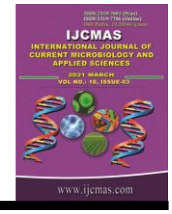
Int.J.Curr.Microbiol.App.Sci (2021) *10*(03): 674-693

EXCELLENT PUBLISHERS

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 10 Number 03 (2021)**
Journal homepage: http://www.ijcmas.com



Original Research Article https://doi.org/10.20546/ijcmas.2021.1003.086

Effect of Long Term Zero Tillage and Different Moisture Regimes on Soil Organic Carbon and its Fractions in Legume based Cropping Systems of North-western Indo-Gangetic Plains

Mamta Phogat[1*], Rita Dahiya[2], P. S. Sangwan[1], Vishal Goyal[1], S. K. Kakraliya[3] and M. Santhosh Kumar[1]

[1]Department of Soil Science, [2]Department of Physics, CCS Haryana Agricultural University Hisar, India
[3]Central Soil Salinity Research Institute, Karnal, India

**Corresponding author*

A B S T R A C T

Keywords

Zero tillage, Moisture regimes, Legumes, Soil health, Sustainability, Soil organic carbon and Carbon fractions

Article Info

Accepted:
14 February 2021
Available Online:
10 March 2021

Conventional tillage and cereal-cereal cropping systems cause degradation of soil health and quality by depleting soil organic carbon as well as other nutrients. Therefore we studied the "Effect of long term zero tillage and different moisture regimes on soil organic carbon and its fractions in legume based cropping systems of north-western Indo-Gangetic Plains". Field experiment was conducted during2017-18 and 2018-19 on an on-going long term experiment on 'Effect of varying moisture regimes in zero-till wheat succeeding mungbean and sorghum' since 2006 at Soil Research Farm, Department of Soil Science, CCS HAU, Hisar. The experiments consisted of two cropping systems (mungbean-wheat, MW and sorghum-wheat, SW), three tillage practices viz. CT-CT (conventional tillage in both *kharif* & *rabi* seasons), CT-ZT (conventional tillage in *kharif* & zero tillage in *rabi* seasons) and ZT-ZT (zero tillage in both *kharif* & *rabi* seasons); and three moisture regimes {IW/CPE = 0.60($M_{0.60}$), 0.75 ($M_{0.75}$) and 0.90 ($M_{0.90}$)}.The zero tillage ZT-ZT increased the soil organic (SOC) by 24.75, 23.16 % and 10.61, 9.98 % in surface and subsurface depth as compared to conventional tillage CT-CT in MW and SW, respectively, over all the moisture regimes. The soil organic carbon was found 11.1 and13.1 % higher in $M_{0.90}$ as compared to $M_{0.60}$ in MW and 9.6 and 10.0 % higher in $M_{0.90}$ than $M_{0.60}$ in SW over all the tillage practices in surface and subsurface soil respectively. The highest value of soil organic carbon (0.87 and 0.52 %) in surface and sub-surface soil was observed in ZT-ZT under MW cropping system in $M_{0.90}$. At surface and sub-surface depths, the dissolved organic carbon (DOC) was significantly higher (15.24 and 17.26 %) in mungbean-wheat cropping system as compared to sorghum-wheat cropping system. The DOC was also significantly higher in ZT-ZT (23.33 and 16.54; and 22.09 and 14.43 %) and CT-ZT (9.33 and 9.02; and 10.17 and 8.87 %) as compared to CT-CT over all the moisture regimes in mungbean-wheat and sorghum-wheat cropping systems at surface and sub-surface depths, respectively. The DOC was substantially higher at $M_{0.90}$ (20.39 and 18.80; and 21.79 and 21.04 %) and $M_{0.75}$ (7.89 and 6.34; and 8.08 and 7.15 %) as compared to $M_{0.60}$ over all the tillage practices in mungbean-wheat and sorghum-wheat cropping systems at surface and sub-surface depths, respectively. At surface depths, the light fraction (LF) carbon was significantly higher (6.51 %) in mungbean-wheat cropping system as compared to sorghum-wheat cropping system and sub-surface depth. It was 7.39 % higher in MW as compared to SW cropping system. The LF carbon was significantly higher in ZT-ZT (35.09 and 32.87; and 21.00 and 20.67 %) and CT-ZT (23.68 and 22.69; and 24.20 and 17.79 %) as compared to CT-CT over all the moisture regimes in mungbean-wheat and sorghum-wheat cropping systems at surface and sub-surface depths, respectively. At $M_{0.90}$ (25.93 and 16.17; and 23.01 and 20.75 %) and $M_{0.75}$ (12.35 and 10.64; and 11.50 and 11.32 %) light fraction carbon was substantially higher as compared to $M_{0.60}$ over all the tillage practices in mungbean-wheat and sorghum-wheat cropping systems at surface and sub-surface depths, respectively. The heavy fraction (HF) carbon was also significantly highest in ZT-ZT over all the moistute regimes under MW as compared to SW cropping system. The HF was higher in magnitude as compared to LF carbon in surface as well as in sub-surface soils. Therefore Long term zero tillage with inclusion of legumes can be a promising alternative to sustainably increase organic carbon in soilfor cereal-cereal cropping systems which ultimately plays a pivotal role to sustain the crop productivity and optimum ecosystem functioning with improving soil health.

Introduction

Soil organic carbon plays a key role in maintaining or boosting soil fertility and the plant growth. Soil fertility and productivity is important indicator for scientists because of its essential role in soil chemical, physical and biological properties (Gregorich and Janzen, 1994). Maintenance of adequate amount of soil organic matter (SOM) is required for sustainable agro ecosystems. We need to both increase C input and decrease SOC decomposition and loss. We can increase carbon input by using residue management and we can decrease carbon output by using conservation practices like zero tillage or reduced tillage. Short and medium term SOC changes are difficult to detect because of the high background C content and its temporal and spatial variability (Bosatta and Agren, 1994). As the accumulation of greenhouse gases rises in the atmosphere and consequently because of climate changes, there is a pressing need to protect organic carbon in agricultural soils. Soil organic carbon is the primary constituent of soil organic matter (SOM) and it is formed from decomposition of organic materials on or below the soil surface. Amount of turnover and decomposition rate of SOM is mostly regulated by interactions between different kinds of soil components (physical, chemical and biological) and environment (Taylor *et al.,* 2009). Proper management practices can aid in sustaining or even rising the SOC level besides the added benefits of improved physical condition, fertility and water storage of the soil (Blanco and Lal, 2010; Stockmann *et al.,* 2013).The SOC can be divided into fractions based on their chemical characteristics and residence time, and they can affect soil productivity (McLauchlan *et al.,* 2006). The labile/light fraction of soil organic carbon plays a crucial role in understanding improvements in soil quality (Kapkiyai *et al.,* 1999). The LF consists of a heterogeneity mixture of plant residues, animals and microbes that may be found in different stages of decomposition. This pool of soil organic matter is about many times greater than soil microbial biomass in agricultural soils (Liang *et al.,* 1998). The dissolved organic carbon (DOC), microbial biomass carbon (MBC), and particulate organic matter carbon (POMC) fractions are considered to be better measures of treatments induced changes than the overall carbon quantities (Dong *et al.,* 2009; Yang *et al.,* 2005). The DOC is a vital pool for soil, and can impact many other chemical and biological processes and may indicate short-term responses to crop management practices (Chantigny, 2003; Marschner and Kalbitz, 2003). Furthermore, cropping systems have differing effects on DOC (Lorenz and Lal, 2005). The SOC associated with the sand fraction is a labile pool of C and hence influenced by land use and management (Shrestha and Lal, 2007) Whereas SOC of clay fraction is more stable (HF) and it was affected more by physical and chemical processes than by land use changes. In the beginning zero tillage practice was aimed to conserve soil, water, to reduce cost of production (Holland 2004). Beyond this, the practice has multiple benefits in increasing the overall system performance. In recent years, water, energy and labour scarcity, the increasing production costs, decreasing farm profitability and variability caused by climate change are major challenges facing farmers in India's Indo-Gangetic Plains (IGP). Unsuitable management practices cause degradation ofsoil health because of depletion of organic carbon in soil and other nutrients as well as decline in crop productivity and sustainability (Ramos et. al. 2011). Due to conventional production practises, the sustainability of cereal-cereal cultivation systems in the Indo-Gangetic Plains (IGP) of India is at risk. Wheat is India's second most important cereal crop after rice, occupying an area of 31.2 million ha and producing 95.8 million tonnes. For better crop production, the common perception among farmers is to plough the soil 2-3 times after harvesting the rainy season crops. This has, however, contributed to the growth of hard-pan and low efficiency of input use (Das et.al.2014). Therefore, conventional production practises need to be enhanced or replaced with resource-conserving technologies (RCTs) by repeated ploughing adopted in wheat under the rice-wheat or maize-wheat cropping system to adapt to evolving climate changes and to increase productivity and farm profitability and soil health on a sustainable basis (Ladha *et al.,* 2014). It's necessary to increase crop production on a sustainable basis while keeping resources like the environment and our resources for food sources. In India, the cradle of the Green Revolution, the Indo-Gangetic Plains (IGP) covers about 20% and 27% of the total geographical and net cultivated area, respectively, and produces about half of the food consumed in the country (Dhillon *et al.,* 2010, Das *et al.,* 2018). By 2050, the world's population will be over 9 billion and 37% will live in China and India, requiring an expected 59% to 98% increase in food demand, putting more pressure on natural resources. India will have to double its cereal production to feed the 1.6 billion people of India by 2050 (Swaminathan and Bhavani, 2013). The challenge is to reach this aim with less resources and with a lower environmental footprint while buffering the risks of climate variability to ensure long-term sustainability. Over the next 50 years, five of the top ten issues facing humanity (i.e. food, electricity, water, the atmosphere and poverty) are directly linked to soil health. The growing concern for food security by improved soil management practises therefore calls for the adoption of conservation agriculture. Conservation agriculture is a resource-saving system for agricultural crop production that, in this era of climate change, aims to offer equal benefits along with high and sustainable levels of production while at the same time protecting the environment (FAO, 2010). The most important pillar of conservation farming is zero tillage. Time itself needs land reclamation. It supports both farmers and environmentalists. Zero tillage, a facet of conservation agriculture, refers to soil management schemes that result in crop residues covering at least 30% of the soil surface (Jarecki and Lal, 2003). According to the CTIC, at least 30% of the soil surface is covered with residue after planting. conservation agriculture uses three principals: (1) direct planting of crops with no till, (2) covering crops with crop residues (at least 30% of soil surface), and (3) rotating crops with various crops in rotation (FAO, 2011; Hobbs *et al.,* 2008). Several studies have shown that we can increase the amount of the soil organic matter (SOM) by introducing zero tillage systems (Powlson *et al.,* 2012). In the lower soil layers, a decrease in SOC with zero tillage were found, it indicates a balanced budget across the soil profile (Rold´an et al.2005). Tillage operations play a critical role in decreasing soil organic carbon (SOC) and changing soil characteristics (Baker *et al.,* 2007; Victoria *et al.,* 2012). Tillage physically incorporates the carbon as crop residue into the soil, as opposed to transferring particulate, colloidal or soluble carbon. However, constant tillage destroys the soil aggregates and exposes the protected SOC to environment which then undergoes rapid decomposition by aerobic microbes (Al-Kaisi and Yin, 2005). As a result, studies show that up to 75% of SOC of the native land was removed by conventional tillage practices (Lal *et al.,* 2007). Zero tillage can limit the release of greenhouse gases into the atmosphere. The agricultural management practises can affect the stored carbon from soil in different ways (Lin *et al.,* 2002). SOC turnover in topsoil is regulated by soil mineralogy and microclimate (rainfall, temperature and radiation). Root biomass and root exudates of plant increase the soil nutritional status (Kuzyakov, 2002; Chaudhary *et al.,* 2012). Residue mulch under zero tillage can improve the sequestration process of soil carbon. Minimal disturbance in zero tillage, permitted the growth of macroaggregates and prevented the degradation of soil organic carbon (Six *et al.,* 2000a). Plant litter on the soil surface increased the quality of organic matter by slow decomposition (Feng*et al.,* 2010; Johansen *et al.,* 2012; Boeckx *et al.,* 2011; Brouder and Gomez-Macpherson, 2014, Tits *et al.,* 2014; Chaplot *et al.,* 2015; Guo *et al.,* 2015). Tillage damages soil quality by lowering SOM contents by increasing higher oxidation rate. Moreover, this triggers the degradation of soil's physical properties and a potential decrease in crop productivity (Du Preez*et al.,* 2001). Organic C in soil were found to increase with tillage conversion from traditional tillage to zero tillage in a few cm of soil (Bowman *et al.,* 1999, Hermle *et al.,* 2008). Introducing zero tillage after years of conventional tillage increased SOC in a large variety of soils (West and Post, 2002; Baker *et al.,* 2007). Zero tillage tillage has increased the organic matter content and the water-holding capacity in arid and semi-arid conditions of soil (Du Preez *et al.,* 2001). Carbon storage of zero tillage contrasted favourably with that of traditional tillage in sandy loam, silt loam and clay loam soils after 11 years of continuous cultivation (Campbell *et al.,* 1996a). On-farm conservation tillage practises like zero tillage and inclusion of cover crops will substantially improve soil productivity due to retention of crop residues. Madari *et al.,* (2005) showed that there was substantial impact of zero tillage with residue cover on aggregate stability, aggregate size, and soil organic carbon. Higher carbon storage was achieved by adopting zero tillage (Dick *et al.,* 1991 and Panday *et al.,* 2008). oil and crop management practises, such as zero tillage improved soil organic carbon content compared to traditional practises. (Sainju *et al.,* 2007; Zhang *et al.,* 2007; Andruschkewitsch *et al.,* 2013). Long-term zero tillage in soil raised soil carbon stock in surface layer by 19, 34.7 and 38.8% over traditional tillage in 15 years in sandy loam soil, loam soil and clay loam soil, respectively (Singh *et al.,* 2014). Dong *et al.,* (2009) stated that tillage and residue management impact was more on dissolved organic material, microbial biomass, and particulate organic matter than the total organic carbon. Improved crop management methods, including zero tillage and inclusion of legumes in cropping systems, will increase the soil organic carbon (SOC) and SOC fractions more than the conventional approaches do (Andruschkewitsch *et al.,* 2013; Blanco-Canqui and Lal, 2007; Mishra *et al.,* 2010; Sainju *et al.,* 2007). There is currently a higher soil organic C storage rate under ZT than CT because of the residue accumulation at the soil surface (Piovanelli*et al.,* 2006). Soils handled by ZT turn SOM, microbial populations, and their functions as well as availability of nutrients (Thomas *et al.,* 2007). Zero tillage system keeps the land in good condition and increases the soil quality because of residue retention on soil surface over intensive tillage systems (Kumar *et al.,* 2012). Sustainable intensification of cereal (rice/maize/pearlmillet) systems focused on conservation agriculture (CA) integrated with mungbean enhanced soil organic carbon. (Choudhary *et al.,* 2018). Legumes with their inherent characteristics such as leaf dropping, deep root, biological N fixation, and greater root exudate release enhance soil health (Hazra *et al.,* 2018). In wheat after mungbean, the enhanced carbon concentration improve the soil's overall consistency (Singh *et al.,* 2015). The inclusion of legumes in cereal-cereal rotation shifts the balance of nutrient input-output, nutrient and carbon input through non-harvested crop residues (root carbon) that are likely to impact long-term productivity (Hazra *et al.,* 2014). In addition, system intensification via short-term mungbean (Vignaradiata) integration may provide an opportunity to increase farmers' benefit (Kumar *et al.,* 2018).There is also a need to improve the efficiency of water use, particularly to save water in arid and semi-arid regions. Conventional practises have contributed to groundwater over-exploitation, leading to an unprecedented decline in the water table in many parts of North-West India (Humphreys *et al.,* 2010). Water is rapidly scarce in the IGP, as well as in many other parts of Asia. Between 1955 and 1990, per capita water supply declined by 40 to 60% in many Asian countries (Gleik, 1993). In early seventies, much of the studies were focused on irrigation scheduling on the basis of growth stages and soil moisture depletion. However, in nineties many workers found that moisture supplies on IW/CPE basis were more economical and convenient than the other criteria (Raghu *et al.,* 1983 and Khera *et al.,* 1987). The positive effects of CA-based options in cereal-based systems have resulted in higher crop yields, water saving, labour usage and improvement in soil health (Gathala *et al.,* 2013; Jat *et al.,* 2015). Many authors have reported that higher productivity of ZT can be achieved in dry areas also and this could be due to higher soil water retention (Triplett and Dick, 2008). Zero tillage can be a promising option for increasing or maintaining the crop yield in a sustainable manner by enhancing soil organic carbon in form of crop residues. Zero tillage preserves soil health, primarily through erosion reduction and soil organic matter enhancement (American Society of Agricultural Engineers, 1985). The use of legume crops and zero tillage systems has been shown to greatly reduce the risk of soil erosion (Lentz and Bjorneberg, 2003). Good soil health plays a pivotal role to sustain the crop productivity and optimum ecosystem functioning. Improved soil aggregation and higher soil organic carbon (SOC) stock are the essential components of good soil health (Denef *et al.,* 2001). In fact, land use pattern and crop management practices have a differential influence on soil carbon and aggregate dynamics (Pinheiro *et al.,* 2004). Therefore, location–specific management practices are required in tillage and residue management practices suitable to varying soils, crops, and climatic conditions.

The present study goal was to research how soil organic carbon and its fractions are affected by long term zero tillage and different moisture regimes in cereal-cereal based cropping systems of north-western Indo-Gangetic Plains. In evaluating its suitability for crop production, the properties of a soil play a significant role. There is a lot of literature available on the impact of zero tillage practises on soil organic carbon and its fractions but there is little knowledge on the combined effect of zero tillage adoption and the introduction of legumes into the cropping system and moisture regimes on soil organic carbon and its fractions in various cropping systems. It was hypothesised that, for a few uninterrupted years, the adoption of zero tillage in the agricultural production system in general and in wheat, particularly with different crop rotations, might significantly improve the soil organic carbon and its fractions, eventually affecting sustainability of the system. The present investigation was therefore conducted to tackle this issue.

Materials and Methods

The present study was carried out at an on-going long-term experiment at Soil Research Farm, Department of Soil Science, CCS HAU, Hisar. The coordinates of the experimental site is 29.10^0N, 75.46^0E and at an altitude of 215.2 meters above mean sea level. The experimental soil was sandy loam (71.5% sand, 9.3% silt and 19.2% clay) and classified as TypicHaplustepts. The experimental soil was slightly alkaline, low in organic carbon content, low in available nitrogen, medium in available phosphorus and high in available potassium (Kumar, 2008). The experimental site has a semi-arid climate with hot and dry summer and extremely cold winter. The mean monthly maximum and minimum temperature show a wide range of fluctuations during summer as well as winter seasons. The mean maximum and minimum temperature was 39.0 °C in May, 2018 and 12.4 °C in January, 2018 and 42.2 °C in May 2019 and 13.0 °C in February, 2019, respectively. Total rainfall received during study period was 29.9 mm and 44.1 mm from November, 2017 to April, 2018 and November, 2018 to April, 2019, respectively.

The experiment was carried out with two main-plot treatments, viz. (i) Mungbean-wheat and,(ii) Sorghum-wheat cropping systems and with three sub-plot treatmentsviz. (i)Conventional tillage in both *kharif* & *rabi* seasons, (ii) conventional tillage in *kharif* & zero tillage in *rabi* seasons and, (iii) zero tillage in both *kharif* & *rabi* along with three sub-sub-plot treatments of soil moisture regimes viz, IW/CPE of 0.60, 0.75 & 0.90.The experimental design was split-split-plot and replicated thriceIn CT-CT plots, the fields were ploughed during both *kharif* and *rabi* seasons. In CT-ZT plots, the fields were ploughed during *kharif* only and no tillage was done during *rabi* season. In ZT- ZT plots, no tillage was done during both the *kharif* and *rabi* seasons. In CT practice, the residues of the preceding crop i.e. wheat/mungbean/sorghum were manually removed, and seed bed tilth for wheat/mungbean/sorghum was prepared by two disc to about 10 cm followed by planking (leveling with a 3 m long wooden block) of the fields. In plots with ZT practice, the crop was harvested and no tillage was done for preparation of seed bed for the succeeding crop, and crop was sown with zero till machine. The wheat (WH 1105) was sown on November 23, 2017 during 2017-18 and on November 25, 2018 during 2018-19. The wheat was harvested on 25 April 2018 during 2017-18 and on 24 April 2019 during 2018-19.

The weather parameters (rainfall, PAN evaporation, maximum and minimum air temperatures) during the study period were obtained from meteorological station of Department of Agricultural Meteorology, CCS HAU, Hisar which is situated nearby the experimental site (Figs. 1 & 2).

Ten plants in each scenario were randomly selected and marked for recording of plant height of the crops. In all the crops, at harvesting stage the numbers of effective tillers were counted from the 1 m2 area randomly from four spots in each treatment, averaged and expressed as number of effective tillers/m^2 area. Spike length was measured in cm from 10 randomly selected tillers of tagged plants from each scenario at harvest. The length was measured from neck to the tip of the spike and average length was computed. Representative samples of one thousand grains were taken for each plot and their weights were recorded in gram, then their average weight was calculated and recorded. After harvesting 1x1 m^2 plot area, the bundles of wheat crop were sun dried and then weight was recorded and converted into kg ha^{-1} for calculating biological yield. Grains were separated with the help of mini plot thresher for biological yield. The grain yield obtained from 1x1 m^2 plot area was converted into kg ha^{-1}. Then straw yield was obtained by subtracting the grain yield from total biological yield of 1x1 m^2 plot area and expressed in kg ha^{-1}. The significance of treatment effects was analyzed using analysis of variance by split-split plot design using OP Stat software, CCS HAU Hisar.

Collection and processing of soil samples

Soil samples were collected from 0-15 cm and 15-30 cm soil depth after the harvest of wheat crop during 2017-18 and 2018-19 using post hole auger. Five samples per plot were taken and composite sample was obtained by mixing the collected soil samples thoroughly by hand on a clean thick polythene sheet. The composite samples were brought to laboratory, and divided into two parts. One part was air dried, grounded, then sieved (2 mm) and finally stored in cloth bags after proper labelling. These samples were kept in the laboratory for further soil analysis for chemical properties, soil organic carbon and nutrient availability.

Determination of soil organic carbon and carbon fractions

The soil organic carbon and carbon fractions for both the years i.e. 2017-18 and 2018-19 (data has been showed as pooled of both years in results) were determined by adopting standard procedures as described below:

Soil organic carbon: Total soil organic carbon was determined using Walkley and Black (1934) wet digestion method. The soil was digested in mixture of potassium dichromate and concentrated sulphuric acid. The excess of potassium dichromate was determined by titration using standard ferrous ammonium sulphate solution in the presence of sodium fluoride using diphenylamine as indicator.

Organic carbon stock: Organic carbon stock was estimated using mathematical equation (Benbi*et al.,* 2012).

Dissolved organic carbon: Fifty ml of deionised water was added into 10 g of soil and shaken in horizontal shaker for one hour. Then, it was centrifuged for 30 minutes at 8000 rpm. The solution was filtered through Whatman No. 1 filter paper and filtrate was collected and stored in the freezer for analysis. Dissolved organic carbon was determined by dichromate acid oxidation method (Ciavitta*et al.,* 1989).

Light and heavy carbon fractions: Light fraction of SOC in soil samples was isolated by densiometric method modified by Janzen *et al.,* (1992). The represented soil samples (10 g) were dispersed with a NaI solution (40 ml) having specific gravity of 1.70 g cm^{-3} (1.70 gm in 1ml of distilled water). The soil suspension was then shaken for one hour and the suspension was allowed to equilibrate for 48 hours. The suspension was centrifuged for 5 minutes and the clear supernatant was filtered under suction in a Buchner funnel. The light fraction (LF) organic carbon remained on the filter was washed with 0.01M $CaCl_2$ and the distilled water and then transferred from the filter paper into a glass container.

The precipitates retained at the bottom of the centrifuge tube were remixed with NaI solution, shaken, centrifuged and the supernatant filtered again to ensure quantitative removal of LF of organic carbon. The remaining heavy fraction (HF) organic carbon was shaken with 0.01M $CaCl_2$, centrifuged and the clear supernatant was discarded. This was followed by a similar treatment with distilled water. The heavy fraction remained in centrifuge tube was later on transferred to glass container and oven-dried at 65 ^oC for 24 h. The dried LF and HF fractions were ground and analyzed for total carbon by dichromate digestion of modified Walkley and Black's rapid titration method as described by Nelson and Sommers (1996).

Statistical analysis: Data were exposed to analysis of variance for split-split plot design to know the significant difference among the treatments. Least significant difference values were used to compare the treatment means at p= 0.05 using OPSTAT software (Sheoran *et al.,* 1998).

Results and Discussion

Soil organic carbon

The long term zero tillage had significant effect on soil organic carbon (SOC) in wheat preceding mungbean (MW) and sorghum (SW) crops at different moisture regimes in the surface (0-15 cm) and sub-surface (15-30 cm) depths. The SOC decreased with the increasing depth in MW and SW cropping systems under all the tillage practices and moisture regimes. The data on soil organic carbon (Table 1) of 0-15 cm depth indicated that mungbean-wheat cropping system (0.75 %) had significantly higher soil organic carbon content as compared to sorghum-wheat cropping system (0.71 %) in the twelve years of experimentation. The zero tillage practice in both the seasons (ZT-ZT) or during *rabi* (CT-ZT) resulted in increase in the contents of organic carbon in soil in both the cropping systems. The increase was, however, of higher magnitude in mungbean-wheat as compared to sorghum-wheat cropping system. The soil organic carbon was observed highest in ZT-ZT (0.79 and 0.83 %) followed by CT-ZT (0.69 and 0.75 %) and CT-CT (0.64 and 0.67 %) in SW and MW cropping systems over all the moisture regimes. The increase in moisture regime also resulted in significantly higher accumulation of soil organic carbon in all the tillage practices in both the cropping systems. The soil organic carbon was observed highest in MW (0.78 %) and SW (0.74 %) under IW/CPE of 0.90 ($M_{0.90}$) followed by $M_{0.75}$ and $M_{0.60}$ over all the tillage practices. The interactive effect of cropping system and tillage; cropping system and moisture regime; tillage and moisture regime; and cropping system, tillage and moisture regime on soil organic carbon was found non-significant.

The data on soil organic carbon (Table 2) in the sub-surface (15-30 cm) depth indicated that MW cropping system (0.46 %) also increased the soil organic carbon content significantly as compared to SW cropping system (0.43 %). The ZT-ZT and CT-ZT resulted in increased in the contents of organic carbon in 15-30 cm soil in both the cropping systems as compared to CT-CT. The increase was of higher magnitude in mungbean-wheat as compared to sorghum-wheat cropping system. The soil organic carbon was observed highest in ZT-ZT (0.45 and 0.49 %) followed by CT-ZT (0.43 and 0.46 %) and CT-CT (0.41 and 0.44%) in SW and MW cropping systems over all the moisture regimes. The SOC increased with increasing moisture regime in all the tillage systems in both the cropping systems. The SOC was observed highest under $M_{0.90}$ (0.49 and 0.45 %) followed by $M_{0.75}$ (0.46 and 0.43 %) and $M_{0.60}$ (0.43 and 0.41 %) over all the tillage practices in MW and SW, respectively. The interactive effect of cropping system and tillage; and cropping system, tillage and moisture regime was found non-significant; however, interactive effect of cropping system and moisture regime; and tillage and moisture regime was significant on soil organic carbon in subsurface depth.

The effect of long term zero tillage had substantial effect on soil organic carbon stock and carbon sequestration rate in wheat preceding mungbean and sorghum crops (Table 3). The carbon stock of 24.03 Mg ha^{-1} under CT-CT increased to 24.85 Mg ha^{-1} in CT-ZT and 26.97 Mg ha^{-1} in ZT-ZT up to 30 cm soil depth after 12 years of zero tillage in SW cropping system. Similarly, the carbon stock of 24.77 Mg ha^{-1} under CT-CT increased to 26.32 Mg ha^{-1} in CT-ZT and 28.35 Mg ha^{-1} in ZT-ZT ha in 30 cm soil layer in wheat preceding mungbean. The increase in carbon stock was higher in mungbean wheat cropping system as compared to sorghum wheat cropping system. The carbon sequestration rate was highest in ZT-ZT in MW (0.30 Mg ha^{-1} yr^{-1}) and SW (0.25 Mg ha^{-1} yr^{-1}).

Dissolved organic carbon

The data on effect of long term zero tillage in wheat on dissolved organic carbon (g kg^{-1}) in surface (0-15 cm) and subsurface (15-30 cm) soil depths at different moisture regimes under mungbean-wheat (MW) and sorghum-wheat (SW) cropping systems is presented in Tables 4 and 5. The ZT-ZT increased dissolved organic carbon over CT-ZT and CT-CT in all the moisture regimes under mungbean-wheat and sorghum-wheat cropping systems. The results indicated that dissolved organic carbon (DOC) decreased with depth. The DOC was 0.55 and 0.48 g kg^{-1}at surface depth and 0.51 and 0.43 g kg^{-1}at sub-surface in MW and SW cropping systems, respectively. Under ZT-ZT, dissolved organic carbon was significantly highest (0.62 and 0.52 g kg^{-1}) followed by CT-ZT (0.55 and 0.48 g kg^{-1}) and CT-CT (0.50 and 0.44 g kg^{-1}) at 0-15 cm over all the moisture regimes under MW and SW cropping systems, respectively. The DOC was also observed highest in ZT-ZT (0.56 and 0.46 g kg^{-1}) followed by CT-ZT (0.51 and 0.44 g kg^{-1}) and CT-CT (0.46 and 0.40 g kg^{-1}) at 15-30 cm over all the moisture regimes under MW and SW cropping systems, respectively. Present study revealed that dissolved organic carbon was substantially higher at $M_{0.90}$ (0.61 and 0.53 g kg^{-1}) as compared to $M_{0.75}$ (0.55 and 0.47 g kg^{-1}) and $M_{0.60}$ (0.51 and 0.44 g kg^{-1}) over all the tillage practices in mungbean-wheat and sorghum-wheat cropping systems at surface depth, respectively. The similar effect of moisture regimes were observed at 15-30 cm soil depth. The interactive effect of cropping system and tillage was significant but non-significant interaction was observed between cropping system and moisture regimes; tillage and moisture regimes; and cropping, tillage and moisture regimes on DOC in surface and subsurface soil depths.

Light fraction carbon

Light fraction carbon (g kg^{-1}) as affected by long term zero tillage in wheat in surface (0-15 cm) and subsurface (15-30 cm) soil depths at different moisture regimes under mungbean-wheat (MW) and sorghum-wheat (SW) cropping systems is presented in Tables 6 and 7. The ZT-ZT increased light fractions (LF) of carbon over CT-ZT and CT-CT in all the moisture regimes under MW and SW cropping systems. It is clear from the data that LF carbon decreased with depth. The LF carbon was 0.91 and 0.85 g kg^{-1}at surface soil and 0.84 and 0.78 g kg^{-1} at sub-surface soil depth in MW and SW cropping systems, respectively. Under ZT-ZT, light fraction carbon was significantly highest (1.03 and 0.96; and 0.88 and 0.84 g kg^{-1}) followed by CT-ZT (0.94 and 0.88; and 0.91 and 0.82 g kg^{-1}) and CT-CT (0.76 and 0.72; and 0.73 and 0.69 g kg^{-1}) at surface and subsurface depths over all the moisture regimes under MW and SW cropping systems, respectively. The LF carbon was significantly highest at $M_{0.90}$ (1.02 and 0.91 g kg^{-1}) as compared to $M_{0.75}$ (0.91 and 0.87 g kg^{-1}) and $M_{0.60}$ (0.81 and 0.78 g kg^{-1}) over all the tillage practices in MW and SW cropping systems at 0-15 cm soil depth. The similar effect of moisture regimes were found at 15-30 soil depth. The interactive effect of cropping system and moisture regimes; tillage and moisture regimes were found significant at 0-15 cm, whereas interactive effect of cropping system and tillage; tillage and moisture regimes were observed significant at 15-30 cm depth.

Heavy fraction carbon

The experimental results on effect of long term zero tillage (g kg^{-1}) on heavy fraction (HF) carbon in wheat in surface (0-15 cm) and subsurface (15-30 cm) soil depths at different moisture regimes under mungbean-wheat (MW) and sorghum-wheat (SW) cropping systems is presented in Tables 8 and 9. The zero tillage practice in both the seasons (ZT-ZT) increased HF of carbon over zero tillage during *rabi* (CT-ZT) and conventional tillage in both *kharif* & *rabi* seasons (CT-CT) in all the moisture regimes under mungbean-wheat and sorghum-wheat cropping systems. The HF carbon decreased at 15-30 cm depth.

Table.1 Effect of long-term zero tillage on soil organic carbon (%) content in 0-15 cm soil depth at different moisture regimes under mungbean-wheat and sorghum-wheat cropping systems

Moisture Regime (IW/CPE)	Sorghum-Wheat			Mean	Mungbean-Wheat			Mean
	CT-CT	CT-ZT	ZT-ZT		CT-CT	CT-ZT	ZT-ZT	
$M_{0.60}$	0.61	0.65	0.76	0.67	0.63	0.70	0.79	0.71
$M_{0.75}$	0.63	0.70	0.78	0.70	0.67	0.75	0.84	0.75
$M_{0.90}$	0.67	0.73	0.82	0.74	0.70	0.79	0.87	0.78
Mean	0.64	0.69	0.79	0.71	0.67	0.75	0.83	0.75
CD (p= 0.05	A= 0.032, B =0.015, A x B =NS, C =0.018, A x C= NS, B x C = NS, A x B x C= NS							

CT = conventional tillage, ZT = zero tillage, $M_{0.60}$ = moisture regime at IW/CPE=0.60, $M_{0.75}$= moisture regime at IW/CPE= 0.75, $M_{0.90}$= moisture regime at IW/CPE=0.90; A= cropping factor, B= tillage factor, C= moisture regime factor

Table.2 Effect of long-term zero tillage on soil organic carbon (%) content in 15-30 cm soil depth at different moisture regimes under mungbean-wheat and sorghum-wheat cropping systems

Moisture Regime (IW/CPE)	Sorghum-Wheat			Mean	Mungbean-Weat			Mean
	CT-CT	CT-ZT	ZT-ZT		CT-CT	CT-ZT	ZT-ZT	
0.60	0.40	0.41	0.43	0.41	0.41	0.44	0.45	0.43
0.75	0.41	0.42	0.45	0.43	0.44	0.45	0.49	0.46
0.90	0.43	0.45	0.48	0.45	0.47	0.48	0.52	0.49
Mean	0.41	0.43	0.45	0.43	0.44	0.46	0.49	0.46
CD (p= 0.05	A= 0.020, B =0.007, A x B = NS, C =0.007, A x C= 0.009, B x C =0.011, A x B x C= NS							

CT = conventional tillage, ZT = zero tillage, $M_{0.60}$ = moisture regime at IW/CPE=0.60, $M_{0.75}$= moisture regime at IW/CPE= 0.75, $M_{0.90}$= moisture regime at IW/CPE=0.90; A= cropping factor, B= tillage factor, C= moisture regime factor

Table.3 Effect of long - term zero tillage on carbon stock (Mg ha^{-1}) and carbon sequestration rate (Mg ha^{-1} yr^{-1}) in 30 cm soil depth over all the moisture regimes under mungbean-wheat and sorghum-wheat cropping systems

Cropping system	Tillage	Soil organic carbon stock (Mg ha^{-1})	Carbon sequestration rate (Mg ha^{-1} yr^{-1})
Sorghum-wheat (SW)	CT-CT	24.03	--
	CT-ZT	24.85	0.07
	ZT-ZT	26.97	0.25
	Mean	25.29	
Mungbean-wheat (MW)	CT-CT	24.77	--
	CT-ZT	26.32	0.13
	ZT-ZT	28.35	0.30
	Mean	26.48	

CT = conventional tillage and ZT = zero tillage

Table.4 Effect of long-term zero tillage on dissolved organic carbon (g kg^{-1}) in 0-15 cm soil depth at different moisture regimes under mungbean-wheat and sorghum-wheat cropping systems

Moisture Regime (IW/CPE)	Sorghum-Wheat			Mean	Mungbean-Wheat			Mean
	CT-CT	**CT-ZT**	**ZT-ZT**		**CT-CT**	**CT-ZT**	**ZT-ZT**	
$M_{0.60}$	0.41	0.45	0.47	0.44	0.44	0.50	0.58	0.51
$M_{0.75}$	0.43	0.48	0.51	0.47	0.49	0.54	0.61	0.55
$M_{0.90}$	0.49	0.52	0.57	0.53	0.57	0.60	0.66	0.61
Mean	0.44	0.48	0.52	0.48	0.50	0.55	0.62	0.55
CD (p= 0.05	A= 0.010, B =0.011, A x B =0.016, C =0.010, A x C= NS, B x C=NS, A x B x C=NS							

CT = conventional tillage, ZT = zero tillage, $M_{0.60}$ = moisture regime at IW/CPE=0.60, $M_{0.75}$= moisture regime at IW/CPE= 0.75, $M_{0.90}$= moisture regime at IW/CPE=0.90; A= cropping factor, B= tillage factor, C= moisture regime factor

Table.5 Effect of long-term zero tillage on dissolved organic carbon (g kg^{-1}) in 15-30 cm soil depth at different moisture regimes under mungbean-wheat and sorghum-wheat cropping systems

Moisture Regime (IW/CPE)	Sorghum-Wheat			Mean	Mungbean-Wheat			Mean
	CT-CT	**CT-ZT**	**ZT-ZT**		**CT-CT**	**CT-ZT**	**ZT-ZT**	
$M_{0.60}$	0.36	0.41	0.42	0.40	0.40	0.46	0.52	0.46
$M_{0.75}$	0.39	0.43	0.45	0.42	0.45	0.49	0.56	0.50
$M_{0.90}$	0.45	0.47	0.52	0.48	0.52	0.56	0.61	0.56
Mean	0.40	0.44	0.46	0.43	0.46	0.51	0.56	0.51
CD (p= 0.05	A=0.021 , B=0.009 , A x B= = 0.013,C=0.009, A x C= NS, B x C= NS, A x B x C=NS							

CT = conventional tillage, ZT = zero tillage, $M_{0.60}$ = moisture regime at IW/CPE=0.60, $M_{0.75}$= moisture regime at IW/CPE= 0.75, $M_{0.90}$= moisture regime at IW/CPE=0.90; A= cropping factor, B= tillage factor, C= moisture regime factor

Table.6 Effect of long-term zero tillage on light fraction carbon (g kg^{-1}) in 0-15 cm soil depth at different moisture regimes under mungbean-wheat and sorghum-wheat cropping systems

Moisture Regime (IW/CPE)	Sorghum-Wheat			Mean	Mungbean-Wheat			Mean
	CT-CT	CT-ZT	ZT-ZT		CT-CT	CT-ZT	ZT-ZT	
$M_{0.60}$	0.67	0.81	0.87	0.78	0.68	0.84	0.91	0.81
$M_{0.75}$	0.78	0.94	1.01	0.91	0.90	1.02	1.14	1.02
$M_{0.90}$	0.71	0.90	0.99	0.87	0.74	0.96	1.03	0.91
Mean	0.72	0.88	0.96	0.85	0.76	0.94	1.03	0.91
CD (p= 0.05	A= 0.035, B =0.021, A x B =NS, C =0.015, A x C= 0.021, B x C =0.026, A x B x C=NS							

CT = conventional tillage, ZT = zero tillage, $M_{0.60}$ = moisture regime at IW/CPE=0.60, $M_{0.75}$= moisture regime at IW/CPE= 0.75, $M_{0.90}$= moisture regime at IW/CPE=0.90; A= cropping factor, B= tillage factor, C= moisture regime factor

Table.7 Effect of long-term zero tillage on light fraction carbon (g kg^{-1}) in 15-30 cm soil depth at different moisture regimes under mungbean-wheat and sorghum-wheat cropping systems

Moisture Regime (IW/CPE)	Sorghum-Wheat			Mean	Mungbean-Wheat			Mean
	CT-CT	CT-ZT	ZT-ZT		CT-CT	CT-ZT	ZT-ZT	
$M_{0.60}$	0.64	0.73	0.75	0.71	0.66	0.81	0.79	0.75
$M_{0.75}$	0.67	0.84	0.85	0.79	0.71	0.92	0.89	0.84
$M_{0.90}$	0.77	0.88	0.91	0.85	0.82	0.99	0.97	0.93
Mean	0.69	0.82	0.84	0.78	0.73	0.91	0.88	0.84
CD (p= 0.05	A=0.009 , B=0.014 , A x B= = 0.019,C=0.014, A x C= NS, B x C= 0.024, A x B x C=NS							

CT = conventional tillage, ZT = zero tillage, $M_{0.60}$ = moisture regime at IW/CPE=0.60, $M_{0.75}$= moisture regime at IW/CPE= 0.75, $M_{0.90}$= moisture regime at IW/CPE=0.90; A= cropping factor, B= tillage factor, C= moisture regime factor

Table.8 Effect of long-term zero tillage on heavy fraction carbon (g kg^{-1}) in 0-15 cm soil depth at different moisture regimes under mungbean-wheat and sorghum-wheat cropping systems

Moisture Regime (IW/CPE)	Sorghum-Wheat			Mean	Mungbean-Wheat			Mean
	CT-CT	CT-ZT	ZT-ZT		CT-CT	CT-ZT	ZT-ZT	
$M_{0.60}$	4.71	5.43	5.50	5.21	4.89	5.53	5.70	5.37
$M_{0.75}$	4.83	5.57	5.60	5.33	4.95	5.74	5.93	5.54
$M_{0.90}$	4.90	5.63	5.71	5.41	4.96	5.82	5.98	5.59
Mean	4.81	5.54	5.60	5.32	4.93	5.70	5.87	5.50
CD (p= 0.05	A= 0.13, B =0.06, A x B =NS, C =0.10, A x C= NS, B x C =NS, A x B x C=NS							

CT = conventional tillage, ZT = zero tillage, $M_{0.60}$ = moisture regime at IW/CPE=0.60, $M_{0.75}$= moisture regime at IW/CPE= 0.75, $M_{0.90}$= moisture regime at IW/CPE=0.90; A= cropping factor, B= tillage factor, C= moisture regime factor

Table.9 Effect of long-term zero tillage on heavy fraction carbon (g kg^{-1}) in 15-30 cm soil depth at different moisture regimes under mungbean-wheat and sorghum-wheat cropping systems

Moisture Regime (IW/CPE)	Sorghum-Wheat			Mean	Mungbean-Wheat			Mean
	CT-CT	CT-ZT	ZT-ZT		CT-CT	CT-ZT	ZT-ZT	
$M_{0.60}$	2.61	3.32	3.50	3.14	2.78	3.46	3.75	3.33
$M_{0.75}$	2.66	3.43	3.65	3.25	2.85	3.65	3.88	3.46
$M_{0.90}$	2.71	3.53	3.70	3.31	2.89	3.91	3.97	3.59
Mean	2.66	3.43	3.62	3.23	2.84	3.67	3.87	3.46
CD (p= 0.05	A=0.11 , B=0.01 , A x B= = NS, C=0.05, A x C= NS, B x C= 0.09, A x B x C=NS							

CT = conventional tillage, ZT = zero tillage, $M_{0.60}$ = moisture regime at IW/CPE=0.60, $M_{0.75}$= moisture regime at IW/CPE= 0.75, $M_{0.90}$= moisture regime at IW/CPE=0.90; A= cropping factor, B= tillage factor, C= moisture regime factor

Fig.1 Meterological weather data during Nov-2017 to April-2018

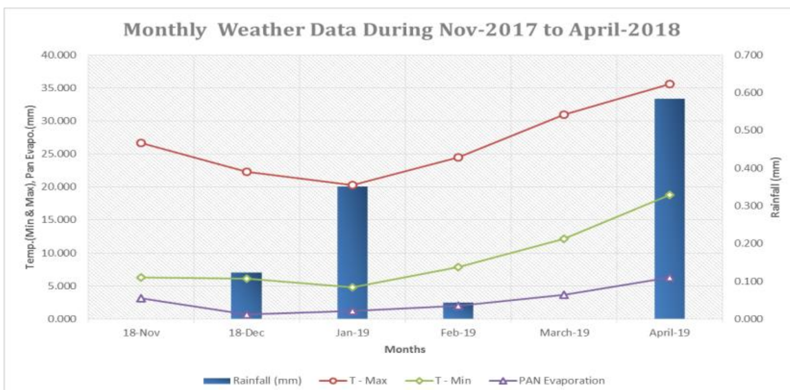
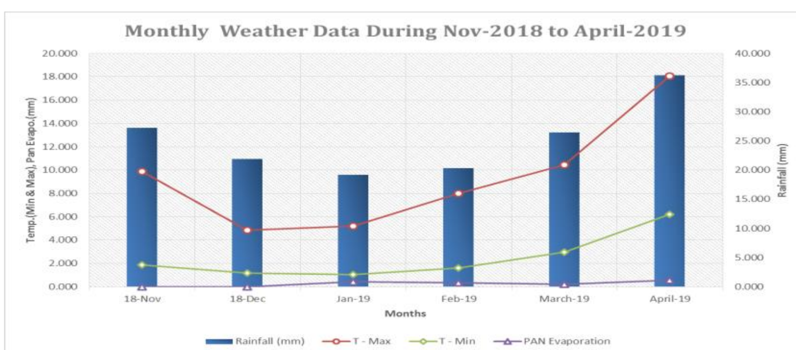


Fig.2 Meterological weather data during Nov-2018 to April-2019



The HF carbon was 5.50 and 5.32 g kg^{-1} of surface soil and 3.46 and 3.23 g kg^{-1} at sub-surface in MW and SW cropping systems, respectively. Under ZT-ZT, HF carbon was significantly highest (5.87 and 5.60 g kg^{-1}) followed by CT-ZT (5.70 and 5.54 g kg^{-1}) and CT-CT (4.93 and 4.81 g kg^{-1}) in 0-15 cm over all the moisture regimes under mungbean-wheat and sorghum-wheat cropping systems, respectively.

Similarly, the HF was significantly highest in ZT-ZT (3.87 and 3.23 g kg^{-1}) followed by CT-ZT (3.67 and 3.43 g kg^{-1}) and CT-CT (2.84 and 2.66 g kg^{-1}) in 15-30 cm soil depth over all the moisture regimes under MW and SW cropping systems, respectively. The heavy fraction carbon was significantly highest at $M_{0.90}$ (5.59 and 5.41; and 3.59 and 3.31 g kg^{-1}) amongst $M_{0.75}$ (5.54 and 5.33; and 3.46 and 3.25 g kg^{-1}) and $M_{0.60}$ (5.37 and 5.21; and 3.33 and 3.14 g kg^{-1}) over all the tillage practices in MW and SW cropping systems at surface and subsurface depths, respectively. In this study, the interactive effects of cropping system and tillage; cropping system and moisture regimes; tillage and moisture regimes; and cropping, tillage and moisture regimes on heavy fraction carbon was non-significant in surface soil but it was significant in sub-surface soils for tillage and moisture regimes.

Soil organic carbon

The adoption of long term zero tillage for twelve years in wheat increased soil organic carbon (SOC) content of surface (0-15 cm) and sub-surface (15-30 cm) soil depths in MW and SW cropping systems (Tables 1 and 2). The MW cropping system increased the SOC content of surface (0-15 cm) soil by 6.12 % over SW cropping system. The zero tillage ZT-ZT increased the SOC by 24.75 and 23.16 % and CT-ZT increased SOC by 7.14 and 7.12 % as compared to conventional tillage CT-CT in MW and SW, respectively over all the moisture regimes. The soil organic carbon was found 11.1% higher in $M_{0.90}$ and 6.8 % higher in $M_{0.75}$ as compared to $M_{0.60}$ in MW and 9.6 % higher in $M_{0.90}$ and 4.3 % higher in $M_{0.75}$ than $M_{0.60}$ in SW over all the tillage practices. Impact of long term zero tillage in wheat soil organic carbon at different moisture regimes at 15-30 cm in mungbean-wheat and sorghum-wheat cropping systems on was also substantial. The MW cropping system increased the soil organic carbon content by 6.96 % over SW cropping system in twelve years in sub-surface (15-30 cm) depth. The zero tillage ZT-ZT and CT-ZT increased the soil organic carbon by 10.6, 10.0 and 3.8, 3.2 % as compared to conventional tillage CT-CT in MW and SW, respectively over all the moisture regimes. The SOC was found 13.1 % higher in $M_{0.90}$ and 6.2 % higher in $M_{0.75}$ as compared to $M_{0.60}$ in MW and 10.0 % higher in $M_{0.90}$ and 3.2 % higher in $M_{0.75}$ than $M_{0.60}$ in SW over all the tillage practices. The highest soil organic carbon in ZT-ZT might be due to less disturbance coupled with addition of higher amount of organic material in zero tillage treatments in terms of crop residues retention as well as root biomass. The conventional tillage increases organic matter decomposition and decreases carbon content by increasing organic matter oxidation (Six *et al.*, 1999; Thomas *et al.*, 2007). The crop roots remains intact in the root zone due to non-disturbance of the soil under zero tillage, which might facilitate augmentation of organic carbon input in root zones (up to 30 cm) through their decay. There are conflicting results regarding studies that compared soil organic carbon content under ZT and CT. Some researchers have found that ZT increased carbon content in the soil (Mishra *et al.*, 2010; Gonzalez-Sanchez *et al.*, 2012) while others reported no effect or contradictory results (Baker *et al.*, 2007; Blanco-Canqui and Lal, 2008). Reasons for contradictory results can be due to differences in soil composition (texture and native organic matter content), unique site conditions (temperature and moisture) and sampling at different soil depths (Franzluebbers, 2010). Wheat succeeding mungbean has more soil organic carbon as compared to wheat succeeding sorghum which might be due to differences in quantity and chemical composition of crop residue biomass and/or root exudates among the crop rotations (Congreves *et al.,* 2015). The narrow C: N ratio of legume residue caused rapid decomposition and hence higher SOC compared to other cropping sequences. Further, tap roots of the legume resulted higher SOC content in deeper layers. Greater soil carbon (31 %) was observed by inclusion of cowpea and sunhemp in maize based crop rotations (Thierfelder *et al.,* 2012). Saha and Ghosh (2013) also reported the positive effects on soil carbon content of legume residue application in cereal cropping systems. Higher moisture regimes also resulted in higher root mass and consequently higher crop residues. The left over organic material led to build up of soil organic carbon. Our results are in consistent with other studies on no till practice (Mishra *et al.,* 2010; Tebrugge and During, 1999). The carbon sequestration rate was 14.43 and 6.24 % higher in ZT-ZT and CT-ZT over CT-CT in MW, and 12.24 and 3.42 % higher in ZT-ZT and CT-ZT over CT-CT in SW cropping system. Hence, ZT-ZT has more potential to store and enhance carbon sequestration rate in soils (Table 3) by providing better conditions in terms of moisture and temperature for higher biomass production and reduced oxidation. The similar results were reported by Gonzalez-Sanchez *et al.,* (2012). The C-sequestration under ZT is believed due to decreased SOC decomposition, because of the less aerobic environment and better physical protection of SOC within aggregates (Balesdent *et al.,* 2000).

Dissolved organic carbon

The ZT-ZT practice significantly increased dissolved organic carbon (DOC) in surface (0-15 cm) and sub-surface (15-30 cm) depths over all the moisture regimes in mungbean-wheat and sorghum-wheat cropping systems (Tables 4 and 5). At surface and sub-surface depths, DOC was significantly higher (15.24 and 17.26 %) in mungbean-wheat cropping system as compared to sorghum-wheat cropping system. The DOC was also significantly higher in ZT-ZT (23.33 and 16.54; and 22.09 and 14.43 %) and CT-ZT (9.33 and 9.02; and 10.17 and 8.87 %) as compared to CT-CT over all the moisture regimes in mungbean-wheat and sorghum-wheat cropping systems at surface and sub-surface depths, respectively. At $M_{0.90}$ (20.39 and 18.80; and 21.79 and 21.04 %) and $M_{0.75}$ (7.89 and 6.34; and 8.08 and 7.15 %) dissolved organic carbon was substantially higher as compared to $M_{0.60}$ over all the tillage practices in mungbean-wheat and sorghum-wheat cropping systems at surface and sub-surface depths, respectively. This increase in dissolved organic carbon under ZT-ZT practice and mungbean-wheat cropping system might be due to increased crop residues under ZT-ZT as dissolved organic carbon is derived from plant residues, litter and humus of soil. The DOC is the most mobile and active form of organic material and it represents only small amount of carbon fractions (Kalbitz *et al.,* 2000). However, Chantigny (2003) reported that conventional tillage may increase dissolved organic carbon because of fast decomposition of organic material. Cropping systems have anecdotal effects on soil dissolved organic carbon because of production of difference in quantity and quality of residues (Lorenz and Lal, 2005). Bhattacharya *et al.,* (2015) reported higher labile carbon pool in plots having mungbean residue.

Light and heavy fractions

The ZT-ZT practice significantly increased light fraction (LF) and heavy fraction (HF) of soil organic carbon in surface (0-15 cm) and sub-surface (15-30 cm) depths over all the moisture regimes in mungbean-wheat and sorghum-wheat cropping systems (Tables 6-9). At surface depths, light fraction carbon was significantly higher (6.51 %) in mungbean-wheat cropping system as compared to sorghum-wheat cropping system and at sub-surface depth; it was 7.39 % higher in mungbean-wheat cropping system as compared to sorghum-wheat cropping system. The light fraction carbon was significantly higher in ZT-ZT (35.09 and 32.87; and 21.00 and 20.67 %) and CT-ZT (23.68 and 22.69; and 24.20 and 17.79 %) as compared to CT-CT over all the moisture regimes in mungbean-wheat and sorghum-wheat cropping systems at surface and sub-surface depths, respectively. At $M_{0.90}$ (25.93 and 16.17; and 23.01 and 20.75 %) and $M_{0.75}$ (12.35 and 10.64; and 11.50 and 11.32 %) light fraction carbon was substantially higher as compared to $M_{0.60}$ over all the tillage practices in mungbean-wheat and sorghum-wheat cropping systems at surface and sub-surface depths, respectively. The LF carbon accounts for 2-17 % of soil organic carbon (Curtin and Fraser, 2003). Like LF of carbon, heavy fraction (HF) carbon also builds up significantly higher values in ZT-ZT over all the moisture regimes under mungbean-wheat as compared to sorghum wheat cropping system. The HF carbon constitutes 75-85 % of total soil organic carbon.. The HF carbon found in association with organic matter and minerals and it is less prone to mineralization and transformation into other forms. Sekhon *et al.*, (2009) reported similar results. This increase in LF carbon and HF carbon under ZT-ZT practice and mungbean-wheat cropping system might be due to increased crop residues under ZT-ZT as these fractions of carbon are heterogeneous mixture of topical crop residues, microbes and small animals, which may be present in various stages of decomposition. In agricultural soils, light fraction carbon is generally several times greater than that of soil microbial biomass (Liang *et al.*, 1998).

The results from the present investigation concluded that long term zero tillage practices had potential to enhance or maintain the soil organic carbon and its fraction in wheat under mungbean-wheat and sorghum-wheat cropping systems. The results also concluded that legume based cropping system is better as compared to non-legume based cropping system at different moisture regimes in arid and semi-arid climatic conditions in sandy loam soils. Finally it is concluded that adoption of long term zero tillage in wheat and inclusion of legumes in the cropping systems would be beneficial for improving the soil health and quality on sustainable basis.in wheat of north-western Indo-Gangetic Plains.

Acknowledgements

The first author acknowledges the facilities and financial assistance provided by CCS Haryana Agricultural University, Hisar, Haryana.

References

A. Rold´an, J. R. Salinas-Garc´ıa, M. M. Alguacil, and F. Caravaca, “Changes in soil enzyme activity, fertility, aggregation and C sequestration mediated by conservation tillage practices and water regime in a maize field,” *Applied Soil Ecology*, vol. 30, no. 1, pp. 11–20, 2005.

Al-Kaisi, M. M. and Yin, X. (2005).Tillage and crop residue effects on soil carbon and carbon dioxide emission in corn–soybean rotations.*Journal of Environmental Quality*, 34: 437-445.

American Society of Agricultural Engineers, 1985.Erosion and soil productivity. Proceedings of the National Symposium on Erosion and Soil Productivity 8–85.

Andruschkewitsch, R., Geisseler, D., Koch, H.J. and Ludwig, B. (2013). Effects of tillage on contents of organic carbon, nitrogen, water-stable aggregates and light fraction for four different long-term trials. *Geoderma*, 192:368-377.

Balesdent, J., Chenu, C., Balabane, M. (2000).Relationship of soil organic matter dynamics to physical protection and tillage.*Soil & Tillage Research.* 53: 215–230.

Benbi, D.K., Toor, A.S. and Kumar, S. (2012). Management of organic amendments in rice-wheat cropping system determines the pool where carbon is sequestered. Plant and Soil, 68: 25-43.

Bhattacharyya, R., Das, T. K., Sudhishri, S., Dudwal, B., Sharma, A. R., Bhatia, A., and Singh, G. (2015). Conservation agriculture effects on soil organic carbon accumulation and crop productivity under a rice-wheat cropping system in the western Indo-Gangetic Plains. *European Journal of Agronomy*,70: 11–21. https://doi.org/10.1016/j.eja.2015.06.006

Blanco-Canqui, H. and Lal, R. (2007).Soil structure and organic carbon relationships following 10 years of wheat straw management in no-till.*Soil & Tillage Research*, 95: 240-254.

Blanco-Canqui, H. and Lal, R. (2010).Soil and Water Conservation. In: *Principles of Soil Conservation and Management, Springer, Dordrecht.*

Blanco-Canqui, H. and Lal, R., (2008). No-tillage and soil-profile carbon sequestration: an on-farm assessment. *Soil Science Society of American Journal*, 72: 693–701.

Boeckx, P., Van Nieuland, K. and Van Cleemput, O. (2011).Short-term effect of tillage intensity on N_2 O and CO_2 emissions.*Agronomy for Sustainable Development*, 31: 453-461.

Bosatta, D.A. and Agren, G.I. (1994).Theoretical analysis of microbial biomass dynamics in soils.*Soil Biol. Biochem*. 26:143–148.

Bowman, R. A., Vigil, M. F., Nielsen, D. C. and Anderson, R. L. (1999). Soil organic matter changes in intensively cropped dryland systems. *Soil Science Society of America Journal*, 63: 186-191.

Brouder, S. M. and Gomez-Macpherson, H. (2014). The impact of conservation agriculture on smallholder agricultural yields: a scoping review of the evidence. *Agriculture, Ecosystems & Environment*, 187: 11-32.

Campbell, C. A., McConkey, B. G., Zentner, R. P., Selles, F. and Curtin, D. (1996a).Tillage and crop rotation effects on soil organic C and N in a coarse-textured TypicHaploboroll in southwestern Saskatchewan.*Soil & Tillage Research*, 37: 3-14.

Chantigny, M.H. (2003). Dissolved and water-extractable organic matter in soils: a review on the influence of land use and management practices. *Geoderma*113:357–380.

Chaplot, V., Abdalla, K., Alexis, M., Bourennane, H., Darboux, F., Dlamini, P., Everson, C., Mchunu, C., Muller-Nedebock, D., Mutema, M., Quenea, K., Thenga, H. and Chivenge, P. (2015). Surface organic carbon enrichment to explain greater CO2 emissions from short-term no-tilled soils. *Agriculture, Ecosystems & Environment*, 203: 110-118.

Chaudhary, D. R., Saxena, J., Lorenz, N. and Dick, R. P. (2012).Distribution of recently fixed photosynthate in a switchgrass plant-soil system.*Plant, Soil and Environment*, 58: 249-255.

Choudhary, Madhu; Jat, Hanuman S.; Datta, Ashim; Yadav, Arvind K.; Sapkota, Tek B.; Mondal, Sandip; Meena, R.P.; Sharma, Parbodh C.; Jat, M.L. (2018). *Sustainable intensification influences soil quality, biota, and productivity in cereal-based agroecosystems. Applied Soil Ecology*, *S0929139317313136–*. doi:10.1016/j.apsoil.2018.02.027

Ciavatta,C., VittoriAntisari, L. and Sequi, P. (1989). Determination of organic carbon in soils and fertilizers.*Communications* in *Soil Science*.20: 1-90.

Congreves, K.A., Hayes, A., Verhallen, L.L., Van Eerd, L.L., 2015. Long term impact of tillage and crop rotation on soil health at four temperate agroecosystems.*Soil & Tillage Research*. 152: 17–28.

Curtin, D. and Fraser, P.M. (2003). Soil organic matter as influenced by straw management practices and inclusion of grass and clover seed crops in cereal rotations*. Australian journal of science and research*.41: 95-106.

D. S. Powlson, A. Bhogal, B. J. Chambers *et al.*, "+e potential to increase soil carbon stocks through reduced tillage or organic material additions in England and Wales: a case study," *Agricultural Ecosystem and Environment*, vol. 146, no. 1, pp. 23–33, 2012.

Das TK, Bhattacharyya R, Sudhishri S, Sharma AR, Saharawat YS, Bandyopadhyay KK, Sepat S, Bana RS, Aggarwal P, Sharma RK, Bhatia A, Singh G, Kar A, Singh B, Singh P, Pathak H, Vyas AK, Jat ML (2014) Conservation agriculture in an irrigated cotton–wheat system of the western Indo-Gangetic Plains: crop and water productivity and economic profitability. Field Crop Res 158:24–33 2.

Das, T.K., Saharawat, Y.S., Bhattacharyya, R., Sudhishri, S., Bandyopadhyay, K.K., Sharma, A.R., Jat, M.L., 2018. Conservation agriculture effects on crop and water productivity, profitability and soil organic carbon accumulation under a maize–- wheat cropping system in the North–western Indo–Gangetic Plains. Field Crop Res. 215, 222–231.

Denef, K., Six, J., Paustian, K., Merckx, R., 2001. Importance of macroaggregate dynamics in controlling soil carbon stabilization: short–term effects of physical disturbance induced by dry–wet cycles. Soil Biol. Biochem. 33, 2145–2153.

Dhillon, B.S., Kataria, P., Dhillon, P.K., 2010. National food security vis-à-vis sustainability of agriculture in high crop productivity regions.Curr. Sci. 98, 33–36.

Dick, W.A., McCoy, E.L., Edwards, W.M., Lal, R. (1991). Continuous application of no-tillage to Ohio soils.*Agronomy Journal*.83: 65–73.

Dong, W., Hu, C., Chen, S. and Zhang, Y. (2009).Tillage and residue management effects on soil carbon and CO_2emmision in a wheat-maize double-cropping system.*Nutrient Cycling in Agroecosystems*, 83: 27-37.

Du Preez, C. C., Steyn, J. T. and Kotze, E. (2001).Long-term effects of wheat residue management on some fertility indicators of a semi-arid Plinthosol.*Soil & Tillage Research*, 63: 25-33.

FAO (2010). What is conservation agriculture; FAO CA-website http://www.fao.org/ag/ca/1a.html. Accessed on 13/08/2019.

FAO (2011). The state of the world's land and water resources for food and agriculture(SOLAW)-Managing systems at risk. Food and Agriculture Organization of the United Nations, Rome and Earthscan, London.

Feng, F. X., Huang, G. B., Chai, Q. and Yu, A. Z. (2010). Tillage and straw management impacts on soil properties, root growth, and grain yield of winter wheat in Northwestern China. Crop Science, 50, 1465-1473.

Franzluebbers, A.J. (2010). Achieving soil organic carbon sequestration with conservation agricultural systems in the southeastern United States.*Soil Science Society of American Journal*, 74: 347–357.

Gathala, M., Kumar, V., Sharma, P.C., Saharawat, Y., Jat, H.S., Singh, M., Kumar, A., Jat, M.L., Humphreys, E., Sharma, D.K., Sharma, S., Ladha, J.K., 2013.Optimizing intensive cereal-based cropping systems addressing current and future drivers of agricultural change in the northwestern Indo-Gangetic Plains of India. Agric. Ecosyst. Environ. 177, 85–97.

Gleik, P.H. (ed.). 1993.Water crisis: A guide to the world's fresh water resources. Pacific Institute for Studies in Development, Environment and Security. Stockholm Environment Institute. Oxford Univ. Press, New York.

Gonzalez-Sanchez, E.J., Ordonez-Fernandez, R., Carbonell-Bojollo, R., Veroz-Gonzalez, O., Gil-Ribes, J.A. (2012).Meta-analysis on atmospheric carbon capture in Spain through the use of conservation agriculture.*Soiland Tillage Research*, 122: 52–60.

Gregorich, E.G. and Janzen, H.H. (1994).Storage of soil carbon in the light fraction and macro-organic matter. In: *CRC press*.167-190.

Guo, L. J., Zhang, Z. S., Wang, D. D., Li, C. F. and Cao, C. G. (2015).Effects of shortterm conservation management practices on soil organic carbon fractions and microbial community composition under a rice-wheat rotation system.*Biology and Fertility of Soils*, 51: 65-75.

Hazra K.K., Singh S.S., Nath C.P., Borase D.N., Kumar N., Parihar A.K. and Swain D.K. (2018). Adaptation mechanisms of winter pulses through rhizospheric modification in mild–alkaline soil. National Academy Science Letters 41, 193–196.

Hermle, S., Anken, T., Leifeld, J. and Weisskopf, P. (2008).The effect of the tillage system on soil organic carbon content under moist, cold-temperate conditions.*Soil & Tillage Research*, 98: 94-105.

Hobbs, P. R., Sayre, K. and Gupta, R. (2008).The role of conservation agriculture in sustainableagriculture. Philosophical Transactions of the Royal Society of London B: *Biological Sciences*, 363: 543-555.

Holland, J.M., 2004. The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agric. Ecosyst. Environ. 103, 1–25.

Humphreys, E., Kukal, S.S., Christen, E.W., Hira, G.S., Balwinder-Singh, Sudhir-Yadav, Sharma, R.K., 2010. Halting the groundwater decline in north-west India – which crop technologies will be winners? Adv. Agron. 109, 155–217.

Janzen, H. H., Campbell, C. A., Brandt, S. A., Lafond, G. P. and Smith, L. T. (1992). Light-fraction organic matter in soils from long-term crop rotations.*Soil Science Society of America Journal*, 56: 1799-1806.

Jarecki, M.K. and Lal, R. (2003).Crop management for soil carbon sequestration.*Critical Reviews in Plant Sciences*, 22: 471-502.

Jat, H.S., Singh, G., Singh, R., Choudhary, M., Jat, M.L., Gathala, M.K., Sharma, D.K., 2015. Management influence on maize–wheat system performance, water productivity and soil biology. Soil Use Manage. 31, 534–543.

Johansen, C., Haque, M. E., Bell, R. W., Thierfelder, C. and Esdaile, R. J. (2012). Conservation agriculture for small holder rainfed farming: Opportunities and constraints of new mechanized seeding systems. *Field Crops Research*, 132: 18-32.

Kalbitz, K., Solinger, S., Park, J.H., Michalzik, B. and Matzner, E. (2000). Controls on the dynamics of dissolved organic matter in soils: A review. *Soil*

Science, 165(4): 277-304.

Kapkiyai, J.J.; Karanja, N.K.; Qureshi, J.N.; Smithson, P.C. and Woomer, P.L. (1999).Soil organic matter and nutrient dynamics in a Kenyan nitisol under long-term fertilizer and organic input management.*Soil Biol. Biochem*. 31:1773–1782.

Khera, K.L., B. Singh, B.S. Sandhu and S.S. Prihar (1987).Timings of irrigations to late-sown bread-wheat on sandy loam soil. Indian J. Agric. Sci. 57: 262-266.

Kumar, B., and R.P.R. Sharma (2000). Effect of preceding crops and nitrogen rates on growth, yield and yield attributes of wheat. *Indian Journal of Agricultural Research*, 34: 34-38.

Kumar, S., Dahiya, R., Kumar, P., Jhorar, B.S. &Phogat, V.K. (2012).Long-term effect of organic materials and fertilizers on soil properties in pearl millet-wheat cropping system.*Indian Journal of Agricultural Research*, 46 (2): 161-66.

Kuzyakov, Y. (2002). Factors affecting rhizosphere priming effects. *Journal of Plant Nutrition and Soil Science*, 165: 382-396.

Ladha, J.K., Kumar, V., Alam, M.M., Sharma, S., Gathala, M., Chandna, P., Saharawat, Y.S., Balasubramanian, V., 2014.Integrating crop and resource management technologies for enhanced productivity, profitability, and sustainability. In: Ladha, J.K., Singh, Y., Erenstein, O., Hardy, B. (Eds.), Integrated Crop and Resource Management in the Rice–Wheat System of South Asia. International Rice Research Institute, Los Baños, Philippines, pp. 69–108.

Lal, R., Reicosky, D.C. and Hanson, J.D. (2007).Evolution of the plow over 10,000 years and the rationale for no-till farming.*Soil and Tillage Research*, 93:1-12.

Lentz, R.D., Bjorneberg, D.L., 2003. Polyacrylamide and straw residue effects on irrigation furrow erosion and infiltration. J. Soil Water Conserv. 58, 312–319.

Liang, B.C.; MacKenzie, A.F.; Schnitzer, M.; Monreal, C.M.; Voroney, R.P. and Beyaert, R.P. (1998). Management-induced change in labile soil organic matter under continuous corn in eastern Canadian soils. *Biology & Fertility of Soils*, 26: 88–94.

Lin, E., Li, Y. E. and Guo, L. (2002). Carbon emissions and sinks in agro-ecosystems of China. Science in China. Series C, *Life Sciences*, 45, 30-39.

Lorenz, K. and Lal, R. (2005). The depth distribution of soil organic carbon in relation to land use and management and the potential of carbon sequestration in subsoil horizons. *Advances in Agronomy*, 88:35–66.

Madari, B., Machado, P.L., Torres, O.A., de Andrade, E. and Valencia, A.L. (2005). No tillage and crop rotation effects on soil aggregation and organic carbon in a RhodicFerralsol from southern Brazil. *Soil &Tillage Research*, 80:185-200.

Marschner, B. and Kalbitz, K. (2003).Controls of bioavailability and biodegradability of dissolved organic matter in soils.*Geoderma*, 113:211–235.

McLauchlan, K.K.; Hobbie, S.E. and Post, W.M. (2006). Conversion from agriculture to grassland builds soil organic matter on decadal timescales. *Ecol. Appl.*16:143–153.

Mishra, M.; David, A.N. and Lal, R. (2010). Tillage effects on soil carbon storage and dynamics in Corn Belt of Ohio USA. *Soil Tillage & Research*, 107:88-96.

Nelson, D. W. and Sommers, L. E. (1996).Soil Science Society of America and American Society of Agronomy, 677 S. Segoe Rd., Madison, WI 53711, USA.*Methods of Soil Analysis.Part 3.Chemical Methods*-SSSA Book Series no. 5.

Panday, S.C., Singh, R.D., Saha, S., Singh, K.P., Prakash, V., Kumar, A., Kumar, M. and Srivastava, A.K. (2008). Effect of tillage and irrigation on yield, profitability, water productivity and soil health in rice-wheat cropping systems in north-west Himalayas.*Indian Journal of Agricultural Sciences*, 78(12):1018-22.

Pinheiro, E.F.M., Pereira, M.G., Anjos, L.H.C., 2004. Aggregate distribution and soil organic matter under different tillage systems for vegetable crops in a Red Lat

Piovanelli, C.; Gamba, C.; Brandi, G.; Simonini, S. and Batistoni, E. (2006). Tillage choices affect biochemical properties in the soil profile. *Soil & Tillage Research*, 90: 84–92.

Raghu, J.S., S.R. Sharma and S.D. Choubey (1983).Scheduling of irrigation in wheat using pan evaporation. JNKVV Res. J. 17: 26-29.

Ramos, M. E., Robles, A. B., S´anchez-Navarro, A., and Gonz ´alez-Rebollar, J. L., "Soil responses to different management practices in rainfed orchards in semiarid environments," *Soil and Tillage Research*, vol. 112, no. 1, pp. 85–91, 2011.

Saha, R. And Ghosh, P.K. (2013). Soil organic carbon stock, moisture availability and crop yield as influenced by residue management and tillage practices in maize-mustard cropping system under hill agro-ecosystem. *National Academy Science Letters*,36(5): 461–468.

Sainju, U.M., Lenssen, A., Caesar-Tonthat, T. and Waddell, J. (2007).Dryland plant biomass and soil carbon and nitrogen fractions on transient land as influenced by tillage and crop rotation.*Soil &Tillage Research*, 93:452–461.

Sekhon, K.S., Singh, J.P. and Mehla, D.S. (2009).Soil organic pools after seven years of manures and mineral fertilizers application in a rice-wheat rotation.*Arch. Agron. Soil Sci*., 55(2): 197-206.

Sheoran, O.P., Tonk, D.S., Kaushik, L.S., Hasija, R.C., Pannu, R.S., 1998. In: Hooda, D.S., Hasija, R.C. (Eds.), Statistical Software Package for Agricultural Research Workers. Recent Advances in Information Theory, Statistics & Computer Applications. Department of Mathematics Statistics, CCS HAU, Hisar, pp. 139–143.

Shrestha, R.K. and Lal, R. (2007). Soil carbon and nitrogen in 28-year old land uses in reclaimed coal mine soils of Ohio. *J. Environ. Qual*.36:1775–1783.

Singh, A., Phogat, V. K., Dahiya, R. and Batra, S. D. (2014).Impact of long-term zero till wheat on soil physical properties and wheat productivity under rice–wheat cropping system.*Soil & Tillage Research*, 140: 98-105.

Six, J. A. E. T., Elliott, E. T. and Paustian, K. (2000a). Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. *Soil Biology & Biochemistry*, 32: 2099-2103.

Stockmann, U., Adams, M. A., Crawford, J. W., Field, D. J., Henakaarchchi, N., Jenkins, M., Minasny, B., McBratney, A. B., de Courcelles, V. D. R., Singh, K., Wheeler, I., Abbott, L., Angers, D. A., Baldock, J., Bird, M., Brookes, P. C., Chenu, C., Jastrow, J. D. and Zimmermann, M. (2013). The knowns, known unknowns and unknowns of sequestration of soil organic carbon. *Agriculture, Ecosystems & Environment*, 164: 80-99.

Taylor, L. L., Leake, J. R., Quirk, J., Hardy, K., Banwart, S. A. and Beerling, D. J. (2009). Biological weathering and the long-term carbon cycle: integrating mycorrhizal evolution and function into the current paradigm. Geobiology, 7, 171-191.

Tebrugge, F. and During, A.R. (1999).Reducing tillage intensity - a review of results from a long-term study in Germany.*Soil &Tillage Research*, 53:15-28.

Thierfelder, C., Cheesman, S., Rusinamhodzi, L. (2012). A comparative analysis of conservation agriculture systems: benefits and challenges of rotations and intercropping in Zimbabwe. *Field Crops Research*, 137: 237–250.

Thomas, G.A., Dalal, R.C. and Standley, J. (2007).No-till effects on organic matter, pH, cation exchange capacity and nutrient distribution in a Luvisol in the semi-arid subtropics *Soil & Tillage Research*, 94: 295–304.

Tits, M., Elsen, A., Bries, J. and Vandendriessche, H. (2014).Short-term and longterm effects of vegetable, fruit and garden waste compost applications in an arable crop rotation in Flanders.*Plant and Soil*, 376: 43-59.

Triplett, G. B. and Dick, W. A. (2008). No-tillage crop production: A revolution in agriculture! Agronomy Journal, 100 (Supplement_3), S-153.

Victoria, R., Banwart, S., Black, H., Ingram, J., Joosten, H., Milne, E., Nollemeyer, E. and Baskin, Y. (2012).The benefits of soil carbon.Foresight chapter in UNEP Yearbook, 19-33.

Walkley, A. & Black, I.A. (1934).An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method.*Soil Science*, 37: 29–38.

West, T. O. and Post, W. M. (2002). Soil organic carbon sequestration rates by tillage and crop rotation. *Soil Science Society of America Journal*, 66: 1930-1946.

Yang, H.M., X.Y. Zgang and G.X. Wang (2005). Relationship between stomatal character, photosystetic character and seed seed chemical compostion in grass pea at differnnt water availabilities. J. Agric. Sci

Zhang, J., Song, C. and Yang, W. (2007). Tillage effects on soil carbon fractions in the Sanjiang Plain, Northeast China. *Soil & Tillage Research*, 93:102-108.

How to cite this article:

Mamta Phogat, Rita Dahiya, P. S. Sangwan, Vishal Goyal, S. K. Kakraliya and Santhosh Kumar, M. 2021. Effect of Long Term Zero Tillage and Different Moisture Regimes on Soil Organic Carbon and its Fractions in Legume based Cropping Systems of North-western Indo-Gangetic Plains. *Int.J.Curr.Microbiol.App.Sci.* 10(03): 674-693.
doi: https://doi.org/10.20546/ijcmas.2021.1003.086