more prominent under CT, especially ZT, and FIRB in such a way that the average concentrations in the 0–30 cm profile were narrow significantly different from those under CT. The marked stratification of $_C$POM- is generally observed under continuous ZT management (Salvo *et al*., 2010) and is produced by the maintenance of crop residues at the soil surface and the absence of soil disturbance. The $_C$POM-, disproportionately to its small contribution to total SOC, has a large effect on nutrient-supplying capacity and structural stability of soils, and for these reasons it is considered a key attribute of soil quality (Haynes, 2005) [22]. Of the two POM fractions isolated in the present study, $_f$POM was, in general, more sensitive to soil tillage and land use than $_c$POM. On the other hand, $_c$POM is more dependent on plant derived C inputs and, therefore, more variable in time and space (also in depth) than $_f$POM (Lee *et al*., 2009; Duval *et al*., 2013). For those reasons, $_f$POM can be considered more reliable and useful indicator of soil changes associated with tillage and crop residue management.

In the present study, both the $_c$POM and $_f$POM increased with the application of fertilizers/or VC (Table 4). At 0–15 cm depth, $_c$POM increased more than 100% in both treatments receiving VC (integrated, organic) as compared to an increase of 45% in NPK over the control treatment. A similar trend was observed for $_f$POM, where the organic treatment accumulated 78% greater $_f$POM (1.89 g kg$^{-1}$) than the control. This was followed by an increase of69% in integrated (1.33 gkg$^{-1}$) and 32% in NPK (0.60 gkg$^{-1}$) over the control. The application of fertilizers and manures increased the POM due to the production of greater production of the plant biomass and excretion of root exudates (Malhi and Gill 2002) [11]. A similar trend was observed in the sub-surface layer, however, the contents of both $_c$POM and $_f$POM fractions were comparatively lower. The sum of$_f$ POM and $_c$POM as a proportion of SOC ranged from 61 to 69% in the surface layer and 55 to 60% in the sub-surface layer. Other researchers (Franzluebbers and Arshad 1997) [12] also observed a decrease of POM with an increase in soil depth. Other studies have also shown great divergence of C content of POM with a change in management regimes (Gambardella and Elliott 1992; Franzluebbers and Arshad 1997) [12]. Our results are supported by numerous reports (Yang *et al*., 2012; Ibrahim *et al*., 2015) [5, 24], indicating that higher C input induced by fertility management practices resulted in significantly larger physically uncompleted organic carbon ($_f$POM,$_c$ POMand LFC) pools (Table 4).Gosling *et al*. (2013) [18] also indicated that $_f$POM, $_c$POM and LFC were strongly influenced by factors related to the recent history of organic matter addition. In our study the proportion of organic C in $_f$POM, $_c$POM was greater than that in LFC, which is consistent with previous reports (Gregorich *et al*., 2006; Yan *et al*., 2007) [19, 90].

### ($KMnO_4$-oxidizable carbon (KOC) and non- $KMnO_4$ oxidizable carbon (NKOC)

The plots receiving organic manure had significantly higher KOCand NKOCcompared to mineral-fertilized plots and CK (Table 5). Moreover, KOC and NKOCaccounted for the highest proportion of SOC compared with other labile organic C fractions. The proportion of KOC and NKOC varied from 16.42 to 29.08% with the mean value of 22.75% of total SOC. The impacts of different fertilizer treatments on the proportion of KOC and NKOCwere similar to POC, with highest proportions in100% RDN as CF+ VC@ 5tha$^{-1}$ ($F_5$) and lowest in control ($F_1$) plots. C extractable with KOC and NKOCconsists of amino acids, simple carbohydrates, a portion of soil microbial biomass and other simple organic compounds and is the fraction of SOC with a rapid turnover time (Zou *et al*., 2005) [95]. Since KOC and NKOCcan respond rapidly to changes in C supply, it is considered an important indicator of soil quality (Xu *et al*., 2011) [89]. Our study indicated that KOC and NKOCwas higher in total and as a proportion of the total C in manure-treated soils compared to mineral fertilized soils and unfertilized soils.

### Carbon pool index (CPI) and carbon management index (CMI)

There were significant differences among all fertility treatments for CPI and CMI (Table 5). Changes in CPI under different fertilizer treatments decreased in the order $F_5$>$F_6$> $F_4$>$F_3$> $F_2$, with values ranging from 1.17 to 3.35. With reference to CMI, it showed a similar trend to CPI as influenced by different fertilizer treatments. The highest values of CMI were associated with the treatments where the entire amount of nitrogen was applied through organic manure, followed by $F_4$ treatment. There was also a significant improvement in CMI fewer than75% RDN as CF+ VC@ 5tha$^{-1}$($F_4$) treatment compared with $F_2$ treatment. The index incorporates a measure of the impact on total soil C (CPI) and the lability of that C (LI) thus reflecting both C sequestration and nutrient cycling potential. Since the index is the product of these two measures, only treatments that score highly on both will have a high CMI. In our research, the effects of fertilization regimes on CMI were significant increasing in treatments receiving organic manure compared to those treatments receiving mineral fertilizers. This is confirmed by numerous studies on long-term fertilization systems (Xu *et al*., 2011; Ghosh *et al*., 2016) [89, 89]. Tirol-Padre and Ladha, (2004) [83] explained that variations of CMI in different fertilizer treatments are attributed to the increase in annual C addition and the changes in organic matter quality, thus affecting the susceptibility of C to $KMnO_4$ oxidation.

**Table 5:** Effect of 7 years of application of treatment son different carbon pool

| Treatments | 0-5 cm layer | | | | | 5-15 cm layer | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **KOC (g kg$^{-1}$)** | **NKOC (g kg$^{-1}$)** | **LI** | **CPI** | **CMI** | **KOC (g kg$^{-1}$)** | **NKOC (g kg$^{-1}$)** | **LI** | **CPI** | **CMI** |
| **Tillage crop residue practices** | | | | | | | | | | |
| **$T_1$** | $0.79^{c}$ | $1.52^{c}$ | $1.46^{d}$ | $1.38^{d}$ | $55.9^{d}$ | $0.68^{cd}$ | $1.4^{cd}$ | $1.19^{c}$ | $0.95^{d}$ | $46.7^{c}$ |
| **$T_2$** | $1.05^{bc}$ | $3.07^{b}$ | $1.52^{bc}$ | $2.77^{c}$ | $81.4^{cd}$ | $0.79^{b}$ | $2.2^{ab}$ | $1.46^{b}$ | $1.96^{c}$ | $74.2^{b}$ |
| **$T_3$** | $1.45^{a}$ | $3.48^{a}$ | $1.91^{a}$ | $3.56^{b}$ | $106.9^{a}$ | $0.96^{a}$ | $2.6^{a}$ | $1.69^{ab}$ | $2.73^{ab}$ | $99.6^{a}$ |
| **$T_4$** | $0.77^{c}$ | $2.25^{c}$ | $1.49^{cd}$ | $1.43^{cd}$ | $64.1^{d}$ | $0.62^{d}$ | $1.9^{d}$ | $1.13^{c}$ | $0.89^{d}$ | $49.9^{c}$ |
| **$T_5$** | $0.98^{b}$ | $2.79^{bc}$ | $1.54^{bc}$ | $2.88^{ab}$ | $99.3^{b}$ | $0.76^{bc}$ | $1.9^{bc}$ | $1.31^{bc}$ | $2.09^{bc}$ | $84.2^{b}$ |
| **$T_6$** | $1.15^{ab}$ | $3.76^{a}$ | $1.96^{a}$ | $3.63^{a}$ | $113.5^{a}$ | $0.88^{a}$ | $2.9^{a}$ | $1.81^{a}$ | $2.98^{a}$ | $103.9^{a}$ |
| **$T_7$** | $0.51^{c}$ | $0.63^{d}$ | $0.99^{e}$ | $0.91^{e}$ | $40.7^{e}$ | $0.42^{e}$ | $0.59^{e}$ | $0.82^{d}$ | $0.58^{e}$ | $33.1^{d}$ |
| **Fertilizer Management Practices** | | | | | | | | | | |
| **$F_1$** | $1.08^{c}$ | $1.62^{d}$ | $1.00^{d}$ | 1.00 | 100 | $0.34^{e}$ | $1.3^{d}$ | $1.00^{d}$ | 1.00 | 100 |
| **$F_2$** | $1.15^{c}$ | $2.49^{c}$ | $1.22^{c}$ | $1.77^{c}$ | $53.9^{c}$ | $0.78^{cd}$ | $1.8^{d}$ | $1.07^{cd}$ | $0.96^{d}$ | $47.1^{d}$ |
| **$F_3$** | $1.28^{c}$ | $3.06^{bc}$ | $1.37^{c}$ | $2.08^{c}$ | $62.1^{c}$ | $0.86^{bc}$ | $2.4^{cd}$ | $1.16^{c}$ | $1.84^{cd}$ | $56.9^{cd}$ |
| **$F_4$** | $1.48^{bc}$ | $3.09^{b}$ | $1.48^{bc}$ | $2.41^{bc}$ | $98.7^{bc}$ | $0.53^{de}$ | $2.9^{bc}$ | $1.36^{b}$ | $2.05^{bc}$ | $83.3^{bc}$ |
| **$F_5$** | $1.89^{a}$ | $4.37^{a}$ | $1.92^{a}$ | $3.35^{a}$ | $114.8^{a}$ | $1.33^{a}$ | $3.7^{a}$ | $1.85^{a}$ | $2.89^{a}$ | $106.2^{a}$ |
| **$F_6$** | $1.22^{c}$ | $2.78^{c}$ | $1.29^{c}$ | $2.97^{a}$ | $86.2^{bc}$ | $0.81^{bc}$ | $1.9^{d}$ | $1.12^{c}$ | $2.42^{ab}$ | $78.6^{bc}$ |

****** Different letters within columns are significantly different at P=0.05 according to Duncan Multiple Range Test (DMRT) for separation of means

KOC =$KMnO_4$-oxidizable carbon; NKOC= non-$KMnO_4$oxidizable carbon; LI=Lability index;

CPI = Carbon pool index; CMI=Carbon management index

## Soil enzymes activities

### Nitrifying and denitrifying bacteria

In the turning jointing stage, compared with CT, the ZT and FIRB treatments significantly increased nitrifying bacteria **[**Gn] by 77% and 229%, respectively. At the booting stage, the Gn rates in ZT and FIRB soils were 2.16 and 3.37 times greater than that in CT soil, respectively. At the milking stage, the Gn rates in ZT and FIRB soils were 1.96 and 3.08 times greater than that in CT soil, respectively. Similarly, Table 6 shows the denitrifying bacteria [D] rates of the different treatments. In the jointing stage, the D rates in ZT and FIRB soils were 2.77 and 2.26 times greater than that in CT soil. At the booting stage, compared with CT, the ZT and FIRB treatments significantly increased D by 3.03% and 2.37%, respectively. At the milking stage, the ZT and FIRB treatments increased D by 3.39% and 2.95%, respectively.

The Gn rates of the different treatments were $T_6 > T_3 > T_4 > T_7$. The D rates were $T_3 > T_6 > T_2 \geq T_4$. Two processes of N cycle exhibited similar characteristics. This similarity may be attributed to the close association among the different transformation processes involved in the N cycle (Nannipieri and Paul 2009) [53]. The NTS and NT treatments had higher Gn and D rates, whereas CT treatment had lower Gn and D rates. This discrepancy may be due to the varying N content in the different treated soils. In contrast to CT, ZT, FIRB and straw incorporation treatments had greater N transformation and mineralization rates (Robarge 2010).

### *Phosphataseenzyme activity*

The activity of phosphatase enzyme in soil was significantly influenced by the application of different levels of manures in conjunction with inorganic fertilizers in rice-wheat cropping system. In wheat crop enzyme activity increased up-to booting stage and later showed decreasing trend. The sharp increase in the enzyme activities at booting which coincides with the active growth stage of the crop, enhanced root activity and the release of extracellular enzymes like urease into soil solutions during the active growth phase which resulted in higher rate of mineralization of nutrients in the soil. Significantly highest phosphatase activity of 33.90, 46.08, 24.65µg of PNP $g^{-1}$ soil $h^{-1}$ was found at jointing, booting and milking stage of wheat in treatment $F_5$ (100%RDF +VC @ 5 t $ha^{-1}$). However, the values were on par with $F_3$ (50%RDF +VC @ 5 t $ha^{-1}$) and $F_4$ (75%RDF +VC @ 5 t $ha^{-1}$) and significantly different from all other treatments (Table 6).

The increase in phosphates activity with integrated application of organic manures and inorganic fertilizers may be attributed to the increasing population of microorganisms like bacteria etc., due to increased availability of substrate through organic manures.However, results indicated that FIRB system with residue retention showed statistically significant differences in the phosphatase enzyme activity in the soil comparing with ZT with residue removal and CT. The activity of phosphatase tended to be higher in the FIRB treatment compared to the ZT and CT treatments.This result is in agreement with the findings of Spiers and McGill (1979) that greater phosphatase activity in NPK +OM (organic manure); NPK and OM plots were due to mainly higher organic matter contents and microbial population. Similarly Jin *et al*. (2009) [26] and Naresh *et al*. (2017) [56] reported the positive effects of CA practices on soil enzyme activities. The generally higher enzyme activities in FIRB mainly resulted from the larger water availability in the plots rather than the better soil fertilities.

Singh and Ghosal (2013) concluded that application of FYM and wheat straw along with inorganic fertilizer significantly increased the activity of alkaline phosphatase in 0-10 cm soil layer as compared with the application of inorganic fertilizer alone in a double no-till rice-wheat system. Mathew *et al*., (2012) [50] reported that acid and alkaline phosphatase activity was higher under NT than CT soil at 0-5 cm soil depth in a longterm tillage experiment in continuous corn system in a silt loam soil.

**Table 6:** Change in nitrifying and denitrifying bacteria and phosphataseenzyme activity in soil profile as affected by tillage crop residue practices and nutrient management practices

| Treatments | Nitrifying bacteria (×10$^{3}$/g) | | | Denitrifying bacteria (×10$^{4}$/g) | | | Phosphatase(µg PNP g$^{-1}$ h$^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Jointing stage | Booting stage | Milky stage | Jointing stage | Booting stage | Milky stage | Jointing stage | Booting Stage | Milky stage |
| **Tillage crop residue practices** | | | | | | | | | |
| T$_1$ | 2.0 ± 0.4$^{c}$ | 4.2 ± 6.5$^{a}$ | 35.4 ± 4.1$^{c}$ | 35.6 ± 10.3$^{cd}$ | 42.0 ± 8.5 $^{c}$ | 59.7 ± 5.3$^{bc}$ | 20.5± 4.1$^{c}$ | 34.8± 4.3$^{cd}$ | 16.1± 4.1$^{c}$ |
| T$_2$ | 5.9 ± 1.0$^{b}$ | 7.2 ± 0.6$^{c}$ | 48.6 ± 9.2$^{bc}$ | 41.2 ± 8.8$^{bc}$ | 63.8 ± 10.7$^{bc}$ | 95.1 ± 20.6$^{b}$ | 24.9± 5.7$^{cd}$ | 46.3± 9.3$^{a}$ | 17.3± 8.5 $^{c}$ |
| T$_3$ | 6.5 ± 0.7$^{b}$ | 13.9 ± 1.3$^{b}$ | 64.3 ± 6.2$^{b}$ | 69.3 ± 6.6$^{a}$ | 110.8 ±10.7$^{b}$ | 137.1± 9.9$^{a}$ | 25.8± 6.6$^{a}$ | 49.1±10.7$^{b}$ | 17.9± 8.8$^{bc}$ |
| T$_4$ | 3.9 ± 1.4$^{bc}$ | 11.6 ± 0.8$^{bc}$ | 48.2 ± 8.2$^{bc}$ | 23.8 ± 0.9$^{d}$ | 32.8 ± 2.4$^{d}$ | 57.3 ± 20.1$^{a}$ | 24.5± 5.7$^{cd}$ | 38.3± 8.4$^{a}$ | 21.3± 7.1$^{a}$ |
| T$_5$ | 9.9 ± 0.7$^{a}$ | 19.6 ± 1.0$^{b}$ | 107.8 ± 4.1$^{a}$ | 34.5 ± 5.7$^{cd}$ | 54.3 ± 4.3$^{cd}$ | 82.2± 11.6$^{a}$ | 29.8± 8.8$^{bc}$ | 50.8± 9.9$^{a}$ | 27.1± 6.6$^{a}$ |
| T$_6$ | 10.1 ± 1.7$^{a}$ | 19.9 ± 0.8$^{b}$ | 119.3 ± 8.4$^{a}$ | 60.9 ± 3.9$^{ab}$ | 82.5 ± 11.8$^{b}$ | 114.5 ± 9.3$^{a}$ | 31.2± 9.2$^{bc}$ | 52.3± 11.8$^{b}$ | 29.1± 10.3$^{cd}$ |
| T$_7$ | 1.80± 0.6$^{c}$ | 3.9 ± 0.7$^{c}$ | 29.8± 3.4$^{c}$ | 17.6 ± 2.4$^{c}$ | 23.8 ± 3.9$^{c}$ | 28.7 ± 4.1$^{c}$ | 17.9± 3.9$^{ab}$ | 26.2± 3.4$^{c}$ | 15.7± 2.4$^{c}$ |
| Fertilizer Management Practices | | | | | | | | | |
| F$_1$ | 3.06± 0.21 | 12.05 ±1.78 | 17.74 ±3.24 | 19.6 ± 2.6$^{c}$ | 21.8 ± 3.3$^{c}$ | 26.7 ± 4.1$^{c}$ | 20.65± 2.7$^{a}$ | 35.66±3.24$^{c}$ | 16.53±2.90$^{b}$ |
| F$_2$ | 5.91 ± 0.13 | 14.08 ±1.84 | 22.02 ±2.70 | 44.2 ± 5.3 | 53.8 ± 7.7$^{bc}$ | 65.1 ± 9.6$^{b}$ | 24.30± 4.0$^{b}$ | 39.87± 6.2$^{b}$ | 19.85± 5.1$^{a}$ |
| F$_3$ | 7.36 ± 0.22 | 15.36 ±1.29 | 24.48±3.84 | 56.3 ± 6.6$^{a}$ | 78.8 ±8.7$^{b}$ | 97.1± 9.9$^{a}$ | 32.75± 5.4$^{bc}$ | 44.97± 7.8$^{bc}$ | 22.54± 6.3$^{bc}$ |
| F$_4$ | 4.55 ± 0.14 | 18.57±1.79 | 20.10 ±1.17 | 53.8 ± 5.9$^{d}$ | 62.8 ± 7.4$^{d}$ | 87.3 ± 8.1$^{a}$ | 27.92± 4.7$^{a}$ | 41.95± 6.6$^{a}$ | 21.48± 5.9$^{a}$ |
| F$_5$ | 6.77 ± 0.15 | 16.54 ±2.18 | 23.39 ±1.01 | 74.5 ± 7.7$^{cd}$ | 84.3 ± 8.3$^{cd}$ | 92.2± 11.6$^{a}$ | 33.90± 5.6$^{c}$ | 46.08± 9.9$^{a}$ | 24.65± 7.6$^{a}$ |
| F$_6$ | 8.92 ± 0.38 | 20.13 ±1.80 | 26.23 ±4.59 | 80.9 ± 8.9$^{ab}$ | 92.5 ± 9.8$^{b}$ | 98.5 ± 10.3$^{a}$ | 34.60±6.29$^{a}$ | 47.26±10.7$^{b}$ | 26.16± 8.3$^{a}$ |

****** Different letters within columns are significantly different at P=0.05 according to Duncan Multiple Range Test (DMRT) for separation of means.

### β-glucosidase enzyme activity

β-Glucosidase is a common and predominant enzyme in soils. This enzyme plays an important role in soils because it is involved in catalyzing the hydrolysis and biodegradation of various β-glucosidase present in plant debris decomposing in the ecosystem (Martinez and Tabatabai 1997) [3]. B-glucosidase is characteristically useful as a soil quality indicator, and may give a reflection of past biological activity, the capacity of soil to stabilize the soil organic matter, and can be used to detect management effect on soils (Ndiaye *et al.* 2000) [52]. In RWCS, application of all combinations of organic nutrient sources significantly improved the enzyme activity compared with the control (Table 7). Plots receiving VC alone or in combination with CR showed the highest stimulation of β-glucosidase activity in the RWCS. The magnitude of increase in β-glucosidase activity at jointing, booting and milky stage over the control ranged from 34.1, 51.1 and 86.2%, respectively.

β-glucosidase enzyme is sensitive to any change in the management practices in soil and directly related to the amount of organic matter and considered as a promising soil quality indicator for assessing the changes induced by tillage practices (Ekenler and Tabatabai, 2003) [8]. De la Horra *et al.*, (2003) [11] observed that NT exhibited significantly higher activity of β-glucosidase enzyme at the surface (0-5 cm) soil layer as compared with CT. Roldan *et al.*, (2003) [64] concluded that NT with moderate amount of crop residue (33%) and legume cover has significantly improved soil enzyme activities (DHA, urease, protease, β-glucosidase and acid phosphatase).

### Urease enzyme activity

Urease enzyme activity was significant in each of fertilization treatments and tillage systems. Urease activity showed a significant decrease with mineral fertilizer treatment F$_2$ compared with mixture of fertilizers F$_3$, F$_4$ and F$_5$. Vermicompost showed a significant increase in urease activity compared with all fertilization treatments. Applications of nitrogen fertilizers significantly decrease urease activity while addition of organic manure increased its activity.In general, greater urease activity was observed at fertilizers treated plotsthan the control plot. This observation result was in agreement with the finding of Garcia-Gil *et al.* (2000) [70] that mineral fertilization plot had the greatest urease activity than unfertilized plot. The application of fertilizer as well as retention of residue in ZT and FIRB system plant could affect the soil urease activity and its activity was higher in 6 tha$^{1}$residue retention treated plot during the entire investigation.Tillage systems also showed significant effect on urease activity. A significant increase in the activity of urease was realized with ZT and FIRB treatments, and with residue retention of4and 6 tha$^{-1}$. Mohammadi (2011) [51] concluded that the effect of organic amendments on enzyme activities is probably a combined effect of a higher degree of stabilization of enzymes to humic substances and an increase in microbial biomass with increased soil carbon concentration.

Raiesi and Kabiri (2016) [62] reported higher urease activity in a barley crop under reduced tillage practices comprising of chisel and disk plough as compared with CT practices comprising of rotary and mouldboard plough in a 6 year study in semi-arid calcareous soil in central Iran. Zhang *et al.*, (2016) [91] observed that activity of the enzymes (urease and sucrase) increased with the amount of straw applied. Incorporation of maize straw was more effective to increase enzyme activities as compared with wheat straw incorporation because of narrow C: N ratio of maize straw than wheat straw which facilitates faster decomposition of maize straw.

### Dehydrogenase*enzyme activity*

This enzyme has been considered as a sensitive indicator of soil quality and it has been proposed as a valid biomarker to indicate changes in total microbial activity due to changes in soil management, under different agronomic practices. Soil management influences soil microorganisms and soil microbial processes through changes in the quantity and quality of plant residues in the soil profile (Kandelern *et al.*, 1999).

The result that showed only soils receiving VC (51.2%) and NPK + VC (27.2%) were found to have significantly higher dehydrogenase activity among the fertilizer treatments over the control plots coincided with the observation of Simek *et al.* (1999) [73], that dehydrogenase activity was lower in soil that had received the largest amount of fertilizers; this suggests that dehydrogenase activity was highly sensitive to the inhibitory effects associated with large amount of fertilizer additions. Dehydrogenase is involved in the oxidation of SOM and occurs in viable cells and not in stabilized soil complexes. Therefore, the present results are in agreement with observations where soil amended with organics also provides the greatest dehydrogenase activity. Another possible reason of higher enzyme activity in the manure treated plot as suggested by Parham *et al.* (2002) [61] is that manure promoted biological and microbial activities, which accelerated the breakdown of organic substances in the added manure.

**Table 7:** Effect of tillage crop residue practices and nutrient management practice son the soil enzymatic activities

| Treatments | β-glucosidase(μg PNP $g^{-1}h^{-1}$) | | | Urease (μg $NH_3$ $g^{-1}h^{-1}$) | | | Dehydrogenase(μg INTF $g^{-1}h^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Jointing stage** | **Booting stage** | **Milky stage** | **Jointing stage** | **Booting stage** | **Milky stage** | **Jointing stage** | **Booting stage** | **Milky stage** |
| | | | | **Tillage crop residue practices** | | | | | |
| $T_1$ | 4.58 ± 0.14 | 4.23 ± 0.66 | 0.46 ± 0.04 | 14.08 ±1.84 | 19.97 ±0.94 | 16.82± 2.42 | 4.21 ± 0.28 | 4.83 ± 0.34 | 3.55 ± 0.17 |
| $T_2$ | 4.94 ± 0.58 | 4.75 ± 0.84 | 0.60 ± 0.05 | 15.36 ±1.29 | 22.02 ±2.70 | 18.90 ± 1.33 | 5.91 ± 0.13 | 5.40 ± 0.12 | 4.83 ± 0.07 |
| $T_3$ | 5.15 ± 0.21 | 4.96± 0.56 | 2.88± 0.19 | 18.57±1.79 | 24.48±3.84 | 19.36 ± 1.01 | 7.36 ± 0.22 | 6.46 ± 0.27 | 5.06 ± 0.54 |
| $T_4$ | 4.48 ± 0.43 | 4.38 ± 0.05 | 0.23 ± 0.03 | 14.02 ±2.72 | 20.10 ±1.17 | 17.41 ±0.85 | 4.55 ± 0.14 | 4.91 ± 0.51 | 4.74 ± 0.17 |
| $T_5$ | 4.98 ± 0.59 | 4.85 ± 0.59 | 0.84 ± 0.26 | 16.54 ±2.18 | 23.39 ±1.01 | 19.19 ± 1.22 | 6.77 ± 0.15 | 6.56 ± 0.03 | 4.96 ± 0.18 |
| $T_6$ | 5.75 ± 0.41 | 5.14 ± 0.46 | 3.25 ± 0.09 | 20.13 ±1.80 | 26.23 ±4.59 | 20.79 ± 2.71 | 8.92 ± 0.38 | 7.71 ± 0.37 | 6.41 ± 0.15 |
| $T_7$ | 3.28 ± 0.15 | 2.31 ± 0.68 | 0.19±0.09 | 12.05 ±1.78 | 17.74 ±3.24 | 14.38 ± 1.54 | 3.06± 0.21 | 2.86± 0.23 | 1.97± 0.28 |
| | | | | **Fertilizer Management Practices** | | | | | |
| $F_1$ | 2.66± 0.19$^{a}$ | 3.28± 0.36$^{b}$ | 0.41± 0.04$^{c}$ | 14.4± 0.65 | 17.3± 0.84$^{a}$ | 13.1± 0.21$^{bc}$ | 4.06± 0.21 | 3.86± 0.23 | 1.97± 0.08 |
| $F_2$ | 4.25± 0.21$^{d}$ | 4.57± 0.56$^{a}$ | 0.68± 0.06$^{c}$ | 16.3± 1.05 | 23.5$^{d}$± 1.14 | 14.9± 0.59$^{a}$ | 5.21 ± 0.28 | 4.83 ± 0.34 | 3.55 ± 0.17 |
| $F_3$ | 5.35± 0.43$^{c}$ | 5.96± 0.59$^{e}$ | 0.85± 0.09$^{a}$ | 18.1± 1.19 | 27.9$^{a}$± 1.21 | 19.5± 0.78 $^{ab}$ | 5.91 ± 0.13 | 5.60 ± 0.12 | 3.83 ± 0.27 |
| $F_4$ | 5.48± 0.46$^{e}$ | 6.29± 0.68$^{d}$ | 0.93± 0.12$^{e}$ | 19.9± 1.41 | 30.3± 1.56$^{cd}$ | 24.2± 0.84$^{b}$ | 6.13± 0.15 | 6.02± 0.03 | 3.96 ± 0.28 |
| $F_5$ | 6.39± 0.58$^{b}$ | 6.94± 0.84$^{c}$ | 1.04± 0.36$^{b}$ | 20.2± 1.59 | 36.4$^{b}$±1.84$^{c}$ | 30.1± 0.89$^{b}$ | 6.92 ± 0.38 | 6.71 ± 0.37 | 4.41 ± 0.35 |
| $F_6$ | 5.67± 0.48$^{b}$ | 6.41± 0.76$^{c}$ | 0.98± 0.19$^{b}$ | 21.8± 1.68 | 39.4± 2.05 | 34.6± 1.15$^{b}$ | 7.77± 0.22 | 7.56 ± 0.27 | 4.96 ± 0.31 |

## Energy dynamics and energy use efficiencies

Keeping in view current energy crisis, studies on energy dynamics and energy use efficiency in agricultural production systems also assume great importance to identify promising production systems which have less dependency on non-renewable energy sources. In the current study, the estimation of energy use in different tillage crop residue practices revealed that $T_7$ CT utilized highest energy (28.9 GJ $ha^{-1}$) followed by $T_4$ FIRB without residue retention(26.4 GJ $ha^{-1}$), $T_5$ FIRB with 4 $tha^{-1}$ residue retained and $T_6$ FIRB with 6 $tha^{-1}$ residue retained, respectively. $T_7$ CT practices used highest energy input because rice consumes higher energy with respect to puddling, nursery rising as well as human labour for transplanting and thrashing operations in rice; besides more energy input in tillage operations in wheat. $T_4$ also consumed more energy owing to regular spraying of weedicides in rice crop being prone to weed infestation besides relatively frequent irrigation requirements in rice and wheat (Kumar *et al*., 2013; Naresh *et al*., 2015) [13, 54]. $T_1$ ZT without residue retained and $T_2$ZT with 4 $tha^{-1}$ residue retained tillage practices also produced higher energy equivalents which resulted in greater net energy returns quite close to $T_3$ZT with 6 $tha^{-1}$ residue retained practice was primarily due to higher yield of this system. The energy use efficiency was highest in $T_3$ (7.42) followed by $T_2$ (7.12), $T_1$ (7.08), $T_6$ (7.04) and least in $T_7$ (6.15). Due to lesser energy input and higher output $T_3$ had 20% and 5% higher energy use efficiency than $T_7$ and $T_6$(Figure 6& 7). Based upon the energy output and energy input use under different tillage methods in rice-wheat cropping system, $T_3$ had energy gains of 8%, 7%, 4% and 2% than $T_7$, $T_4$, $T_5$and $T_6$, respectively (Figure 6& 7).

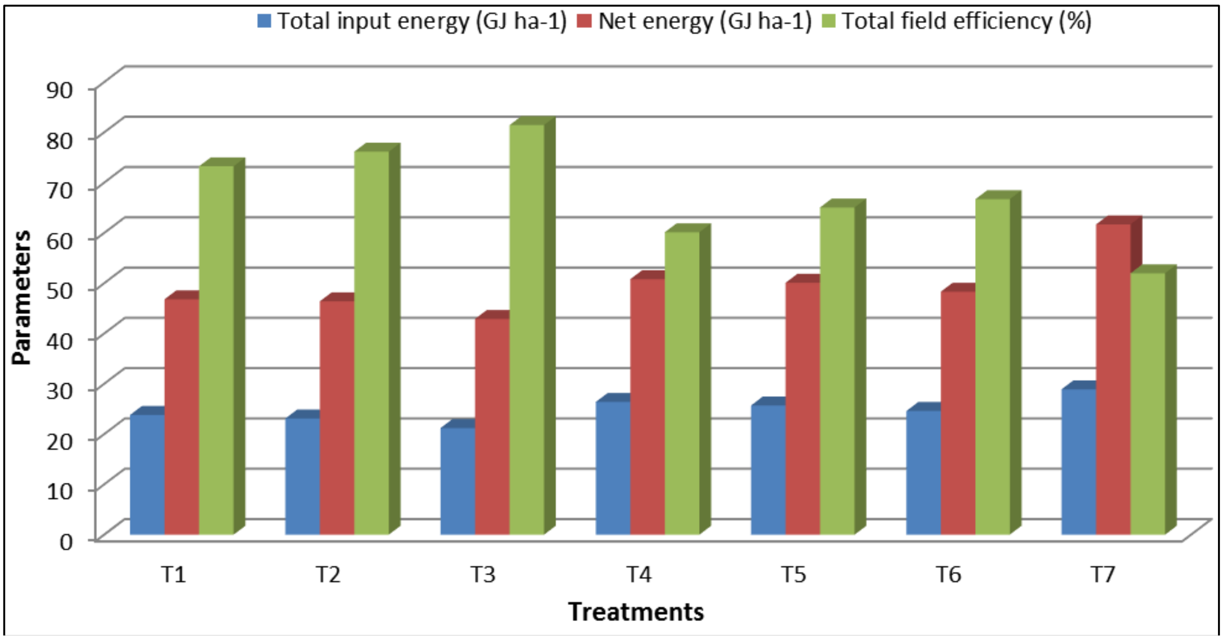

**Fig 6:** Effect of tillage crop residue management practice on Total input energy, net energy and total field efficiency

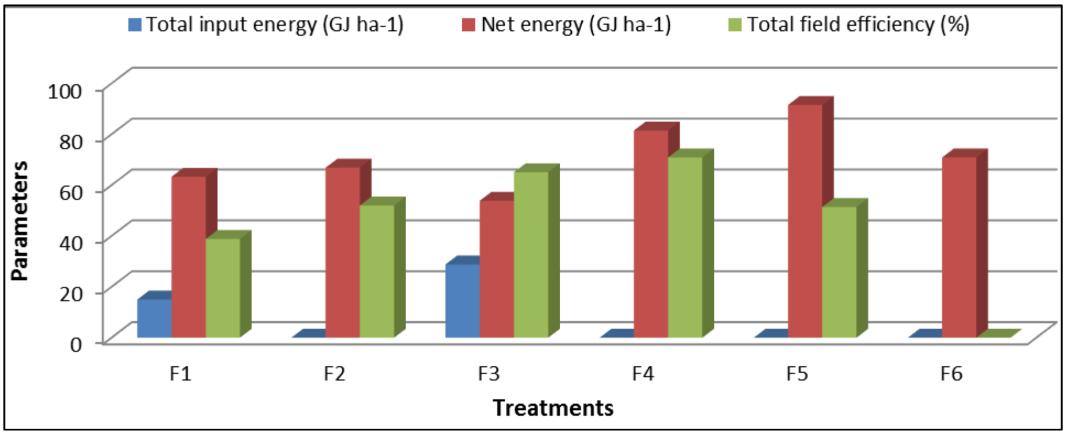

**Fig 7:** Effect of nutrient management practice on total input energy, net energy and total field efficiency

## Conclusions

Fertilizer application has played an important role in improving the total SOC and labile C pools content in the soil after 7 years. Because there was low SOC content in the western Uttar Pradesh of India, the long-term application of organic manure and inorganic fertilizer increased the content of SOC. SOC concentrations and storage were highest in surface soil and depth interval down to 30 cm under 50% RDF +VC @ 5tha$^{-1}$ and 100% RDF+VC @ 5tha$^{-1}$, below which concentrations did not change with depth. At the same time, on average the estimate of soil C storage to 30 cm depth was higher than that for soil C accumulated to 15 cm depth. These findings suggest that the estimate of soil C accumulation to 30 cm depth was more effective than that for soil C accumulated to 15 cm depth. 50% RDF +VC @ 5tha$^{-1}$were the most efficient management system for sequestering SOC. A large amount of C was also sequestered in soil under 100% RDF+VC @ 5tha$^{-1}$ treatment. Soil microbial biomass C, POC, $_c$POM and $_f$POM were all significantly greater under organic manure plus inorganic fertilizers, especially in the surface. The labile fraction organic C contents decreased significantly with increasing soil depth. These labile pools were highly correlated with each other and SOC, indicating that they were sensitive to changes in SOC.

In western Uttar Pradesh of India, the effects of manure and fertilizer application practices on soil C sequestration were studied so that irrigated farming soil could contribute to both sustainable food production and mitigation of greenhouse gas emissions through soil C sequestration. Our results have very significant implications for soil C sequestration potential in semiarid agro-ecosystems of western Uttar Pradesh of India. SOC concentration in surface soil (0–15 cm) and SOC storage of the profile (0–30 cm) were slightly increased by the 7 yr of fertilizer treatments, but they were sharply increased by the manure and straw amendment (VC, 50%RDF+VC @ 5tha$^{-1}$ and 100% RDF+VC @ 5tha$^{-1}$). Results were additive with higher rates of organic manure resulting in further beneficial effects. Great improvement in the values of CMI under organic or integrated organic-mineral fertilized treatments indicated enhanced delivery of C sequestration and nutrient cycling soil ecosystem services compared to mineral fertilized treatments. Thus, returning crop residue to the soil or adding vermin-compost manure on the soil surface is crucial to improving the SOC level. The large scale implementation of the straw or manure plus inorganic fertilizer amendments will help to enhance the capacity of carbon sequestration and promote food security in the region. Therefore, local government should encourage farmers to manage the nutrients and soil fertility based on integrated nutrient management by combining organic matter with inorganic fertilizer to improve soil carbon pools and increase crop productivity for long-term.

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