भारत के चार मुख्य मृदा वर्गों में अस्थिर कार्बन और सूक्ष्म जीवों का कार्बन उपयोगिता दक्षता पर खाद प्रयोग तथा उर्वरण का दीर्घकालिक प्रभाव

Long term impact of manuring and fertilization on labile carbon and carbon utilization efficiency of microbes in four major soil groups of India

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CERTIFICATE

This is to certify that the thesis entitled **“Long term impact of manuring and fertilization on labile carbon and carbon utilization efficiency of microbes in four major soil groups of India”** submitted to the Faculty of the Post–Graduate School, ICAR–Indian Agricultural Research Institute, New Delhi in partial fulfillment of the requirements for the degree of **Master of Science in Soil Science and Agricultural Chemistry**, embodies the results of *bonafide* research work carried out by **Mr. ABINASH DAS**, under my guidance and supervision, and that no part of this thesis has been submitted for any other degree or diploma.

It is further certified that any assistance and help availed during the course of investigation as well as source of information have been duly acknowledged by him.

Date:
Place: New Delhi

(T.J. Purakayastha**)**
Chairperson
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Dedicated to
“My family
&
My chairman”

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CHAPTER 1

Introduction

1. INTRODUCTION

Global climate change resulting from greenhouse gas emission is becoming a concern in all regions of the world (Hansen *et al.*, 2013). An exponential increase in the level of greenhouse gases has been recorded since the beginning of the industrial revolution. The atmospheric concentration of carbon dioxide (CO_2) has increased globally by 40 per cent from 278 ppm in the pre-industrial era to the current value of 410 ppm (ESRL, 2017). Although increasing levels of greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O) are attributed mainly to agriculture, soil provides a major sink, as well as a source, for one of the main greenhouse gases, carbon dioxide (CO_2) (IPCC, 2006). Hence, it is important to quantify the potential C sink capacity of different soils as influenced by various soil and nutrient management. The turnover rate soil organic C (SOC) is very fast in tropical climate of India than in temperate climate. Therefore, climate is one of the major limitations for carbon build-up in Indian soils. However, if the soils are managed properly SOC could be stabilized for long-term carbon sequestration. The content of organic C has long been recognized as a key component of soil quality (Reeves, 1997) and thus SOC maintenance in cropland soils is a major determinant of the productivity and long-term stability of agricultural systems (Carter, 2002). SOC storage has been widely considered as a promising measure for mitigating global climate change through C sequestration in soils (Lal, 2004). Moreover, particulate organic carbon (POC) can be used as an indicator of soil quality rather than total organic matter (Cambardella and Elliott, 1992; Chan, 2001). In temperate and some tropical soils, tillage, irrigation, and chemical fertilizers have been used to complement and even enhance the functions of soil organic matter SOM (Sanchez and Miller, 1986). The reduction in SOM content can be due to increased soil erosion, faster SOM mineralization and oxidation of SOC, smaller quantities of organic inputs and/or more easily decomposed organic inputs in managed systems as compared to natural forests. In some managed systems, however, increases in SOM contents have occurred due to improvements in plant productivity and the consequent increases in additions of above- and below-ground organic inputs to the soil (Sanchez *et al.*, 1982; Lugo and Brown, 1993). Soil organic matter is an essential component with key multifunctional roles in soil quality and related to many physical, chemical and biological properties of soil (Smith *et al.*, 2000). Losses and gains of SOM are influenced by land-management practices such as cropping frequency (Campbell *et al.*, 1995), reduced tillage (Reicosky *et al.*, 1995), fertilizer application (Gregorich *et al.*, 1996), manure application (Sommerfeldt *et al.*, 1988) and also by cultivation of perennial legumes and grasses (Campbell *et al.*, 1991). Optimum levels of SOM can be managed through crop rotation, fertility maintenance including use of inorganic fertilizers and organic manures, tillage methods, and other cropping system components (Purakayastha *et al*., 2008). Among these, management practices, proper cropping systems and balanced fertilization are believed to offer the greatest potential for increasing soil organic carbon (SOC) storage in agricultural soils (Lal, 2002). Because of large pool sizes and inherent spatial variability, SOC change slowly with management practices (Franzluebbers *et al.*, 1995). Therefore, measurement of SOC alone may not adequately reflect changes in soil quality and nutrient status (Franzluebbers *et al.*, 1995; Bezdicek *et al.*, 1996). The turnover rate of different fractions of SOC determines the potential carbon storage and loss in the soil. During the last few decades, researchers have identified specific soil organic matter fractions with functional significance in the turnover of soil (Janzen *et al.*, 1992; Fortuna *et al.*, 2003). Among these fractions, soil microbial biomass C and water-soluble C fractions are the most active and labile pools, which have short turnover times (Janzen *et al.*, 1992). Active (or labile) C such as potentially mineralizable C (PMC) that indicate microbial activity and C mineralization and microbial biomass C (MBC) that refer to microbial biomass, change seasonally (Franzluebbers *et al.*, 1995; Franzluebbers *et al.*, 1997). Similarly, particulate organic C (POC) that represents coarse organic matter and considered as intermediate C levels between slow and active fractions, provide substrates for microbes and influence soil aggregation (Cambardella and Elliott, 1992; Six *et al.*, 1999). SOC is closely associated with a wide range of physical, chemical, and biological properties of soil and thus plays a critical role in soil processes and functioning (Smith *et al.*, 2000). Balanced use of NPK fertilizer either maintained or enhanced the SOC over the initial values. Soil organic C constitutes a large pool of C in the global C cycle representing a dynamic balance between C inputs through photosynthesis and deposition and losses via respiration, erosion and leaching. Soil organic C storage may be increased directly by increasing C returns to the soil as crop residue, manure or other organic amendments. Carbon inputs to the system also may be increased indirectly by fertilization or irrigation treatments that increase crop productivity, biomass and root production (Stewart *et al.*, 2007). Crop residues returned to croplands can sustain soil organic carbon (SOC) content and improve soil fertility and biological activity (Cayuela *et al.*, 2009). Predicting carbon (C) mineralization of crop residues returned to soils is important for forecasting carbon dioxide (CO_2) emissions into the atmosphere and soil nitrogen (N) availability. It is therefore important to predict the C mineralization of residues returned to soils and the associated nitrogen (N) mineralization (Li *et al.*, 2013). Carbon mineralization of crop residues is an important process because it regulates carbon dioxide (CO_2) emissions into the atmosphere and releases nutrient elements essential to crop growth (Raiesi, 2006; Guntiñas *et al.*, 2011). The management induced changes in SOC is more frequently evidenced to the changes in the labile fractions of C. In this regards, dissolved organic C (DOC) and water-extractable organic C (WEOC) account for only a small proportion of the total organic matter in the soil (McGill *et al.*, 1986). Dissolved organic C is probably the most bioavailable fraction of soil organic matter (Marschner *et al.*, 2002). Numerous biotic and abiotic factors control the temporal and spatial dynamics of DOC and WEOC (Kalbitz *et al.*, 2000; Murphy *et al.*, 2000). Land use and related management practices affect soil properties, and thereby are likely to influence DOC and WEOC. However, their impacts on the amount and composition of DOC and WEOC have not been extensively studied, and the information appears fragmented and sometimes contradictory. Many studies report significant fluctuations in DOC and WEOC following a change in land use or management practices. However, the processes driving the effects are largely unknown. Soil microbes are the living part of soil organic matter and play critical roles in soil C and N cycling and ecosystem functioning (Doran, 1987). They serve as both source and sink of plant nutrients (Dalal, 1998). The activity of soil microbes greatly influences short-term dynamics and long-term stability of organic matter in soil. Microbes are usually C-limited in agricultural soils (Smith and Paul, 1990), and microbial biomass and activities are thus closely related to labile organic C in soil. It is well-known that soil microbial biomass and activity respond sensitively to changes in organic C levels or quality resulting from agronomic practices and other disturbances (Powlson *et al.*, 1987; Lundquist *et al.*, 1999; Tu *et al.*, 2006). High microbial activities are inherently coupled to high C turnover and CO_2 release; thus management practices that reduce microbial access to organic matter should promote soil C accumulation. Labile soil organic carbon fractions are important indicators of soil C dynamics, which is

affected by different management practices (Mi *et al.*, 2016). Fertilization, as another most common management practice, can also alter the aggregate distribution, and, in turn, affect the quality and quantity of SOM significantly (Aoyama *et al.* 1999; Manna *et al.* 2006). It is known that (SOM dynamics are sensitive to fertilizations, but it is different from soil to soil (Chen *et al.*, 2009). High levels of SOC have beneficial effects on crop productivity (Rasmussen and Parton, 1994; Pan *et al.*, 2003; Yang *et al.*, 2012). Hence, SOC dynamics monitoring in agricultural soils is very important. However, short-term changes in SOC are difficult to measure against the large background of relatively stable organic C in soil (Haynes, 2005). Manure application is also an important management practice to improve the nutrient status of soil and increase the content of soil organic matter (SOM) and soil organic carbon (SOC) (Knights *et al.*, 2000; Yang *et al.*, 2004). Some of the soil C fractions, such as microbial biomass C (MBC) (Nannipieri *et al.*, 1990), particulate organic C (POC) and potentially mineralizable C (Powlson and Jenkinson, 1981; Camberdella and Elliott, 1992), and KMnO4 oxidizable C (Blair *et al.*, 1995) are likely to be more sensitive to management practices than the total SOC (Campbell *et al.*, 1997). This labile organic C fraction represents a small proportion of SOC, and is characterized by rapid turnover times and responds more quickly to changes than SOC (Blair *et al.*, 1995; Needelman *et al.*, 1999). Rudrappa *et al.* (2006) found that balanced fertilization (NPK) is more effective on enhancing C accumulation in soil than unbalanced fertilization (N or NP). Mineral fertilizer application could potentially increase soil C concentration since the increased yields resulting from fertilizer application can lead to increased residue and root addition to the soil organic C pool (Riley, 2007). Soil management induced changes on the equilibrium between input of primary OM and decomposition, e.g. by additional input of OM from plants or manure on one hand, or by enhanced aeration due to tillage on the other, lead to measurable changes in OC contents of organic–mineral fractions (Schulten and Leinweber, 2000).

Long-term experiments provide opportunities for monitoring changes in crop yields and nutrient balances and identifying the factors associated with such changes and hence can serve as means to evaluate sustainability of the management systems in agriculture. Number of long term manurial experiments has been used to monitor changes in soil C pool and nutrient dynamics in rice based production systems

(Mohanty *et al.*, 2013). Long term studies have shown that practices like improved fertilizer management, manuring and compost application, residue incorporation, crop rotation, green manuring, reduced tillage, adjusting irrigation method and restoration of waste land enhanced soil carbon build up and storage (Kimble *et al.*, 2002). These practices not only promote sustainable agriculture but also mitigate the impact of climate change through both carbon sequestration and minimized emissions of GHGs (Nayak *et al.*, 2012). Long-term field experiments (LTFEs) provide direct observations of changes in SOC storage and N balance over the decades and are critical for predictions of future soil productivity and soil–environment interactions (Richter *et al.*, 2007). It focuses on effects of fertilization on soil quality, fertility and productivity had been carried out by different agronomist under various type of soil and cropping systems (Blair *et al.*, 2006a,b; Kundu *et al.*, 2007). Although the effects of fertilization on SOC and soil structure have been well documented, previous studies focused mainly on the total soil C pool (Haynes and Naidu, 1998; Lal, 2003). Less is known about the responses of SOC fractions to long-term fertilizer application (Sleutel *et al.*, 2006). Since SOC fractions with variable physical and biochemical properties are characterized by differential stabilities and turnover rates (Baldock *et al.*, 1997), it is needed to examine the effects of fertilizer management on SOC fractions to assess whether the sequestered C can be stored in the long-term.

Rice-wheat cropping system is one of the largest agricultural production systems of the world occupying 13.5 million ha (Mha) of cultivated land in the Indo-Ganetic Plains mainly in Inceptisols and other areas representing Molliols, Vertisols and Alfisols of India. Integrated nutrient management system envisages the combined use of synthetic/chemical fertilizers in conjunction with organic manures (farm yard manure, compost, poultry manure, city waste compost etc.), legumes in cropping systems (as green manure/fodder/vegetable etc.), bio-fertilizers is thought of as an alternative nutrient supply system instead of using high analysis chemical fertilizers alone. The long-term application of various organic sources in conjunction with chemical fertilizer might be having differential response to SOC as well as labile component of SOC in contrasting soil types (e.g., Inceptisols, Mollisols, Vertisols and Alfisols) located in different climatic condition. Litter decomposition plays an important role in carbon (C) cycling in terrestrial ecosystems (Aerts 2006; Field *et al.* 1998; Shiels 2006). One noteworthy feature of litter decomposition is the variability

of litter decomposition rate (k) among ecosystems and under different climatic conditions. This might be responsible for variations in expected build-up of C in soil and their degradability. For a given set of biotic and abiotic conditions, the turnover of different SOM pools depends mechanistically on the quality and biochemical recalcitrance of the organic matter and its accessibility to decomposers. With other factors equal, clay soils retain more SOM with longer mean residence times (MRTs) than do sandy soils (Sorensen, 1974). Readily decomposable materials can become chemically protected from decomposition by association with clay minerals and by sorption to humic colloids (Christensen *et al.*, 1992, Jenkinson *et al.*, 1988). Clay mineralogy also plays an important role. For example, montmorillonitic clays and allophanes generally afford more protection than illites and kaolinites (Dalal *et al.*, 1996). Relatively labile material may become physically protected by incorporation into soil aggregates (Tisdal *et al.*, 1982) or by deposition in micropores inaccessible even to bacteria. Soil microorganisms control organic carbon (C) sequestration and decomposition in soils, and therefore have a strong impact on the terrestrial C cycle. While abiotic controls of soil organic C sequestration have been intensively studied during the last two decades (Sollins *et al.*, 1996; Lützow *et al.*, 2006), the importance of the microbial processing of organic C i.e., C utilization efficiency (CUE) has only recently received more attention (Schmidt *et al.*, 2011). Yet, the ecophysiology of microbial C cycling is still little understood which is in part due to methodological restrictions (Dilly, 2005; Ekschmitt *et al.*, 2005). Recently Spohn *et al.* (2016) reported that either a decrease in microbial CUE or a decline in the microbial turnover time will cause enhanced soil C losses while factors triggering increases in microbial CUE or in microbial turnover time may increase soil C sequestration. The interaction of SOC and added carbonaceous substrate is quite complex and is mainly governed by substrate quality and available nutrients in soils. The preservation of native SOC at equilibrium is mainly controlled by the positive or negative priming effect (PE) accelerated by the above factors. Mechanisms governing the direction of PE are still unclear (Georgiou *et al.*, 2015) but nutrient availability has been suggested to play a decisive role (Jia *et al.*, 2017). Under high nutrient availabilities, microbes switch from SOM decomposition to labile OC utilization, leading to negative priming (“preferential substrate utilization” hypothesis; Blagodatskaya *et al.*, 2007). On the opposite, under low nutrient availabilities soil microbes utilize labile OC to synthesize extracellular enzymes for the acquisition of nutrients from SOM, thereby leading to positive priming ("microbial nutrient mining" hypothesis; Craine *et al.*, 2007). The balance between the PE of native SOC and CUE is extremely vital for short term C sequestration.

With this background the All India Coordinated Research Project on Integrated Farming System located in Pantnagar (Mollisols), Ludhiana (Inceptisols), Jabalpur (Vertisols) and Ranchi (Alfisols) with rice-wheat cropping system for all the locations except Ranchi having maize-wheat cropping system was used for the present study. In this study we attempted to address the issues of long term impact of manuring and fertilization on labile carbon and carbon utilization efficiency by microbes and priming effect on native SOC in four major soil groups of India as stated above with the following objectives.

i. To study long-term manuring and fertilization effects on C-mineralization in four major soil groups of India.
ii. To correlate the water extractable organic carbon and $KMnO_4$ oxidisable C with mineralizable C in soil.
iii. To study the size of mineralizable C on C-utilization efficiency by microbial community.

CHAPTER 2

Review of Literature

2. BACKGROUND

The literature pertinent to the present investigation entitled, **"Long term impact of manuring and fertilization on labile carbon and carbon utilization efficiency of microbes in four major soil groups of India"** have been reviewed in this chapter under the following heads:

2.1 C-mineralization as affected by different management

2.2 Labile soil C fractions

2.3 Carbon utilization efficiency

2.4 Priming effect on soil organic C

2.1 C-mineralization as affected by different management

Mineralizable part of soil organic C (SOC) considered as labile fraction is influenced by various soil and crop management practices. Long-term manuring and fertilization might cause a visible change in this labile C fraction as the change in more recalcitrant fraction of SOC is very slow.

Mohanty *et al.* (2013) conducted a incubation study with soils (0-15 cm and 15-30 cm depth), collected from 41 years of rice-rice system to evaluate the differences in C and N mineralization kinetics due to long term fertilization treatments and showed that long term integrated application of chemical fertilizer and organic manure (NPK + FYM, N + FYM) in soil resulted in higher potentially mineralizable C (C_0), potentially mineralizable N (N_0), rates of mineralization (dCmin/dt and dNmin/dt), microbial and mineralization quotients as compared to either of them applied alone (N, NPK, and FYM). This indicated that long term application of FYM along with inorganic fertilizer maintained soil organic C pool and improved the N supplying capacity of soil in comparison to fertilizer alone and FYM alone.

Land use induced significant changes in the cumulative CO_2 production which showed the highest values for agricultural soils (300 µg C–CO_2 g^{-1} 28 d^{-1}) and the lowest for grassland soils (120 µg C–CO_2 g^{-1} 28 d^{-1}). In agricultural soils, a large availability of potentially mineralizable C (C_0) was determined. Grassland soils were characterized by a high stability of soil organic matter (SOM) and consequently a low mineralization activity. The management practices did not affect C mineralization activity even if total nitrogen and soil C/N ratio varied between the two soils (Moscatelli *et al.*, 2007).

Li *et al.* (2013) conducted a laboratory incubation experiment to investigate C mineralization of residues of soybean (Glycine max), maize (Zea mays), and their mixture placed on the soil surface and incorporated into the soils in a Mollisol in northeast China and observed that maize residue had lower C mineralization rates than soybean residue due to low N concentration and thus net N immobilization during maize residue decomposition; non-additive effects on the contribution of each residue type to C mineralization of the residue mixture were not observed. In addition, the C mineralization rate was higher when the residues were placed on the soil surface compared to those incorporated into the soils, most likely due to the limitation of O_2 or N availability.

The long-term effects of temperature on soil C mineralisation were investigated in two experiments using ^{14}C labelled wheat straw incubated in organic soils from five coniferous forests located in different climate zones of Western Europe. The incubation temperatures for samples in the first experiment were 4, 10, 16, 23 or 30ºC, with constant moisture, and the loss of ^{14}C was monitored for 550 days in the laboratory. Double negative exponential functions fitted to the ^{14}C loss data at different temperatures were used to define the relative proportions of labile and recalcitrant components in the original straw. The estimated proportions of these constituents were related to incubation temperatures with the amount of C reflecting the labile fraction increasing with increasing temperature. The incubation temperatures for samples mixed with the labelled straw in the second experiment were 4, 16 or 30ºC until the same percentage of ^{14}C loss was reached. The samples were then incubated again at a common temperature for 30 days and CO_2 production was measured to assess the lability of the remaining material. For all the soils, the amount of readily decomposed material was higher in samples conditioned at 4º than at 30ºC. The conclusion was drawn as temperature not only controls rates of C mineralisation in soil but also affects the processes of decomposition so that material produced at higher temperatures was more recalcitrant than at lower temperatures (Dalias *et al.*, 2001).

Cai and Qin (2006) analyzed the dynamics of soil organic carbon content (SOC) in a long-term fertilization experiment carried out in the Huang-Huai-Hai Plain of China. Their study comprised of 7 treatments which included 4 combinations of inorganic fertilizer i.e. NPK, NP, PK, NK; 2 combinations of organic fertilizers i.e. ON, 1/2ON (1/2 each of organic and inorganic fertilizer) and as well as a control plot. It was found that, based on the type of carbon inputs in the 14yr old experiment from 1989 to 2003, the SOC content in 2003 almost reached the equilibrium values in PK and ON. There was still space for NPK, NP and 1/2ON to reach the SOC content at equilibrium (SOCe). The corresponding decomposition rate constant (k) varied greatly. The values of k in PK, NK and CK were very close to that obtained in native prairie (control) of 0.02 yr^{-1} (Huggins *et al.*, 1998), while the values in 1/2ON and ON were as large as 0.11 and 0.18 yr^{-1}, respectively. An exponential increase of SOC decomposition rate with the increase in SOC content was seen to be a critical factor that resulted in low SOC content at equilibrium.

2.2 Labile soil C fractions and relationships with C mineralization

Soil total organic carbon (TOC) and SOC pools including hot water-soluble organic C (HWOC), microbial biomass C (MBC), water-extractable organic C (WEOC), mineralizable organic C (Cmin), potassium permanganate oxidizable organic C ($KMnO_4$-C), and the oxidizable fractions of decreasing oxidizability (easily-oxidizable, oxidizable, and weakly oxidizable) were investigated as sensitive parameters to the application of organic manure, rice straw, and inorganic fertilizer nitrogen (N) in an 11-year field experiment under rice-wheat system by Benbi *et al.* (2015). After 11 years of experiment, WEOC, HWOC, and $KMnO_4$-C were 0.32%–0.50%, 2.2%–3.3%, and 15.0%–20.6% of TOC, respectively. The easily-oxidizable, oxidizable, and weakly-oxidizable fractions were 43%–57%, 22%–27%, and 10%–19% of TOC, respectively. There was improvement in WEOC, HWOC, KMnO4-C, easily-oxidizable fraction, Cmin, and MBC by applications of farmyard manure and rice straw. During the 11-year period, the greatest increase was observed in WEOC and the minimum in $KMnO_4$-C. WEOC exhibited a relatively greater sensitivity to management than TOC, suggesting that it may be used as a sensitive indicator of management-induced changes in soil organic matter under rice-wheat system. All other labile SOC pools had the same sensitivity to management as TOC. Most of the SOC pools were positively correlated to each other though their amounts differed considerably. Long-term applications of farmyard manure and rice straw resulted in build-up of labile as well as the recalcitrant pool of SOC, suggesting the need for continued application of organic amendments for permanence of the accrued C under the experimental conditions.

Zsolnay (1996) indicated that DOM/ WEOM concentration tends to be larger in forest than in agricultural soils. He reported that in forest floor, DOC concentration ranges from 5 to 440 mg l^{-1}, whereas WEOC content ranges from 1000 to 3000 mg l^{-1}. In agricultural soils, he reported values varying from 0 to 70 mg l^{-1} for DOC and from 5 to 900 mg l^{-1} for WEOC. Several studies that have compared forest to agricultural soils using either paired or unrelated sites have confirmed that the forest floor produces larger amounts of DOM/WEOM and generally shows higher concentrations than the A horizon of arable (Ne´meth *et al.*, 1988; Ellert and Gregorich, 1995; Quideau and Bockheim, 1996; Delprat *et al.*, 1997) or grassland soils (Hughes *et al.*, 1990; Quideau and Bockheim, 1997; Khomutova *et al.*, 2000). Nevertheless, on the long term, DOM/WEOM content tends to be proportional to the whole soil organic matter content (Saviozzi *et al.*, 1994; Delprat *et al.*, 1997; Gregorich *et al.*, 2000), suggesting that DOM/WEOM production and concentration should be determined primarily by the amount of organic matter present in soil (Zsolnay, 1996; Kalbitz *et al.*, 2000)(Chantigny, 2003).

Liming has been found to influence DOM/WEOM. An increase is generally recorded following liming of agricultural soils (Karlik, 1995). Urea-based and ammonium-based fertilizers temporarily solubilize soil organic matter and can induce a marked increase in DOC/WEOC content due to an increase in soil pH (Hartikainen and Yli-Halla, 1996; Liu *et al.*, 1995; Myers and Thien, 1988). Under field conditions, many authors have reported no consistent effect of N fertilization on DOM in forest soils (Emmett *et al.*, 1998; Gundersen *et al.*, 1998). McDowell *et al.* (1998) proposed that N fertilization of forest soils would stimulate DOC consumption by microbes, but under field conditions, this material would be replaced at the same rate by the decomposition of fresh litter, root exudation, and microbial by-products.

Conflicting results are reported under field conditions on the effect of N fertilization on WEOM in agricultural soils. Some studies report no significant effect (Zsolnay and Gorlitz, 1994; Rochette and Gregorich, 1998), whereas others report a decrease (Mazzarino *et al.*, 1993; Liang *et al.*, 1998) or an increase in WEOC content (Campbell *et al.*, 1999b; McTiernan *et al.*, 2001). Over the long term, repeated inorganic N applications have not been found to significantly influence the amount of

DOM in forest (Gundersen *et al.*, 1998; Yano *et al.*, 2000) or in agricultural soils (Zsolnay and Gorlitz, 1994). Nevertheless, comparing various cropping systems with and without N fertilization, Campbell *et al.* (1999a, b) reported a greater WEOC concentration in long-term plots with N additions. They attributed this increase to a greater crop residue input in fertilized soils than in unfertilized soils (Chantigny, 2003).

Majumdar *et al.* (2007) investigated the dynamics of SOC pools viz., total organic carbon, oxidisable organic carbon and its four different fractions such as very labile, labile, less labile and non-labile carbon, microbial biomass carbon, mineralizable carbon, and particulate organic carbon in relation to crop productivity using a 34 year old rice−wheat−jute cropping system with different management strategies in the hot humid, subtropics of India. They reported that cultivation over the years caused a net decrease, while balanced fertilization with NPK maintained the SOC pools at par with the fallow. Only 22% of the C applied as FYM was stabilized into SOC, while the rest got lost.

Application of graded doses of NPK from 50% to 150% in the maize–wheat–cowpea cropping system in semiarid, sub-tropical India, significantly enhanced SOC, particulate organic C (POC) and $KMnO_4$ oxidizable C ($KMnO_4$–C) fractions in soil. Also, the increase in these C fractions was greater when FYM was applied conjointly with 100% NPK (Hati *et al.*, 2007).

Moharana *et al.* (2012) reported that integrated use of FYM and NPK fertilizer using STCR based targeted yield approach increased soil fertility and pools of soil organic carbon. The highest values of TOC and Walkley Black Carbon were maintained in FYM treated plot, while the highest values of Labile Carbon and MBC (273 mg kg−1) were found in FYM + NPK. Highly strong relationships were exhibited between LBC and MBC with yield, indicating that these pools are more important for nutrient turn over and their availability to plants than total SOC.

Purakayastha *et al.* (2008) reported that impact of long term manuring and fertilization on changes in different SOC fractions over ten years period in a Typic Haplustept under maize–wheat–cowpea cropping system with graded dose of NPK from 50% to 150% significantly enhanced SOC, POC and $KMnO_4$ oxidizable carbon fractions in soil. Soil organic carbon fractions were greater when FYM was applied conjointly with 100% NPK in 0–45 cm soil depth. Compost application, even once a year, invariably led to higher increments in both SOC and microbial pools and the combinations of chemical fertilizers with compost generally showed comparable effects in the long term experiments.

Manna *et al.* (2006) reported that particulate organic carbon (POC) and nitrogen (PON) decreased significantly in control, N and NP application over fallow and continuous use of NPK + FYM or NPK + lime would sustain yield in a soybean–wheat system without deteriorating soil quality in the Long Term Fertilizer Experiment.

Balota *et al.* (2004) observed that total C was increased by 45%, microbial biomass by 83% and MBC:total C ratio by 23% in no tillage (NT) at 0–5cm depth over conventional tillage (CT). C and N mineralization increased 74% with NT compared to CT systems for the 0–20cm depth. Under NT, the metabolic quotient (CO_2 evolved per unit of MBC) decreased by 32% averaged across soil depths suggesting microbial population in CT were more metabolically active than the NT systems. In the long-term tillage management under tropical conditions these soil microbial properties were shown to be sensitive indicators.

The application 150% NPK showed higher total organic C (TOC) (12.9 g C kg^{-1}) over either 50% NPK (9.3 g C kg^{-1}) or 100% NPK (10.0 g C kg^{-1}) in 0–15 cm soil layer. There was an improvement in TOC in 100% NPK or 100% NP (9.3 g C kg^{-1}) over 100% N (8.7 g C kg^{-1}) in the same depth. The application of FYM with 100% NPK showed 15.2, 9.9 and 5.2 g C kg^{-1} in 0–15, 15–30 and 30–45 cm, respectively. Graded doses of NPK from 50 to 150% of recommendation NPK significantly enhanced other organic C fractions like, microbial biomass C (MBC), particulate organic C (POC) and $KMnO_4$ oxidizable C ($KMnO_4$–C) in all the three soil depths. The TOC in 0–45 cm soil depth in 150% NPK (63.5 Mg C ha^{-1}) was increased by 39% over that in 50% NPK treatment (51.5 Mg C ha^{-1}) and 29% over that in 100% NPK treatment (54.1 Mg C ha^{-1}). Integrated use of farmyard manure with 100% NPK (100% NPK + FYM) was found out to be the most efficient management system in accumulating largest amount of organic C (72.1 Mg C ha^{-1}) in soil. Nevertheless, this treatment also sequestered highest amount of organic C (731 kg C ha^{-1} $year^{-1}$). Microbial metabolic quotient (qCO_2) was significantly lower in 100% NPK + FYM over other treatments to indicate this to be the most efficient manuring practice to preserve organic carbon in soil where it facilitates aggradations of more recalcitrant organic C in soil. As compared to POC, total TOC proved to be a better predictor of MBC as it strongly correlated with total carbon mineralized from soil (Rudrappa *et al.*, 2006).

Manna *et al.* (2006) observed the negative yield trend in unbalanced use of inorganic N and NP application at all the three sites i.e. Barrackpore (Typic Eutrochrept), Ranchi (Typic Haplustalf) and Akola (Typic Haplustert), respectively. The yield trend was positive as observed in the NPK and NPK + FYM treatments at Ranchi and Akola. Results showed that the SOC in the unfertilized plot (control) decreased by 41.5, 24.5, and 15.5% compared to initial values in Barrackpore, Ranchi and Akola, respectively, wherein the treatment receiving NPK and NPK + FYM either maintained or improved it over initial SOC content in these sites. There was an increase or maintenance of SOC content in the treatment receiving NPK and NPK + FYM compared to the unfertilized plot (control) where SOC decreased by 41.5, 24.5, and 15.5% compared to initial values in Barrackpore, Ranchi and Akola, respectively. Active fractions of SOC, viz., water-soluble carbon and soil microbial biomass C and N improved significantly with the application of NPK and NPK + FYM. The estimated annual C input values in NPK + FYM treatments were 4392, 4159 and 3113 kg ha^{-1} year^{-1} in rice–wheat–jute, sorghum–wheat and soybean–wheat system, respectively.

The SOC, TN and labile SOM fractions were affected by management systems and N fertilization. Management systems had greater effects on total SOM and its fractions than did N fertilization. Compared with traditional farming practices, the two ISSM systems increased SOC, TN, labile SOM fractions and CMI. Appropriate N fertilization application (N150) resulted in higher SOC and TN. Though N application increased DOM−N, it was prone to decrease most of the other labile SOM fractions (POM−C, POM−N, DOM−C, MBN, $KMnO_4$−oxidizable C), especially under higher N rate. Our study indicates that those recently developed integrated soil crop system management in rice rapeseed rotation was suitable for improving soil organic matter. Nitrogen rate is a key factor in affecting labile SOM fractions. There is a need to evaluate the long-term integrated soil crop management and N fertilization for the environmental effects (e.g. greenhouse gas production) in rice−rapeseed rotations (Tian *et al.*, 2013).

Mi *et al.* (2016) observed that cattle manure showed the most profound effect on TOC, TN and labile organic C fractions and produced the highest 4-year average rice grain yield (9.67 t ha^{-1}). The cattle manure combined with NPK resulted in the highest level of TOC (19.2 g kg^{-1}) and TN (1.86 g kg^{-1}) in the surface soil (0–5 cm). Additionally, $KMnO_4$-C and MBC concentrations in the cattle manure plus NPK treatment were 1.3 and 1.5 times higher at the 0–5 cm depth, 1.4 and 1.6 times higher at the 5–10 cm depth, 1.2 and 1.4 times higher at the 10–20 cm depth compared to NPK fertilizer alone, respectively. However, POC was not sensitive to different management practices in the deeper soil layer (10–20 cm). DOC was not significantly affected by fertilization in the 0–20 cm soil layer, suggesting it was unsuitable as an early indicator of soil quality.

Dong *et al.* (2008) evaluated the effect of long-term continuous application of chemical fertilizers on microbial biomass and functional diversity of a black soil (Udoll in the USDA Soil Taxonomy) in Northeast China and concluded that the soil microbial biomass C ranged between 94 and 145 mg kg$^{−1}$, with the NK treatment showing a lower biomass probably due to its lowest available P content.

Li *et al.* (2010) evaluated the long term fertilization effects of different treatments like NPK, NPKRS (NPK and rice straw), NPK2RS (NPK and double amount of rice straw), NPKPM (NPK and pig manure), and NPKGM (NPK and green manure (Astragalus sinicus L.)) in rice-rice cropping system in subtropical china and observed that application of chemical and organic fertilizers sustained relatively high rice productivity. After rice cultivation, SOC and total N increased linearly with cultivation years, and accumulated only in surface layer steadily but slowly. SOC and total N contents of surface soil increased linearly with cultivated years from 3.9–5.7 g kg^{-1} and 0.46–0.57 g kg^{-1} in initial stage to 7.1–9.2 g kg^{-1} and 0.87–0.95 g kg^{-1} in 2005 respectively. From 1991 to 2006, average annual yield ranged from 7795 to 8572 kg ha^{-1} among different fertilizer treatments. Organic amendments usually enhanced rice yields significantly except for the treatment with NPKRS.

Li *et al.* (2008) evaluated effects of Long-Term combined application of organic and mineral fertilizers on microbial biomass carbon (MBC) on a 15-year long-term fertilizer experiment in Drab Fluvo-aquic soil in Changping County, Beijing, China. In different fertilization treatments MBC changed from 96.49 to 500.12 mg kg^{-1}. Compared to the control, the other treatments increased MBC,

MBC/organic C ratios. In general, the application of mineral fertilizers plus swine manure or straw increased microbiological activities, MBC and it was positively correlated with soil chemical properties like soil organic matter, soil total nitrogen and soil total phosphorus.

Sharma *et al.* (2014) conducted a study to assess the impact of different land use systems on labile C pools like Potassium permanganate oxidizable (KOC) and microbial biomass carbon (MBC) and soil organic carbon stocks in the foothill Himalayas. The results showed the trend forest N>horticulture N>agriculture N>degraded lands in each of the depths for KOC and MBC both. There was decrease of carbon content with depth, being sharpest for agricultural soils, where the values in the lowest depth (30–50 cm) were nearly 50% (MBC and SOC) or over 50% (KOC) of that in surface. Among the different carbon pools KOC seemed to be strongly related with soil textural properties including CEC, but overall it seems that land use played a major role in determining C levels in soils.

The results of the long-term experiment on the Heilu soil indicated that manure alone and manure + N+P fertilizer treatments restored TOC and MB-C to the level of the native sod, indicating the importance of manure addition in maintaining soil fertility over the long term (20 years). The straw return + N+P fertilizer treatment had a significantly higher TOC than N+P fertilizer alone. Organic matter additions in the form of manure or straw, either alone or in combination with chemical fertilizers, appears to be more effective in maintaining or restoring organic matter in Heilu soil on the Loess Plateau than chemical fertilizer alone (Wu *et al.*, 2004).

Samples from all fields were separated into five size and density fractions. Fertilization had a distinct influence on both the OC amount present in the free particulate organic matter (POM) fractions and their relative proportion on the whole-soil OC compared to an unfertilized control treatment. This increase in OC was equal or smaller for the POM occluded in micro aggregates (53–250µm) and much smaller for the amount of OC present in the silt + clay sized fraction (Slutel *et al.*, 2006).

Yan *et al.* (2007) evaluated the long-term fertilization on labile organic matter fractions and the results showed that fertilizer N decreased or did not affect the C and N amounts in soil fractions, except N mineralization and soil total N. The C and N amounts in soil and its fractions increased with the application of fertilizer PK and rice straw. Furthermore, application of manure was most effective in maintaining soil organic matter and labile organic matter fractions. Soils treated with manure alone had the highest microbial biomass C and C and N mineralization. A significant correlation was observed between the C content and N content in soil, POM, LFOM, microbial biomass, or the readily mineralized organic matter. The amounts of POM–C, and LFOM–C closely correlated with soil organic C. Microbial biomass C was closely related to the amounts of POM–C. there is a close correlation of MBC with POM rather than SOM. Carbon mineralization was closely related to the amounts of POM–N, POM–C, microbial biomass C, and soil organic C.

Rudrappa *et al.* (2006) carried out an experiment to assess the influence of long-term applications of fertilizers and manures on different organic C fractions in a Typic Haplustept under intensive sequence of cropping with maize–wheat–cowpea in a semiarid sub-tropic of India. In this, they also studied the relationships between different organic fractions of soil. Correlation coefficients between different organic C fractions were found to be dissimilar in the three soil depths (0-15, 15-30, 30-45cm). High correlation between total organic carbon and particulate organic carbon (POC), microbial biomass carbon (MBC), $KMnO_4$ oxidizable C and mineralized C (Cmin) in soil were found. The correlation coefficients were higher in surface than in sub-surface soils. . The extent of correlation between TOC and POC was greater in 30–45 cm than in either 0–15 or 15–30 cm. This indicated that the POC was well protected in 30–45 cm soil layer. As the soils of other two depths were disturbed very frequently as a part of plough layer, the residence time of POC (a physically protected organic C) in these soil depths was reduced. On the contrary, MBC, $KMnO_4$–C and Cmin values were highly correlated with TOC in surface soil. As the total C input in surface soil is greater than that in sub-surface soil, the chances of accumulation of more labile C in surface soil are higher. Microbial biomass C and POC were linearly related to TOC. The correlation between TOC and MBC ($R^2 = 0.90$) was higher than that between POC and MBC ($R^2 = 0.82$). This suggests that POC was largely of older in origin. However, an opposite trend was reported in a no-till experiment (Cambardella and Elliott, 1994; Gregorich *et al.*, 1994). Such a relationship also indicates that MBC is dependent on other labile C pool. In the present study, MBC was found highly correlated with $KMnO_4$–C. The extent of correlation between MBC and Cmin was greater in surface than in sub-surface soil. This clearly indicates differential pattern of accumulation of various organic C pools in different soil depths. Two labile pools, i.e. $KMnO_4$–C and Cmin also significantly correlated. Therefore, $KMnO_4$–C could well be considered as labile pool as was reported by Blair *et al.* (1995).

The relation of MBC with water soluble C and Total soil organic C has been studied by Zak *et al.*, 1990 in Cedar Creek Natural History Area (CCNHA) located at north of Minneapolis, Minnesota in east-central Minnesota. They found a significant positive correlation between microbial biomass C and organic C (r^2=0.886), H_2O soluble C (r^2= 0.874). The linear relationship between soil C pools and microbial biomass in the old microbial C:organic C = 1: 100; microbial C:H_2O-soluble C = 5: 1). If H_2O-soluble C is readily metabolized by an active microbial population, then pool turnover should be rapid because it was consistently 20% of microbial C.

2.3. Carbon utilization efficiency

The crop residues management has become one of the important aspects of sustaining long-term fertility in cropping systems. Crop residues incorporation can change microbial processes, which affect availability of nutrient and crop yield. Carbon (C) use efficiency of soil microbes during decomposition of rice straw was determined in a paddy soil, under aerobic and anaerobic (flooded) conditions at different temperatures (5, 15, and 25ºC). Flooding had a tendency to reduce C mineralization and enhance methane (CH_4) production; however, with decreasing temperature CH_4 production became negligible. This study showed that fermentation waste products were recycled by anaerobes during the long-term incubation resulting in a lower net residue-C mineralization in flooded systems compared to non-flooded conditions. As a result, it was observed that microbial production was similar under flooded and non-flooded conditions even though anaerobes decomposed less straw-C than aerobes. These results indicated that less straw-C was mineralized compared to aerobic conditions due to higher substrate use efficiency under flooded conditions even if the decomposition was significant. Analysis of kinetics of C mineralization curves confirmed that the C mineralized in the flooded treatment was mainly from labile pools with significant amounts coming from more recalcitrant pools, such as cellulose and lignin depending on temperature (Devevre and Horwath, 2000).

Carbon metabolism is at the core of ecosystem function. Decomposers play a critical role in this metabolism as they drive soil C cycle by mineralizing organic matter to CO2. Their growth depends on the carbon-use efficiency (CUE), defined as the ratio of growth over C uptake. By definition, high CUE promotes growth and possibly C stabilization in soils, while low CUE favors respiration. CUE decreases as temperature increases and nutrient availability decreases. More limited evidence shows a similar sensitivity of CUE to temperature and nutrient availability in terrestrial decomposers. Increasing CUE with improved nutrient availability might explain observed declines in respiration from fertilized stands, while decreased CUE with increasing temperature and plant C: N ratios might decrease soil C storage (Manzoni *et al.*, 2012).

The Carbon use efficiency (CUE) to make new microbial biomass is an important aspect in soil and ecosystem C cycling models. It is generally assumed that CUE of microbial activity in soils is low, however measured values vary widely. It is hypothesized that in especially short-term incubations CUE of microbes' high values which reflect the build-up of storage compounds in response to a sudden increase in substrate availability and so these are not the exact representative of CUE of microbial activity in unamended soil. This hypothesis was tested by Dijkstra *et al.* (2015) who measured the $^{13}CO_2$ release from six position-specific ^{13}C-labeled glucose isotopomers in ponderosa pine and pinon-juniper soil. Comparison was done between the position-specific CO_2 production pattern with patterns expected for 1) balanced microbial growth (synthesis of all compounds needed to build new microbial cells) at a low, medium, or high CUE, and 2) synthesis of storage compounds (glycogen, tri-palmitoyl-glycerol, and polyhydroxybutyrate). Results showed that instead of synthesis of storage compounds the position-specific CO_2 production is responsible for the observed high CUE. Moreover the position-specific CO_2 production best matches the observed CO_2 production pattern in these two soils.

CUE determines energy and material flows to higher trophic levels, conversion of plant produced carbon into microbial products and rates of ecosystem carbon storage. Thermodynamic calculations support a maximum CUE value of ~ 0.60 (CUE_{max}). Kinetic and stoichiometric constraints on microbial growth suggest that CUE in multi-resource limited natural systems should approach ~ 0.3 ($CUE_{max}/2$).

However, the mean CUE values reported for aquatic and terrestrial ecosystems differ by two fold (~ 0.26 vs. ~ 0.55) (Sinsabaugh *et al.*, 2013).

Very little is known about how microbial CUE is affected by nutrient availability despite the importance of the microbial CUE for the terrestrial C cycle. Therefore Spohn *et al.* (2016) studied microbial CUE and microbial biomass turnover time in soils of a long-term fertilization experiment in a temperate grassland comprising five treatments (control, PK, NK, NP, NPK). A novel substrate-independent method based on incorporation of ^{18}O from labeled water into microbial DNA was used to determine the microbial CUE and the turnover of microbial biomass. All three N treatments (NK, NP, and NPK) had 28-37% smaller microbial respiration compared to the control, whereas the PK treatment did not affect microbial respiration. N-fertilization decreased microbial C uptake, while the microbial growth rate was not affected. Microbial CUE ranged between 0.31 and 0.45, and was 1.3- to 1.4- fold higher in the N-fertilized soils than in the control. The turnover time ranged between 80 and 113 days and was not significantly affected by fertilization. Structural equation modelling revealed that by N fertilization controlled microbial CUE exclusively and that neither NPP (as a proxy for C inputs) nor the abundance of legumes (as a proxy for the quality of the organic matter inputs) had an effect on microbial CUE. Results showed that N fertilization did not only decrease microbial respiration, but also microbial C uptake, indicating that less C was intracellularly processed in the N fertilized soils.

Microbial CUE and turnover of microbial biomass C was determined using a novel substrate independent method based on incorporation of ^{18}O from labeled water into microbial DNA with concurrent measurements of basal respiration. Microorganisms showed decreasing C uptake rates with decreasing C contents in the deeper soil layers. In the forest soils, both top soil and subsoil, there was no adaptation of microbial CUE i.e., microbes used C at the same efficiency in both the layers indicating that microbial CUE is insensitive to organic matter quality but the microbial biomass C had a longer turnover time in the subsoil compared to the topsoil. However pasture soil microbial CUE decreased in the lower soil layers compared to the topsoil indicating that microorganisms in the deeper soil layers allocated relatively more C to respiration. In the organic soil layer, microorganisms respired more per unit microbial biomass C than in the subsoil, but had a similar CUE despite the high C-to-nitrogen and C-to-phosphorus ratios of the litter layers. In the forest soils, a lower microbial C uptake rate in the deeper soil layers was partially compensated by a longer turnover time of microbial biomass C. The turnover time of the microbial biomass in addition to microbial CUE strongly affects soil C cycling (Spohn *et al.*, 2016).

A primary control on soil CO_2 flux is the efficiency with which the microbial community uses C. Frey *et al.* (2013) measured the temperature response of microbial efficiency in soils amended with substrates varying in lability and in response to chronic soil warming *in situ.* They found that the efficiency with which soil microorganisms use organic matter is dependent on both temperature and substrate quality, with efficiency declining with increasing temperatures for more recalcitrant substrates. However, the utilization efficiency of a more recalcitrant substrate increased at higher temperatures in soils exposed to almost two decades of warming 5 ^{o}C above ambient. Their work suggests that climate warming could alter the decay dynamics of more stable organic matter compounds, thereby having a positive feedback to climate that is attenuated by a shift towards a more efficient microbial community in the longer term.

Plant-microbial interactions alter C and N balance in the rhizosphere and affect the microbial carbon use efficiency (CUE)–the fundamental characteristic of microbial metabolism. Blagodatskaya *et al.* (2014) analyzed respiratory activity, microbial DNA content and CUE by manipulating the C and nutrients availability in the soil under *Beta vulgaris*. Microorganisms in the rhizosphere and root-free soil differed in their CUE dynamics due to varying time delays between respiration burst and DNA increase. Constant CUE in an exponentially growing microbial community in rhizosphere demonstrated the balanced growth. In contrast, the CUE in the root-free soil increased more than three times at the end of exponential growth and was 1.5 times higher than in the rhizosphere. Plants alter the dynamics of microbial CUE by balancing the catabolic and anabolic processes, which were decoupled in the root free soil.

2.4 Priming effect on soil organic C

The availability of soil organic C for microbial decomposition is crucial for many processes within the C cycle since it controls the rate of CO_2 flux to the atmosphere, determines the sources contributing to soil CO_2, affects microbial activity and composition, and reflects C sequestration. Soil organic C consists of various heterogeneous pools which differ in their stability and availability and are characterized by particular turnover rates. Older, more recalcitrant C pools are less decomposable by microorganisms in comparison to younger C pools. According to their turnover time various C pools contribute differently to soil CO_2 as the major product of microbial decomposition. The energy rich readily degradable compounds rapidly fuel catabolic and anabolic activities of soil microbes, leading to potential shifts in microbial community composition , and increased (positive priming effect) or decreased (negative priming effect) decomposition of native SOC. Under high nutrient availabilities, microbes shift from SOC decomposition to labile organic C utilization leading to negative priming (Blagodatskya *et al.*, 2007). On the other hand, under low nutrient availabilities, microbes utilize labile organic C to synthesize extracellular enzymes for the acquisition of nutrients from SOM thereby leading to positive priming (Craine *et al.*, 2007). In contrast to priming, microbial anabolism may increase SOC contents in the form of residues (mainly necromass) and represents a not-yet-fully-investigated fate of fresh C added in to soil.

CHAPTER 3

Materials and Methods

3. MATERIALS AND METHODS

The research work entitled, "**Long term impact of manuring and fertilization on labile carbon and carbon utilization efficiency of microbes in four major soil groups of India"** was undertaken in a long-term field experiment, which is in progress since 1983-1984, at Ludhiana, Jabalpur, Ranchi and Pantnagar under AICRP on Farming system research, located at the Indian Institute of Farming System Research, Modipuram, Meerut, Uttar Pradesh.

The details of field experiment and methodology adopted have been described under the following heads:

3.1 General description of study area

3.2 Treatment details

3.3 Laboratory studies

3.4 Computation and statistical analysis

3.1 General description of study area

Ludhiana

Ludhiana is situated in Punjab and is located at 30^{o}56′N, 75^{o}52′E and 247 m above mean sea level (m.s.l.). The fixed plot long-term study entitled as, "Permanent Plot Experiment on Integrated Nutrient Supply System in Cereal-based Crop Sequences" was conceptualized and initiated during wet season of 1983-84 with rice-wheat cropping system in the Department of Agronomy, Punjab Agricultural University, Ludhiana. The climate of Ludhiana is semi-arid subtropical with hot dry summers and cool winters. Average annual rainfall is 500 mm and potential evapotranspiration 1500 mm. The soils are Typic Ustochrepts-Ustipsamments alluvial with sandy loam texture.

Pantnagar

Pantnagar is located at 29^{o}N, 79^{o}5′E and 244 m above m.s.l. in the foot hills of Shivalik range of the Himalayas. The fixed plot long-term study entitled as, "Permannent Plot Experiment on Integrated Nutrient Supply System in Cereal-based Crop Sequences" was conceptualized and initiated during wet season of 1983-84 with rice-wheat cropping system in the Department of Agronomy, College of Agriculture, GBPUAT, Pantnagar. Climatically, the area is sub-humid subtropical with hot humid summers and severe cold winters. Average annual rainfall is about 1350 mm. The soils are Aquic Hapludoll with clay loam texture and alkaline reaction.

Jabalpur

Jabalpur is situated in central Madhya Pradesh and is located at 23º90'N latitude, 79^{o}58′E longitude and 411.8 m above m.s.l. The The fixed plot long-term study entitled as, "Permanent Plot Experiment on Integrated Nutrient Supply System in Cereal-based Crop Sequences" was conceptualized and initiated during wet season of 1983-84 with rice-wheat cropping system in the Department of Agronomy, College of Agriculture, Jawahar Lal Nehru Krishi Viswavidyalaya (JNKVV), Jabalpur. Jabalpur lies in subtropical regions thus, it enjoys the features of dry and sub humid climate. This area is recognized as agro-ecological sub region number 10.1 and named as "hot sub humid (dry) eco-region (Malwa Plateau, Vindhyan Scrapland and Narmada Valley). Climatically, the area is sub-humid subtropical with hot humid summers and severe cold winters. Average annual rainfall is about 1350 mm. The soils are Typic Haplusterts with sandy clay texture and neutral reaction.

Ranchi

Ranchi is located at 23^{o}30′N, 85^{o}15′E and 120 m above m.s.l. The fixed plot long-term study entitled as, "Permanent Plot Experiment on Integrated Nutrient Supply System in Cereal-based Crop Sequences" was conceptualized and initiated during wet season of 1983-84 with maize-wheat cropping system at the research farm of Birsa Agricultural University, Kanke, Ranchi. This area has sub-humid climate with severe hot, dry summer and cool winter. Average annual rainfall is about 1450 mm. The soils are red Typic Haplustalf with sandy clay loam texture and moderately acidic in reaction.

The initial physico-chemical characteristics and available nutrient status of the soils of all the above four locations have been provided in the following Table 3.1.1.

Table 3.1.1 Initial characteristics of the experimental soil

Properties	Inceptisol - Ludhiana	Mollisol - Pantnagar	Vertisol - Jabalpur	Alfisol - Ranchi
Sand	54.0	32.0	28.0	55.0
Silt	28.0	39.0	19.0	22.0
Clay	18.0	29.0	53.0	23.0
Texture	Sandy loam	Silty Clay loam	Clay	Sandy clay loam
pH	8.15	7.3	7.54	6.5
EC (dS m^{-1})	0.32	0.35	0.48	0.10
Org. C (g kg^{-1})	3.1	14.2	6.0	4.2
Available N (kg ha^{-1})	143.0	280.0	238.0	255.0
Available P (kg ha^{-1})	11.0	14.5	8.6	14.2
Available K (kg ha^{-1})	101.0	120.0	287.0	195.0
Soil classification	Typic Ustochrept	Aquic Hapludoll	Typic Haplusterts	Typic Haplustalf

3.2 Treatment details

The treatments represented different combinations of inorganic and organic sources of nutrients to rice and wheat. In rice, the full recommended levels of N, P, and K and 50% of N were supplemented through FYM, crop residue (wheat straw in Ludhiana Pantnagar, Jabalpur and paddy straw in Ranchi) and green manuring croprs like *Sesbania* (*Sesbania aculeate* L. in Ludhiana), Green gram (*Vigna radiata* L. in Pantnagar)/*Sunhemp* (*Crotalaria juncea* L. in Jabalpur)/*Karanj* (*Pongamia pinnata* L. in Ranchi). The wheat did not receive any organic sources of nutrients but received N–P–K fertilizer. The experiment included two crops per year, rice (July–October) and wheat (November–April) in Ludhiana, Jabalpur and Pantnagar except Ranchi where it is maize (July–October) and wheat (November–April) with 12 treatments which were laid out in a randomized design and replicated thrice. Of the 12 treatments, five selected for the present study is given in the Table 3.2.1.

The details of 100% recommended dose of NPK used in four locations is provided in the following Table 3.2.2.

3.3 Laboratory studies

3.3.1. Collection, preparation and preservation of soil samples

Soil samples were collected to a depth of 0−15 cm from the respective plots with the help of soil core sampler in the year 2015. Each soil sample was divided into two parts, one part was kept in a refrigerator at 4^{o}C for analysis of microbial biomass carbon (MBC) and C mineralization study, carbon utilization efficiency (CUE) and the other part was air dried for analysis of C and its fractions.

3.3.2. Analysis of soil samples

Total soil carbon (TSC), soil inorganic (SIC) and organic carbon (SOC)

The representative soil sample was homogenized to pass through 0.2 mm sieve and the total soil carbon (TSC) was determined by dry combustion method (Nelson and Sommers, 1982) in CHNS analyser (Euro Vector make, Euro EA3000 model)**,** total inorganic carbon (TIC) was determined by treating the soil with dilute H_2SO_4 as per the procedure given by Synder and Trofymow (1982). Soil sample of 1 g was taken in a diffusion tube and 2N H_2SO_4 @ 3 ml g^{-1} was added in that diffusion tube. A shell vial containing 4 ml of 0.5N NaOH was inserted into that tube and it was capped immediately. The tubes were shaken in a reciprocal shaker at low speed for 12 hours. The amount of inorganic C was determined by back titrating the unused NaOH. Total soil organic carbon (SOC) was determined by the difference of TSC and SIC.

Carbon mineralization (C_{min})

In incubation experiment, carbon dioxide (CO_2-C) flux as measure of C mineralization was determined. Forty gram of wet soil in field capacity was taken and placed in a 50 ml beaker kept in 500 ml capacity respiration jar to trap the evolved CO_2 and the jar was closed with the help of a lid. The respiration jars were kept in a BOD incubator for 240 days at 37 ^{o}C. The CO_2 evolved is measured by Gas Chromatograph (Make Agilent, Model GC-4890) with the help of a packed column (PORAPAK-Q) and TCD detector as per the method given by Cleve *et al.* (1979). The cumulative C mineralization data were fitted in single pool first-order exponential decay model (Farrar *et al.*, 2012) for estimation of decay rate constant (k) by using the following relationship.

$$C_t = C_0.e^{-kt}$$

where,

C_t – amount of SOC (g kg^{-1}) remaining at different time interval up to 240 days, C_0 – Initial SOC (g kg^{-1}), k–decay rate constant (day^{-1}), t – time in days.

Potassium permanganate ($KMnO_4$) oxidisable carbon

Potassium permanganate ($KMnO_4$) oxidisable carbon ($KMnO_4$-C) in soil sample was determined by using 0.2 M $KMnO_4$ stock solution through Field-kit method as described by Weil *et al.* (2003). For this, 2.0 ml of the 0.2 M $KMnO_4$ stock solution was taken in a 50 ml graduated polypropylene conical centrifuge tube. Distilled water was added to the tube to the 20 ml mark and capped well. It was then swirled gently to mix the contents thoroughly. 5.0 g of uniformly dried soil was added to the tube and capped tightly. It was shaken vigorously for 2 minutes and then allowed to stand for 5-10 minutes for soils to settle down. Later on 45 ml of distilled water was added to a clean graduated centrifuge tube. With the help of electronic pipette, 0.5 ml of 0.005M $KMnO_4$ solution was added to the tube followed by filling and pipetting the

Table 3.2.1 Season− wise treatment details

	Wet season *(Kharif)*	Winter season *(Rabi)*
T_1	No fertilizer, no organic manure(control)	No fertilizer, no organic manure (control)
T_2	100% rec. NPK dose through fertilizers	100% rec. NPK dose through fertilizers
T_3	50% rec. NPK dose through fertilizers+ 50% N through FYM (farmyard manure)	100% rec. NPK dose through fertilizers
T_4	50% rec. NPK dose through fertilizers+ 50 N through straw	100% rec. NPK dose through fertilizes
T_5	50% rec. NPK dose through fertilizers+ 50% N through GM (green manure)	100% rec. NPK dose through fertilizers

Table 3.2.2 Recommended Fertilizer Dose of different crops in the selected sites

Location/soil type	Cropping system	100% recommended fertiliser dose (kg ha^{-1})			
		N	P	K	$ZnSO_4$‡
Ludhiana (Inceptisol)	Rice (*Oryza sativa* L.), cv. PR-116 (Wet season)	120	30	30	60
	Wheat (*Triticum aestivum* L.), cv. PBW-343 (Winter season)	120	60	30	-
Pantnagar (Mollisol)	Rice (*Oryza sativa* L.), cv. PR-113 (Wet season)	120	40¶	-	-
	Wheat (*Triticum aestivum* L.), cv. PBW-343 (Winter season)	120	40¶	-	-
Jabalpur (Vertisol)	Rice (*Oryza sativa* L.), cv. MR-219 (Wet season)	120	60	40	
	Wheat (*Triticum aestivum* L.), cv. GW-273 (Winter season)	120	60	40	
Ranchi (Alfisol)	Maize (*Zea mays* L.), cv. M-9000(Wet season)	100	22	21	-
	Wheat (*Triticum aestivum* L.), cv. DWR-162 (Winter season)	100	22	21	-

‡Applied to all plots once in every three years before rice crop

¶Phosphosrus treatment included since wet season of the year 2000 diluted solution several times to ensure complete transfer of the solution. Then, distilled water was added to the 50 ml mark, capped and shaken well. Finally the absorbance of the pink color of $KMnO_4$ was recorded at 550 nm wavelength. The process was repeated using 0.5ml of the 0.01M $KMnO_4$ and 0.02M $KMnO_4$ standard solutions. A standard curve was constructed with absorbance on the x-axis and concentration on the y-axis. After measuring the concentration of the standard solutions, about 45 ml of distilled water was added to a separate clean graduated centrifuge tube, using an electronic pipette, 0.5 ml of soil-$KMnO_4$ mixture solution stand to settle earlier was taken and added in the tube, then fill and empty the pipette with the diluted solution several times to ensure that all the solution is delivered. The tube was marked to 50 ml mark by distilled water, capped and shaken well to mix. Then, the absorbance was measured on the spectrometer at 550 nm wavelength. To estimate the amount of carbon oxidized, the assumption of Blair *et al.* (1995) considered that 1.0 mol of MnO_4 was consumed (reduced from $Mn^{7+} \rightarrow Mn^{2+}$) in the oxidation of 0.75 mol (9000 mg) of carbon.

$KMnO_4$ oxidisable C (mg kg^{-1}) = [0.02mol/l – (a + b ×absorbance)] X (9000mg C/mol) × (0.021 solution/0.005 kg soil).

Where, 0.02 mol/l is the initial solution concentration, a is the intercept and b is the slope of the standard curve, 9000 is the mg C (0.75 mol) oxidised by 1 mol of MnO_4 changing from ($Mn^{7+} \rightarrow Mn^{2+}$), 0.021 is the volume of $KMnO_4$ solution reacted, and 0.005 is the kg of soil used.

Particulate organic matter carbon (POM−C)

The particulate organic matter (POM) was separated from the soil following the procedure outlined by Camberdella and Elliot (1992). A 10 g portion of 2 mm sieved air-dried soil sample was shaken with 0.5% sodium hexametaphosphate solution on a shaker for 15 hours. Then the soil suspension was passed through 0.053 mm sieve using a mild jet of water from the top of the sieve. The solid portion retained on the sieve was transferred to pre-weighed filter paper by washing with jet of water. It contained both particulate organic matter and sand particles. The filter papers were kept inside the forced air oven at 50 °C temperature for 72 hours for drying, and finally the weights of boats were recorded. The solid materials in the boats were ground in a pestle and mortar to make it a fine powder. The materials were passed through 0.2 mm sieve, and total organic carbon content in POM was determined by dry combustion method in a CHNS analyzer (Euro Vector make, Euro EA3000 model).

Microbial biomass carbon (MBC)

Soil microbial biomass was estimated by the substrate induced respiration method (Bailey *et al.* 2007) using a gas chromatograph (Make Agilent, Model GC-4890) and the following equation from (Anderson and Domsch, 1978) used:

$$x = 40.04y+0.37$$

Where, x = microbial biomass C (mg kg^{-1}) and y = rate of CO_2 evolution (ml CO_2 kg^{-1} soil hr^{-1})

For this, the field moist soil samples were taken and mixed well with 0.5 ml of 1% glucose solution in a glass tube and immediately covered by wax paper, followed by rubber capping after 1 hour. Then about 2 hours later, the CO_2 trapped at the head space of the tube was measured by injecting the CO_2 taken from the tube to the gas chromatograph, first by running the standard CO_2 levels. Then, by having the value of peak height, peak area, the MBC was computed by applying the above equation.

Microbial quotient (MQ) and microbial metabolic quotient (MMQ)

Microbial quotient was calculated as the ratio of MBC to SOC. Microbial metabolic quotient was calculated as the ratio of average amount of carbon mineralized (CO_2-C) in the last four weeks of incubation to MBC.

Dissolved organic carbon (DOC)

Dissolved organic carbon (DOC) was evaluated by the methods of Jones and Willett (2006). In brief, 5g of dry soil was extracted with 25 ml ultra-pure water in a centrifuge tube by shaking the mixture for 1 hour on a reciprocal shaker (200 rpm), and then centrifuged @ 13,000 rpm for 30 min at 4^{o}C. The supernatant was then filtered through a 0.45 µm glass fiber filter. The C content in the supernatant was estimated by reducing the volume of supernatant to approximately 5 ml by evaporating it in a hot air oven and following the procedure given by Synder and Trofymow (1982).

Assessment of carbon utilization efficiency (CUE)

The carbon utilization efficiency (CUE) was measured as per the changes in microbial biomass carbon (MBC) over time and was calculated as

$$\mathrm{CUE} = \frac{\mathrm{dMBC}}{(\mathrm{dBc} + \Sigma\mathrm{CO2} - \mathrm{C})}$$

where, dMBC is the change in microbial biomass carbon over a period of time and ΣCO_2-C is the cumulative C lost via respiration. The CO_2 evolved during respiration was quantified by alkali trap method (Anderson 1982) periodically at 15, 30 and 45 days of incubation. During incubation studies for carbon mineralization, to estimate total CO_2 efflux, the CO_2 trapped in NaOH solution was precipitated with 0.5M barium chloride ($BaCl_2$) solution and then the NaOH is titrated with 0.2M hydrochloric acid (HCl) against phenolphthalein indicator (Zibilske, 1994). Soil microbial biomass was estimated by the substrate induced respiration method (Bailey *et al.* 2007) using a gas chromatograph (Agilent Model GC- 4890) at 15, 30 and 45 days of incubation. The substrates used were no residue (control), wheat (*Triticum aestivum* L.) residue (WR), maize (*Zea mays* L.) residue (MR) and *Sesbania (Sesbania aculeate L.)* residue (DR). The C: N ratio of WR, MR and DR were 80:1, 56:1 and 28:1, respectively. 25 gram soil was taken at field capacity and above residues were added @2.23 mg/g soil (eqv. 5 t/ha) and the samples were incubated for a period of 45 days.

Priming effect (PE)

A separate set of experiment was used for assessment of priming effect (PE). In 50 ml beaker glass beads (1mm, 25 g) + soil extract (1:2::w:v) + N, P, K same amount as observed available nutrients in 4 soils (i.e. 4 different orders having different treatments) + residue (control, wheat, maize and *Sesbania*) were added and whole set up was kept in BOD incubator in 37ºC. Readings for CO_2 evolution were taken at 15, 30 and 45 days of experiment by alkali trap method (Anderson, 1982).

PE = Positive/Negative depending upon the CO_2-C evolved from soil + residue, soil alone (S) and residue alone (R) treatments. If the sum of the CO_2-C evolved from S+R is less than that from soil+residue mixture, it was treated as positive PE and the vice-versa as negative PE.

3.4 Computation and statistical analysis

The experimental data on soil carbon and its fractions and C mineralization were analyzed in one way (effect of nutrient management) analysis of variance (ANOVA) separately for each soil in a randomized block design (RBD) using Window based statistical software, SPSS version 16.0. The data related CUE and PE were subjected to two way (effect of nutrient management × residue) ANOVA in the same statistical package. The Duncan’s Multiple Range Test at probability 5 % was used to segregate significance of difference among the mean values. Simple correlation between various soil C fractions and C_{min} was done using the same package.

CHAPTER 4

Results

4. RESULTS

The findings emerged out from the investigation entitled, **“Long term impact of manuring and fertilization on labile carbon and carbon utilization efficiency of microbes in four major soil groups of India”** was undertaken in a long-term field experiment, which is in progress since 1983-1984, at Ludhiana (Inceptisol), Pantnagar (Mollisol), Jabalpur (Vertisol) and Ranchi (Alfisol) under AICRP on Farming system research, Modipuram, Meerut, Uttar Pradesh. The results of the experiment are depicted in this chapter under the following headings:

4.1 Long-term manuring and fertilization effects on soils C and C-mineralization

4.1.1 Total soil carbon (TSC), soil organic carbon (SOC) and soil inorganic carbon (SIC)
4.1.2 C mineralization (C_{min})
4.1.3 Decay rate constants of SOC
4.1.4 Microbial biomass carbon (MBC)
4.1.5 Microbial quotient (MQ)
4.1.6 Microbial metabolic quotient (MMQ)

4.2 Relationships of SOC and its various fractions with mineralizable C

4.2.1 Dissolved organic carbon (DOC)
4.2.2 Particulate organic matter carbon (POM-C)
4.2.3 Potassium permanganate oxidizable carbon ($KMnO_4$-C)
4.2.4 Correlation analysis

4.3 Carbon utilization efficiency (CUE)

4.3.1 Initial MBC, final MBC and changes in MBC (dMBC)
4.3.2 Total C mineralization ($\sum CO_2$-C)
4.3.3 Carbon utilization efficiency (CUE)
4.4. Priming Effect (PE) on native SOC
4.4.1 C mineralization from soil alone
4.4.2 C mineralization from residue alone
4.4.3 C mineralization from soil plus residue mixture
4.4.4 Priming effect on native SOC

4.1.1 Total soil carbon (TSC), soil organic carbon (SOC) and soil inorganic carbon (SIC)

Long term effect of manuring and fertilization on Total soil carbon (TSC), soil organic carbon (SOC) and soil inorganic carbon (SIC) were obtained as follows.

Inceptisol:

Samples collected from 0-15 cm soil were found to show significant variation in the TSC and SOC contents (Table 4.1.1). It was found that the highest amount of TSC as well as SOC (8.13 and 7.62 mg kg^{-1}) were observed with T5 (50%NPK+50%N-GM) followed by T4 (50%NPK+50%N-Straw) 7.58 and 6.98 mg kg^{-1}, respectively. T1 (control) invariably possessed lowest amount of TSC and SOC but it was at par with T2 (100%NPK) and T3 (50%NPK+50%N-FYM). Results showed that the highest SIC was with T4 (50%NPK+50%N-Straw) followed by T5 (50%NPK+50%N-GM) i.e. 0.61 and 0.51 mg kg^{-1}, respectively. All other treatments were lower than the T4 and T5 being at par with each other.

Mollisol:

It was observed that TSC and SOC both were highest in T3 (50%NPK+50%N-FYM) followed by T4 (50%NPK+50%N-Straw), T5 (50%NPK+50%N-GM), T2 (100%NPK) and lowest in T1 (control) (Table 4.1.1). All the treatments were higher than control. There was no significant difference between T1 (control) and T2 (100%NPK), while all other treatments had higher SIC than T1. But among the treatments no significant difference was found.

Vertisol:

It was found that all the treatments had significantly higher TSC over the control. The highest TSC was found in T5 (50%NPK+50%N-GM) followed by T2 (100%NPK), T4 (50%NPK+50%N-Straw) and T3 (50%NPK+50%N-FYM) having 11.46, 10.15, 9.55 and 9.19 mg kg^{-1}, respectively (Table 4.1.1). The T4 and T3 were statistically at par with each other. Results showed that there was significant variation in SOC contents under different treatments. It was highest in T5 followed by T2, T4, T3 and T1 having 10.47, 9.14, 8.58, 8.17 and 6.48 mg kg^{-1}, respectively. The SIC contents in all the treatments were more than that in T1.

Table 4.1.1 Long term effect of manuring and fertilization on Total soil carbon (TSC), soil organic carbon (SOC) and soil inorganic carbon (SIC) in four soil orders

Treatment	Inceptisol			Mollisol			Vertisol			Alfisol		
	TSC	SOC (g kg^{-1})	SIC	TSC	SOC (g kg^{-1})	SIC	TSC	SOC (g kg^{-1})	SIC	TSC	SOC (g kg^{-1})	SIC
Control	$6.27^{d‡}$	5.93^{d}	0.34^{c}	9.84^{b}	9.60^{b}	0.23^{b}	7.38^{d}	6.48^{e}	0.9^{b}	7.28^{c}	7.02^{c}	0.26^{b}
100%NPK	6.77^{c}	6.36^{c}	0.40^{bc}	12.15^{a}	11.90^{a}	0.25^{b}	10.15^{b}	9.14^{b}	1.02^{a}	8.46^{b}	8.13^{b}	0.34^{a}
50%NPK + 50%N-FYM	6.55^{cd}	6.18^{cd}	0.37^{c}	13.33^{a}	12.98^{a}	0.35^{a}	9.19^{c}	8.17^{d}	1.02^{a}	9.30^{a}	8.95^{a}	0.35^{a}
50% NPK + 50% N-Straw	7.58^{b}	6.98^{b}	0.61^{a}	12.69^{a}	12.33^{a}	0.36^{a}	9.55^{c}	8.58^{c}	0.98^{a}	8.26^{b}	7.9^{b}	0.36^{a}
50% NPK + 50% N-GM	8.13^{a}	7.62^{a}	0.51^{ab}	12.38^{a}	11.99^{a}	0.39^{a}	11.46^{a}	10.47^{a}	0.99^{a}	8.7^{b}	8.34^{b}	0.35^{a}

‡Values followed by different lowercase letters in a column are significant according to Duncan’s Multiple Range Test (DMRT) at 5% level of significance

Alfisol:

It was observed that TSC and SOC were highest in T3 (50%NPK+50%N-FYM) having 9.30 and 8.95 mg kg^{-1}, respectively (Table 4.1.1). There was no significant difference between all the other treatments i.e. T4, T5 and T2. T1 contained the lowest amount of TSC and SOC. The SIC content in all the treatments were higher over T1 but having no significant difference among themselves.

4.1.2 Soil C mineralization (C_{min})

Long term effect of manuring and fertilization on soil C mineralization was obtained as follows.

Inceptisol:

The cumulative carbon mineralization (C_{min}) showed significant variation between the treatments in 0−15 cm soil depth (Fig. 4.1.2.1a). The highest cumulative C_{min} was found in treatment T3 (50% NPK+50%N-FYM) as compared to other treatments throughout the period except the last stage where T5 (50% NPK+50%N-GM) showed higher cumulative C_{min} than the T3 and it was followed by T4 (50%NPK+50%N-Straw), T2 (100% NPK) and T1 (control). The total C mineralization was highest with T5 followed by T3 but there was no significant difference (Fig. 4.1.2.2). The lowest total carbon mineralization was found in T1 but it was statistically at par with T2.

Mollisol:

The cumulative C_{min} which continued up to 235 days varied significantly between the treatments in 0−15 cm soil depth (Fig. 4.1.2.1 b). The highest C_{min} mineralization was observed in T5 treatment (50% NPK+50%N-GM) followed by that in T3 treatment (50% NPK+50%N-FYM) and T4 treatment (50%NPK+50%N-Straw). The cumulative C_{min} mineralization was lower in T2 (100% NPK) and T1 (control) and both are statistically at par with each other. The total C_{min} over 235 days period in 0−15 cm soil depth was significantly higher in T5 (50% NPK+50%N-GM) followed by T3 (50% NPK+50%N-FYM). Rest of the treatments followed the same trend as that of cumulative C_{min} pattern (Fig. 4.1.2.2).

Vertisol:

The cumulative C_{min} up to 235 days varied significantly between the treatments in 0−15 cm soil depth. The results showed that the C_{min} followed the same trend as that of Mollisol at the initial period but at the later stage, the highest C_{min} was noticed in T3 (50% NPK+50%N-FYM) followed by T5 treatment (50% NPK+50%N-GM) T4 (50%NPK+50%N-Straw), T2 (100% NPK) treatments and the lowest was recorded with T1 (control) (Fig. 4.1.2.1 c). The highest total C_{min} over 235 days was highest with T3 treatment, followed by T5 and T4. Similarly there was no significant difference between T2 and T1 though T1 mineralized the least amount of C (Fig. 4.1.2.2).

Alfisol:

There was a significant variation in the cumulative C_{min} up to 235 days period between all the treatments. Results showed that the highest cumulative C_{min} was found in T3 (50% NPK+50%N-FYM) throughout the period followed by T4 (50%NPK+50%N-WR) and T5 (50% NPK+50%N-GM) being at par with each other. The T1 invariably mineralized the lowest amount of C than any other treatments (Fig. 4.1.2.1 d). The highest total C_{min} was noticed in T3 treatment followed by T4 and T5. The lowest total C mineralization was found in T1 treatment (Fig. 4.1.2.2).

4.1.3 Decay rate constant (k)

Long term effect of manuring and fertilization on the Decay rate constants (k) were obtained as follows.

Inceptisol:

Among different treatments the highest decay rate constant was with T3 (50%NPK+50%N-FYM) showed of 8×10^{-4} day^{-1} followed by T4 (50%NPK+50%N-Straw) and T5 (50%NPK+50%N-GM) having 6×10^{-4} day^{-1}. Both T2 (100% NPK) and T1 (control) had decay rate constant of 5×10^{-4} day^{-1} (Table 4.1.3, Fig. 4.1.3 a).

Mollisol:

T1 (control) and T5 (50%NPK+50%N-GM) had same decay rate constants of 6×10^{-4} day^{-1}. Rest of the treatments showed lower decay rate constant (k) of 5×10^{-4} day^{-1} (Table 4.1.3, Fig. 4.1.3 b).

Table 4.1.3 Long term effect of manuring and fertilization on decay rate constant (k) in four soil orders

	$k \times 10^{-4}$ (day^{-1})			
Treatment	Inceptisol	Mollisol	Vertisol	Alfisol
Control	5	6	6	5
100%NPK	5	5	5	4
50%NPK + 50%N-FYM	8	5	7	4
50% NPK + 50% N-Straw	6	5	7	4
50% NPK + 50% N-GM	6	6	6	4

Table 4.1.4 Long term effect of manuring and fertilization on Microbial biomass carbon (MBC) in four soil orders

‡Values followed by different lowercase letters in a column are significant according to

	MBC (mg kg^{-1})			
Treatment	Inceptisol	Mollisol	Vertisol	Alfisol
Control	$469^{d\ddagger}$	482^{c}	379^{e}	494^{b}
100%NPK	516^{c}	514^{b}	413^{d}	511^{b}
50%NPK + 50%N-FYM	567^{b}	590^{a}	548^{a}	571^{a}
50% NPK + 50% N-Straw	481^{d}	514^{b}	458^{c}	510^{b}
50% NPK + 50% N-GM	603^{a}	525^{b}	480^{b}	572^{a}

Duncan's Multiple Range Test (DMRT) at 5% level of significance

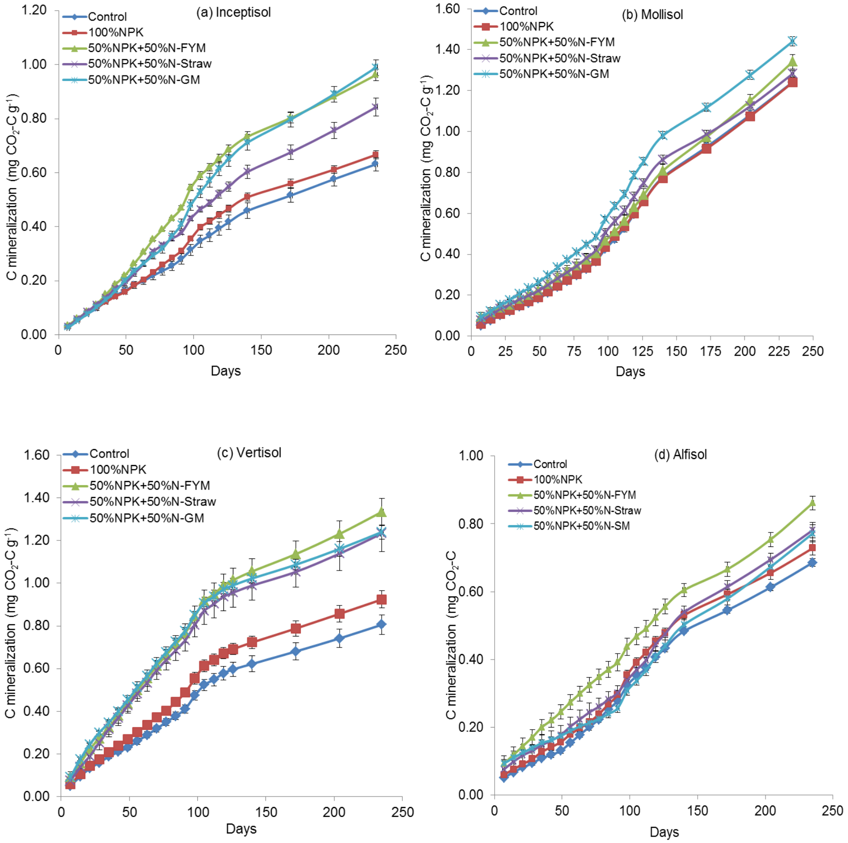

Figure 4.1.2.1 Long term effect of manuring and fertilization on cumulative C mineralization in four soil orders, each data point is associated with standard error of mean in the form of bar.

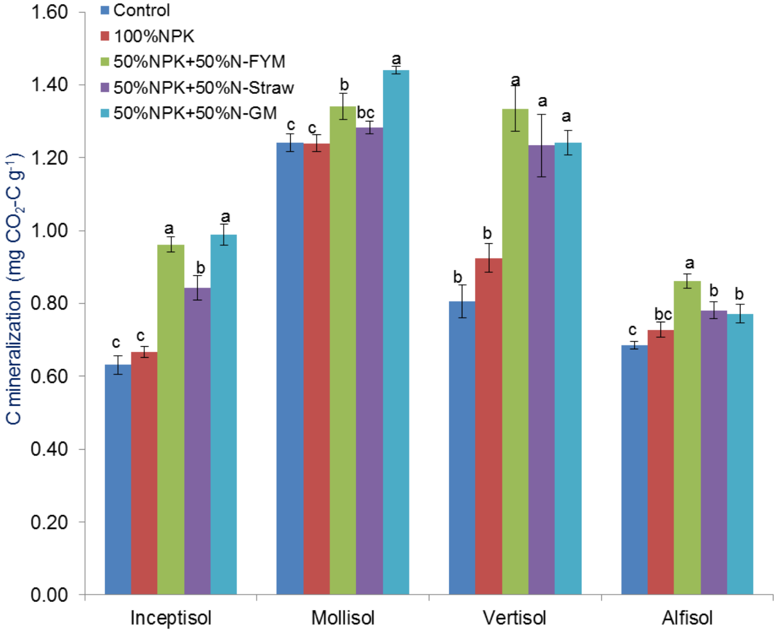

Figure 4.1.2.2 Long term effect of manuring and fertilization on total C mineralization in four soil orders, the histogram followed by different lower case letters in a particular soil order are significant according to Duncan's Multiple Range (DMRT) Test at P=0.05.

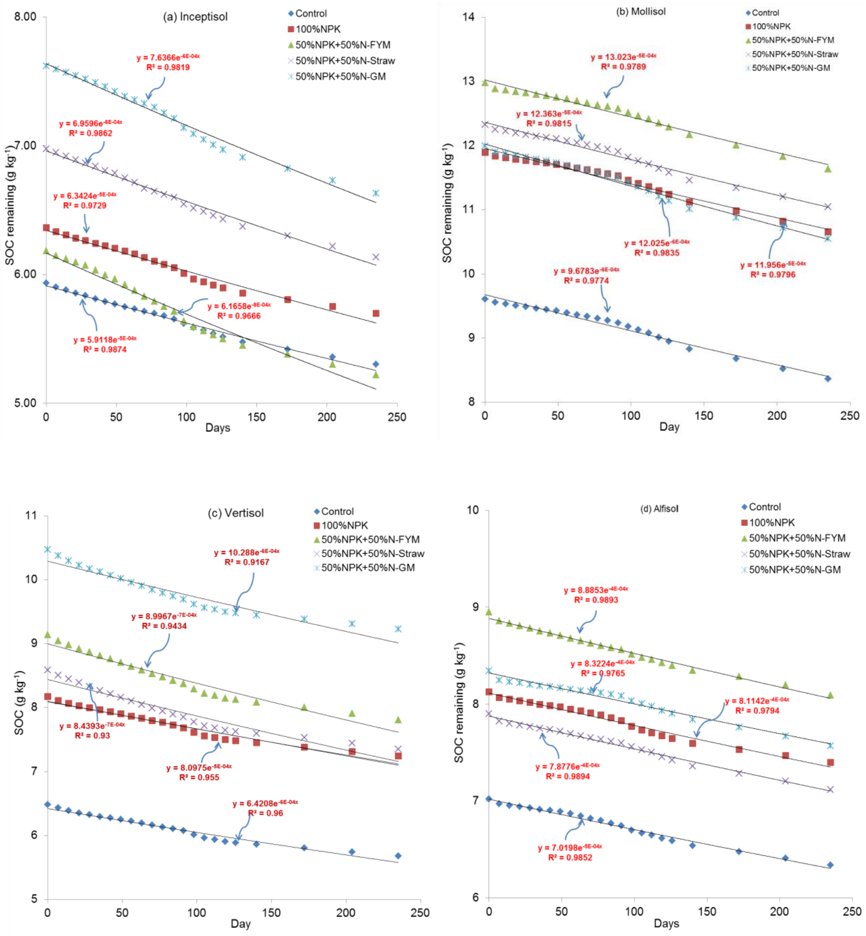

Figure 4.1.3 Fitting of data pertaining to SOC remaining versus days in first order exponential model in four soil orders under long term manuring and fertilization

Vertisol:

The highest decay rate constants (k) were found in T3 (50%NPK+50%N-FYM) and T4 (50%NPK+50%N-Straw) having 7×10^{-4} day^{-1} followed by T5 (50%NPK+50%N-GM) and T1 (control) having 6×10^{-4} day^{-1}. T2 (100% NPK) showed the lowest decay rate constant of 5×10^{-4} day^{-1} (Table 4.1.3) (Fig. 4.1.3 c).

Alfisol:

Here T1 (control) showed the highest decay rate constant (k) of 5×10^{-4} day^{-1} and rest of the treatments showed 4×10^{-4} day^{-1} (Table 4.1.3) (Fig. 4.1.3 d).

4.1.4 Soil microbial biomass carbon (MBC)

Long term effect of manuring and fertilization on Microbial biomass carbon (MBC) was obtained as follows.

Inceptisol:

The MBC was highest with T5 treatment (50%NPK+50%N-GM) (603 mg kg^{-1}) and it was lowest in T1 (control) (469 mg kg^{-1}) (Table 4.1.4). The increase in MBC were 28.57%, 20.89%, 10.02% and 2.55% in treatment T5, T3 (50%NPK+50%N-FYM), T4 (50%NPK+50%N-WR) and T2 (100% NPK), respectively over the control (Fig. 4.1.4). The MBC followed the trend, T5>T3>T2 and there was no significant difference between T4 and T1.

Mollisol:

All the treatments showed significantly higher amount of MBC over the T1 (control) (Table 4.1.4). The highest MBC content (590 mg kg^{-1}) was found in T3 (50%NPK+50%N-FYM) where the increase of MBC over T1 was 22.4%. Rest of the treatments like T2 (100% NPK), T5 (50%NPK+50%N-GM) and T4 (50%NPK+50%N-WR) showed no significant difference with respect to MBC content. The treatment T1 invariably showed the lowest MBC (Fig. 4.1.4). The T3 showed the highest MBC, T1 being the lowest. But there was no significant difference in MBC between T5, T4 and T2.

Vertisol:

The highest MBC (548 mg kg^{-1}) was with T3 (50%NPK+50%N-FYM) followed by T5 (50%NPK+50%N-GM), T4 (50%NPK+50%N-WR), T2 (100%NPK) and T1 (control) (Table 4.1.4). The increase in MBC were 44.6%, 26.64%, 20.84% and 8.97% in treatments containing GM, FYM, WR and 100% NPK, respectively over the control (379 mg kg^{-1}) (Fig. 4.1.4). Both T5 and T4 and T2 and T1 were statistically at par. T2 and T1 were also statistically at par.

Alfisol:

All the treatments showed higher amount of MBC compared to T1 (control) (Table 4.1.4). The MBC was highest in T5 (50%NPK+50%N-GM) followed by T3 (50%NPK+50%N-FYM) treatment, 572 and 571 mg kg^{-1} MBC, respectively but there was no significant difference between T5 and T3 treatment (Fig. 4.1.4). Addition of straw in T4 (50%NPK+50%N-Straw) (510 mg kg^{-1}) or supplementing all the nutrients by inorganic fertilizers only i.e. by 100% NPK in T2 (511 mg kg^{-1}) showed no significant increase in MBC over the T1 (494 mg kg^{-1}).

4.1.5 Microbial quotient (MQ)

The long term effect of manuring and fertilization on Microbial quotient (MQ) was obtained as follows.

Inceptisol:

Results showed that the MQ was observed highest in T3 treatment (50%NPK+50%N-FYM) and lowest in T4 (50%NPK+50%N-Straw) having values of 0.092 and 0.069, respectively (Table 4.1.5). There was no significant difference among the treatments viz. T2 (100% NPK), T1 (control) and T5 (50%NPK+50%N-GM) had MQ of 0.081, 0.079 and 0.079, respectively.

Mollisol:

Results showed that the highest MQ was found in T1 (0.050) followed by T3, T5, T4 and T2 obtained MQ of 0.045, 0.044, 0.042 and 0.044, respectively (Table 4.1.5). There was no significant difference in between these treatments.

Vertisol:

The results showed that the MQ was highest in T3 followed by T1 being 0.067 and 0.058, respectively having no significant difference (Table 4.1.5). These treatments were followed by T4, T5 and T2 having MQ of 0.053, 0.046 and 0.045, respectively. The treatments T2 and T5 were statistically at par.

Table 4.1.5 Long term effect of manuring and fertilization on microbial quotient (MQ) in four soil orders

	MQ			
Treatment	Inceptisol	Mollisol	Vertisol	Alfisol
Control	$0.079^{b‡}$	0.050^{a}	0.058^{b}	0.071^{a}
100%NPK	0.081^{b}	0.044^{b}	0.045^{d}	0.063^{b}
50%NPK + 50%N-FYM	0.092^{a}	0.045^{b}	0.067^{a}	0.064^{b}
50% NPK + 50% N-Straw	0.069^{c}	0.042^{b}	0.053^{c}	0.064^{b}
50% NPK + 50% N-GM	0.079^{b}	0.044^{b}	0.046^{d}	0.069^{ab}

‡ Values followed by different lowercase letters in a column are significant according to Duncan's Multiple Range Test (DMRT) at 5% level of significance

Table 4.1.6 Long term effect of manuring and fertilization on microbial metabolic quotient (MMQ) in four soil orders

	MMQ (g CO_2-C h^{-1} kg^{-1} MBC)			
Treatment	Inceptisol	Mollisol	Vertisol	Alfisol
Control	$0.15^{c‡}$	0.43^{a}	0.22^{b}	0.19^{b}
100%NPK	0.14^{c}	0.42^{a}	0.21^{b}	0.19^{b}
50%NPK + 50%N-FYM	0.19^{b}	0.42^{a}	0.25^{ab}	0.24^{a}
50% NPK + 50% N-Straw	0.23^{a}	0.40^{a}	0.27^{a}	0.22^{a}
50% NPK + 50% N-GM	0.21^{a}	0.41^{a}	0.22^{b}	0.22^{a}

‡ Values followed by different lowercase letters in a column are significant according to Duncan's Multiple Range Test (DMRT) at 5% level of significance

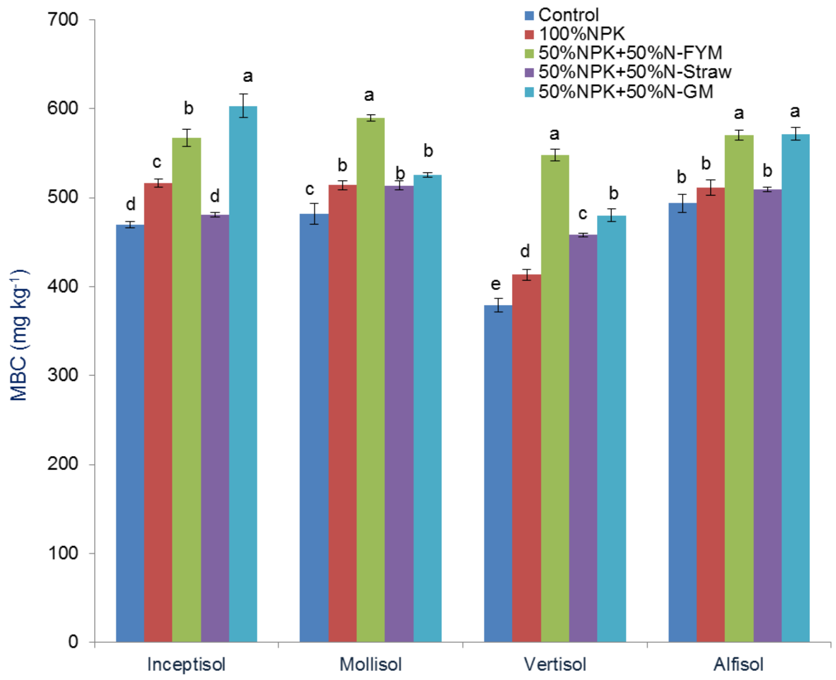

Figure 4.1.4 Long term effect of manuring and fertilization on microbial biomass C (MBC) in four soil orders, the histogram followed by different lowercase letters are significant according to Duncan's Multiple Range Test (DMRT) at P=0.05

Alfisol:

The results showed that the highest MQ was found in T1 of about 0.071 followed by T5, T2, T3 and T4. There was no significant difference between T2, T3 and T4 (Table 4.1.5).

4.1.6 Microbial metabolic quotient (MMQ)

Long term effect of manuring and fertilization on Microbial metabolic quotient (MMQ) in four soil orders was obtained as follows.

Inceptisol:

The highest MMQ was noticed in T4 (50%NPK+50%N-Straw) followed by T5 (50%NPK+50%N-GM) of about 0.23 and 0.21 g CO_2-C h^{-1} kg^{-1} MBC, respectively (Table 4.1.6). There was no significant difference in between T4 and T5 treatments. These treatments were followed by T3 (50%NPK+50%N-FYM) having MMQ of 0.19 g CO_2-C h^{-1} kg^{-1} MBC. There was no significant difference in MMQ in between treatments T1 (control) and T2 (100% NPK) having values of 0.15 and 0.14 g CO_2-C h^{-1} kg^{-1} MBC.

Mollisol:

The MMQ was recorded highest of 0.43 g CO_2-C h^{-1} kg^{-1} MBC in T1 treatment but there was no significant difference in MMQ among all the treatments (Table 4.1.6).

Vertisol:

The MMQ was recorded highest in T4 followed by T3 of about 0.27 and 0.25 g CO_2-C h^{-1} kg^{-1} MBC, respectively (Table 4.1.6). The T3 was statistically at par with T4 and rest of the treatments. The T1 and T5 had same MMQ of 0.22 g CO_2-C h^{-1} kg^{-1} MBC. There was no significant difference in between treatments T1, T2 and T5.

Alfisol:

There was no significant difference between T3, T4 and T5 with respect to MMQ (Table 4.1.6). The MMQ was highest in T3 treatment (0.24 g CO_2-C h^{-1} kg^{-1} MBC). There was no significant difference in MMQ between T1 and T2. Both the treatments had MMQ of 0.19 g CO_2-C h^{-1} kg^{-1} MBC (Table 4.1.6).

4.2.1 Soil dissolved organic carbon (DOC)

Long term effect of manuring and fertilization on dissolved organic carbon (DOC) was obtained as follows.

***Inceptisol**:*

It was observed that the DOC varied significantly among the treatments (Table 4.2.1). The DOC was highest in T5 treatment (50%NPK+50%N-GM) followed by T3 (50%NPK+50%N-FYM) and the increase of DOC in T5 and T3 were 3.5 and 3.3 times over T1 (control) i.e. 44 mg kg^{-1}, respectively. The treatment, T4 (50%NPK+50%N-Straw) and T2 (100%NPK) showed 2.64 and 2 times increase in DOC over T1.

***Mollisol**:*

It was found that the treatments varied significantly with respect to DOC content (Table 4.2.1). The DOC was observed highest in T3 (50%NPK+50%N-FYM) followed by T5 (50%NPK+50%N-GM), T2 (100% NPK), T4 (50%NPK+50%N-Straw) and T1 (control) having 159, 104, 88, 75 and 42 mg kg^{-1}, respectively (Table 4.2.1).

***Vertisol**:*

The DOC was recorded highest in T3 (50%NPK+50%N-FYM) (282 mg kg^{-1}) which was 2.71 times of T1 (control) i.e. 104 mg kg^{-1} (Table 4.2.1). The treatment T2 (100% NPK) showed 1.71 times increase in DOC over the T1, whereas T5 (50%NPK+50%N-GM) and T4 (50%NPK+50%N-Straw) were at par with each other.

***Alfisol**:*

The highest DOC (122 mg kg^{-1}) was found in T3 treatment (50%NPK+50%N-FYM) followed by T5 (50%NPK+50%N-GM) (58 mg kg^{-1}) (table 4.2.1). The treatment T2 (100% NPK) or T4 (50%NPK+50%N-Straw) did not have any significant improvement in DOC fraction as compared to T1 (control) (22 mg kg^{-1}) or the T5 treatment.

4.2.2 Particulate organic matter carbon (POM-C)

Long term effect of manuring and fertilization on particulate organic matter carbon (POM-C) in terms of mg kg^{-1} of POM and mg kg^{-1} of soil were obtained as follows.

Table 4.2.1 Long term effect of manuring and fertilization on Dissolved organic carbon (DOC) in four soil orders

	DOC (mg kg^{-1})			
Treatment	Inceptisol	Mollisol	Vertisol	Alfisol
Control	44^{d}	42^{e}	104^{d}	22^{c}
100%NPK	88^{c}	88^{c}	178^{b}	40^{bc}
50%NPK + 50%N-FYM	146^{a}	159^{a}	282^{a}	122^{a}
50% NPK + 50% N-Straw	116^{b}	75^{d}	142^{c}	42^{bc}
50% NPK + 50% N-GM	152^{a}	104^{b}	150^{c}	58^{b}

‡Values followed by different lowercase letters in a column are significant according to Duncan's Multiple Range Test (DMRT) at 5% level of significance

Table 4.2.2 Long term effect of manuring and fertilization on Particulate organic matter carbon (POM-C) in four soil orders

Treatment	Inceptisol		Mollisol		Vertisol		Alfisol	
	POM-C (mg kg^{-1} POM)	POM-C (mg kg^{-1} soil)	POM-C (mg kg^{-1} POM)	POM-C (mg kg^{-1} soil)	POM-C (mg kg^{-1} POM)	POM-C (mg kg^{-1} soil)	POM-C (mg kg^{-1} POM)	POM-C (mg kg^{-1} soil)
Control	3.61^{d‡}	2.45^{c}	7.10^{e}	1.79^{b}	11.75^{c}	1.35^{c}	4.08^{e}	2.01^{c}
100%NPK	3.71^{cd}	2.52^{c}	7.99^{c}	2.6^{a}	25.6^{b}	3.16^{b}	5.08^{b}	2.32^{b}
50%NPK + 50%N-FYM	5.04^{a}	3.37^{a}	10.36^{a}	3.35^{a}	33.96^{a}	4.64^{a}	5.78^{a}	2.63^{a}
50% NPK + 50% N-Straw	4.22^{b}	2.86^{b}	7.76^{d}	2.80^{a}	25.56^{b}	3.45^{b}	4.27^{d}	1.87^{c}
50% NPK + 50% N-GM	3.79^{c}	2.50^{c}	9.04^{b}	2.83^{a}	26.13^{b}	3.51^{b}	4.66^{c}	2.08^{bc}

‡Values followed by different lowercase letters in a column are significant according to Duncan's Multiple Range Test (DMRT) at 5% level of significance

Inceptisol:

There was significant variation in POM-C contents in various treatments (Table 4.2.2). The T3 (50%NPK+50%N-FYM) had the highest amount of POM-C both in terms of mg kg^{-1} of POM and mg kg^{-1} of soil in the order of 5.04 and 3.37 mg kg^{-1}, respectively. It was followed by T4 (50%NPK+50%N-Straw) and T5 (50%NPK+50%N-GM). In POM-C (mg kg^{-1} of POM), T2 (100%NPK) showed no significant difference with T5 or T1 (control) but the control had the lowest amount of POM-C (mg kg^{-1} of POM). With respect to POM-C (mg kg^{-1} of soil), T5, T2 and T1 were statistically at par.

Mollisol:

The highest amount of POM-C (mg kg^{-1} of POM) was found in T3 followed by T5, T2, T4 and T1 containing 10.36, 9.04, 7.99, 7.76 and 7.10 mg POM-C kg^{-1} of POM, respectively (Table 4.2.2). All the treatments showed significant variation between the treatments, T1 being the lowest. But in case of POM-C (mg kg^{-1} of soil), the T1 was found to be the lowest and rest of the treatments were at par. The T3 had the highest amount of 3.35 mg of POM-C kg^{-1} of soil.

Vertisol:

The highest amount of POM-C was found in T3 (33.96 mg kg^{-1}) followed by T5, T2 and T4 with 26.13, 25.6 and 25.56 mg of POM-C kg^{-1} of POM, respectively which were not significantly different (Table 4.2.2). The T1 invariably had the lowest amount of POM-C. In case of POM-C (mg kg^{-1} of soil), it followed the exactly same trend that of POM-C (mg kg^{-1} of POM). The highest value was found in T3 (4.64 mg of POM-C kg^{-1} of POM) followed by T5, T4 and T2 containing 3.51, 3.45 and 3.16 mg of POM-C kg^{-1} of soil, respectively.

Alfisol:

Significant variation was found between different treatments with respect to POM-C (mg kg^{-1} of POM) content (Table 4.2.2). The POM-C was highest in T3 followed by T2, T5, T4 and T1 having 5.78, 5.08, 4.66, 4.27 and 4.08 mg of POM-C kg^{-1} of POM, respectively. In case of POM-C (mg kg^{-1} of soil), the highest value was with T3 treatment 2.63 mg followed by T2 having 2.32 mg of POM-C kg^{-1} of soil, respectively, which were significantly different.

Irrespective of different soils and treatments, in all the four orders the highest amount of POM-C was found in T3 (50%NPK+50%N-FYM) treatment.

4.2.3 Potasssium permanganate oxidizable carbon ($KMnO_4$-C)

Long term effect of manuring and fertilization on $KMnO_4$ oxdizable C (KMnO4-C) was obtained as follows.

***Inceptisol**:*

There was significant variation in the $KMnO_4$ –C contents in various treatments. The highest amount of $KMnO_4$-C was recorded in T3 (50%NPK+50%N-FYM) followed by T4 (50%NPK+50%N-Straw), T5 (50%NPK+50%N-GM) and T2 (100%NPK) having 355, 332, 321 and 313 mg kg^{-1} of soil, respectively. But there was no significant difference between T4, T5 and T2. The lowest amount of $KMnO_4$-C was found in T1 (control) having 250 mg kg^{-1} of soil (Table 4.2.3).

***Mollisol**:*

All the other treatments apart from T1 (control) are significantly different and obtained higher amount of $KMnO_4$ oxdizable C. The highest amount of $KMnO_4$ oxdizable C was obtained in T3 (50%NPK+50%N-FYM) treatment (503 mg kg^{-1}) followed by T5 (50%NPK+50%N-GM), T4 (50%NPK+50%N-Straw) and T2 (100%NPK) obtained 493, 484 and 461 mg kg^{-1} of $KMnO_4$ oxdizable C, respectively. T2 and T3 are statistically different but T5 and T4 are statistically at par with both T3 and T2. The lowest amount of $KMnO_4$ oxdizable C was found in T1 (control) having 319 mg kg^{-1} of soil (Table 4.2.3).

***Vertisol**:*

The $KMnO_4$-C was highest in T3 (50%NPK+50%N-FYM) having 564 mg kg^{-1} soil. The T4 (50%NPK+50%N-Straw) and T5 (50%NPK+50%N-GM) recorded 505 and 479 mg kg^{-1} of $KMnO_4$-C which are at par with each other (Table 4.2.3). These treatments were followed by T2 (100%NPK) and T1 (control) having 407 and 281 mg kg^{-1} of $KMnO_4$-C, respectively.

***Alfisol**:*

The highest amount of $KMnO_4$-C was noticed in T5 (50%NPK+50%N-GM) (349 mg kg^{-1}) followed by T3 (50%NPK+50%N-FYM) (315 mg kg^{-1}) which were at par with each other (Table 4.2.3). Similarly, the T4 (50%NPK+50%N-Straw), T2

Table 4.2.3 Long term effect of manuring and fertilization on potassium per manganite oxidisable C ($KMnO_4$-C) in four soil orders

	$KMnO_4$-C (mg kg^{-1})			
Treatment	Inceptisol	Mollisol	Vertisol	Alfisol
Control	$250^{c\ddagger}$	319^{c}	281^{d}	254^{b}
100%NPK	313^{b}	461^{b}	407^{c}	260^{b}
50%NPK + 50%N-FYM	355^{a}	503^{a}	564^{a}	315^{a}
50% NPK + 50% N-Straw	332^{b}	484^{ab}	505^{b}	239^{b}
50% NPK + 50% N-GM	321^{b}	493^{ab}	479^{b}	349^{a}

‡ Values followed by different lowercase letters in a column are significant according to Duncan's Multiple Range Test (DMRT) at 5% level of significance

Table 4.2.4.1 Correlations between various fractions of soil organic C in Inceptisol

	Correlation coefficient (r)					
	MBC	POM-C	DOC	$KMnO_4$-C	C_{min}	SOC
MBC	1					
POM-C	0.22	1				
DOC	0.80**	0.51	1			
$KMnO_4$-C	0.51	0.63*	0.79**	1		
C_{min}	0.73**	0.48	0.87**	0.63*	1	
SOC	0.50	-0.18	0.63*	0.34	0.55*	1

MBC: Microbial biomass C, POM-C: Particulate organic matter C, DOC: Dissolved organic C, $KMnO_4$-C: Potassium permanganate oxidisable C, SOC: Soil organic C
*Significant at P=0.05
**Significant at P=0.05

Table 4.2.4.2 Correlations between various fractions of soil organic C in Mollisol

	Correlation coefficient (r)					
	MBC	POM-C	DOC	$KMnO_4$-C	C_{min}	SOC
MBC	1					
POM-C	0.74**	1				
DOC	0.93**	0.80**	1			
$KMnO_4$-C	0.68**	0.70**	0.72**	1		
C_{min}	0.40	0.40	0.51	0.45	1	
SOC	0.73**	0.63*	0.70**	0.89**	0.31	1

MBC: Microbial biomass C, POM-C: Particulate organic matter C, DOC: Dissolved organic C, $KMnO_4$-C: Potassium permanganate oxidisable C, C_{min}: C mineralization, SOC: Soil organic C
*Significant at P=0.05
**Significant at P=0.05

Table 4.2.4.3 Correlations between various fractions of soil organic C in Vertisol

	Correlation coefficient (r)					
	MBC	POM-C	DOC	$KMnO_4$-C	C_{min}	SOC
MBC	1					
POM	0.91**	1				
DOC	0.81**	0.79**	1			
$KMnO_4$-C	0.90**	0.94**	0.71**	1		
C_{min}	0.84**	0.82**	0.55*	0.91**	1	
SOC	0.38	0.53*	0.15	0.52*	0.47	1

MBC: Microbial biomass C, POM-C: Particulate organic matter C, DOC: Dissolved organic C, $KMnO_4$-C: Potassium permanganate oxidisable C, SOC: Soil organic C
*Significant at P=0.05
**Significant at P=0.05

Table 4.2.4.4 Correlations between various fractions of soil organic C in Alfisol

	Correlation coefficient (r)					
	MBC	POM-C	DOC	$KMnO_4$-C	C_{min}	SOC
MBC	1					
POM	0.47	1				
DOC	0.75**	0.73**	1			
$KMnO_4$-C	0.82**	0.29	0.56*	1		
C_{min}	0.68**	0.47**	0.79**	0.37	1	
SOC	0.74**	0.64**	0.79**	0.51*	0.72**	1

MBC: Microbial biomass C, POM-C: Particulate organic matter C, DOC: Dissolved organic C, KMnO4-C: Potassium permanganate oxidisable C, SOC: Soil organic C
*Significant at P=0.05
**Significant at P=0.05

(100%NPK) and T1 (control) recorded significantly lower amount of $KMnO_4$-C than T5 and T3.

4.2.4 Correlation analysis

The correlations between various labile C fractions with C mineralization (C_{min}) in soils under long-term effect of manuring and fertilization were obtained as follows.

Inceptisol:

The DOC with $KMnO_4$-C as well as DOC with C_{min} had strong correlation with correlation coefficients of 0.79 and 0.87, respectively (Table 4.2.4.1). The MBC and DOC also had stronger correlation with r value of 0.80. Similarly, the MBC and C_{min} had r value of 0.73. The MBC and POM-C were least correlated. The POM-C and SOC were negatively correlated, whereas the DOC and C_{min} had coefficient values of 0.66 and 0.55 with SOC.

Mollisol:

The MBC and DOC were highly correlated with correlation coefficient of 0.93. Similarly, the POM with DOC and POM with MBC had correlation coefficients of 0.80 and 0.74, respectively (Table 5.2.4.2). The C_{min} did correlate significantly with none of the soil labile C pools. The correlation between DOC and $KMnO_4$-C was significant (r= 0.72). Except C_{min}, other parameters were well correlated with SOC. It had correlation coefficients of 0.73, 0.63, 0.70 and 0.89 with MBC, POM-C, DOC and $KMnO_4$-C, respectively.

Vertisol:

The MBC was highly correlated with POM, DOC, $KMnO_4$-C and C_{min} having correlation coefficients of 0.91, 0.81, 0.90 and 0.84, respectively (Table 4.2.4.3). The POM-C had significant correlations with DOC, $KMnO_4$-C and the C_{min} having correlation coefficients of 0.795, 0.941 and 0.824, respectively. The Cmin and $KMnO_4$-C had correlation coefficient of 0.91. The SOC had correlation coefficients of 0.53 and 0.52 with POM-C and $KMnO_4$-C.

Alfisol:

The MBC and $KMnO_4$-C showed the highest correlation coefficient of 0.82. The MBC significantly correlated with DOC (r=0.75) (Table 4.2.4.4). The C_{min} and

DOC had correlation coefficient of 0.79. The SOC was well correlated with MBC, POM-C, DOC, $KMnO_4$-C and C_{min} having correlation coefficients of 0.74, 0.64, 0.79, 0.51 and 0.72, respectively.

4.3.1 Initial MBC, final MBC and changes in MBC (dMBC)

The initial MBC, final MBC and changes in MBC (dMBC) was observed as follows.

Inceptisol:

The results showed that initial MBC content in soil in T1 (control), T2 (100%NPK), T3 (50%NPK+50%N-FYM), T4 (50%NPK+50%N-Straw) and T5 (50%NPK+50%N-GM) treatments were 469, 516, 567, 481 and 604 mg kg^{-1}, respectively (Table 4.3.1.1). After addition of different substrates and incubation for 15 days, the MBC content increased significantly in all treatments and the highest value found at T3 with *Sesbania* residue (SR) (758 mg kg^{-1}) and T5 with SR (744 mg kg^{-1}). There was no significant difference in between these sub treatments. It was followed by T3 with maize residue (MR), T5 with MR and T3 with wheat residue (WR) having 713, 704 and 687 mg kg^{-1} MBC, respectively. T5 with MR was statistically at par with T3 with MR and T3 with WR. The lowest MBC was shown by T1 with control sub treatment (494 mg kg^{-1}). Similarly dMBC was also significant and the highest dMBC was found in T3 with SR (191 mg kg^{-1}) followed by T2 with SR (150 mg kg^{-1}). The lowest dMBC was found in T5 with control sub treatment (24 mg kg^{-1}). After 30 days of incubation MBC content showed a decreasing trend from initial values in such a way that dMBC was negative. For 30 days of incubation the highest MBC was obtained in T3 with SR (558 mg kg^{-1}) which was followed by T4 with SR, T5 with SR, T4 with WR, T3 with MR and T3 with WR having 486, 482, 479, 472 and 467 mg kg^{-1} MBC being at par with each other. The lowest MBC was observed in T1 with control sub treatment (164 mg kg^{-1}) (Table 4.3.1.2). After 45 days of incubation MBC was still decreasing from the 30 days values and dMBC were negative. For 45 days of incubation the MBC was highest in T3 with SR followed by T3 with WR and T3 with T5 with SR having 540, 506 and 484 mg kg^{-1}. T3 with MR was statistically at par with T5 with SR. The lowest value of MBC was observed in T1 with control sub treatment (138 mg kg^{-1}) (Table 4.3.1.3).

Table 4.3.1.1 Interaction effect of long term manuring and added C substrate on C utilization efficiency (CUE) estimated in Inceptisol over 15 days of incubation

Treatment	Inceptisol					
	Sub treatment	MBC-I	MBC-15D	dMBC (MBC-15D-MBC-I)	∑Cmin-15D	CUE-15D (dMBC/dMBC+∑CO2-C)
			(mg kg^{-1})		(mg CO_2-C kg^{-1})	
Control	Control	469	494^{k‡}	24^{hi}	157^{n}	0.13^{defg}
	WR	469	530^{j}	60^{gh}	566^{j}	0.10^{fgh}
	MR	469	570^{i}	101^{ef}	586^{ij}	0.15^{bcdef}
	SR	469	616^{fg}	147^{bc}	612^{gh}	0.19^{abc}
100%NPK	Control	516	573^{i}	57^{ghi}	232^{l}	0.20^{ab}
	WR	516	602^{gh}	86^{fg}	694^{e}	0.11^{efgh}
	MR	516	629^{f}	112^{cdef}	745^{d}	0.13^{cdefg}
	SR	516	667^{d}	150^{b}	807^{b}	0.16^{bcdef}
50%NPK+50%N-FYM	Control	56	654de	87^{fg}	287^{k}	0.23^{a}
	WR	567	687^{c}	120^{bcdef}	769^{c}	0.14^{bcdefg}
	MR	567	713^{b}	146^{bc}	800^{b}	0.15^{bcdef}
	SR	567	758^{a}	191^{a}	864^{a}	0.18^{abcd}
50%NPK+50%N-Straw	Control	481	523^{j}	43^{hi}	194^{m}	0.18^{abcd}
	WR	481	572^{i}	92^{efg}	592^{hi}	0.13^{cdefg}
	MR	481	588^{hi}	107^{def}	604^{hi}	0.15^{bcde}
	DR	481	607^{e}	126^{bcde}	631^{g}	0.08^{gh}
50%NPK+50%N-GM	Control	604	627^{f}	24^{i}	268^{k}	0.08^{gh}
	WR	604	650de	46^{hi}	664^{f}	0.07^{h}
	MR	604	704^{bc}	100^{ef}	670^{f}	0.13^{defg}
	DR	604	744^{a}	140^{bcd}	683^{ef}	0.17^{bcde}

MBC-I: Microbial biomass carbon-Initial, MBC-15D: Microbial biomass carbon-15 Days of incubation, dMBC: Change in microbial biomass carbon, ∑Cmin: Summations of carbon mineralization-15 Days of incubation CUE: Carbon utilization efficiency.

‡ Values followed by different lowercase letters in a column are significant according to Duncan's Multiple Range Test (DMRT) at 5% level of significance

Table 4.3.1.2 Interaction effect of long term manuring and added C substrate on C utilization efficiency (CUE) estimated in Inceptisol over 30 days of incubation

			Inceptisol			
Treatment	Sub treatment	MBC-I	MBC-30D	dMBC (MBC-30D-MBC-I)	∑Cmin-30D	CUE-30D (dMBC/dMBC+∑CO2-C)
			(mg kg^{-1})		(mg CO_2-C kg^{-1})	
Control	Control	469	$164^{j\ddagger}$	-305	224^{n}	3.77
	WR	469	312^{f}	-157	666^{j}	-0.31
	MR	469	325^{f}	-144	704^{i}	-0.26
	SR	469	355^{e}	-114	744^{h}	-0.18
100%NPK	Control	516	243^{i}	-273	312^{l}	-7.05
	WR	516	395^{d}	-122	839^{ef}	-0.17
	MR	516	395^{d}	-121	904^{d}	-0.15
	SR	516	418^{c}	-99	978^{b}	-0.11
50%NPK+50%N-FYM	Control	56	288^{g}	-279	379^{k}	-2.78
	WR	567	467^{b}	-100	942^{c}	-0.12
	MR	567	472^{b}	-95	1000^{b}	-0.11
	SR	567	558^{a}	-9	1073^{a}	-0.01
50%NPK+50%N-Straw	Control	481	239^{i}	-241	265^{n}	-10.08
	WR	481	479^{b}	-1	743^{h}	0.00
	MR	481	422^{c}	-58	768^{gh}	-0.08
	DR	481	486^{b}	5	776^{g}	0.01
50%NPK+50%N-GM	Control	604	265^{n}	-339	356^{k}	-19.52
	WR	604	395^{d}	-209	815^{f}	-0.34
	MR	604	406^{cd}	-197	846^{e}	-0.30
	DR	604	482^{b}	-122	862^{e}	-0.16

MBC-I: Microbial biomass carbon-Initial, MBC-30D: Microbial biomass carbon-30 Days of incubation, dMBC: Change in microbial biomass carbon, ∑Cmin: Summations of carbon mineralization-30 Days of incubation CUE: Carbon utilization efficiency.

‡ Values followed by different lowercase letters in a column are significant according to Duncan's Multiple Range Test (DMRT) at 5% level of significance

Table 4.3.1.3 Interaction effect of long term manuring and added C substrate on C utilization efficiency (CUE) estimated in Inceptisol over 45 days of incubation

			Inceptisol			
Treatment	Sub treatment	MBC-I	MBC-45D	dMBC (MBC-45D-MBC-I)	∑Cmin-45D	CUE-45D (dMBC/dMBC+∑CO2-C)
			(mg kg^{-1})		(mg CO_2-C kg^{-1})	
Control	Control	469	$138^{l\ddagger}$	-332	257^{o}	4.43
	WR	469	199^{k}	-270	706^{k}	-0.62
	MR	469	226^{j}	-244	752^{j}	-0.48
	SR	469	306^{h}	-163	797^{i}	-0.26
100%NPK	Control	516	205^{jk}	-312	355^{m}	-7.13
	WR	516	336^{g}	-181	899^{fg}	-0.25
	MR	516	383^{f}	-133	978^{e}	-0.16
	SR	516	407^{e}	-109	1044^{c}	-0.12
50%NPK+50%N-FYM	Control	56	256^{i}	-312	444^{l}	-2.35
	WR	567	506^{b}	-61	1012^{d}	-0.06
	MR	567	479^{c}	-88	1080^{b}	-0.09
	SR	567	540^{a}	-27	1159^{a}	-0.02
50%NPK+50%N-Straw	Control	481	218^{jk}	-263	306^{n}	-6.06
	WR	481	267^{i}	-214	803^{hi}	-0.36
	MR	481	389^{ef}	-91	833^{h}	-0.12
	DR	481	450^{d}	-31	836^{h}	-0.04
50%NPK+50%N-GM	Control	604	220^{j}	-384	412^{l}	-13.86
	WR	604	455^{d}	-149	880^{g}	-0.20
	MR	604	459^{d}	-145	924^{f}	-0.19
	DR	604	484^{c}	-120	931^{f}	-0.15

MBC-I: Microbial biomass carbon-Initial, MBC-45D: Microbial biomass carbon-45 Days of incubation, dMBC: Change in microbial biomass carbon, ∑Cmin: Summations of carbon mineralization-45 Days of incubation CUE: Carbon utilization efficiency

‡ Values followed by different lowercase letters in a column are significant according to Duncan's Multiple Range Test (DMRT) at 5% level of significance

Table 4.3.1.4 Interaction effect of long term manuring and added C substrate on C utilization efficiency (CUE) estimated in Mollisol over 15 days of incubation

			Mollisol			
Treatment	Sub treatment	MBC-I	MBC-15D	dMBC (MBC-15D-MBC-I)	∑Cmin-15D	CUE-15D (dMBC/dMBC+∑CO2-C)
			(mg kg^{-1})		(mg CO$_2$-C kg^{-1})	
Control	Control	481	650^{r‡}	169^{p}	244^{m}	0.41^{k}
	WR	481	881^{q}	400^{o}	608^{i}	0.40^{l}
	MR	481	1090^{o}	609^{l}	635^{h}	0.49^{j}
	SR	481	1246^{l}	765^{k}	652^{h}	0.54^{i}
100%NPK	Control	514	1101no	587l^{m}	276^{kl}	0.68^{cd}
	WR	514	1476^{j}	961^{i}	670^{g}	0.59^{g}
	MR	514	1983^{e}	1469^{e}	683^{fg}	0.68^{cd}
	SR	514	2064^{c}	1550^{c}	704^{e}	0.69^{bc}
50%NPK+50%N-FYM	Control	589	1156^{m}	567^{m}	311^{j}	0.65^{e}
	WR	589	1737^{h}	1148^{h}	708de	0.62^{f}
	MR	589	2079^{c}	1490^{e}	726^{e}	0.67^{d}
	SR	589	2550^{a}	1961^{a}	779^{a}	0.72^{a}
50%NPK+50%N-Straw	Control	514	987^{p}	474^{n}	262^{l}	0.64^{e}
	WR	514	1393^{k}	879^{j}	643^{h}	0.58^{h}
	MR	514	1805^{g}	1291^{g}	690^{ef}	0.65^{e}
	DR	514	2036^{d}	1522^{d}	691^{ef}	0.69^{bc}
50%NPK+50%N-GM	Control	526	1119^{n}	593^{l}	286^{k}	0.68^{d}
	WR	526	1693^{i}	1167^{h}	698^{ef}	0.63^{e}
	MR	526	1906^{f}	1380^{f}	724^{cd}	0.66^{f}
	DR	526	2270^{b}	1744^{b}	750^{b}	0.70^{b}

MBC-I: Microbial biomass carbon-Initial, MBC-15D: Microbial biomass carbon-15 Days of incubation, dMBC: Change in microbial biomass carbon, ∑Cmin: Summations of carbon mineralization-15 Days of incubation, CUE: Carbon utilization efficiency

‡ Values followed by different lowercase letters in a column are significant according to Duncan's Multiple Range Test (DMRT) at 5% level of significance

Table 4.3.1.5 Interaction effect of long term manuring and added C substrate on C utilization efficiency (CUE) estimated in Mollisol over 30 days of incubation

			Mollisol			
Treatment	Sub treatment	MBC-I	MBC-30D	dMBC (MBC-30D-MBC-I)	∑Cmin-30D	CUE-30D (dMBC/dMBC+∑CO2-C)
			(mg kg^{-1})		(mg CO$_2$-C kg^{-1})	
Control	Control	481	523^{p‡}	42^{p}	350^{k}	0.11^{k}
	WR	481	635^{o}	154^{o}	806^{h}	0.16^{j}
	MR	481	862^{k}	381^{j}	854^{g}	0.31^{h}
	SR	481	910^{j}	428^{i}	883^{f}	0.33^{gh}
100%NPK	Control	514	753^{m}	239^{m}	400^{i}	0.37^{e}
	WR	514	1139^{g}	625^{f}	912^{ef}	0.41^{d}
	MR	514	1337^{d}	823^{c}	925de	0.47^{ab}
	SR	514	1390^{c}	876^{b}	946^{d}	0.48^{a}
50%NPK+50%N-FYM	Control	589	928^{j}	338^{k}	451^{i}	0.43^{c}
	WR	589	1296^{e}	707^{e}	984^{c}	0.42^{cd}
	MR	589	1449^{b}	859^{b}	1008^{bc}	0.46^{d}
	SR	589	1598^{a}	1008^{a}	1088^{a}	0.48^{a}
50%NPK+50%N-Straw	Control	514	696^{n}	183^{n}	372^{k}	0.33^{g}
	WR	514	828^{l}	315^{l}	895^{f}	0.26^{i}
	MR	514	993^{i}	479^{h}	924de	0.34^{fg}
	DR	514	1220^{f}	707^{e}	947^{d}	0.43^{c}
50%NPK+50%N-GM	Control	526	909^{g}	384^{j}	424^{i}	0.48^{ab}
	WR	526	1053^{h}	528^{g}	949^{d}	0.36^{ef}
	MR	526	1284^{e}	759^{d}	985^{c}	0.44^{c}
	DR	526	1303^{e}	777^{d}	1014^{b}	0.43^{c}

MBC-I: Microbial biomass carbon-Initial, MBC-30D: Microbial biomass carbon-30 Days of incubation, dMBC: Change in microbial biomass carbon, ∑Cmin: Summations of carbon mineralization-30 Days of incubation CUE: Carbon utilization efficiency

‡ Values followed by different lowercase letters in a column are significant according to Duncan's Multiple Range Test (DMRT) at 5% level of significance

Table 4.3.1.6 Interaction effect of long term manuring and added C substrate on C utilization efficiency (CUE) estimated in Mollisol over 45 days of incubation

Treatment	Sub treatment	MBC-I	MBC-45D	dMBC (MBC-45D-MBC-I)	∑Cmin-45D	CUE-45D (dMBC/dMBC+∑CO2-C)
			(mg kg^{-1})		(mg CO_2-C kg^{-1})	
Control	Control	481	$489^{m\ddagger}$	8^{p}	415^{m}	0.02^{l}
	WR	481	539^{l}	58^{o}	948^{j}	0.06^{j}
	MR	481	736^{j}	255^{k}	1002^{i}	0.20^{h}
	SR	481	818^{h}	336^{i}	1038^{h}	0.24^{f}
100%NPK	Control	514	716^{j}	202^{l}	490^{l}	0.29^{e}
	WR	514	1012^{f}	498^{f}	1082^{fg}	0.32^{d}
	MR	514	967^{g}	452^{h}	1092^{efg}	0.29^{e}
	SR	514	1228^{b}	714^{a}	1123^{de}	0.39^{a}
50%NPK+50%N-FYM	Control	589	759^{i}	170^{m}	556^{k}	0.23^{fg}
	WR	589	1133^{d}	544^{e}	1166^{c}	0.32^{d}
	MR	589	1205^{c}	616^{c}	1204^{b}	0.34^{c}
	SR	589	1254^{a}	664^{b}	1301^{a}	0.34^{c}
50%NPK+50%N-Straw	Control	514	534^{l}	20^{p}	467^{l}	0.04^{k}
	WR	514	654^{k}	140^{n}	1062^{gh}	0.12^{i}
	MR	514	828^{h}	314^{j}	1086^{fg}	0.22^{g}
	DR	514	1080^{e}	567^{d}	1106^{ef}	0.34^{c}
50%NPK+50%N-GM	Control	526	665^{k}	140^{n}	526^{k}	0.21^{h}
	WR	526	1065^{e}	540^{e}	1127^{de}	0.32^{cd}
	MR	526	998^{f}	472^{g}	1156^{cd}	0.29^{e}
	DR	526	1209^{bc}	684^{b}	1208^{b}	0.36^{b}

(Column group heading over all value columns: Mollisol)

MBC-I: Microbial biomass carbon-Initial, MBC-45D: Microbial biomass carbon-45 Days of incubation, dMBC: Change in microbial biomass carbon, ∑Cmin: Summations of carbon mineralization-45 Days of incubation CUE: Carbon utilization efficiency

‡ Values followed by different lowercase letters in a column are significant according to Duncan's Multiple Range Test (DMRT) at 5% level of significance

Mollisol:

The results showed that initial MBC content in T1, T2, T3, T4 and T5 treatments were 481, 514, 589, 514 and 526 mg kg^{-1}, respectively (Table 4.3.1.4). . After addition of different substrates and incubation for 15 days, MBC content was increased significantly in all treatments having highest at T3 with SR (2550 mg kg^{-1}) followed by T5 with SR (2270 mg kg^{-1}). There was no significant difference in between the treatments like T3 with MR and T2 with SR. The lowest MBC was found in T1 with control sub treatment (650 mg kg^{-1}). Similarly dMBC was also significant and it was maximum in T3 with SR (1961 mg kg^{-1}) followed by T5 with SR (1744 mg kg^{-1}). The lowest dMBC was found in T1 with control sub treatment (169 mg kg^{-1}) After 30 days of incubation MBC content showed a decreasing trend from 15 days values. For 30 days highest MBC was obtained to be highest in T3 with SR (1598 mg kg^{-1}) (Table 4.3.1.5). This was followed by T3 with MR and T2 with SR having 1449 and 1390 mg kg^{-1} of MBC. The lowest MBC was observed in T1 with Control sub treatment (523 mg kg^{-1}). Similarly, the dMBC was also significant and it was highest in T3 with SR (1008 mg kg^{-1}) followed by T3 with MR (859 mg kg^{-1}). The lowest dMBC was found in T1 with control sub treatment (42 mg kg^{-1}) (Table 4.3.1.5). After 45 days of incubation MBC content showed a decreasing trend from 30 days values. For 45 days of incubation the highest MBC was obtained in T3 with SR (1254 mg kg^{-1}) (Table 4.3.1.6) which was followed by T2 with SR and T3 with MR having 1228 and 1205 mg kg^{-1} of MBC. T5 with SR was having MBC statistically at par with both T2 with SR and T3 with MR. The lowest MBC was observed in T1 with Control sub treatment (489 mg kg^{-1}). Similarly dMBC was also significant and it was maximum in T2 with SR (714 mg kg^{-1}) followed by both T5 with SR (684 mg kg^{-1}) and T3 with SR (664 mg kg^{-1}) having no significant difference. The lowest dMBC was found in T1 with control sub treatment (8 mg kg^{-1}).

Vertisol:

The results showed that MBC content of initial soil in T1, T2, T3, T4 and T5 treatments were 379, 413, 548, 458 and 480 mg kg$^{-1,}$ respectively (Table 4.3.1.7). After addition of different substrates and incubation for 15 days, MBC content was increased significantly in all treatments having highest at T3 with SR (3299 mg kg^{-1}) followed by T5 with SR (2897 mg kg^{-1}). The lowest MBC was shown by T1 with control sub treatment (436 mg kg^{-1}). Similarly dMBC was also significant and it was maximum in T3 with SR (2751 mg kg^{-1}) followed by T5 with SR (2416 mg kg^{-1}). The lowest dMBC was found in T1 with control sub treatment (57 mg kg^{-1}) (Table 4.3.1.7). After 30 days of incubation MBC content showed a decreasing trend from 15 days values. For 30 days of incubation the highest MBC was obtained in T3 with SR (1187 mg kg^{-1}) (Table 4.3.1.8). This was followed by T5 with SR and T4 with SR having 1009 and 963 mg kg^{-1} of MBC. Lowest MBC was observed in T1 with Control sub treatment (389 mg kg^{-1}). Similarly dMBC was also significant and it was maximum in T3 with SR (639 mg kg^{-1}) followed by T5 with SR (529 mg kg^{-1}). The lowest dMBC was found in T1 with control sub treatment (10 mg kg^{-1}). After 45 days of incubation MBC content showed a decreasing trend from 30 days values. For 45 days of incubation the highest MBC was obtained in T3 with SR (884 mg kg^{-1}) (Table 4.3.1.9). This was followed by T5 with SR and T5 with MR having 859 and 796 mg kg^{-1} of MBC. T3 with MR was statistically at par with both T3 with SR and T5 with SR. The lowest MBC was observed in T1 with Control sub treatment (402 mg kg^{-1}). Similarly dMBC was also significant and it was maximum in T5 with SR (379 mg kg^{-1}) followed by both T3 with SR (336 mg kg^{-1}) and T3 with MR (317 mg kg^{-1}) having no significant difference. The lowest dMBC was found in T1 with control sub treatment (23 mg kg^{-1}).

Alfisol:

The results showed that MBC content of initial soil in T1, T2, T3, T4 and T5 treatments were 494, 512, 571, 510 and 572 mg kg^{-1}, respectively. After addition of different substrates and incubation for 15 days, MBC content was increased significantly in all treatments having highest at T3 with SR (987 mg kg^{-1}) and it was followed by T3 with MR (894 mg kg^{-1}) and T5 with SR (879 mg kg^{-1}) having no significant difference (Table 4.3.1.10). The lowest MBC was shown by T1 with control sub treatment (564 mg kg^{-1}). Similarly dMBC was also significant and it was maximum in T3 with SR (416 mg kg^{-1}) followed by T3 with MR (323 mg kg^{-1}) and T5 with SR (307 mg kg^{-1}) having no significant difference. The lowest dMBC was found in T1 with control sub treatment (70 mg kg^{-1}). After 30 days of incubation MBC content showed a decreasing trend from initial values in such a way that dMBC was negative. For 30 days of incubation the highest MBC was obtained in T3 with SR (551 mg kg^{-1}). This was followed by T3 with WR having 512 mg kg^{-1}. There was no significant difference in between treatments like T5 with WR, T5 with MR, T5 with

Table 4.3.1.7 Interaction effect of long term manuring and C substrate added on C utilization efficiency (CUE) estimated in Vertisol over 15 days of incubation

Treatment	Vertisol					
	Sub treatment	MBC-I	MBC-15D	dMBC (MBC-15D-MBC-I)	∑Cmin-15D	CUE-15D (dMBC/dMBC+∑CO2-C)
		(mg kg^{-1})			(mg CO_2-C kg^{-1})	
Control	Control	379	$436^{n\ddagger}$	57^{q}	149^{i}	0.28^{h}
	WR	379	518^{m}	139^{p}	478^{g}	0.23^{i}
	MR	379	593^{l}	214^{o}	494^{g}	0.30^{g}
	SR	379	1435^{h}	1056^{h}	568^{f}	0.65^{c}
100%NPK	Control	413	882^{k}	469^{m}	264^{h}	0.64^{c}
	WR	413	1108^{j}	695^{j}	565^{f}	0.55^{e}
	MR	413	1933^{g}	1520^{g}	646^{cd}	0.70^{b}
	SR	413	2766^{d}	2353^{c}	638^{cd}	0.79^{a}
50%NPK+50%N-FYM	Control	548	1228^{i}	680^{jk}	270^{h}	0.72^{b}
	WR	548	1463^{h}	915^{i}	665^{bc}	0.58^{d}
	MR	548	2847^{c}	2299^{d}	695^{a}	0.77^{a}
	SR	548	3299^{a}	2751^{a}	708^{a}	0.80^{a}
50%NPK+50%N-Straw	Control	458	852^{k}	394^{n}	269^{h}	0.59^{d}
	WR	458	1092^{j}	634k^{l}	562^{f}	0.53^{e}
	MR	458	2043^{f}	1585^{f}	626^{de}	0.72^{b}
	DR	458	2623^{e}	2165^{e}	600^{e}	0.78^{a}
50%NPK+50%N-GM	Control	480	1083^{j}	603^{l}	267^{h}	0.69^{b}
	WR	480	1109^{j}	629^{kl}	640^{cd}	0.50^{f}
	MR	480	2769^{d}	2289^{d}	683^{ab}	0.77^{a}
	DR	480	2897^{b}	2416^{b}	666^{bc}	0.78^{a}

MBC-I: Microbial biomass carbon-Initial, MBC-15D: Microbial biomass carbon-15 Days of incubation, dMBC: Change in microbial biomass carbon, ∑Cmin: Summations of carbon mineralization-15 Days of incubation, CUE: Carbon utilization efficiency

‡ Values followed by different lowercase letters in a column are significant according to Duncan's Multiple Range Test (DMRT) at 5% level of significance

Table 4.3.1.8 Interaction effect of long term manuring and C substrate added on C utilization efficiency (CUE) estimated in Vertisol over 30 days of incubation

Vertisol						
Treatment	Sub treatment	MBC-I	MBC-30D	dMBC (MBC-30D-MBC-I)	∑Cmin-30D	CUE-30D (dMBC/dMBC+∑CO2-C)
			(mg kg^{-1})		(mg CO$_2$-C kg^{-1})	
Control	Control	379	$389^{o‡}$	10^{n}	241^{m}	0.04^{k}
	WR	379	552^{k}	173^{k}	625^{j}	0.22^{gh}
	MR	379	419^{n}	40^{m}	667^{i}	0.06^{k}
	SR	379	614^{j}	235^{ij}	780^{gh}	0.23^{fgh}
100%NPK	Control	413	426^{n}	13^{n}	377^{l}	0.03^{k}
	WR	413	674^{i}	261^{h}	781^{gh}	0.25^{f}
	MR	413	765^{h}	352^{g}	828^{f}	0.30^{de}
	SR	413	853^{f}	440^{d}	871^{e}	0.34^{c}
50%NPK+50%N-FYM	Control	548	611^{j}	63^{l}	427^{k}	0.13^{j}
	WR	548	802^{g}	254^{hi}	907^{cde}	0.22^{gh}
	MR	548	927^{d}	379^{f}	948^{ab}	0.29^{e}
	SR	548	1187^{a}	639^{a}	977^{a}	0.40^{a}
50%NPK+50%N-Straw	Control	458	472^{m}	14^{m}	370^{l}	0.04^{k}
	WR	458	611^{j}	153^{k}	754^{h}	0.17^{i}
	MR	458	671^{i}	213^{j}	806^{fg}	0.21^{h}
	DR	458	963^{c}	505^{g}	805^{fg}	0.39^{ab}
50%NPK+50%N-GM	Control	480	504^{l}	24^{mn}	409^{kl}	0.06^{k}
	WR	480	751^{h}	271^{h}	875^{de}	0.24^{fg}
	MR	480	893^{e}	413^{e}	914^{bcd}	0.31^{cd}
	DR	480	1009^{b}	529^{b}	920^{bc}	0.37^{b}

MBC-I: Microbial biomass carbon-Initial, MBC-30D: Microbial biomass carbon-30 Days of incubation, dMBC: Change in microbial biomass carbon, ∑Cmin: Summations of carbon mineralization-30 Days of incubation CUE: Carbon utilization efficiency

‡ Values followed by different lowercase letters in a column are significant according to Duncan's Multiple Range Test (DMRT) at 5% level of significance

Table 4.3.1.9 Interaction effect of long term manuring and C substrate added on C utilization efficiency (CUE) estimated in Vertisol over 45 days of incubation

Vertisol						
Treatment	Sub treatment	MBC-I	MBC-45D	dMBC (MBC-45D-MBC-I)	∑Cmin-45D	CUE-45D (dMBC/dMBC+∑CO2-C)
			(mg kg^{-1})		(mg CO$_2$-C kg^{-1})	
Control	Control	379	$402^{l‡}$	23^{j}	330^{n}	0.06^{h}
	WR	379	431^{k}	52^{i}	752^{j}	0.07^{h}
	MR	379	462^{ji}	83^{h}	794^{i}	0.09^{g}
	SR	379	490^{i}	111^{g}	901^{h}	0.11^{fg}
100%NPK	Control	413	429^{k}	16^{j}	485^{m}	0.03^{i}
	WR	413	665^{f}	252^{d}	967^{f}	0.21^{cd}
	MR	413	685^{ef}	272^{c}	977^{f}	0.22^{bc}
	SR	413	731^{d}	318^{b}	1022^{e}	0.24^{ab}
50%NPK+50%N-FYM	Control	548	556^{h}	8^{j}	573^{k}	0.01^{i}
	WR	548	672^{f}	124^{fg}	1111^{bc}	0.10^{g}
	MR	548	865^{ab}	317^{b}	1139^{b}	0.22^{bc}
	SR	548	884^{a}	336^{b}	1208^{a}	0.22^{bc}
50%NPK+50%N-Straw	Control	458	469^{j}	11^{j}	478^{m}	0.02^{i}
	WR	458	596^{g}	138^{f}	913^{gh}	0.13^{f}
	MR	458	674^{f}	216^{e}	947^{fg}	0.19^{d}
	DR	458	704^{e}	246^{d}	949^{fg}	0.21^{cd}
50%NPK+50%N-GM	Control	480	489^{i}	9^{j}	528^{l}	0.02^{i}
	WR	480	680^{f}	200^{e}	1057^{de}	0.16^{e}
	MR	480	796^{c}	316^{b}	1075^{cd}	0.23^{abc}
	DR	480	859^{b}	379^{a}	1136^{b}	0.25^{a}

MBC-I: Microbial biomass carbon-Initial, MBC-45D: Microbial biomass carbon-45 Days of incubation, dMBC: Change in microbial biomass carbon, ∑Cmin: Summations of carbon mineralization-45 Days of incubation CUE: Carbon utilization efficiency

‡ Values followed by different lowercase letters in a column are significant according to Duncan's Multiple Range Test (DMRT) at 5% level of significance

Table 4.3.1.10 Interaction effect of long term manuring and C substrate added on C utilization efficiency (CUE) estimated in Alfisol over 15 days of incubation

Alfisol						
Treatment	Sub treatment	MBC-I	MBC-15D	dMBC (MBC-15D-MBC-I)	∑Cmin-15D	CUE-15D (dMBC/dMBC+∑CO2-C)
			(mg kg^{-1})		(mg CO$_2$-C kg^{-1})	
Control	Control	494	$564^{k\ddagger}$	70^{i}	172^{m}	0.29^{cdef}
	WR	494	599^{j}	105^{h}	505^{j}	0.17^{j}
	MR	494	646^{i}	152^{f}	600^{fg}	0.20^{i}
	SR	494	740^{f}	246^{cd}	654^{cde}	0.27^{efgh}
100%NPK	Control	512	649^{i}	137^{fg}	209^{l}	0.39^{a}
	WR	512	725^{fg}	213^{e}	551^{hi}	0.28^{defg}
	MR	512	776^{e}	264^{c}	608^{fg}	0.30^{cde}
	SR	512	831^{c}	319^{b}	683^{bc}	0.30^{cde}
50%NPK+50%N-FYM	Control	571	727^{fg}	156^{f}	278^{k}	0.36^{b}
	WR	571	773^{e}	202^{e}	626^{ef}	0.24^{h}
	MR	571	894^{b}	323^{b}	702^{ab}	0.31^{c}
	SR	571	987^{a}	416^{a}	731^{a}	0.36^{b}
50%NPK+50%N-Straw	Control	510	630^{i}	120^{gh}	200^{lm}	0.37^{ab}
	WR	510	718^{g}	208^{e}	546^{i}	0.27^{efgh}
	MR	510	741^{f}	231^{de}	649^{de}	0.26^{fgh}
	DR	510	834^{c}	324^{b}	676^{bcd}	0.32^{c}
50%NPK+50%N-GM	Control	572	689^{h}	117^{gh}	257^{k}	0.31^{cd}
	WR	572	774^{e}	202^{e}	578^{gh}	0.26^{fgh}
	MR	572	798^{d}	226^{de}	689^{b}	0.25^{gh}
	DR	572	879^{b}	307^{b}	707^{ab}	0.30^{cde}

MBC-I: Microbial biomass carbon-Initial, MBC-15D: Microbial biomass carbon-15 Days of incubation, dMBC: Change in microbial biomass carbon, ∑Cmin: Summations of carbon mineralization-15 Days of incubation, CUE: Carbon utilization efficiency,

‡ Values followed by different lowercase letters in a column are significant according to Duncan’s Multiple Range Test (DMRT) at 5% level of significance

Table 4.3.1.11 Interaction effect of long term manuring and C substrate added on C utilization efficiency (CUE) estimated in Alfisol over 30 days of incubation

Alfisol						
Treatment	Sub treatment	MBC-I	MBC-30D	dMBC (MBC-30D-MBC-I)	∑Cmin-30D	CUE-30D (dMBC/dMBC+∑CO2-C)
			(mg kg^{-1})		(mg CO$_2$-C kg^{-1})	
Control	Control	494	$199^{k\ddagger}$	-295	254^{l}	7.24
	WR	494	294^{i}	-200	671^{h}	-0.42
	MR	494	325^{h}	-169	738^{g}	-0.30
	SR	494	386^{g}	-108	808^{e}	-0.15
100%NPK	Control	512	258^{j}	-253	318^{k}	-3.91
	WR	512	387^{g}	-125	728^{g}	-0.21
	MR	512	455^{d}	-57	763^{fg}	-0.08
	SR	512	433^{ef}	-79	869^{cd}	-0.10
50%NPK+50%N-FYM	Control	571	382^{g}	-189	429^{i}	-0.78
	WR	571	512^{b}	-59	810^{e}	-0.08
	MR	571	489^{c}	-82	896^{bc}	-0.10
	SR	571	551^{a}	-19	941^{a}	-0.02
50%NPK+50%N-Straw	Control	510	218^{k}	-292	317^{k}	-11.86
	WR	510	413^{f}	-97	728^{g}	-0.15
	MR	510	441^{de}	-69	797^{ef}	-0.10
	DR	510	453^{de}	-56	857^{d}	-0.07
50%NPK+50%N-GM	Control	572	329^{h}	-243	392^{j}	-1.62
	WR	572	476^{c}	-96	754^{g}	-0.15
	MR	572	482^{c}	-90	868^{cd}	-0.12
	DR	572	476^{c}	-96	908^{ab}	-0.12

MBC-I: Microbial biomass carbon-Initial, MBC-30D: Microbial biomass carbon-30 Days of incubation, dMBC: Change in microbial biomass carbon, ∑Cmin: Summations of carbon mineralization-30 Days of incubation, CUE: Carbon utilization efficiency

‡ Values followed by different lowercase letters in a column are significant according to Duncan’s Multiple Range Test (DMRT) at 5% level of significance

SR and T3 with MR. The lowest MBC was observed in T1 with Control sub treatment (199 mg kg^{-1}) (Table 4.3.1.11). After 45 days of incubation MBC content showed a decreasing trend from 30 days values in such a way that dMBC was negative. For 45 days of incubation the highest MBC was obtained in T3 with MR (346 mg kg^{-1}) and T5 with MR (333 mg kg^{-1}) having no significant difference (Table 4.3.1.12). This was followed by T3 with WR, T3 with SR and T5 with WR having 304, 304 and 292 mg kg^{-1} of MBC having no significant difference. The lowest MBC was observed in T1 with Control sub treatment (141 mg kg^{-1}).

Table 4.3.1.12 Interaction effect of long term manuring and C substrate added on C utilization efficiency (CUE) estimated in Alfisol over 45 days of incubation

	Alfisol					
Treatment	Sub treatment	MBC-I	MBC-45D	dMBC (MBC-45D-MBC-I)	∑Cmin-45D	CUE-45D (dMBC/dMBC+∑CO2-C)
			(mg kg^{-1})		(mg CO$_2$-C kg^{-1})	
Control	Control	494	141^{i‡}	-353	287^{n}	5.35
	WR	494	221^{e}	-273	781^{j}	-0.54
	MR	494	238de	-256	835^{i}	-0.44
	SR	494	176^{gh}	-318	882^{gh}	-0.56
100%NPK	Control	512	189^{gh}	-323	361^{m}	-8.34
	WR	512	282^{bc}	-230	884^{fgh}	-0.35
	MR	512	333^{a}	-179	898^{fg}	-0.25
	SR	512	223^{e}	-289	977^{cd}	-0.42
50%NPK+50%N-FYM	Control	571	216^{ef}	-355	536^{k}	-1.96
	WR	571	304^{b}	-267	956de	-0.39
	MR	571	346^{a}	-225	1042^{b}	-0.28
	SR	571	304^{b}	-267	1120^{a}	-0.31
50%NPK+50%N-Straw	Control	510	172^{h}	-338	365^{m}	-12.72
	WR	510	260^{cd}	-250	852^{hi}	-0.42
	MR	510	258^{d}	-252	923^{ef}	-0.38
	DR	510	198^{fg}	-312	948de	-0.49
50%NPK+50%N-GM	Control	572	193^{fgh}	-378	473^{l}	-4.01
	WR	572	292^{b}	-279	896^{fg}	-0.45
	MR	572	333^{a}	-238	997^{c}	-0.31
	DR	572	282^{bc}	-290	1067^{b}	-0.37

MBC-I: Microbial biomass carbon-Initial, MBC-45D: Microbial biomass carbon-45 Days of incubation, dMBC: Change in microbial biomass carbon, ∑Cmin: Summations of carbon mineralization-45 Days of incubation CUE: Carbon utilization efficiency

‡ Values followed by different lowercase letters in a column are significant according to Duncan's Multiple Range Test (DMRT) at 5% level of significance

The main effect of different fertilization on Microbial biomass carbon (MBC) for 15, 30 and 45 days were found as follows.

***Inceptisol**:*

It was found that MBC varied significantly after different days of incubation. For all 3 interval of days T3 (50%NPK+50%N-FYM) showed highest MBC (Fig. 4.3.1.1 a). For 15 days of incubation, it was followed by T5 (50%NPK+50%N-GM), T2 (100%NPK), T4 (50%NPK+50%N-Straw) and T1 (control). For 30 days of incubation T3 was followed by T4 (50%NPK+50%N-Straw), T5 (50%NPK+50%N-GM), T2 (100%NPK) and T1 (control). For 45 days of incubation T2 (100%NPK) showed second highest MBC. Rest of the treatments was statistically at par. From 15 to 45 days of incubation MBC was continuously decreasing.

***Mollisol**:*

It was found that MBC varied significantly after different days of incubation. MBC for 15 days of incubation was highest in T3 followed by T5, T4, T2 and T1. For 30 days of incubation the trend was T3 followed by T2, T5, T4 and T1 (Fig. 4.3.1.1 b). For 45 days of incubation T3 showed the highest MBC followed by both T5 and T2 which were not statistically different. T1 showed the lowest MBC. A decreasing trend in MBC was followed from 15 to 45 days of incubation.

***Vertisol**:*

It was found that the MBC varied significantly after different days of incubation. For 15 days of incubation, the MBC was recorded highest in T3 followed by T5. The T2 and T4 were statistically at par. The T1 showed the lowest amount of

MBC. For 30 days of incubation, there was no significant difference between T2 and T4. The highest MBC was observed in T3 and the lowest in T1. For 45 days the order was T3 followed by T5, T2, T4 and T1. MBC decreased significantly from 15 to 45 days of incubation (Fig. 4.3.1.1 c).

***Alfisol*:**

It was found that MBC varied significantly after different days of incubation. For all 3 intervals of incubation days, the T3 recorded the highest MBC (Fig. 4.3.1.1 d). For 15 and 45 days of incubation, the T3 was followed by T5, T2, T4 and T1. But for 30 days of incubation, there was no significant difference between T2 and T4. The T1 showed the lowest MBC. From 15 to 45 days of incubation, the MBC decreased steadily.

The main effect of different sub-treatment (residues) on Microbial biomass carbon (MBC) for 15, 30 and 45 days were as follows.

***Inceptisol*:**

It was found that in 15 and 45 days of incubation, the SR showed the highest MBC over others followed by MR, WR and control. For 30 days of incubation also, the SR showed the highest MBC but MR and WR had no significant effects on MBC (Fig. 4.3.1.2 a). Control showed the lowest amount of MBC. From 15 to 45 days of incubation, the MBC decreased significantly.

***Mollisol*:**

With respect to MBC content, similar trend was found for 15, 30 and 45 days of interval as observed in other soils. The highest MBC was found in SR followed by MR, WR and control. From 15 to 45 days of incubation MBC decreased significantly (Fig. 4.3.1.2 b).

***Vertisol*:**

With respect to MBC content, similar trend was found for all the three intervals of days. The highest MBC was found in SR followed by MR, WR and control. From 15 to 30 days of incubation MBC was decreased significantly as compared to 30 to 45 days (Fig. 4.3.1.2 c).

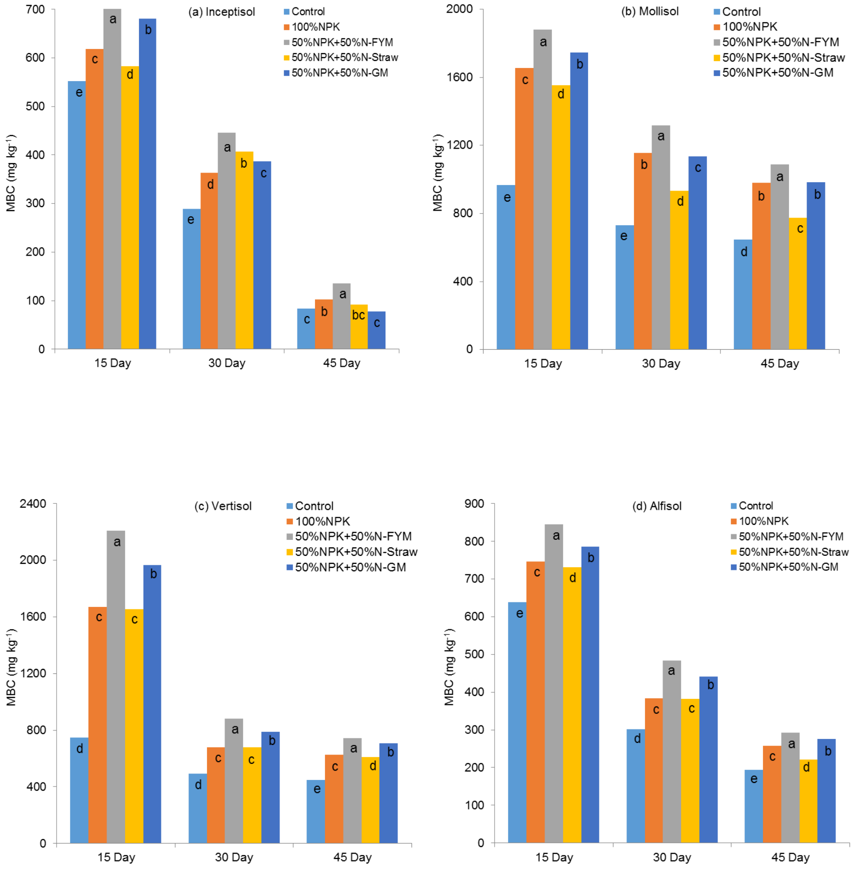

Figure 4.3.1.1 Main effect of fertilization on microbial biomass C (MBC) in (a) Inceptisol (b) Mollisol (c) Vertisol and (d) Alfisol amended with residues with varying C:N ratio; bars with different letters in a particular day are significant according to Duncan's Multiple Range Test (DMRT) at P=0.05.

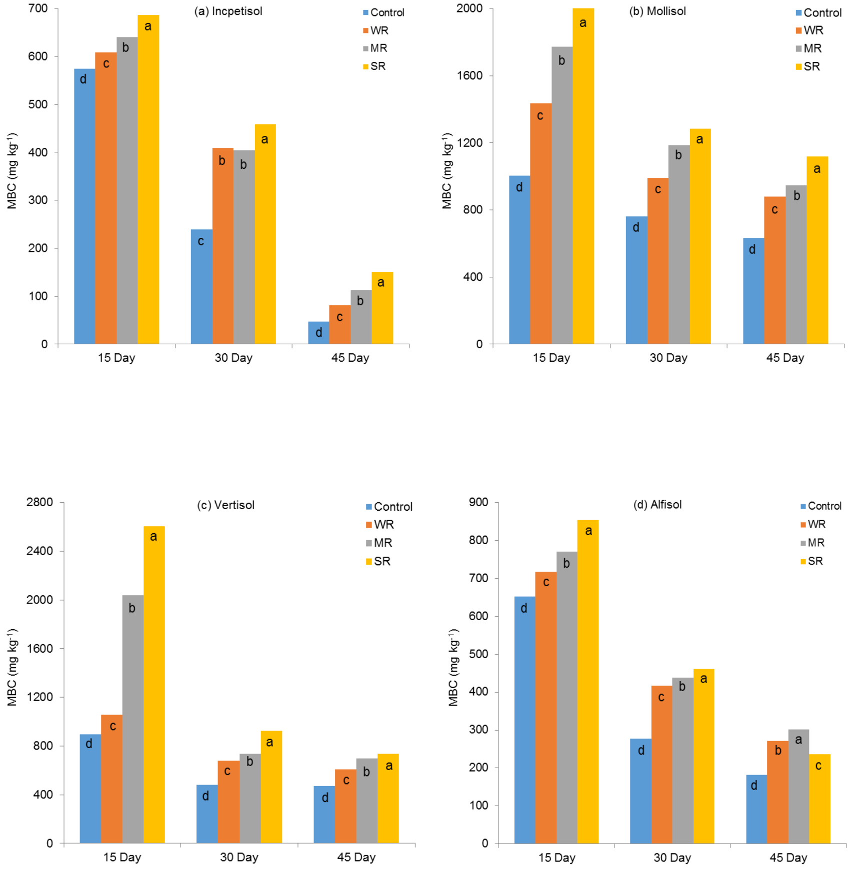

Figure 4.3.1.2 Main effect of wheat residue (WR), maize residue (MR) and Sesbania residue (SR) on microbial biomass C (MBC) in (a) Inceptisol (b) Mollisol (c) Vertisol and (d) Alfisol having long-term history of manuring and fertilization; bars with different letters in a particular day are significant according to Duncan's Multiple Range (DMRT) Test at P=0.05

***Alfisol**:*

It was found that in 15 and 45 days of incubation, the highest MBC was found in SR followed by MR, WR and control. But in 45 days of incubation, the trend was different where MBC was highest in MR followed by WR, SR and control (Fig. 4.3.1.2 d).

The main effect of different fertilization on change in Microbial biomass carbon (dMBC) for 15, 30 and 45 days were obtained as follows.

***Inceptisol**:*

As the dMBC was negative after 15 days of incubation in this soil, therefore, the figures are shown for 15 days only. The dMBC was highest in T3 followed by T5. T1 had the lowest dMBC. There was no significant difference between T2 and T4 (Fig. 4.3.1.3 a).

***Mollisol**:*

The dMBC for 15 days was highest in T3 followed by T5, T2, T4 and T1. For 30 days of incubation, it was highest in T3 followed by T2, T5, T4 and T1. For 45 days of incubation dMBC was highest in T3 and lowest in T1. But there was no significant difference between T5 and T2 (Fig. 4.3.1.3 b).

***Vertisol**:*

The dMBC for 15 days of incubation was highest in T3 followed by T5, T2, T4 and T1. From 15 to 30 days of incubation the dMBC was decreased sharply. For 30 days of incubation it followed the similar trend as that of 15 days. But for 45 days it was highest in T5 followed by T2, T3, T4 and T1 (Fig. 4.3.1.3 c).

***Alfisol**:*

As the dMBC was negative after 15 days of incubation in this soil so figures are shown for 15 days only. The dMBC here was highest in T3 followed by T2 and T5. The treatment T4 was statistically at par with both T2 and T5. T1 showed significantly low amount of dMBC as compared to other treatments (Fig. 4.3.1.3 d).

The main effect of different sub-treatment (residues) on change in Microbial biomass carbon (dMBC) for 15, 30 and 45 days were obtained as follows.

Inceptisol:

As the dMBC was negative after 15 days in this soil so figures are shown for 15 days only. The dMBC was highest in SR followed by MR, WR and control (Fig. 4.3.1.4 a).

Mollisol:

For all 3 intervals of days the dMBC followed the same trend as that of 15 days for Inceptisol (Fig. 4.3.1.4 b).

Vertisol:

For all 3 intervals of days the dMBC followed the same trend as that of 15 days for Inceptisol (Fig. 4.3.1.4 c).

Alfisol:

As the dMBC was negative after 15 days in this soil so figures are shown for 15 days only. The dMBC was highest in SR followed by MR, WR and control (Fig. 4.3.1.4 d).

4.3.2 Total C mineralization (**$\sum CO_2$-C**)

The total C mineralized after addition of different residues was obtained as follows.

Inceptisol:

It was found that the addition of different residues (WR, MR and SR) increased the total C mineralization (**$\sum CO_2$-C)**. There was significant difference in between different treatments and sub treatments. After 15 days of incubation **$\sum CO_2$-C** was highest in T3 with SR (864 mg CO_2-C kg^{-1}) followed by T2 with SR (807 mg CO_2-C kg^{-1}) and T3 with MR (800 mg CO_2-C kg^{-1}) both having no significant difference. These treatments were followed by T3 with WR (769 mg CO_2-C kg^{-1}). The lowest amount of **$\sum CO_2$-C** minearalized in T1 with control sub treatment (157 mg CO_2-C kg^{-1}) (Table 4.3.1.1). After 30 days of incubation cumulative C min was found to be increased. It was found to be highest in T3 with SR (1073 mg CO_2-C kg^{-1}) followed by T3 with MR (1000 mg CO_2-C kg^{-1}) and T2 with SR (978 mg CO_2-C kg^{-1}) both having no significant difference. These treatments were followed by T3 with WR

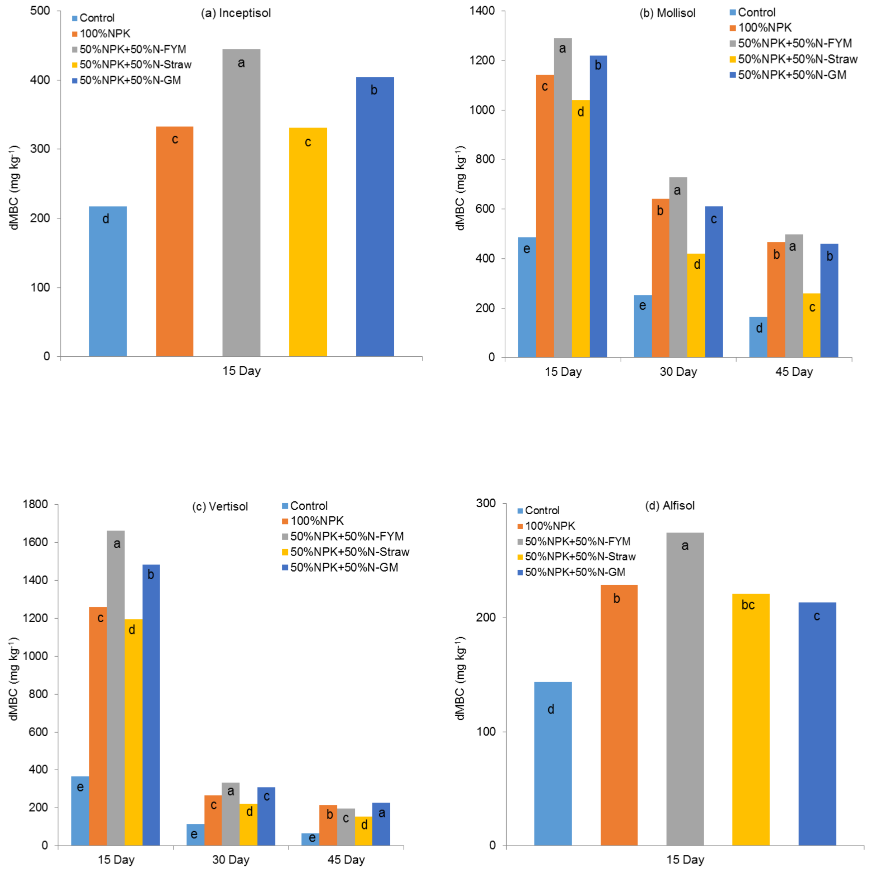

Figure 4.3.1.3 Main effect of fertilization on change in microbial biomass C (dMBC) in (a) Inceptisol (b) Mollisol (c) Vertisol and (d) Alfisol amended with residues with varying C:N ratio; bars with different letters in a particular day are significant according to Duncan's Multiple Range Test (DMRT) at P=0.05

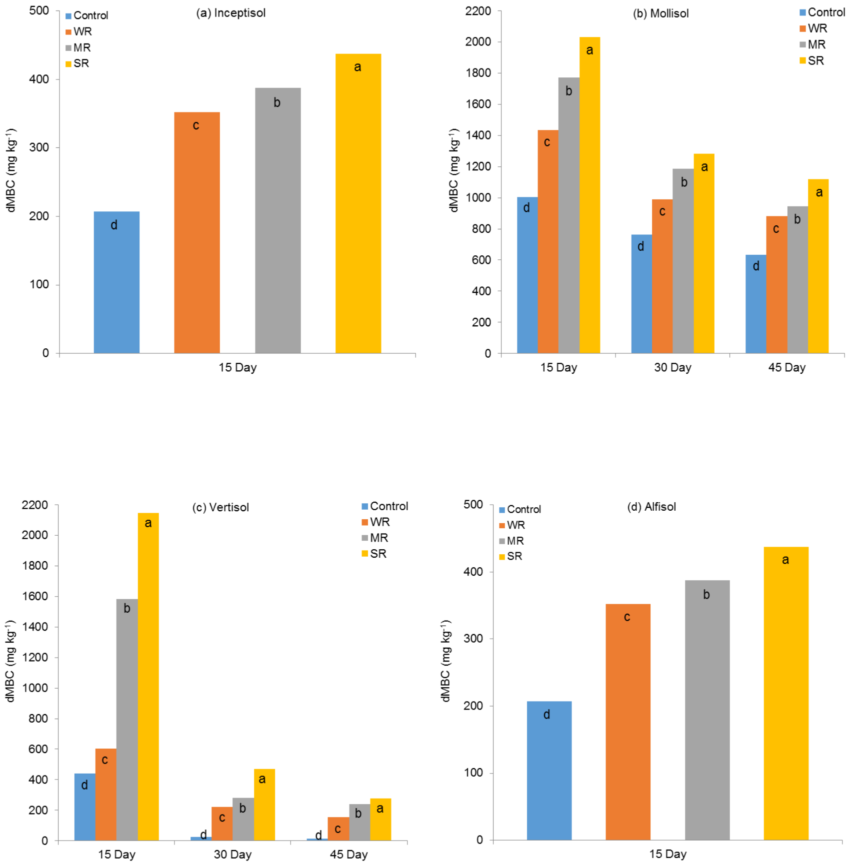

Figure 4.3.1.4 Main effect of wheat residue (WR), maize residue (MR) and Sesbania residue (SR) on change microbial biomass C (dMBC) in (a) Inceptisol (b) Mollisol (c) Vertisol and (d) Alfisol having long-term history of manuring and fertilization; bars with different letters in a particular day are significant according to Duncan's Multiple Range Test (DMRT) at P=0.05

(942 mg CO_2-C kg^{-1}). The lowest amount of **∑CO_2-C** in T1 with control sub treatment (224 mg CO_2-C kg^{-1}) (Table 4.3.1.2). Again after 45 days of incubation **∑CO_2-C** was found to be increased further. It was found to be highest in T3 with SR (1159 mg CO_2-C kg^{-1}) followed by T3 with MR (1080 mg CO_2-C kg^{-1}), T2 with SR (1044 mg CO_2-C kg^{-1}) all having significant difference. These treatments were followed by T3 with WR (1012 mg CO_2-C kg^{-1}). The lowest amount of **∑CO_2-C** in T1 with control sub treatment (257 mg CO_2-C kg^{-1}) (Table 4.3.1.3).

Mollisol:

It was found that the addition of different residues (WR, MR and SR) increased the C mineralization (**∑CO_2-C)** significantly in between different treatments and sub treatments. After 15 days of incubation **∑CO_2-C** was highest in T3 with SR (779 mg CO_2-C kg^{-1}) followed by T5 with SR (750 mg CO_2-C kg^{-1}) and T3 with MR (726 mg CO_2-C kg^{-1}) all having significant difference. The lowest **∑CO_2-C** mineralized in T1 with control sub treatment (244 mg CO_2-C kg^{-1}) (Table 4.3.1.4). After 30 days of incubation cumulative C min was found to be increased. It was found to be highest in T3 with SR (1088 mg CO_2-C kg^{-1}) followed by T5 with SR (1014 mg CO_2-C kg^{-1}) and T3 with WR (984 mg CO_2-C kg^{-1}). T3 with MR (1008 mg CO_2-C kg^{-1}) showed **∑CO_2-C** which was statistically at par with both T5 with SR and T3 with WR. These treatments were followed by T4 with SR (947 mg CO_2-C kg^{-1}). The lowest amount of **∑CO_2-C** in T1 with control sub treatment (350 mg CO_2-C kg^{-1}) (Table 4.3.1.5). Again after 45 days of incubation **∑CO_2-C** was found to be increased further. It was found to be highest in T3 with SR (1301 mg CO_2-C kg^{-1}) followed by T3 with MR (1204 mg CO_2-C kg^{-1}) and T5 with SR (1208 mg CO_2-C kg^{-1}) both having no significant difference. These treatments were followed by T3 with WR (1166 mg CO_2-C kg^{-1}). The lowest amount of **∑CO_2-C** in T1 with control sub treatment (415 mg CO_2-C kg^{-1}) (Table 4.3.1.6).

Vertisol:

It was found that the addition of different residues (WR, MR and SR) increased the C mineralization (**∑CO_2-C)** significantly in between different treatments and sub treatments. After 15 days of incubation, the**∑CO_2-C** was highest in T3 with SR (708 mg CO_2-C kg^{-1}) and T3 with MR (695 mg CO_2-C kg^{-1}) both having no significant difference. The T5 with MR (683 mg CO_2-C kg^{-1}) was statistically at par with T3 with MR. There was no significant difference in between T3 with WR (665 mg CO_2-C kg^{-1}) and T5 with SR (666 mg CO_2-C kg^{-1}). The lowest **$\sum CO_2$-C** mineralized in T1 with control sub treatment (149 mg CO_2-C kg^{-1}) (Table 4.3.1.7). After 30 days **$\sum CO_2$-C** was found to be increased. It was found to be highest in T3 with SR (977 mg CO_2-C kg^{-1}). T3 with MR (948 mg CO_2-C kg^{-1}) was statistically at par with T3 with SR. T5 with SR (920 mg CO_2-C kg^{-1}) was statistically at par with T3 with MR. The lowest amount of **$\sum CO_2$-C** in T1 with control sub treatment (241 mg CO_2-C kg^{-1}) (Table 4.3.1.8). Again after 45 days of incubation **$\sum CO_2$-C** was found to be increased further. It was found to be highest in T3 with SR (1208 mg CO_2-C kg^{-1}) followed by T3 with MR (1139 mg CO_2-C kg^{-1}) and T5 with SR (1136 mg CO_2-C kg^{-1}) both having no significant difference. These treatments were followed by T3 with WR (1111 mg CO_2-C kg^{-1}). The lowest amount of **$\sum CO_2$-C** in T1 with control sub treatment (330 mg CO_2-C kg^{-1}) (Table 4.3.1.9).

Alfisol:

It was found that the addition of different residues (WR, MR and SR) increased the C mineralization **($\sum CO_2$-C)** significantly in between different treatments and sub treatments. After 15 days of incubation C min was highest in T3 with SR (731 mg CO_2-C kg^{-1}) followed by T5 with MR (689 mg CO_2-C kg^{-1}). The T3 with MR (702 mg CO_2-C kg^{-1}) and T5 with SR (707 mg CO_2-C kg^{-1}) were statistically at par with both T3 with SR and T5 with MR. The lowest amount of **$\sum CO_2$-C** in T1 with control sub treatment (172 mg CO_2-C kg^{-1}) (Table 4.3.1.10). After 30 days **$\sum CO_2$-C** was found to be increased. It was found to be highest in T3 with SR (941 mg CO_2-C kg^{-1}). The T5 with SR (908 mg CO_2-C kg^{-1}) was statistically at par with T3 with MR (896 mg CO_2-C kg^{-1}). The lowest amount of **$\sum CO_2$-C** mineralized in T1 with control sub treatment (254 mg CO_2-C kg^{-1}) (Table 4.3.1.11). Again after 45 days of incubation, the **$\sum CO_2$-C** was found to be increased further. It was found to be highest in T3 with SR (1120 mg CO_2-C kg^{-1}) followed by T3 with MR (1042 mg CO_2-C kg^{-1}) and T5 with SR (1067 mg CO_2-C kg^{-1}) both having no significant difference. These treatments were followed by T5 with MR (997 mg CO_2-C kg^{-1}). The lowest amount of **$\sum CO_2$-C** mineralized in T1 with control sub treatment (287 mg CO_2-C kg^{-1}) (Table 4.3.1.12).

The main effect of different fertilization on cumulative C mineralization for 15, 30 and 45 days were obtained as follows.

Inceptisol:

In all 3 interval of days, the fertilization effects were found to follow same trend where T3 (50%NPK+50%N-FYM) showed highest cumulative C mineralization followed by T2 (100%NPK), T5 (50%NPK+50%N-GM), T4 (50%NPK+50%N-Straw) and T1 (control) (Fig. 4.3.1.5 a).

Mollisol:

For 15 days of incubation T3 showed highest cumulative C mineralization followed by T5, T2, T4 and T1. But for 30 and 45 days of incubation the trend has been different where T3 showed highest cumulative C min followed by T5. T2 and T4 were next to it having no statistical significance. T1 showed the lowest cumulative C min for both these days (Fig. 4.3.1.5 b).

Vertisol:

For 15, 30 and 45 days of incubation the trend is similar. T3 showed highest cumulative C mineralization **($\sum CO_2$-C)** followed by T5, T2, T4 and T1 (Fig. 4.3.1.5 c).

Alfisol:

For 15, 30 and 45 days of incubation it followed the same trend where T3 showed highest cumulative C mineralization. It was followed by T5. T1 showed the lowest cumulative C mineralization. T2 and T4 had no significant difference (Fig. 4.3.1.5 d).

The main effect of different sub-treatment (residues) on cumulative C mineralization for 15, 30 and 45 days were obtained as follows.

Inceptisol:

For all 3 intervals of days 15, 30 and 45 days of incubation sesbania residue (SR) showed highest cumulative C mineralization followed by maize residue (MR), wheat residue (WR) and control (Fig. 4.3.1.6 a).

***Mollisol**:*

For 15 and 45 days of incubation SR showed the highest cumulative C mineralization followed by MR, WR and control. For 30 days of incubation SR showed the highest cumulative C min and control showed the lowest. There was no significant difference in between MR and WR (Fig. 4.3.1.6 b).

***Vertisol**:*

For 15 days of incubation there was no significant difference in between SR and MR but SR showed the highest amount of cumulative C mineralization followed by WR and control. For 30 and 45 days of incubation SR showed highest cumulative C mineralization followed by MR, WR and control (Fig. 4.3.1.6 c).

***Alfisol**:*

For all 3 intervals of days 15, 30 and 45 days of incubation SR showed highest cumulative C mineralization followed by MR, WR and control (Fig. 4.3.1.6 d).

4.3.3 Carbon utilization efficiency (CUE)

The C utilization efficiency (CUE) of microbes was determined by studying the substrate induced microbial biomass C and C mineralization for a period of 15, 30 and 45 days of incubation at 37^{o} C.

***Inceptisol**:*

The C utilization efficiency (CUE) was calculated for 15, 30 and 45 days of incubation. It was found that the CUE for 15 days was highest in T3 (50%NPK+50%N-FYM) with *Sesbania* residue (SR) followed by T2 (100% NPK) with control sub-treatment and T1 (control) with SR to a tune of 0.23, 0.20 and 0.19, respectively but these are not statistically significant (Table 4.3.1.1). The lowest CUE was found in T5 (50%NPK+50%N-GM) with wheat residue (WR) i.e. 0.07 (Table 4.3.1.1). For 30 and 45 days CUE calculation was not done because change in MBC (dMBC) was negative for both these days as MBC after 15 days were decreasing in these soils. But MBC for 30 days of incubation and cumulative C-min for 30 and 45 days of incubation were analyzed and found to be highly significant in between different treatments and sub-treatments.

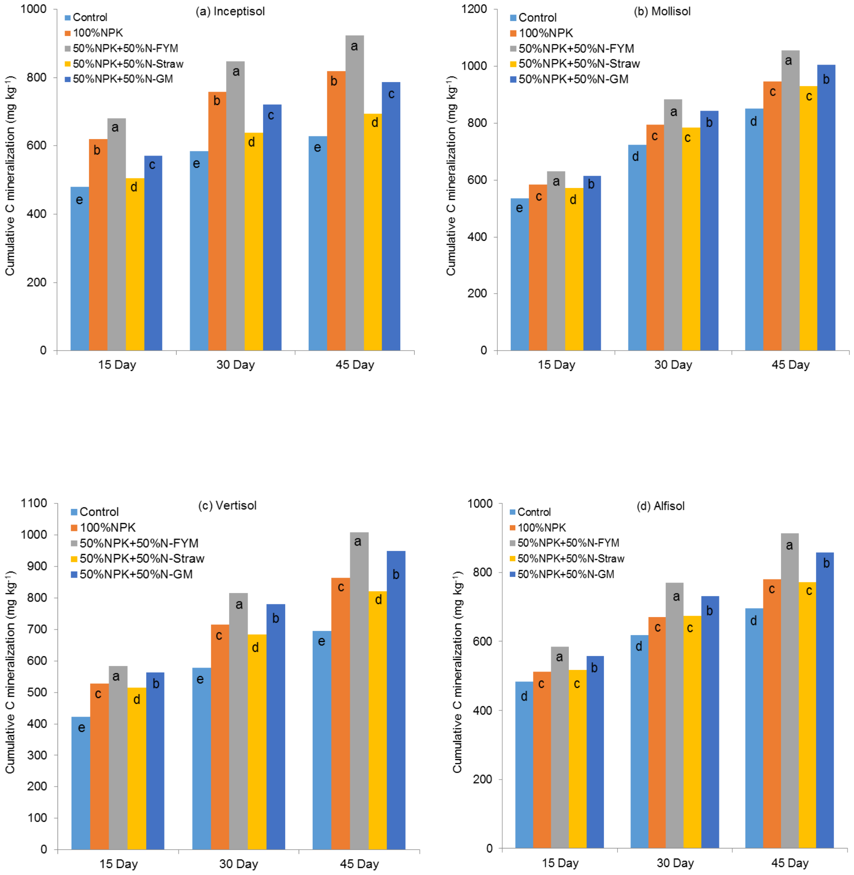

Figure 4.3.1.5 Main effect of fertilization on cumulative C mineralization in (a) Inceptisol (b) Mollisol (c) Vertisol and (d) Alfisol amended with residues with varying C:N ratio; bars with different letters in a particular day are significant according to Duncan's Multiple Range Test (DMRT) at P=0.05.

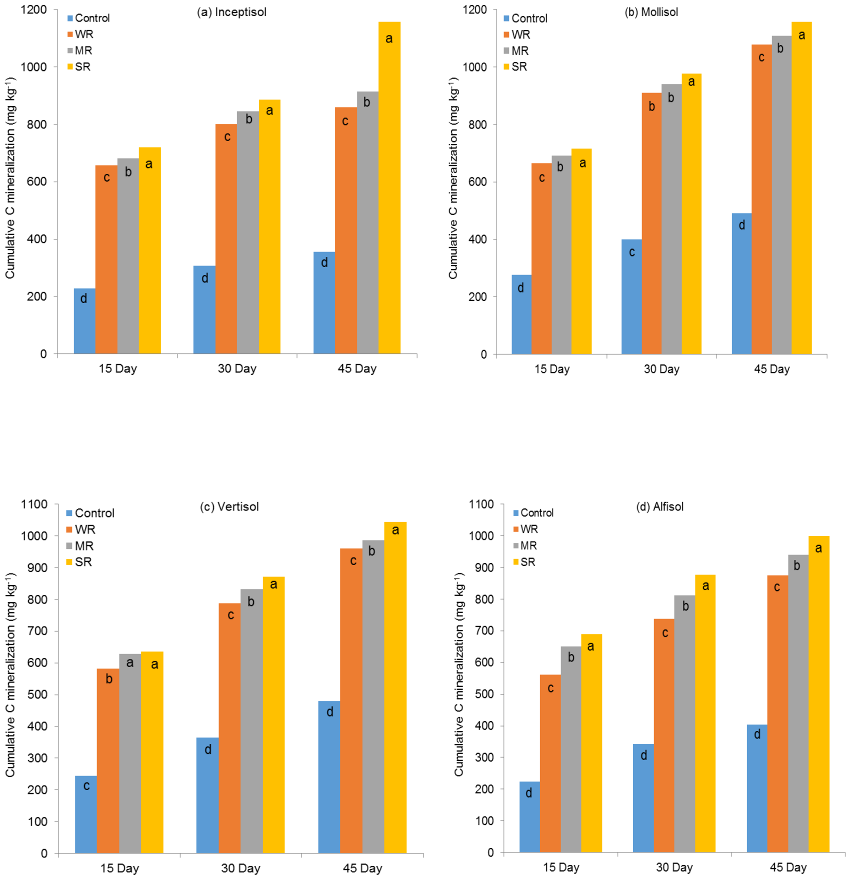

Figure 4.3.1.6 Main effect of wheat residue (WR), maize residue (MR) and Sesbania residue (SR) on cumulative C mineralization in (a) Inceptisol (b) Mollisol (c) Vertisol and (d) Alfisol having long-term history of manuring and fertilization; bars with different letters in a particular day are significant according to Duncan's Multiple Range Test (DMRT) at P=0.05

Mollisol:

It was found that addition of substrate increased CUE as compared to T1 (control). It was found to be highest in T3 (50%NPK+50%N-FYM) with SR followed by T5 (50%NPK+50%N-GM) with SR having values of 0.72 and 0.70 respectively whereas lowest CUE was found in T1 (control) with WR of 0.40 for 15 days of incubation (Table 4.3.1.4). For 30 days of incubation CUE was decreased from CUE for 15 days. It was highest in T2 (100%NPK) with SR and T3 (50%NPK+50%N-FYM) with SR with a value of 0.48 whereas lowest was found in case of T1 (control) with control sub-treatment (Table 4.3.1.5). For 45 days of incubation there was further decrease in CUE compared to 30 days of incubation and it was 0.39 in T2 (100%NPK) with SR and 0.02 in T1 (control) with control sub-treatment which are the highest and lowest values, respectively (Table 4.3.1.6).

Vertisol:

The highest CUE was found in Vertisol than other soil orders studied here. In all the treatments i.e. T3 (50%NPK+50%N-FYM), T5 (50%NPK+50%N-GM), T4 (50%NPK+50%N-Straw) and T2 (100%NPK) except T1 (control) CUE was in the order of 0.80, 0.78, 0.78 and 0.79, respectively which are not significantly different whereas the lowest CUE was observed in T1 (control) with maize residue (MR) i.e. 0.23 for 15 days of incubation (Table 4.3.1.7). The CUE decreased to almost half in 30 days of incubation of the experiment where in T3 (50%NPK+50%N-FYM) with SR and T4 (50%NPK+50%N-WR) with SR were having CUE of 0.40 and 0.39 respectively. The lowest CUE was found in case of T1 (control) with control sub-treatment i.e. 0.04 (Table 4.3.1.8). In 45 days there was further decrease in CUE of microbes and it was highest in T5 (50%NPK+50%N-GM) with SR as 0.25 and lowest in T3 (50%NPK+50%N-FYM) with control sub-treatment (Table 4.3.1.9).

Alfisol:

The highest CUE was found for15 days of incubation in T2 (100%NPK) with control sub-treatment lowest in T1 (control) with MR sub-treatment having 0.39 and 0.20 respectively. The CUE of 0.36 obtained in T3 (50%NPK+50%N-FYM) with SR and control sub-treatment followed by 0.31 and 0.32 in (50%NPK+50%N-FYM) with MR and T4 (50%NPK+50%N-WR) with SR which are not significantly different. T4 (50%NPK+50%N-WR) with control sub-treatment has CUE 0.37 which is statistically at par with T2 (100%NPK) with control sub-treatment and T3 (50%NPK+50%N-FYM) with SR and control sub-treatment (Table 4.3.1.10). For 30 and 45 days CUE has not been calculated as the dMBC was negative after 15 days of incubation. But MBC for 30 days of incubation and cumulative C-min for 30 and 45 days of incubation were analyzed and found to be highly significant in between different treatments and sub-treatments.

The main effect of different fertilization on carbon utilization efficiency (CUE) for 15, 30 and 45 days of incubation were obtained as follows.

Inceptisol:

The CUE is calculated for 15 days of incubation only because after 15 days CUE values were negative. The results were found to be it was highest in T3. The T2 and T4 were statistically at par with both T3 and T1. The 5 showed the lowest CUE (Fig. 4.3.1.7 a).

Mollisol:

There was no significant difference in CUE for 15 days of incubation in between treatments T3, T5 and T2. These treatments were followed by T4 and T1 being the lowest in CUE. For 30 and 45 days of incubation there was significant difference in between different treatments. For 30 days highest CUE were observed in T3 followed by T2 and T5 both as they were statistically at par then T4 and T1. Similarly for 45 days of incubation it was highest in T2 followed by T3, T5, T4 and T1 (Fig. 4.3.1.7 b).

Vertisol:

There were significant difference in between different treatments for CUE for 15 and 30 days of incubation having similar trend. T3 showed the highest CUE followed by T5, T2, T4 and T1. For 45 days CUE were not significantly different for T2 and T5. They were having the highest amount. They were followed by T3 and T4 having CUE which were not significantly different. T1 showed the lowest amount of CUE (Fig. 4.3.1.7 c).

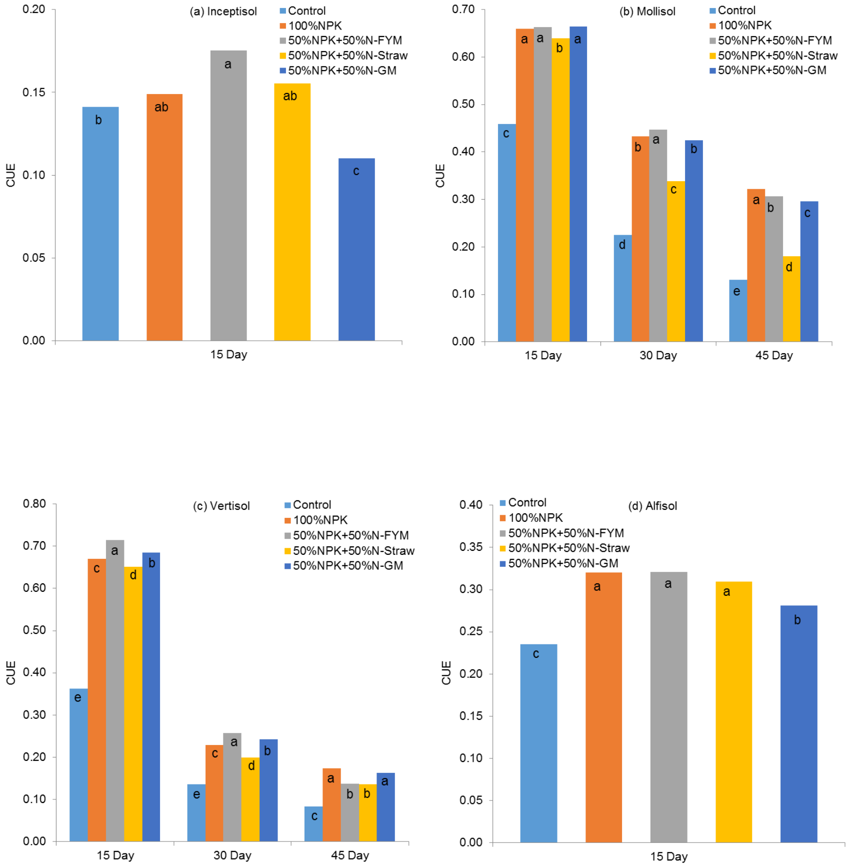

Figure 4.3.1.7 Main effect of fertilization on C utilization efficiency (CUE) in (a) Inceptisol (b) Mollisol (c) Vertisol and (d) Alfisol amended with residues with varying C:N ratio; bars with different letters in a particular day are significant according to Duncan's Multiple Range Test (DMRT) at P=0.05.

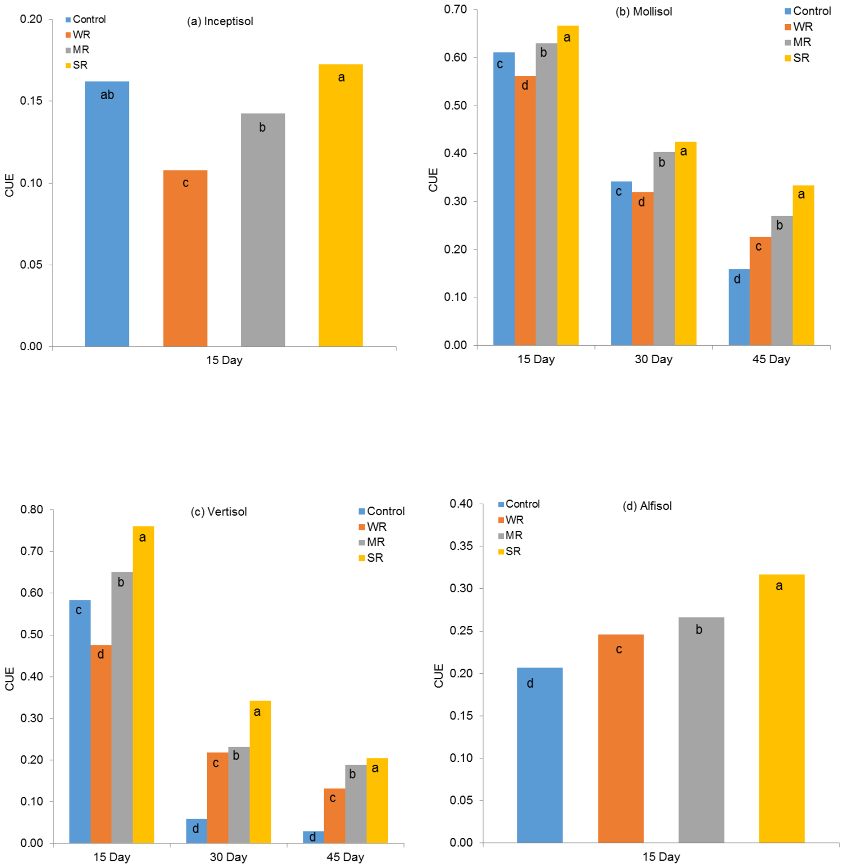

Figure 4.3.1.8 Main effect of wheat residue (WR), maize residue (MR) and Sesbania residue (SR) C utilization efficiency (CUE) in (a) Inceptisol (b) Mollisol (c) Vertisol and (d) Alfisol having long-term history of manuring and fertilization; bars with different letters in a particular day are significant according to Duncan's Multiple Range Test (DMRT) at P=0.05.

***Alfisol**:*

The CUE is calculated for 15 days of incubation only because after 15 days CUE values were negative. The T3, T2 and T4 treatments were showing statistically same amount of CUE. These treatments were followed by T5 and T1 (Fig. 4.3.1.7 d).

The main effect of different sub-treatment (residues) on carbon utilization efficiency (CUE) for 15, 30 and 45 days of incubation were obtained as follows.

***Inceptisol**:*

The CUE was calculated for 15 days of incubation only because after 15 days of incubation CUE values were negative. The highest CUE was found for SR followed by control and MR. Control was statistically at par with SR and MR. WR showed the lowest CUE (Fig. 4.3.1.8 a).

***Mollisol**:*

For 15 and 30 days of incubation the trend was similar. SR showed the highest CUE followed by MR, control and WR. But for 45 days the CUE was highest in SR followed by MR, WR and control (Fig. 4.3.1.8 b).

***Vertisol**:*

For 15 days of incubation, the CUE was highest in SR followed by MR, control and WR. But for 30, 45 days the CUE trend was similar. It was highest in SR followed by MR, WR and control (Fig. 4.3.1.8 c).

***Alfisol**:*

The CUE was calculated for 15 days of incubation only because after 15 days CUE values were negative. CUE was highest in SR followed by MR, WR and control (Fig. 4.3.1.8 d).

4.4.1. C mineralization from soil alone

The C mineralization from Soil alone for 15 and 45 days of incubation in all four orders were obtained as follows.

Inceptisol:

The C mineralization varied significantly among the treatments after 15 days of incubation. For T1, T2, T3, T4 and T5, the C mineralization was obtained as 0.16, 0.23, 0.29, 0.19 and 0.27 mg CO_2-C g^{-1} (Fig. 4.4.1 a). For T1, out of 100% C mineralized in 15 days, 28%, 27% and 26% was coming from soil alone in case of WR, MR and SR respectively. For T2 the contribution of soil towards C mineralization was 33%, 31% and 29% for WR, MR and SR respectively. For T3 37%, 36% and 33% C mineralized from soil alone for WR, MR and SR respectively. For T4 the contribution of soil towards C mineralization was 33%, 32% and 31% for WR, MR and SR respectively. Similarly for T5 from soil alone C mineralization was in the order of 40% for WR and MR both whereas for SR it was 39% (Fig. 4.4.1 b). After 45 days for T1, T2, T3, T4 and T5, the C mineralization was obtained as 0.26, 0.36, 0.44, 0.31 and 0.41 mg CO_2-C g^{-1}, respectively (Fig. 4.4.1 c). For T1 out of 100% C mineralized in 45 days 36%, 34% and 32% was coming from soil alone in case of WR, MR and SR respectively. For T2, the contribution of soil towards C mineralization was 40%, 36% and 34% for WR, MR and SR respectively. For T3, 40%, 41% and 38% C mineralized from soil alone for WR, MR and SR, respectively. For T4 the contribution of soil towards C mineralization was 38% for WR, whereas for MR and SR both it was 37%. Similarly for T5 from soil alone, the C mineralization was in the order of 47%, 45% and 44% for WR, MR and SR, respectively (Fig. 4.4.1 d)

Mollisol:

The C mineralization varied significantly among the treatments after 15 days of incubation. For T1, T2, T3, T4 and T5 treatments, the C mineralization was obtained as 0.24, 0.28, 0.31, 0.26 and 0.29 mg CO_2-C g^{-1}, respectively (Fig. 4.4.2 a). For T1, out of 100% C mineralized in 15 days of incubation, 40%, 38% and 37% was coming from soil alone in the case of WR, MR and SR, respectively. For T2, the contribution of soil towards C mineralization was 41%, 40% and 39% for WR, MR and SR respectively. For T3 44%, 43% and 40% C mineralized from soil alone for WR, MR and SR respectively. For T4 the contribution of soil towards C mineralization was 41% for WR, whereas it was 38% from MR and SR both. Similarly for T5 C mineralization from soil alone was in the order of 41%, 39% and 38% for WR, MR and SR, respectively (Fig. 4.4.2 b). After 45 days, T1, T2, T3, T4

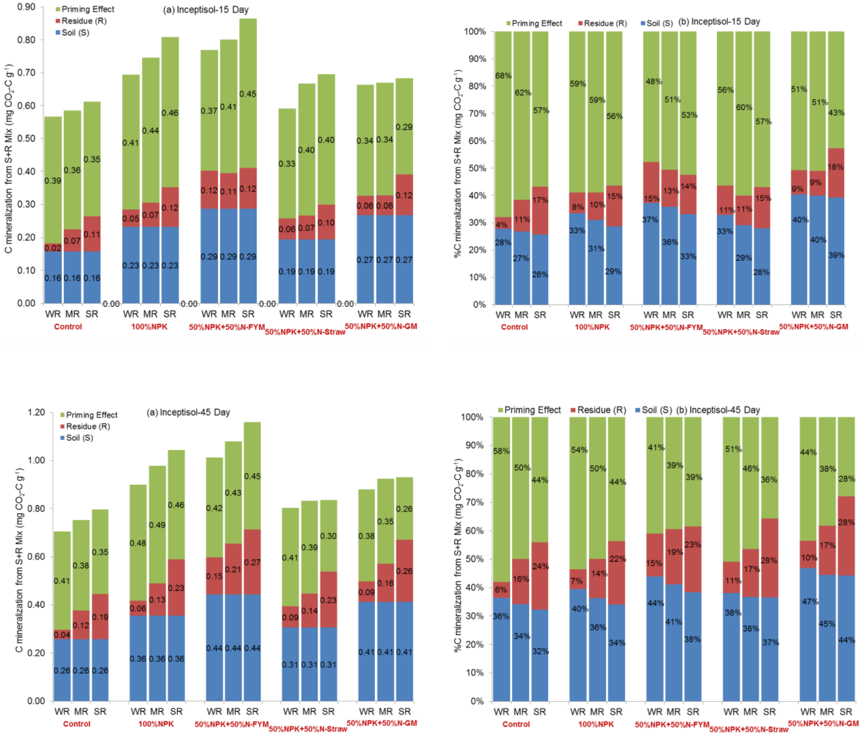

Figure 4.4.1 Effect of wheat residue (WR), maize residue (MR) and *Sesbania* residue (SR) on priming effect of native soil organic C in Inceptisol with long-term history of manuring and fertilization: (a) Inceptisol denotes C mineralization and (b) Inceptisol denotes %C mineralization.

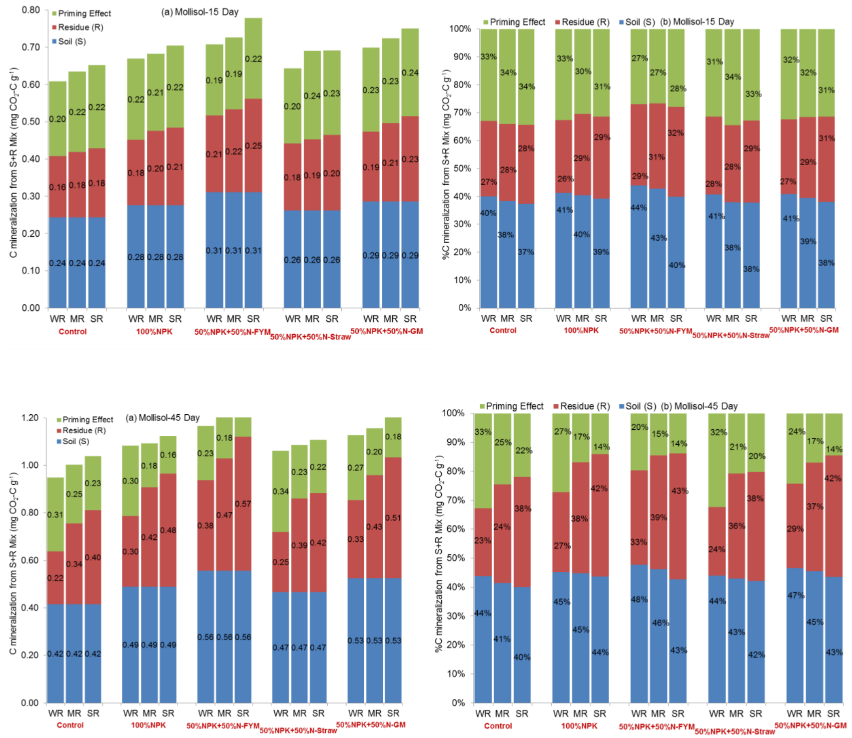

Figure 4.4.2 Effect of wheat residue (WR), maize residue (MR) and *Sesbania* residue (SR) on priming effect of native soil organic C in Mollisol with long-term history of manuring and fertilization: (a) Mollisol denotes C mineralization and (b) Mollisol denotes %C mineralization.

and T5 C min was obtained as 0.42, 0.49, 0.56, 0.47 and 0.53 mg CO_2-C g^{-1}, respectively (Fig. 4.4.2 c). For T1, out of 100% C mineralized in 45 days of incubation 44%, 41% and 40% was coming from soil only in case of WR, MR and SR, respectively. For T2, the contribution of soil towards C mineralization was 45% for WR and MR both, whereas it was 44% for SR. For T3, 48%, 46% and 43% C mineralized from soil only for WR, MR and SR, respectively. For T4 the contribution of soil towards C mineralization was 44%, 43% and 42% for WR, MR and SR, respectively. Similarly for T5 from soil alone, the C mineralization was in the order of 47%, 45% and 43% for WR, MR and SR, respectively (Fig. 4.4.2 d).

Vertisol:

The C mineralization varied significantly among the treatments after 15 days of incubation. For T1, T2 treatments, the C mineralization was obtained as 0.15, 0.26 mg CO_2-C g^{-1} and T3, T4 and T5, the C mineralization was 0.27 mg CO_2-C g^{-1}, respectively (Fig. 4.4.3 a). For T1 out of 100% C mineralized in 15 days 31%, 30% and 26% was coming from soil only in case of WR, MR and SR, respectively. For T2, the contribution of soil towards C mineralization was 39%, 32% and 38% for WR, MR and SR, respectively. For T3, 38%, 35% and 33% C mineralized from soil only for WR, MR and SR, respectively. For T4 the contribution of soil towards C mineralization was 48%, 43% and 45% for WR, MR and SR, respectively. Similarly for T5 from soil alone, the C mineralization was in the order of 38%, 34% and 36% for WR, MR and SR, respectively (Fig. 4.4.3 b). After 45 days for T1, T2, T3, T4 and T5, the C mineralization was obtained as 0.33, 0.48, 0.57, 0.48 and 0.53 mg CO_2-C g^{-1} (Fig. 4.4.3 c). For T1, out of 100% C mineralized in 45 days 44%, 42% and 37% was coming from soil only in case of WR, MR and SR respectively. For T2, the contribution of soil towards C mineralization was 50% for WR and MR both whereas for SR it was 47%. For T3, 52%, 50% and 47% C mineralized from soil only for WR, MR and SR, respectively. For T4 the contribution of soil towards C mineralization was 52% for WR whereas it was 50% for MR and SR both. Similarly for T5 from soil alone C mineralization was in the order of 50%, 49% and 46% for WR, MR and SR, respectively (Fig. 4.4.3 d).

Alfisol:

The C mineralization varied significantly among the treatments after 15 days of incubation. For T1, T2, T3, T4 and T5 treatments, the C mineralization was obtained as 0.17, 0.21, 0.28, 0.20 and 0.26 mg CO_2-C g^{-1}, respectively (Fig. 4.4.4 a). For T1 out of 100% C mineralized in 15 days 34%, 29% and 26% was coming from soil alone in case of WR, MR and SR, respectively. For T2 the contribution of soil towards C mineralization was 38%, 34% and 31% for WR, MR and SR respectively. For T3, 44%, 40% and 38% C mineralized from soil alone for WR, MR and SR, respectively. For T4 the contribution of soil towards C mineralization was 37%, 31% and 30% for WR, MR and SR, respectively. Similarly for T5 from soil alone C mineralization was in the order of 44%, 37% and 36% for WR, MR and SR respectively (Fig. 4.4.4 b). After 45 days of incubation for T1, T2, T3, T4 and T5, the C mineralization was obtained as 0.29, 0.36, 0.54, 0.36 and 0.47 mg CO_2-C g^{-1} (Fig. 4.4.4 c). For T1 out of 100% C mineralized in 45 days of incubation 37%, 34% and 33% was coming from soil alone in case of WR, MR and SR, respectively. For T2, the contribution of soil towards C mineralization was 41%, 40% and 37% for WR, MR and SR, respectively. For T3, 56%, 51% and 48% C mineralized from soil alone for WR, MR and SR, respectively. For T4, the contribution of soil towards C mineralization was 43%, 40% and 38% for WR, MR and SR, respectively. Similarly for T5 from soil alone C mineralization was in the order of 53%, 47% and 34% for WR, MR and SR, respectively (Fig. 4.4.4 d).

4.4.2. C mineralization from residue alone

Inceptisol:

After 15 days of incubation it was found that in T1treatment 0.02, 0.07 and 0.11 mg CO_2-C g^{-1} were mineralized with WR, MR and SR, respectively. In T2 treatment, 0.05, 0.07 and 0.12 mg CO_2-C g^{-1} mineralized with WR, MR and SR, respectively. In T3 treatment, 0.11 mg CO_2-C g^{-1}mineralized from MR and 0.12 mg CO_2-C g^{-1}mineralized from WR and SR both. For T4 0.06, 0.07 and 0.10 mg CO_2-C g^{-1} mineralized from WR, MR and SR, respectively. In T5 treatment, 0.06 mg CO_2-C g^{-1} mineralized from WR and MR both. SR mineralized 0.12 mg CO_2-C g^{-1} (Fig. 4.4.1 a). For T1, out of 100% C mineralized in 15 days of incubation 4%, 11% and 17% were coming from residue only in case of WR, MR and SR, respectively. For T2 the

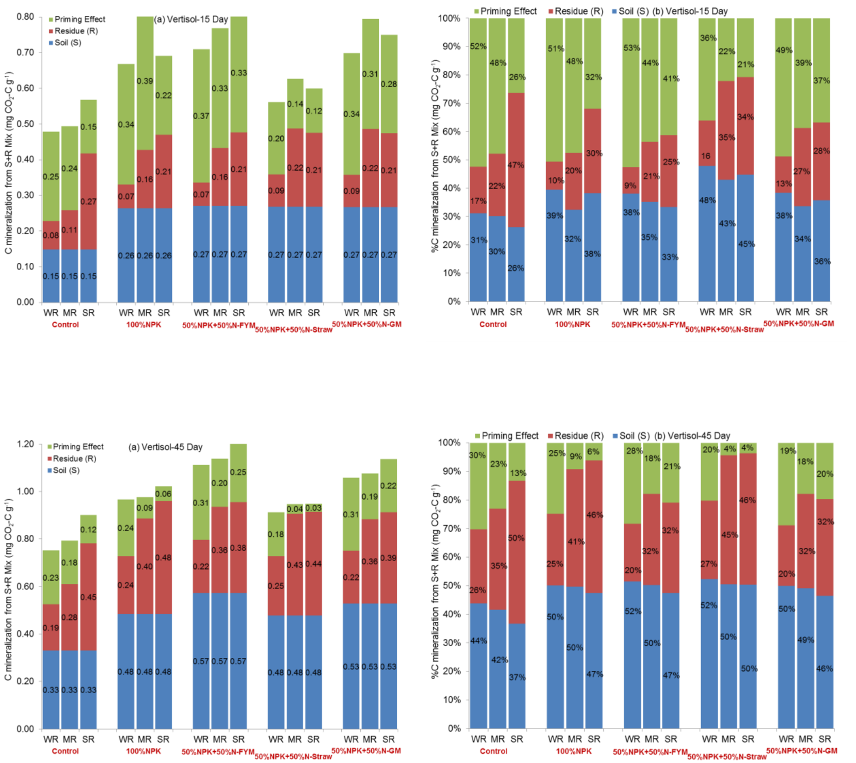

Figure 4.4.3 Effect of wheat residue (WR), maize residue (MR) and *Sesbania* residue (SR) on priming effect of native soil organic C in Vertisol with long-term history of manuring and fertilization: (a) Vertisol denotes C mineralization and (b) Vertisol denotes %C mineralization.

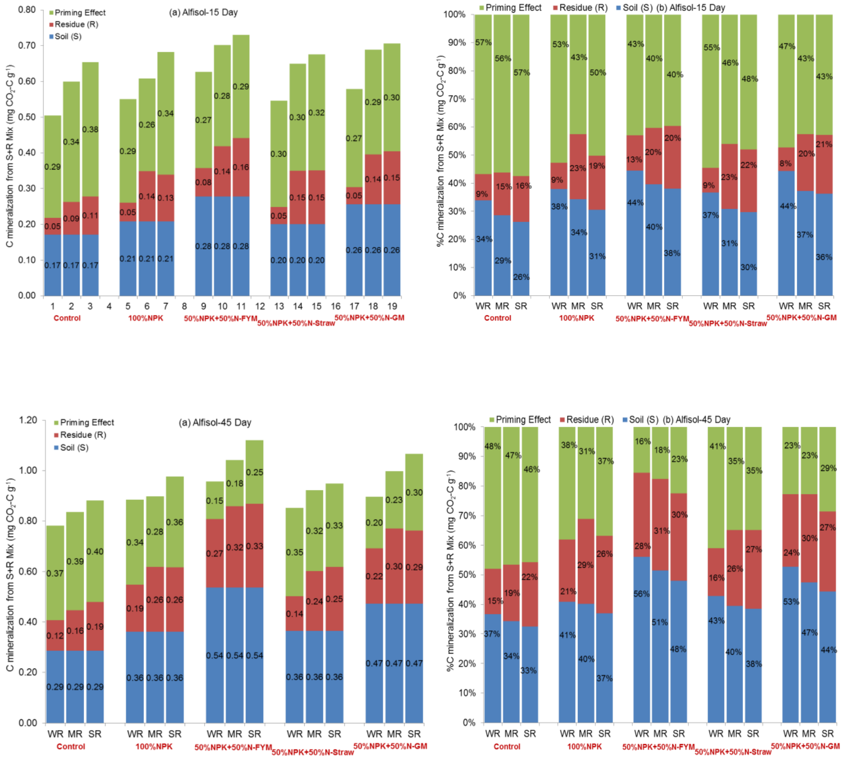

Figure 4.4.4 Effect of wheat residue (WR), maize residue (MR) and *Sesbania* residue (SR) on priming effect of native soil organic C in Alfisol with long-term history of manuring and fertilization: (a) Alfisol denotes C mineralization and (b) Alfisol denotes %C mineralization over 15 days period.

contribution of residue towards C mineralization was 8%, 10% and 15% for WR, MR and SR, respectively. In T3 treatment, 15%, 13% and 14% C mineralized from residue only with WR, MR and SR, respectively. For T4, the contributions of residue towards C mineralization were 11%, 1% and 6% for WR, MR and SR, respectively. Similarly for T5, from residue alone C mineralization was in the order of 9% for WR and MR both whereas for SR it was double i.e. 18% (Fig. 4.4.1 b). After 45 days of incubation in T1 0.04, 0.12 and 0.19 mg CO_2-C g^{-1}mineralized with WR, MR and SR, respectively. In T2 treatment, 0.06, 0.13 and 0.23 mg CO_2-C g^{-1} mineralized with WR, MR and SR, respectively. In T3 treatment, 0.15, 0.21 and 0.27 mg CO_2-C g^{-1} mineralized with WR, MR and SR, respectively. In T4 treatment, 0.09, 0.14 and 0.23 mg CO_2-C g^{-1} mineralized with WR, MR and SR, respectively. In T5 treatment, 0.09, 0.16 and 0.26 mg CO_2-C g^{-1} mineralized with WR, MR and SR, respectively (Fig. 4.4.1 c). In case of T1 treatment, out of 100% C mineralized in 45 days of incubation 6%, 16% and 24% was coming from residue alone in case of WR, MR and SR, respectively. In T2 treatment, the contribution of residue towards C mineralization was 7%, 14% and 22% for WR, MR and SR, respectively. In T3, 15%, 19% and 23% C mineralized from residue alone for WR, MR and SR, respectively. In the case of T4 treatment, the contributions of residue towards C mineralization were 11%, 17% and 28% for WR, MR and SR, respectively. Similarly in T5, from residue alone C mineralization were in the order of 10%, 17% and 28% for WR, MR and SR, respectively (Fig. 4.4.1 d).

Mollisol:

After 15 days of incubation it was found that in T1 treatment 0.16 mg CO_2-C g^{-1}mineralized from WR whereas MR and SR mineralized 0.18 mg CO_2-C g^{-1}. In T2 treatment, 0.18, 0.20 and 0.21 mg CO_2-C g^{-1} mineralized from WR, MR and SR, respectively. In T3 treatment, 0.21, 0.22 and 0.25 mg CO_2-C g^{-1} mineralized from WR, MR and SR, respectively. In T4 treatment, 0.18, 0.19 and 0.20 mg CO_2-C g^{-1} mineralized from WR, MR and SR, respectively. In T5 treatment, 0.19, 0.21 and 0.23 mg CO_2-C g^{-1} mineralized from WR, MR and SR, respectively (Fig. 4.4.2 a). For T1, out of 100% C mineralized in 15 days 27% was coming from WR whereas 28% was contributed by MR and SR both. For T2, the contribution of residue towards C mineralization was 26% for WR whereas 29% for MR and SR both. For T3, 29%, 31% and 32% C mineralized from residue only for WR, MR and SR, respectively. For

T4, the contribution of residue alone towards C mineralization was 28% for WR and MR both whereas for SR contribution was 29%. Similarly for T5, from residue alone C mineralization was in the order of 27%, 29% and 31% for WR, MR and SR respectively (Fig. 4.4.2 b). After 45 days of incubation for T1 0.22, 0.34 and 0.40 mg CO_2-C g^{-1} mineralized from WR, MR and SR, respectively. For T2 0.30, 0.42 and 0.48 mg CO_2-C g^{-1} mineralized from WR, MR and SR, respectively. For T3 0.38, 0.47 and 0.57 mg CO_2-C g^{-1} mineralized from WR, MR and SR, respectively. For T4 0.25, 0.39 and 0.42 mg CO_2-C g^{-1} mineralized from WR, MR and SR, respectively. For T5 0.33, 0.43 and 0.51 mg CO_2-C g^{-1} mineralized from WR, MR and SR, respectively (Fig. 4.4.2 c). In case of T1 treatment out of 100% C mineralized in 45 days of incubation 23%, 34% and 38% was coming from residue alone in case of WR, MR and SR respectively. For T2, the contribution of residue towards C mineralization was 27%, 38% and 42% for WR, MR and SR, respectively. For T3, 33%, 39% and 43% C mineralized from residue alone for WR, MR and SR, respectively. For T4, the contribution of residue towards C mineralization was 24%, 36% and 38% for WR, MR and SR, respectively. Similarly for T5, from residue alone C mineralization was in the order of 29%, 37% and 42% for WR, MR and SR, respectively (Fig. 4.4.2 d).

Vertisol:

After 15 days of incubation it was found that in T1 treatment 0.08, 0.11 and 0.27 mg CO_2-C g^{-1}mineralized from WR, MR and SR, respectively. For T2 and T3, the C mineralization trend was similar. It was 0.07, 0.16 and 0.21 mg CO_2-C g^{-1} mineralized from WR, MR and SR, respectively. For T4 and T5, C min trend was similar. It was 0.09, 0.22 and 0.21 mg CO_2-C g^{-1}mineralized from WR, MR and SR, respectively (Fig. 4.4.3 a). For T1, out of 100% C mineralized in 15 days 17%, 22% and 47% was coming from residue only in case of WR, MR and SR, respectively. For T2, the contribution of residue towards C mineralization was 10%, 20% and 30% in case of WR, MR and SR, respectively. For T3, 9%, 21% and 25% C mineralized from residue only for WR, MR and SR, respectively. For T4, the contribution of residue towards C mineralization was 16%, 35% and 34% for WR, MR and SR, respectively. Similarly for T5, from residue alone C mineralization was in the order of 13%, 27% and 28% for WR, MR and SR, respectively (Fig. 4.4.3 b). After 45 days of incubation for T1, 0.19, 0.28 and 0.45 mg CO_2-C g^{-1}mineralized from WR, MR and SR, respectively. For T2, 0.24, 0.40 and 0.48 mg CO_2-C g^{-1} mineralized from WR, MR and SR, respectively. For T3 0.22, 0.36 and 0.38 mg CO_2-C g^{-1} mineralized from WR, MR and SR, respectively. For T4, 0.25, 0.43 and 0.44 mg CO_2-C g^{-1} mineralized from WR, MR and SR, respectively. For T5, 0.22, 0.36 and 0.39 mg CO_2-C g^{-1} mineralized from WR, MR and SR, respectively (Fig. 4.4.3 c). In case of T1 treatment, out of 100% C mineralized in 45 days of incubation 26%, 35% and 50% was coming from residue only in case of WR, MR and SR, respectively. In T2, the contribution of residue towards C mineralization was 25%, 41% and 46% for WR, MR and SR respectively. In T3, 20% C mineralized from WR only whereas 32% C mineralized from MR and SR both. In T4, the contribution of residue towards C mineralization was 27%, 45% and 46% for WR, MR and SR, respectively. Similarly in T5, from residue alone C mineralization was in the order of 21%, 33% and 34% for WR, MR and SR, respectively (Fig. 4.4.3 d).

Alfisol:

After 15 days of incubation it was found that T1 treatment 0.05, 0.09 and 0.11 mg CO_2-C g^{-1} mineralized from WR, MR and SR, respectively. For T2, 0.05, 0.14 and 0.13 mg CO_2-C g^{-1} mineralized from WR, MR and SR, respectively. For T3, 0.08, 0.14 and 0.16 mg CO_2-C g^{-1} mineralized from WR, MR and SR, respectively. For T4, 0.05 mg CO_2-C g^{-1} mineralized from WR and 0.15 mg CO_2-C g^{-1} mineralized from MR and SR both. For, T5 0.05, 0.14 and 0.15 mg CO_2-C g^{-1} mineralized from WR, MR and SR, respectively (Fig. 4.4.4 a). For T1, out of 100% C mineralized in 15 days 9%, 15% and 16% was coming from residue only in case of WR, MR and SR, respectively. For T2, the contribution of residue towards C mineralization was 9%, 23% and 19% for WR, MR and SR, respectively. For T3, 13%, 20% and 22% C mineralized from residue only for WR, MR and SR, respectively. For T4, the contribution of residue towards C mineralization was 9%, 23% and 22% for WR, MR and SR, respectively. Similarly for T5, from residue alone C mineralization was in the order of 8%, 20% and 21% for WR, MR and SR, respectively (Fig. 4.4.4 b). After 45 days for T1 0.12, 0.16 and 0.19 mg CO_2-C g^{-1} mineralized from WR, MR and SR, respectively. For T2, 0.19 mg CO_2-C g^{-1} mineralized from WR and 0.26 mg CO_2-C g^{-1} mineralized from MR and SR both. For T3, 0.27, 0.32 and 0.33 mg CO_2-C g^{-1} mineralized from WR, MR and SR, respectively. For T4 0.14, 0.24 and 0.25 mg CO_2-C g^{-1} mineralized from WR, MR and SR, respectively. For T5, 0.22, 0.30 and 0.29 mg CO_2-C g^{-1} mineralized from WR, MR and SR, respectively (Fig. 4.4.4 c). For T1, out of 100% C mineralized in 45 days 15%, 19% and 22% was coming from residue only in case of WR, MR and SR, respectively. For T2, the contribution of residue towards C mineralization was 21%, 29% and 26% for WR, MR and SR, respectively. For T3, 28%, 31% and 30% C mineralized from residue only for WR, MR and SR, respectively. For T4, the contribution of residue towards C mineralization was 16%, 26% and 27% for WR, MR and SR, respectively. Similarly for T5, from residue alone C mineralization was in the order of 24%, 30% and 27% for WR, MR and SR, respectively (Fig. 4.4.4 d).

4.4.3. C mineralization from soil plus residue mixture

C mineralization from Soil+Residue mixtures was obtained as follows.

Inceptisol:

The C mineralization from soil+residue mixtures was obtained after 15 days of incubation from T1 treatment was 0.57, 0.59 and 0.62 mg CO_2-C g^{-1} with WR, MR and SR, respectively. C mineralization from T2 treatment was 0.69, 0.74 and 0.81 mg CO_2-C g^{-1} with WR, MR and SR, respectively. The C mineralization from T3 treatment was 0.78, 0.81 and 0.86 mg CO_2-C g^{-1} with WR, MR and SR, respectively. The C mineralization from T4 treatment was 0.58, 0.66 and 0.69 mg CO_2-C g^{-1} with WR, MR and SR, respectively. The C mineralization from T5 treatment was 0.67 mg CO_2-C g^{-1} with WR and MR both whereas SR obtained 0.68 mg CO_2-C g^{-1} (Fig. 4.4.1 a). The C mineralization after 45 days of incubation from T1 treatment was 0.71, 0.76 and 0.80 mg CO_2-C g^{-1} with WR, MR and SR, respectively. The C mineralization from T2 treatment after 45 days of incubation was 0.90, 0.98 and 1.05 mg CO_2-C g^{-1} from WR, MR and SR, respectively. The C mineralization from T3 treatment after 45 days of incubation was 1.01, 1.08 and 1.16 mg CO_2-C g^{-1} from WR, MR and SR, respectively. The C mineralization from T4 treatment after 45 days of incubation was 0.81mg CO_2-C g^{-1} with WR whereas MR and SR obtained 0.84 mg CO_2-C g^{-1}. The C mineralization from T5 treatment after 45 days of incubation was 0.88, 0.92 and 0.93 mg CO_2-C g^{-1} with WR, MR and SR, respectively (Fig. 4.4.1 c).

Mollisol:

The C mineralization from soil+residue mixtures was obtained after 15 days of incubation from T1 treatment was 0.60 mg CO_2-C g^{-1} with WR whereas MR and SR obtained 0.64 mg CO_2-C g^{-1}. The C mineralization for T2 was 0.68, 0.69 and 0.71 mg

CO_2-C g^{-1} with WR, MR and SR, respectively. The C mineralization for T3 was 0.71, 0.72 and 0.78 mg CO_2-C g^{-1} from WR, MR and SR respectively. The C mineralization for T4 was 0.64 mg CO_2-C g^{-1} from WR whereas MR and SR obtained 0.69 mg CO_2-C g^{-1}. The C mineralization for T5 was 0.71, 0.73 and 0.76 mg CO_2-C g^{-1} from WR, MR and SR respectively (Fig. 4.4.2 a). C mineralization after 45 days of incubation from T1 treatment was 0.95, 1.01 and 1.05 mg CO_2-C g^{-1} from WR, MR and SR respectively. The C mineralization from T2 treatment after 45 days of incubation was 1.09 mg CO_2-C g^{-1} from WR and MR both whereas SR obtained 1.13 mg CO_2-C g^{-1}. The C mineralization from T3 treatment after 45 days of incubation was 1.17, 1.21 and 1.21 mg CO_2-C g^{-1} from WR, MR and SR, respectively. The C mineralization from T4 treatment after 45 days of incubation was 1.06, 1.09 and 1.11 mg CO_2-C g^{-1} from WR, MR and SR, respectively. The C mineralization from T5 treatment after 45 days of incubation was 1.13, 1.16 and 1.22 mg CO_2-C g^{-1} from WR, MR and SR respectively (Fig. 4.4.2 c).

Vertisol:

The C mineralization from soil+residue mixtures was obtained after 15 days of incubation from T1 treatment was 0.48, 0.50 and 0.57 mg CO_2-C g^{-1} with WR, MR and SR, respectively. C mineralization for T2 was 0.67, 0.81 and 0.69 mg CO_2-C g^{-1} with WR, MR and SR, respectively. The C mineralization for T3 was 0.71, 0.76 and 0.81 mg CO_2-C g^{-1} with WR, MR and SR, respectively. The C mineralization for T4 was 0.56, 0.63 and 0.60 mg CO_2-C g^{-1} with WR, MR and SR respectively. The C mineralization for T5 was 0.70, 0.80 and 0.76 mg CO_2-C g^{-1} with WR, MR and SR respectively (Fig. 4.4.3 a). The C mineralization after 45 days of incubation from T1 treatment was 0.75, 0.79 and 0.90 mg CO_2-C g^{-1} with WR, MR and SR, respectively. The C mineralization after 45 days of incubation from T2 treatment was 0.96, 0.97 and 1.02 mg CO_2-C g^{-1} from WR, MR and SR, respectively. The C mineralization after 45 days of incubation from T3 treatment was 1.10, 1.13 and 1.20 mg CO_2-C g^{-1} from WR, MR and SR, respectively. The C mineralization after 45 days of incubation from T4 treatment was 0.91 mg CO_2-C g^{-1} from WR and MR and SR both mineralized 0.95 mg CO_2-C g^{-1}. The C mineralization after 45 days of incubation from T5 treatment was 1.06, 1.08 and 1.14 mg CO_2-C g^{-1} from WR, MR and SR, respectively (Fig. 4.4.3 c).

Alfisol:

The C mineralization from soil+residue mixtures was obtained after 15 days of incubation from T1 treatment was 0.51, 0.60 and 0.66 mg CO_2-C g^{-1} from WR, MR and SR respectively. The C mineralization from T2 treatment was 0.55, 0.61 and 0.68 mg CO_2-C g^{-1} with WR, MR and SR, respectively. The C mineralization from T3 treatment was 0.63, 0.70 and 0.73 mg CO_2-C g^{-1} with WR, MR and SR, respectively. The C mineralization from T4 treatment was 0.55, 0.65 and 0.67 mg CO_2-C g^{-1} with WR, MR and SR, respectively. The C mineralization from T5 treatment was 0.58, 0.69 and 0.71 mg CO_2-C g^{-1} with WR, MR and SR respectively (Fig. 4.4.4 a). The C mineralization after 45 days of incubation from T1 treatment was 0.78, 0.84 and 0.88 mg CO_2-C g^{-1} with WR, MR and SR, respectively. The C mineralization from T2 treatment after 45 days of incubation was 0.89, 0.90 and 0.98 mg CO_2-C g^{-1} with WR, MR and SR, respectively. The C mineralization from T3 treatment after 45 days of incubation was 0.96, 1.04 and 1.12 mg CO_2-C g^{-1} with WR, MR and SR, respectively. The C mineralization from T4 treatment after 45 days of incubation was 0.85, 0.92 and 0.94 mg CO_2-C g^{-1} with WR, MR and SR, respectively. The C mineralization from T5 treatment after 45 days of incubation was 0.89, 1.00 and 1.06 mg CO_2-C g^{-1} with WR, MR and SR, respectively (Fig. 4.4.4 c).

4.4.4. Priming effect (PE) on native SOC

Priming effect of different substrates on native SOC in four different orders was found as follows.

***Inceptisol**:*

The highest C mineralization after 15 days of incubation from soil+residue mixture was observed in T3 (50%NPK+50%N-FYM) followed by T2 (100% NPK), T5 (50%NPK+50%N-GM), T4 (50%NPK+50%N-WR) and T1 (control). The effect of different residues showed that the highest priming effect on native SOC was found in *Sesbania* residue (SR) followed by maize residue (MR) and wheat residue (WR). In the case of T1, there was 68% priming of native SOC caused by the application of WR followed by 62% and 57% through MR and SR, respectively. In T2, WR and MR had 59% priming effect and SR had 56% priming effect. In T3, the lowest priming was found in WR of about 48%. In T4, the highest priming effect was found in MR of about 66% followed by WR and SR of 56% and 53%, respectively. The lowest

priming effect was found in T5 treatment with SR of about 43%. Rest of the residues had 51% priming (Fig. 4.4.1 b). For 45 days of incubation, irrespective of different treatments C mineralization from soil+residue mixture was highest in SR followed by MR and WR. The highest C mineralization was found in T3 followed by T2, T5, T4 and T1 treatments. In case of percentage priming effect, the highest priming was observed in WR followed by MR and SR. In case of T1 treatment priming effect were in the order of 58%, 50% and 44% with WR, MR and SR, respectively. In T2 treatment, the priming effects were in the order of 54%, 50% and 44% with WR, MR and SR, respectively. In T3 treatment, the priming effects were in the order of 41%, 39% and 39% with WR, MR and SR, respectively. In T4 treatment, the priming effects were in the order of 51%, 46% and 36% with WR, MR and SR, respectively. In T5 treatment, the priming effects were in the order of 44%, 38% and 28% with WR, MR and SR, respectively (Fig. 4.4.1 d).

***Mollisol**:*

The highest C mineralization after 15 days of incubation from soil+residue mixture was observed in T3 (50%NPK+50%N-FYM) followed by T5 (50%NPK+50%N-GM). The T1 (control) showed the lowest C mineralization. The effect of different residues showed that the highest priming effect on native SOC was found in *Sesbania* residue (SR) followed by maize residue (MR) and wheat residue (WR). In the case of T1, addition of WR, MR and SR showed 33% priming effect on native SOC. In T2, WR, MR and SR had 33%, 30% and 31% priming effects, respectively. In T3, 27% priming effect was found for WR and MR, while 28% priming effect was found for SR. In T4, WR, MR and SR had 31%, 34% and 33% priming effects, respectively. In T5, WR and MR both showed 32% priming effect, whereas SR showed 31% priming effect (Fig. 4.4.2 b). For 45 days of incubation irrespective of different treatments C mineralization from soil+residue mixture was highest in SR followed by MR and WR. The highest C mineralization was found in T3 followed by T5. The T1 showed the lowest C mineralization from soil+residue mixture. In case of percentage priming effect, the highest priming effect was observed in WR followed by MR and SR. In the case of T1 treatment, priming effects were in the order of 33%, 25% and 22% with WR, MR and SR, respectively. In the case of T2 treatment, the priming effects were in the order of 27%, 17% and 14% with WR, MR and SR, respectively. In the case of T3 treatment, the priming effects were in the order of 20%, 15% and 14% with WR, MR and SR, respectively. In the case of T4 treatment, the priming effects were in the order of 32%, 21% and 20% with WR, MR and SR, respectively. In the case of T5 treatment, the priming effects were in the order of 24%, 17% and 14% with WR, MR and SR, respectively (Fig. 4.4.2 d).

Vertisol:

For 15 days, the C mineralization from soil+residue mixture was lowest in T1. Rest of the treatments had highly variable C mineralization from soil+residue mixture. In the case of percent priming, the highest priming effect on native SOC was found in T1 in WR of 52%. In T1, it was followed by MR and SR having priming effects of 48% and 26%, respectively. In T2, WR, MR and SR had 51%, 48% and 32% priming effects, respectively. In T3, WR, MR and SR had 53%, 44% and 41% priming effects, respectively. In T4, WR, MR and SR had 36%, 22% and 21% priming effects, respectively. In T5, WR, MR and SR had 49%, 39% and 37% priming effects, respectively (Fig. 4.4.3 b). For 45 days of incubation, irrespective of different treatments C mineralization from soil+residue mixture was highest in SR followed by MR and WR. The highest C mineralization was found in T3 followed by T5, T2, T4 and T1 treatments. In case of percent priming effect, the highest priming effect was observed in WR followed by MR and SR. In the case of T1 treatment, priming effects were in the order of 30%, 23% and 13% with WR, MR and SR, respectively. In the case of T2 treatment, the priming effects were in the order of 25%, 9% and 6% with WR, MR and SR, respectively. In the case of T3 treatment, the priming effects were in the order of 28%, 18% and 21% with WR, MR and SR, respectively. In the case of T4 treatment, WR showed 20% priming effect, whereas MR and SR both had priming effect of 4%. In the case of T5 treatment, the priming effects were in the order of 19%, 18% and 20% with WR, MR and SR, respectively (Fig. 4.4.3 d).

Alfisol:

The highest C mineralization after 15 days of incubation from soil+residue mixture was observed in T3 (50%NPK+50%N-FYM) followed by T5 (50%NPK+50%N-GM). The T1 (control) showed the lowest C mineralization. In the case of percent priming effect on native SOC, there were variations between the residue treatments. In T1, both WR and SR had 57% priming effect whereas, MR had 56% priming effect. Among the residues, WR showed the highest priming effect. In

T2, WR, MR and SR had 53%, 43% and 50% priming effects, respectively. In T3, WR had 43% priming effect and MR and SR both had 40% priming effect. In T4, WR, MR and SR had 55%, 46% and 48% priming effects, respectively. In T5, WR had 47% priming effect, whereas MR and SR both had priming effect of 43% (Fig. 4.4.4 b). For 45 days of incubation irrespective of different treatments, the C mineralization from soil+residue mixture was highest in SR followed by MR and WR. The highest C mineralization was found in T3 followed by T5. The T1 showed the lowest C mineralization from soil+residue mixture. In the case of percent priming effect, the highest priming effect was observed in WR followed by MR and SR. In the case of T1 treatment, the priming effects were in the order of 48%, 47% and 46% with WR, MR and SR, respectively. In the case of T2 treatment, the priming effects were in the order of 38%, 31% and 37% with WR, MR and SR, respectively. In the case of T3 treatment, priming effects were in the order of 16%, 18% and 23% with WR, MR and SR, respectively. In the case of T4 treatment, WR had 41% priming effect, whereas MR and SR both had 35% priming effect. In the case of T5 treatment, WR and MR both had 23% priming effect and SR had the priming effect of 29% (Fig. 4.4.4 d).

The main effect of manuring and fertilization on priming of native soil organic carbon (SOC) was found as follows.

For 15 and 45 days the priming effects were obtained as follows.

Inceptisol:

For 15 days, the treatments varied significantly with respect to priming effect on native SOC. In Inceptisol, the T1 showed highest priming effect (62%) followed by T2 and T4 both (58%) which were not significantly different. These treatments were followed by T3 (50%), whereas T5 showed least priming effect on native SOC (48%). The magnitude of priming effect on native SOC decreased from the 15 days to 45 days. The T1 showed highest priming effect on native SOC (51%) followed by T2 (49%), T4 (44%), T3 (40%) and T5 (37%) (Fig. 4.4.5 a).

Mollisol:

For 15 days, highest priming effect was observed in T1 (34%) followed by T4 (33%), T5 (32%), T2 (31%) and T3 (27%). For 45 days, the highest priming effect on native SOC was observed in T1 (26%) followed by T4 (24%). The T2 and T5 had similar priming effect (19%). The T3 showed the least priming effect (16%) (Fig. 4.4.5 a).

Vertisol:

For 15 days, the T3 showed the highest priming of native SOC (46%) followed by T2 (43%), T1 (42%), T5 (41%) and T4 (26%). For 45 days, the T1, T3 and T5 had similar effect on priming effect on native SOC (22%). The T4 showed the least priming effect (9%) (Fig. 4.4.5 a).

Alfisol:

For 15 days, T1 showed the highest priming effect on native SOC (57%). The T2 and T4 had similar priming effect (49%). The T3 showed the least priming effect on native SOC (41%). For 45 days, the T1 showed the highest priming effect on native SOC (47%) followed by T4 (37%), T2 (35%), T5 (25%) and T3 (19%) (Fig. 4.4.5 a).

The main effect of different residues having varying C: N ratio on priming of native soil organic carbon (SOC) was found as follows.

For 15 and 45 days the priming effects were obtained as follows.

Inceptisol:

For 15 days, MR and WR showed the highest and similar percent priming effect on native SOC (56%) followed by SR (53%). For 45 days, WR showed the highest percent priming effect on native SOC (49%) followed by MR (45%) and SR (38%) (Fig. 4.4.5 b).

Mollisol:

For 15 days, SR showed the highest priming effect on native SOC (32%). The WR and MR had similar priming effect on native SOC (31%). For 45 days, the trend of priming effect was similar as that of Inceptisol. The WR showed highest percent priming effect on native SOC (27%) followed by MR (19%) and SR (17%) (Fig. 4.4.5 b).

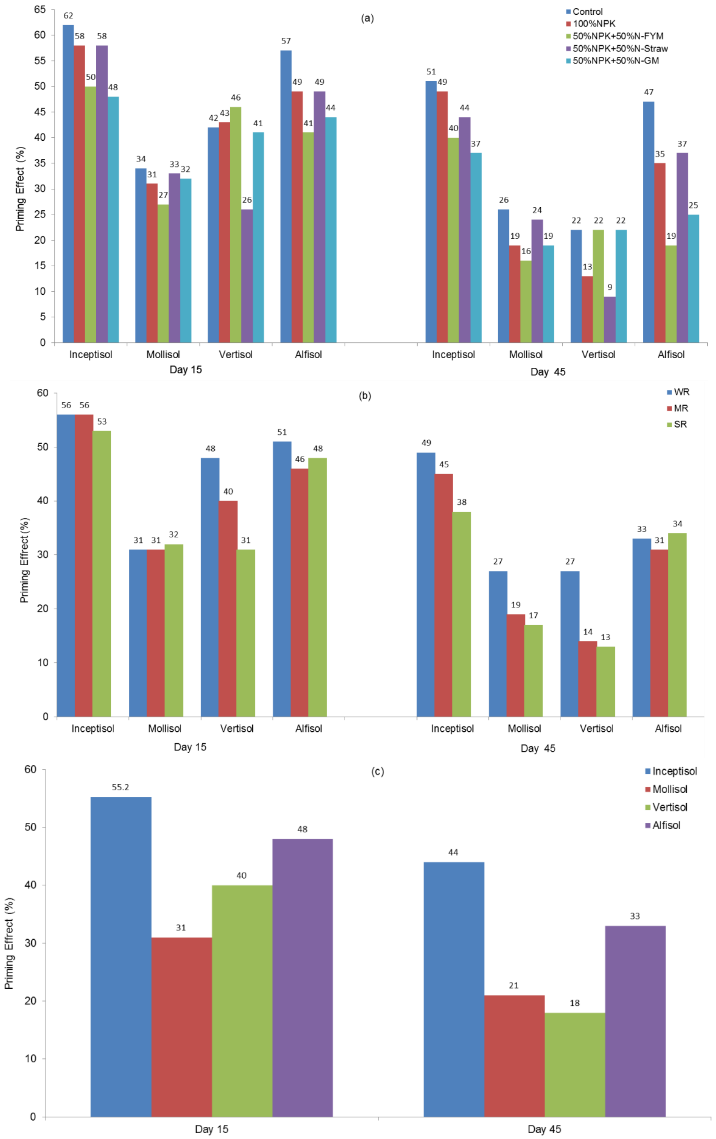

Figure 4.4.5 Effect of long-term (a) manuring and fertilization and (b) wheat residue (WR), maize residue (MR) and *Sesbania* residue (SR) addition and (c) soil order on priming effect of native soil organic C.

Vertisol:

For 15 days, WR showed the highest percent priming effect on native SOC (48%) followed by MR (40%) and SR (31%). For 45 days, the trend of priming effect was similar as that of Inceptisol. The WR showed highest percentage of priming effect on native SOC (27%) followed by MR (14%) and SR (13%) (Fig. 4.4.5 b).

Alfisol:

For 15 days, the WR showed highest percent of priming effect on native SOC (51%) followed by SR (48%) and MR (46%). For 45 days, the highest priming effect on native SOC was found in SR (34%) followed by WR (33%) and MR (31%) (Fig. 4.4.5 b).

The main effect of different soil order on priming of native soil organic carbon (SOC) was found as follows.

Inceptisol showed highest percent priming effect on native SOC (55.2% for 15 days and 44% for 45 days) irrespective of days of experiment and it was followed by Alfisol (48% for 15 days and 33% for 45 days). But for 15 days of experiment the lowest priming effect on native SOC was observed in Mollisol (31%), whereas it was lowest in Vertisol for 45 days (18%) (Fig. 4.4.5 c).

CHAPTER 5

Discussion

5. DISCUSSION

Rice –wheat is a dominant cropping system in Indo-Gangetic alluvial plains occupying an area of 13.5 million hectare covering India, Pakistan, Bangladesh and Nepal and 10.3 Million hectare in China. Due to increase in cost of fertilizer nutrients, it is extremely imperative to look and tap locally available organic sources of nutrients to supplement the nutrient requirements of the crops. The All India Coordinated Research Project (AICRP) on Integrated Farming System (IFS) experiments are in operation since 1983-84 in various soil orders namely Inceptisol, Mollisol, Vertisol and Alfisol located at Ludhiana (Punjab), Pantnagar (Uttarakhand), Jabalpur (Madhya Pradesh) and Ranchi (Jharkhand), respectively. The treatments imposed in rice-wheat cropping systems in all these locations except Ranchi which has been practicing maize-wheat cropping system had recommended dose of fertilizer (100% NPK) and 50% N supplemented through various organic sources like FYM, crop residues (straws) and green manuring crops in wet season crops (rice/maize) and in wheat recommended doses of NPK were applied. Different green manuring crops like *Sesbania* (*Sesbania aculeate* L.), Green gram (*Vigna radiata* L.), *Sunnhemp* (*Crotalaria juncea* L.) and *Karanj* (*Pongamia pinnata* L.) were used in Inceptisol, Mollisol, Vertisol and Alfisol, respectively. Through this study we wanted to assess the impact of long-term manuring and fertilization on soil C and its various labile fractions including C mineralization, C utilization efficiency (CUE) by microbes and priming effect on native SOC.

Soil C

The common recommended management practices leading to improve soil C sequestration under integrated nutrient management include the use of manures, compost, crop residues and bio- solids, mulch farming, conversation tillage, agro-forestry, diverse cropping systems and cover crops (Lal, 2004). All these practices have the potential to alter C storage capacity of agricultural soil (Halvorson *et al.*, 2002; Russell *et al.*, 2005). Soil C increased significantly in all the soil orders due to balanced fertilization and the effect was more dramatic in the treatments where inorganic fertilizer and organic sources were combined. The enhancement of soil C in all the treatments over control was observed highest in green manuring treatment in Inceptisol (30%) and Vertisol (70%) and in FYM treatment in Mollisol (70%) and

Alfisol (42%). In contrary to our results, Nayak *et al.* (2012) and Brar *et al.* (2013) showed higher C content in FYM treated plots in rice-wheat cropping system of Inceptisol, Ludhiana. Substitution of 50% N through FYM, crop residue or green manure to rice has improved significantly in all the soil order. This has happened because of additive effect of NPK and organics and interaction between them. Soil organic carbon is reported to increase by the continuous application of different combinations of N, P and K, whereas it decreased in unfertilized soils (Yadav *et al.*, 1998). According to Su *et al.* (2006), integrated use of FYM and fertilizers either maintained or improved SOC. A similar build-up of SOC due to cropping with the application of chemical fertilizer combined with manure (Rudrappa *et al.* 2006; Purakayastha *et al.*, 2008, Nayak *et al.*, 2012), paddy straw (Verma and Bhagat, 1992), and green manure (Yadav *et al.*, 2000) was also reported. The application of organic amendments, (farmyard manure, straw, green manure) tends to build up SOC in rice based cropping systems (Ghosh *et al.*, 2012; Mohanty *et al.*, 2013). Our results on Alfisol corroborated the findings of Sharma *et al.* (1998) who reported that in a long-term experiment with maize−wheat, there was a 50% increase in SOC due to addition of FYM. The role of rice straw, FYM on the formation of stable soil macroaggregates and aggregate associated C in sandy loam soil of Punjab (Benbi and Senapati, 2010) and through FYM in clay soil of central India (Bandyopadhyay *et al.*, 2010). The extent of increase in soil C was highest in Mollisol (59 to 63%), followed by Vertisol (40 to 70%) and Alfisol (27 to 42%). Our results on Mollisol did not corroborate the findings of Nayak *et al.* (2012) who reported lesser change in SOC in Incpetisol of Kalyani probably be due to high initial SOC and continued application of organic manure in this soil. The soil carbon accumulation may have reached close to saturation point and hence become less responsive to increased carbon inputs. This can be explained by the fact that every soil has its own C carrying capacity, therefore in spite of addition of large amount of C might not increase soil C proportionately (Purakayastha *et al.*, 2008). The dominance of clay and clay type is reported to enhance stabilization of SOC by various chemical means like ligand exchange, cation bridging, van der Waal’s force (Oades, 1989; Vermeer and Koopal, 1998; Vermeer *et al.*, 1998). Vertisols and Mollisols of our study being richer in clay content as well as dominant in 2:1 type fine smectititic minerals (Gupta *et al.*, 1999) might have played a major role in SOC stabilization which in turn enhanced the SOC to a greater extent than either Inceptisol and Alfisol which are poorer in clay content and dominated by

1:1 type clay minerals like lllite and kaolinite. Nevertheless, the type of clay also influenced the degradation of organic matter (OM) and further formation humic substances. Smectites (montmorillonite and nontronite), illite and kaolinite have been reported to serve as catalysts for the formation of humic-like substances from mixtures of phenols (Wang and Huang, 1989; Wang *et al.*, 1983). The rate of phenol polymerization or formation of humic-like substances from phenolic compounds is affected by: (1) the clay mineral type: smectite > illite > kaolinite > quartz (Wang *et al.*, 1978). The majority of the studies revealed an inhibitory effect of phyllosilicates on organic matter biodegradation. Some investigations only demonstrated a reduction in organic matter (OM) biodegradation rate in the presence of phyllosilicates without complete characterization of the actual amount of substrate in solution compared to that adsorbed to mineral surfaces (Chen *et al.*, 2009; Jones and Edwards, 1998; O'Loughlin *et al.*, 2000; Paget *et al.*, 1992). In most of the studies the reduction in biodegradation rate corresponded to an increased binding capacity which follows the order of montmorillonite> hectorite> illite> kaolinite (O'Loughlin *et al.*, 2000). Some studies showed that binding strength played a significant role in controlling the OM degradation rate (Cai *et al.*, 2011; Chen *et al.*, 2009). These were the reasons why Mollisol and Vertisol had higher SOC enrichment than the Inceptisol and Alfisol. Among the Vertisol and Mollisol, though the former soil had more clay content than the latter, both being located in subhumid subtropical climate, the average annual temperature might have impacted significantly the differential build up/enhancement of SOC in these two soils. Among all the soil orders, Inceptisol had the lowest C contents as SOC enrichment across all the treatments followed by Alfisol; the primary reason behind this phenomenon is primarily be due to light texture (sandy loam) Inceptisol and the semi-arid climate in which the soil is located. These factors might be driving factors for faster cycling of C added through various organic sources and low humification rate and weaker stabilization of SOC.

C minerlization

Mineralization of SOC is a catabolic process which fuel C and energy to the heterotrophic soil organisms. The mineralizable part of SOC is considered as labile part of SOC and therefore part of the SOC is easily mineralized in soil, while the resistant C pool is very slowly degraded with a time scale of hundreds to thousands of years (Oades, 1995). Long-term manuring and fertilization significantly enhanced the labile part of the SOC as humification process is extremely slow to make a sizeable change in recalcitrant part of SOC. The differences in cumulative C mineralization patterns indicated that 50%NPK+50%N-FYM higher labile SOC pool across all the soil orders except Mollisol which showed higher C mineralization in 50%NPK+50%N-FYM treatment. The size of the mineralizable C under long term manuring and fertilization in contrasting soil orders of our study varied widely. The size of the mineralizable C pool was significantly higher in treatments applied with 50%NPK+50%N-FYM in Mollisol from Pantnagar and Alfisol from Ranchi and Vertisol from Jabalpur and 50%NPK+50%N-FYM and 50%NPK+50%N-GM (green manure) in Inceptisol from Ludhiana. The balanced fertilized plots might have created favourable condition with better supply of labile C substrate which trigger the microbial activity and thus have more rate of mineralization. The amount of C mineralized in the present study is typical of tropical soils, where higher rates of soil organic matter turnover are reported (Goyal *et al.*, 1993, Rudrappa *et al.*, 2006, Triol Padre). The FYM being a stabilised product and narrow in C:N ratio than straw is less resistant to decomposition, in our study addition of inorganic N (50% of recommended dose) along with these materials further reduced the C:N ratio and enhanced its decomposability in Inceptisol, Vertisol and Alfisol. But in Inceptisol, straw showed comparable C mineralization with that of FYM due to lowering of C:N ratio due to application of fertilizer N in this treatment probably accelerated the C mineralization. Interestingly Mollisol exhibited significantly higher C mineralization in GM treatment probably be due to higher accumulation of good quality SOM. The cumulative C mineralization data was successfully fitted into one C pool first order kinetics in the form of exponential equation with very high R^2 value. The decay rate constant (k) of mineralizable C thus measured from this equation was in general higher in 50%NPK+50%N-FYM especially in Inceptisol and Vertisol clearly indicated the lability of mineralizable C accumulated in these two soils. Though the size of the mineralizable C varied significantly across various treatments and soil orders, the k did not vary much. The decay rate constant (k) estimated using Jenkinsons's two pool C model from long term fertilizer experiment from Indian Inceptisol of semi-arid sub tropics and Inceptisol of Indian Himalayas were reported to be 0.001 $year^{-1}$ (Purakayastha *et al.*, 2008) and 0.0018 $year^{-1}$ (Kundu *et al.*, 2006). The decay rate which we estimated varied from 0.0004 day^{-1} to 0.0008 day^{-1}.

Soil organic C and its various fractions

The SOM fractions, such as microbial biomass C (MBC), dissolved organic C (DOC) and particulate organic matter C (POM−C) are reported to be sensitive indicators of treatment induced changes than the total SOC (Dong *et al.*, 2009; Saviozzi *et al.*, 2001; Yang *et al.*, 2005). Many studies have reported the effects of different management practices on labile SOC pools (Dou *et al.*, 2008 and Plaza-Bonilla *et al.*, 2013). The addition of fertilizer on a regular basis leads to an increase in SOC, soil microbial biomass and also alters soil C and N dynamics (Smith *et al.*, 1994). Soil biota is considered an important component of soil organic matter involved in energy and nutrient cycling. It is well established that the more dynamic soil characteristics such as microbial biomass, soil enzyme activity and respiration respond more quickly to changing crop management or environmental conditions than total or available soil organic matter (Dick, 1992; Doran *et al.*, 1996) or other available soil nutrients. Our study clearly demonstrated enhanced microbial biomass carbon (MBC) in 50%NPK+50%N-GM in Inceptisol, 50%NPK+50%N-FYM in Mollisol, Vertisol and Alfisol. Among various management options, *Sesbania* (*S. aculeata*, *S. rostrata*) offered highest values of both soil dehydrogenase activity (DHA) and (MBC) during maize–wheat cultivation (Jat *et al.*, 2015). Likewise, the treatments receiving different organic sources exhibited higher MBC over chemical fertilizers (Bhaduri *et al.*, 2017), and this could be due to better proliferation of microbes (Chaudhury *et al.*, 2005; Manjaiah and Singh, 2001; Rudrappa *et al.*, 2006). However, quality and content of added organic manures may be a crucial factor for enhancing soil microbial potential or overall biological quality of soil, and crop residues had limited effects on soil microbial functions (Giacometti *et al.*, 2013). In our study the treatments with 50%NPK+50%N-Straw showed less MBC than the treatments with either 50%NPK+50%N-GM or 50%NPK+50%N-FYM. Vertsol in spite of being clay in texture showed less MBC than the order soil orders. It is known that the microbial fraction of clay soils is often greater than it is in sandy soils due to the protective effect of clays on microbial biomass (Jenkinson and Ladd, 1981; Wardle, 1992; Theng and Orchard, 1995; Sparling, 1997, Nayak *et al.*, 2012). Particulate organic matter C (POM−C) being considered as a measure of labile SOM (active C fraction) is primarily of plant−derived remains with recognizable cell structure and typically includes fungal spores, hyphae, and charcoal (Spycher *et al.*, 1983, Waters and Oades, 1991; Gregorich and Ellert, 1995) which are generally physically protected inside the macro aggregates (Six *et al.*, 1998). Particulate organic C makes up a large portion of the light fractions of SOC (Cambardella and Elliott, 1992) and is comprised of plant residues as well as microbial and microfaunal debris (Nichols and Wright, 2006). Therefore, POC is composed of a large proportion of relatively labile organic materials, often of recent origin. Our study clearly demonstrated that 50%NPK+50%N-FYM showed highest POM-C across all the soil orders. This might be due to a possible strong association between SOM and POM, and possibly related to the binding agents such as polysaccharides, fungal hyphae, glomalin (Wright and Upadhyaya, 1996; Wright *et al.*, 1999). The main source of POC in soil is the difficultly decomposable organic residues having high lignocellulose index as is found in root biomass and the organic residues added externally to soil which might have contributed significantly for soil aggregation and thus can physically protect the POM. It was reported that the additional organic carbon input from FYM in 100% NPK + FYM treatment applied over more than three decades in maize−wheat−cowpea cropping system in Inceptisol of semi-arid subtropics further enhanced the POC accumulation (Rudrappa *et al.*, 2006). The POM-C (mg kg^{-1} POM) were greater in Vertisol and Mollisol which was due to lesser sand content in the POM fraction while being sandy loam in texture the sand content was higher in POM separated from Inceptisol. The 50%NPK+50%N-Straw and 50%NPK+50%N-GM showed comparable POM-C with 100%NPK across all the soil order. The increase in POC in fertilized plot was mainly being due to increased yield trend in this treatment over past years. The additional amounts of organic C input from organics in the treatments received NPK along with organics further enhanced the POM-C contents in these treatments. It is suggested that the greater biochemical recalcitrance of root litter (Puget and Drinkwater, 2001) might have also increased the POC contents in soil depending upon the root biomass produced.

The dissolved organic C (DOC) in our study clearly indicated that the 50%NPK+50%-N-FYM maintained it higher over other treatments. The increase in water soluble C with application of inorganic N fertilizers could be as a result of the priming effect of applied inorganic N on fresh organic material in the soil which stimulates the microbial activity helping in the decomposition of SOM with rapid release of the DOC fraction. The beneficial effect of FYM application under rice-wheat cropping system on DOC content was also reported by others (Manna *et al.*, 2006, Brar *et al.*, 2013). The DOC content was higher in GM treatment only Inceptisol. Effects of fertilization on dissolved organic matter in soil solution have previously been shown (Currie *et al.*, 1996; McDowell *et al.*, 1998, 2004; Neff *et al.*, 2000).

The $KMnO_4$-C is considered as labile fraction SOC which serve as sensitive indicator of changes in management induced soil quality (Weil *et al.*, 2003). As $KMnO_4$-C, being a labile C fraction accumulated differentially over the years mainly because of differential C accumulation. The $KMnO_4$-C was invariably higher in 50%NPK+50%N-FYM treatments in all the soil order excepting Vertisol and Alfisol in which 50%NPK+50%-GM /Straw also showed equally higher $KMnO_4$-C along with FYM treatment. $KMnO_4$ extracts relatively younger organic compounds including labile humic materials and polysaccharides, this reagent tends to extract higher amount of $KMnO_4$-C from manure and fertilizer-treated plots than the control (Haynes, 2005). Apparently, crop residues along with full dose mineral N in maize–wheat was more effective in increasing $KMnO_4$-C content of soil as compared to 25 % of recommended urea–N substituted by FYM (Sandeep *et al.*, 2016). After 10 years $KMnO_4$-C contents in all the treatments (50%NPK, 100%NPK, 100%NPK+FYM, 15%NPK) significantly increased (Purakayastha *et al.*, 2008). Application of FYM along with NPK (100%NPK + FYM) showed highest accumulation of $KMnO_4$–C while the control observed lowest value (Purakayastha *et al.*, 2008). In the case of low fertility treatments the increase was less, while in high fertility treatments the extent of increase was more. However, there is a serious gap in research knowledge concerning the mass of belowground residue C produced by plant roots from various crops (Purakayastha *et al.*, 2008). This information is extremely important when addressing the effects of fertility practices on C sequestration as it is related to concerns about global climate change.

Microbial quotient (MQ) represents the fraction of SOC represented by living microbial C. The higher value indicates more lability of SOC and lesser value indicates recalcitrance of SOC. In our study MQ was higher in FYM of control treatment indicating more lability of SOC in this treatment, while straw treatment was lower in MQ indicating less lability of SOC in this treatment. Microbial metabolic quotient (qCO_2) is used as an important parameter for knowing the C mineralization efficiency of microbes. More qCO_2 indicates more mineralization per unit of MBC indicating better cycling of nutrients and nutrient availability to plants and microbes while lesser value is preferred for preservation of C in soil for C sequestration. When qCO_2 is used as a soil organic matter quality parameter, more is desirable for faster mineralization of C and other nutrients like N, P, S etc. In our study the qCO_2 was invariably low in 50%NPK+50%N-Straw treatment in all the soil orders as compared to that in other manuring treatments or 100%NPK fertilization. The Straw treatment had proportionately lesser labile C than the MBC indicating better stabilization of C in this treatment. Our results are in conformity with Graham *et al.* (2002) who also reported that both crop residue and fertilizer inputs increased the microbial quotient since microbial biomass C was increased to a greater extent than total soil organic C. Further, the continuous application of NPK+FYM significantly decreased qCO_2 as compared to 100% NPK in maize−wheat−cowpea cropping system in Inceptisol of subtropical India (Rudrappa *et al.*, 2006). High microbial quotient has been reported with long-term N or recent cattle manure applications and lowly with recent N applications (Fauci and Dick, 1994).

Relationship between SOC and its fractions and C mineralization

Various fractions of SOC e.g., DOC, POM-C, $KMnO_4$-C, MBC and C mineralizable C (C_{min}) responded significantly due to long-term manuring and fertilization. In Inceptisol, the MBC significantly correlated with DOC and C_{min} while in other soil orders MBC significantly correlated with majority of labile fractions of SOC. The highest value of correlation coefficient between labile C e.g., DOC and $KMnO_4$-C with SOC (r = 0.70**, 0.89**) and MBC with SOC (r = 0.73**) in Mollisol indicates that these pools are most affected by change management practices in soils. There was also greater correlation between $KMnO_4$-C and MBC, POM-C and DOC in Mollisol signifies these fractions are mutually inclusive and dependent on each other. However, none of the parameters correlated significantly with C_{min} which indicates that besides these fractions other fractions of C might have contributed to C_{min} in Mollisol. It is worth mentioning that in other soil orders C_{min} significantly correlated with majority of labile C fractions indicating their greater contribution to C_{min}. The POM-C poorly correlated with C_{min} in Inceptisol and Mollisol indicating their physical protection inside soil aggregates not accessible to the microbes for decomposition. However, in Vertisol and Alfisol probably presence of non-aggregate protected POM (free POM) which might have contributed significantly to C_{min}. The results clearly indicate that it is not only the change in SOC under different manuring and fertilization is important but also the change in various labile fractions of SOC which are more important with respect to SOM quality and thus its direct role in availability of nutrients to crops. Moharana *et al.* (2012) reported a strong relationship between crop yields with different pools of carbon and different pools of SOC showed significant and positive relationship with each other indicating a dynamic relationship of different pools of carbon in soil.

C utilization efficiency

C utilization efficiency indicates how efficiently the microbial community utilizes soil C (C uptake) out of the mineralizable C for development of new microbial biomass. While abiotic controls of soil organic C sequestration have been intensively studied during the last two decades (Sollins *et al.*, 1996; Lützow *et al.*, 2006), the importance of the microbial processing of organic C i.e., C utilization efficiency (CUE) has only recently received more attention (Schmidt *et al.*, 2011). CUE was measured over 15, 30 and 45 days of incubation. It was observed that in Inceptisol and Alfisol, the CUE was positive on day 15, whereas on day 30 and 45 the CUE became negative as the change in MBC (dMBC, MBC_{final}-$MBC_{initial}$) were negative in both the above days. In Mollisol and Vertisol the CUE was positive on all the incubation days i.e., day 15, 30 and 45. Our hypothesis was that the soils having varying SOC enrichment would behave differently with respect to CUE. The soils being rich in SOC with special reference to labile C might be having less CUE and vice-versa. From our study it was observed that the balanced fertilization with 100% NPK and supplementation of fertilization with FYM, Straw showed higher CUE than either GM or control treatment in both Inceptisol and Alfisol. In case of Mollisol, NPK and all the organic treatments except straw showed higher CUE than other treatments. In the case of Vertisol, the FYM treatment showed the highest CUE. This suggests that the availability of C from the added substrate was not sufficient for the formation of new microbial biomass and therefore more easily available C (labile C) accumulated in these long term manuring and fertilization treatments supplied essential C and nutrients for faster uptake of C for synthesis of microbial tissue. If easily degradable C source was used the C degradation pattern would have been different; and there would have been more utilization of this C and the microbial community would have been less dependent on SOC. Our observation is supported by the findings of Steinweg *et al.* (2008) who reported that pre-incubation of soil samples for 600 days before addition of cellobiose had highest CUE of 0.80 than the samples pre-incubated for 0 days had CUE of 0.65. During pre-incubation of soil for 600 days most of the labile C was lost via CO_2 produced during C mineralization. The CUE decreased significantly with increase in duration of the incubation period from 15 day to 45 day. This was due to decrease in the change in dMBC values and increase in the ΣCO_2-C values. CUE determines energy and material flows to higher trophic levels, conversion of plant produced carbon into microbial products and rates of ecosystem carbon storage. Thermodynamic calculations support a maximum CUE value of ~ 0.60 (CUEmax) (Sinsabaugh *et al.*, 2013) but the CUE values of our experiments exceeded 0.70 in Mollisol and Vertisol for 15 days incubation and it was ~ 0.20 in Inceptisol ~ 0.30 in Alfisol. The higher value of CUE in Mollisol and Vertisol was due to large changes in MBC (dMBC) due to addition of C substrate. Though there was not much variation in the initial MBC data across all the four soil orders, the soils might have supported different microbial community structure in Mollisol and Vertisol which multiplied fast once C substrate was added. In soils, CUE estimates range from 0.10 to 0.80 (Manzoni *et al.*, 2012), while microbial growth rate (MGR) varies from hours to weeks (Rousk and Bååth, 2011). This variability in both CUE and MGR arises from differences in the intrinsic physiology of specific bacterial and fungal species (Dethlefsen and Schmidt, 2007; Molenaar *et al.*, 2009; Beardmore *et al.*, 2011) and also microbial community sensitivity to the soil environment, i.e. soil temperature and resource quality (Thiet *et al.*, 2006; Frey *et al.*, 2013; Lee and Schmidt, 2014). C Substrate quality is one of the most important factors influencing the degradation of plant residues and the activity and size of soil microbial biomass (Paul and Clark, 1996). C:N ratio is often used to explain factors influencing the turnover rate of plant residues during decomposition (Oades, 1988; Cheshire and Chapman, 1996). We used wheat straw, maize straw and *Sesbania* straw having a C:N ratio of 80:1, 56:1 and 28:1, respectively as C substrates for estimation CUE across various manuring and fertilization in Inceptisol, Mollisol, Vertisol and Alfisol. In general the CUE was highest in *Sesbania* straw followed by maize straw and it was lowest in wheat straw. Devevre *et al.* (2000) reported that added straw with low C:N (39:1) showed higher CUE than the straw with higher C:N (78:1) in an acidic Willow clay soil from USA.

Priming effect on native SOC

Priming effects (PE) are strong, generally short-term changes in the turnover of native soil organic matter induced by comparatively moderate treatments of the soil (Kuzyakov *et al.*, 2000). Such treatments might be, e.g. inputs of organic or mineral fertilizer to the soil (Bol *et al.*, 2003; Clough *et al.*, 2003), exudation of organic substances by roots (Cheng and Kuzyakov, 2005) or remaining plant residues (Liang *et al.*, 1999). In the course of priming large amounts of C, N and other nutrients can be released or immobilized in soil in a very short timescale, generally several days to weeks (Fu *et al.*, 2000; Fontaine *et al.*, 2007). Large changes of the SOM decomposition occurred at the first phase, when the added easily utilizable substrate was used by microorganisms. The microorganisms preferably utilize pools with the highest utilizability and decomposition of the less utilizable C pools was retarded compared to the initial state. Our results clearly showed that the separation of more than two sources of CO_2 efflux after substrate addition, as well as short-term sampling of released CO_2 is crucial for the evaluation of the PE mechanisms. The PE was observed highest in control treatment in all the soil orders except Vertisol on day 15 and 45. In Vertisol the PE was higher in FYM treatment on day 15 and in FYM, Straw and GM on day 45. Among the manuring treatment, GM/FYM in Inceptisol, FYM in Mollisol and Alfisol and Vertisol showed the lowest PE. The direction and magnitude of PE is largely controlled by quality of SOM and added substrate. As the DOC or $KMnO_4$-C, considered as easily utilizable C were higher in FYM treatment, it supported the microbial population caused lower PE on native SOC. Among the added substrate in general *Sesbania* residue showed lowest PE on native SOC mineralization followed by maize residue and it was lowest in wheat residue. As the *Sesbania* residue being narrower in C:N (28:1) might be mineralized easily after utilizing the readily utilizable C like DOC and or $KMnO_4$-C from soil and therefore this treatment would have primed lesser amount of SOC. On the contrarily, the wheat residue being wider in C:N (80:1) could not be easily degraded and as a result the microbial community might have primed the SOC in order to derive C and energy from it resulting in higher PE. The maize residue being in between wheat residue and *Sesbania* residue in terms of C:N ratio (56:1) caused intermediate PE on native SOC. Very recently Lonardo (2017) reported that the effect of chemical structure of added compounds on PE is much larger than the effect of energy-content. These results

suggest that impacts of plant rhizodeposition and residue inputs had additive effects on SOM priming (Mwafulirwa *et al.*, 2017). Ye *et al.* (2015) reported that PE on SOM (CO_2 plus CH_4 production) was slightly positive at the end of the experiment, associated with only a 32% mineralization of the added straw-C (as CO_2 plus CH_4).Among the soils, Inceptisol showed the largest PE followed by Alfisol, Vertisol and the lowest PE was noticed in the case of Mollisol. Inceptisol and Alfisol supporting lower amount of easily utilizable C (DOC/$KMnO_4$-C) than either Mollisol or Vertisol and therefore, the former soils caused higher PE than the latter soils.

CHAPTER 6

Summary and Conclusions

6. SUMMARY AND CONCLUSION

Soil organic carbon (SOC) sequestration is of great interest, partly for the essential role that it plays in mitigating climate change to take atmospheric CO_2 and convert it into soil carbon which is long-lived and enrichment of SOC with labile C is the most significant determinant of soil fertility, and thus of crop productivity and sustainability. Optimum levels of soil organic matter (SOM) can be managed through crop rotation, fertility maintenance including use of inorganic fertilizers and organic manures, tillage methods, and other cropping system components. Among these management practices, proper cropping systems and balanced fertilization are believed to offer the greatest potential for increasing SOC storage in agricultural soils. The SOM fractions, such as microbial biomass C (MBC), dissolved organic C (DOC) and particulate organic matter C (POM−C) are reported to be sensitive indicators of treatment induced changes than the total SOC. There is a paucity of information on the relationships of these labile SOC fractions with long term C mineralization and the impacts of added C substrate quality on C utilization effcicieny (CUE) by microbial community and priming effect on native SOC. Besides this, very limited information is available on the long term impact of integrated use of fertilizer and organic manures like FYM, straw and green manuring on bulid up of SOC in various contrasting soil types e.g., Inceptisol, Mollisol, Vertisol and Alfisol differing in physico-chemical and physical properties including pH, texture, clay mineralogy and the climate at which these soils are located.

In order to address the above issues, soil samples were collected (0−15 cm depth) after the harvest of wheat from long-term field experiment, which is in progress since 1983-1984, at four soil orders namely Inceptisol, Mollisol, Vertisol and Alfisol located in Ludhiana, Pantnagar, Jabalpur and Ranchi respectively under All India Coordinated Project (AICRP) on Integrated Farming System (IFS), the Indian Institute of Farming System Research (IIFSR), Modipuram, Meerut, Uttar Pradesh. Rice-wheat is the cropping system followed in Inceptisol, Mollisol, Vertisol while in Alfisol maize-wheat cropping system is followed. The treatments comprised of control, 100% recommended dose of NPK, integrated use of 50%NPK along with 50%N supplemented through either FYM, straw or green manuring crops were imposed in wet season crops (Rice in Incpetisol, Mollisol and Vertisol and maize in Alfisol). In wheat crop the 100% recommended dose of NPK fertilizer was applied.

To address the above issues, the research work was carried out to achieve the following objectives:

i. To study long-term manuring and fertilization effects on C-mineralization in four major soil groups of India.
ii. To correlate the water extractable organic carbon and $KMnO_4$ oxidisable C with mineralizable C in soil.
iii. To study the size of mineralizable C on C-utilization efficiency by microbial community.

The salient findings of the present investigation are summarized below:

long-term manuring and fertilization effects on soils C and C-mineralization

- In Inceptisol and Vertisol 50%NPK+50%N-GM showed the total soil C (TSC) as well as soil organic C (SOC) whereas for Mollisol and Alfisol it was found to be highest in 50%NPK+50%N-FYM treatment. T1 (control) showed the least amount of TSC and SOC.
- The cumulative C mineralization was observed highest with 50%NPK+50%N-FYM in all soil orders except Mollisol where 50%NPK+50%N-GM showed the highest cumulative C mineralization throughout the incubation period.
- The decay rate constant (k) varied from 0.0008 day^{-1} in 50%NPK+50%N-FYM in Inceptisol to 0.0004 day^{-1} in all treatments of Alfisol.
- The microbial biomass C (MBC) was highest in 50%NPK+50%N-FYM in Mollisol and Vertisol, whereas in Inceptisol 50%NPK+50%N-GM showed the highest MBC. In Alfisol there was no significant difference between 50%NPK+50%N-FYM and 50%NPK+50%N-GM. Both showed similar amount of MBC.
- In Inceptisol and Vertisol, 50%NPK+50%N-FYM showed the highest microbial quotient (MQ), whereas in Mollisol and Alfisol control showed the highest MQ.
- In Inceptisol and Vertisol 50%NPK+50%N-Straw showed the highest microbial metabolic quotient (MMQ), whereas in Mollisol control showed the highest MMQ. In Alfisol there was no significant difference in MMQ between 50%NPK+50%N-FYM, 50%NPK+50%N-Straw and 50%NPK+50%N-GM.

Relationships of SOC and its various fractions with mineralizable C

- Dissolved organic C (DOC) was found to be highest in 50%NPK+50%N-FYM in all the soil orders except Inceptisol where both 50%NPK+50%N-FYM and 50%NPK+50%N-GM showed the similar amount.
- Particulate organic C (POM-C) was found to be highest in 50%NPK+50%N-FYM in all the four soil orders.
- Potassium permanganate oxidisable C ($KMnO_4$-C) was found to be highest in 50%NPK+50%N-FYM for all soil orders except Alfisol where there was no significant difference between 50%NPK+50%N-FYM and 50%NPK+50%N-GM.
- Dissolved organic C (DOC) had strong correlation with $KMnO_4$-C and C mineralization (C_{min}) in Inceptisol. MBC had good correlation with DOC and POM-C in Mollisol. In Vertisol MBC was highly correlated with POM, DOC, $KMnO_4$-C and C_{min}. In Alfisol MBC had good correlation with $KMnO_4$-C and DOC.

Carbon utilization efficiency

- In Inceptisol, the initial MBC, MBC after 15 days of incubation and change in MBC (dMBC) were found to be highest in 50%NPK+50%N-FYM with *Sesbania* residue (SR). In Mollisol initial MBC, MBC after 15, 30 and 45 days and dMBC after 15 and 30 days were highest in 50%NPK+50%N-FYM with *Sesbania* residue (SR). The change in MBC (dMBC) after 45 days was highest in 100%NPK with SR. In Vertisol, the initial MBC, MBC after 15, 30 and 45 days and dMBC after 15 and 30 days were highest in 50%NPK+50%N-FYM with *Sesbania* residue (SR). The change in MBC (dMBC) after 45 days was highest in 50%NPK+50%N-GM with SR. In Alfisol, the initial MBC, MBC after 15 days of incubation and dMBC were found to be highest in 50%NPK+50%N-FYM with *Sesbania* residue (SR).
- The total amount of C mineralized from soil after addition of different residues was found to be highest in 50%NPK+50%N-FYM with *Sesbania* residue (SR) throughout the incubation period for all soil orders.
- In Inceptisol, the CUE for 15 days was highest in 50%NPK+50%N-FYM with Sesbania residue (SR). In Mollisol for 15 days CUE was found to be highest in 50%NPK+50%N-FYM with SR. But for 30 and 45 days 100%NPK with SR showed the highest CUE. In Vertisol for 15 days, all the treatments showed the

CUE which were not significantly different except the control treatment which showed the least CUE. For 30 day, the CUE was highest in 50%NPK+50%N-FYM with SR. For 45 days, the CUE was highest in 50%NPK+50%N-GM. In Alfisol the CUE for 15 days was found to be highest in 100%NPK with control sub-treatment.

- Overall the CUE, the CUE were higher in balanced fertilization (100% NPK) and integrated nutrient management treatments (50%NPK+50%N-FYM/straw/GM) though there were some aberrations observed between different soil orders. The CUE decreased substantially when the length of incubation increased from 15 days to 45 days. In general, the CUE was largely influenced by the added substrate quality being highest with *Sesbania* residue (SR) followed by maize residue (MR) and wheat residue (WR). There were large variations between soil orders with respect to CUE being highest in Mollisol followed by Vertisol, Alfisol and it was lowest in Inceptisol.

Priming Effect on native SOC

- Irrespective of all the treatments in all soil orders, the C mineralization from soil alone was found to be highest in case sub-treatment WR followed by MR and SR.
- Irrespective of all the treatments in all soil orders, the C mineralization from residue alone was found to be highest in case sub-treatment SR followed by MR and WR.
- Irrespective of all the treatments in all soil orders, the C mineralization from soil+residue mixture was found to be highest in case sub-treatment SR followed by MR and WR.
- Irrespective of all the treatments in all soil orders, the priming effect (PE) on native SOC was found to be highest in case sub-treatment WR followed by MR and SR.
- Inceptisol showed highest percentage of priming (for 15 days and 45 days) irrespective of days of experiment and it was followed by Alfisol (for 15 days and 45 days). But for 15 days of experiment the lowest priming of native SOC was found in Mollisol whereas it was lowest in Vertisol for 45 days.

Based on the above observation the following conclusions can be drawn:

Conclusions:

- Long-term (32 years) application of 50% fertilizer N through *Sesbania* (*Sesbania aculeate* L.), *Sunnhemp* (*Crotalaria juncea* L.) along with 50% NPK fertilizer in rice-wheat cropping system emerged as the best management practices for enhancing soil C in Inceptisol (Ludhiana), and Vertisol (Jabalpur), respectively, while this was true for farmyard manure (FYM) in maize-wheat cropping system in Alfisol (Ranchi). Interestingly, 50% fertilizer N supplemented either by FYM, straw or green gram (*Vigna radiata* L.), emerged equally effective for enhancing C in Mollisol (Pantnagar). Overall, the highest enrichment of soil C was noticed in Mollisol followed by Vertisol, Alfisol and Inceptisol.
- Supplementation of fertilizer N through either FYM or various green manuring crops like *Sesbania* (*Sesbania aculeate* L. in Inceptisol), green gram (*Vigna radiata* L. in Mollisol), *Sunhemp* (*Crotalaria juncea* L. in Vertisol) and *Karanj* (*Pongamia pinnata* L. in Alfisol) significantly improved various labile fractions of SOC (e.g., POM-C, MBC, DOC, C_{min}) signifying their potential contributions to nutrient cycling and thereby nutrient availability to various crops in the cropping systems in the above soils. Thus this might decrease the dependency of the crops on chemical fertilizer and increase the soil organic matter quality.
- The higher C utilization efficiency (CUE) in treatments receiving full doses of NPK either applied through fertilizer or 50% of fertilizer N supplemented through various organic sources (FYM, straw, green manuring crop) in Inceptisol, Mollisol and Alfisol and FYM in Vertisol indicating the potential of these soils for short term C sequestration by locking the SOC in the microbial biomass.
- Supplementation of 50% fertilizer N through either green manure or FYM in Inceptisol, Mollisol and Vertisol and FYM in Alfisol showed lower priming effect (PE) on native SOC which in turn might stabilize the SOC for long term C sequestration. Among the added residues, *Sesbania* (*Sesbania aculeate* L.) residues in Inceptisol, Vertisol and Mollisol and maize (*Zea mays* L.) residues in Alfisol could be advocated for lower PE on native SOC for higher C

sequestration and on the other hand wheat residue/maize residue showed higher PE on the native SOC having lower C sequestration potential.

- Among the soils, preservation of SOC (lower PE and higher CUE) was highest in Mollisol followed by Vertisol, Alfisol and Inceptisol and this trend could perfectly be explained by higher CUE and lower PE in these soil orders in the same sequence.

CHAPTER 7

Abstract

Long term impact of manuring and fertilization on labile carbon and carbon utilization efficiency of microbes in four major soil groups of India

ABSTRACT

Soil organic C (SOC) sequestration has been considered as a possible solution to mitigate climate change, to take atmospheric CO_2 and convert it into soil C which is long-lived. Manuring and fertilization is one of the important management strategies employed for long term C sequestration in agricultural soils. Long term effect of manuring and fertilization on total soil C (TSC), soil organic C (SOC), soil inorganic C (SIC), various factions of SOC namely C mineralization (C_{min}), microbial biomass C (MBC), particulate organic matter C (POM-C), dissolved organic C (DOC), potassium permanganate oxidisable C ($KMnO_4$-C) was studied in four major soil groups of India. The effect of added substrate quality on C utilization (CUE) and priming effect (PE) on native SOC was also studied by adding *Sesbania* residue (SR, C:N::80:1), maize residue (MR, C:N::56:1) and wheat residue (WR, C:N::28:1) by incubating the soils for 15, 30 and 45 days. The soil samples were collected in the year 2015 to a depth of 0–15 cm from the fields of All India Coordinated Project (AICRP) on Integrated Farming System continuing in Ludhiana (Inceptisol), Pantnagar (Mollisol), Jabalpur (Vertisol) and Ranchi (Alfisol) continuing since 1983-1984. The treatments comprised of control, 100%NPK, 50%NPK+50%N–FYM, 50%NPK+50%N–straw (wheat straw in Inceptisol, Mollisol and Vertisol and paddy straw in Alfisol), 50%NPK+50%N–GM (green manure, S*esbania* in Inceptisol, green gram in Mollisol, *Sunnhemp* in Vertisol and *Karanj* in Alfisol). The results indicated that application 50%NPK+50%N–FYM increased TSC by 70% and 42% as compared to control treatment in Mollisol and Alfisol, while 50%NPK+50%N–GM increased TSC by 30% and 70% in Inceptisol and Vertisol, respectively. The magnitude of increase in TSC was highest in Mollisol (63%), followed by Vertisol (52%), Alfisol (33%) and Inceptisol (16%). The MBC was highest in 50%NPK+50%N–FYM in all the soil orders except Inceptisol which showed highest MBC in 50%NPK+50%N-GM treatment. The POM-C and DOC and $KMnO_4$-C was significantly higher in 50%NPK+50%N–FYM than the other treatments in all the soil order. The highest value of correlation coefficient was observed between labile C e.g., DOC and KMnO4-C with SOC ($r = 0.70^{**}$, 0.89^{**}) and MBC with SOC (r = 0.73**) in Mollisol However, none of the parameters correlated significantly with C_{min} which indicates that besides these fractions other fractions of C might have contributed to Cmin in Mollisol. It is worth mentioning that in other soil orders C_{min} significantly correlated with majority of labile C fractions indicating their greater contribution to C_{min}. The CUE were higher in 100%NPK, 50%NPK+50%N-FYM and 50%NPK+50%N-Starw in Inceptisol and Alfisol while in Mollisol and Vertisol CUE was highest in 50%NPK+50%N-FYM. Irrespective of soil order, the CUE was highest in SR followed by MR and it was lowest in WR. The CUE was highest in Vertisol (~0.63) and Mollisol (~0.61) followed by Alfisol ((~0.29) and Inceptisol (~0.15) on 15 day. The PE was lowest in 50%NPK+50%N-FYM in Inceptisol (50%), Mollisol (27%) and Alfisol (41%), while it was lowest in 50%NPK+50%N-Straw in Vertsol. In general the, PE on native SOC was recorded lowest in SR followed by MR and WR. Among the soil order, Inceptisol showed highest PE on SOC (55%) followed by Alfisol (48%), Vertisol (40%) and the lowest PE was observed in Mollisol (31%) on 15 day. The CUE and PE decreased as the length of incubation period increased from 15 day to 45 day. Among the nutrient management, 50%NPK+50%N–FYM/50%NPK+50%N–GM emerged as the best management practices for enhancing SOC in the four soil orders studied. Among the soil order, preservation of SOC (lower priming and higher CUE) was highest in Mollisol followed by Vertisol, Alfisol and Inceptisol and this trend could perfectly be explained by higher CUE and lower PE in these soil orders in the same sequence.

भारत के चार मुख्य मृदा वर्गों में अस्थिर कार्बन और सूक्ष्म जीवों का कार्बन उपयोगिता दक्षता पर खाद प्रयोग तथा उर्वरण का दीर्घकालिक प्रभाव

सार

जलवायु परिवर्तन को कम करने के लिए मृदा जैविक कार्बन (एस ओ सी) अधिग्रहण को संभावित समाधान माना जाता है, जिसमे की वायुमण्डलिये कार्बन डाइऑक्साइड को मृदा कार्बन में, लंबे समय के लिए परिवर्तित किया जाता है। कृषि संबंधी मृदा में खाद एवं उर्वरक का प्रयोग, दीर्घकालिक कार्बन अधिग्रहण के लिए महत्वपूर्ण प्रबंधन कार्यनीति में से एक है। कुल मृदा कार्बन (टी एस सी) मृदा जैविक कार्बन (एस ओ सी), मृदा अजैविक कार्बन (एस आई सी), कार्बन खनिजन तथा एस ओ सी के विभिन्न अंश जैसे कि जैविक जैवंश कार्बन (एम बी सी), कणिक्य जैविक कार्बन (पी ओ एम-सी), घुलनशील जैविक कार्बन (डी ओ सी), पोटैशियम परमैंगनेट ऑक्सीडाईज़ेबल कार्बन(केएमएनओ- 4 सी), को भारत के चार मुख्य मृदा समूहों पर अध्ययन किया गया। मूल एस ओ सी पर सब्सट्रेट उपयोग द्वारा कार्बन उपयोगिता दक्षता (सी यू ई) तथा प्राइमिंग का प्रभाव (पी ई) का भी अध्ययन किया गया। इसके लिए ढैंचा अवशेष (एस आर, सी: एन:: 80:1), मक्का अवशेष (एम आर, सी: एन:: 56:1) तथा गेंहू अवशेष (डब्लू आर, सी:एन:: 28:1) का 15, 30 और 45 दिनों के लिए ऊष्मायन किया गया। 1983-84 से जारी लुधियाना (इन्सेप्टिसॉल), पंतनगर (मॉलिसोल), जबलपुर (वर्टिसोल) एवं रांची (अल्फ़ीसोल) में आल इंडिया कोआर्डिनेटड प्रोजेक्ट के अंतर्गत, एकीकृत कृषि प्रणाली से, 0- 15 से. मि. गहराई से सन 2015 में मृदा नमूनों को एकत्रित किया गया। उपचारों के अंतर्गत नियंत्रण, 100% एन पी के, 50% एन पी के+ 50% ऐन -एफ वाई एम, 50% एन पी के+ 50% ऐन-स्ट्रॉ (इन्सेप्टिसॉल, मॉलिसोल एवं वर्टिसोल में गेंहू स्ट्रॉ तथा अल्फ़ीसोल में धान स्ट्रॉ), 50% एन पी के+ 50% ऐन- हरित खाद (इन्सेप्टिसॉल में ढैंचा, मॉलिसोल में मूंग, वर्टिसोल में सनई एवं अल्फ़ीसोल में करंज)। परिणामों के अनुसार मॉलिसोल एवं अल्फ़ीसोल में नियंत्रण के तुलना में 50% एन पी के+ 50% ऐन-एफ वाई एम प्रयोग द्वारा क्रमशः टी एस सी में 70% एवं 42% की बढ़ोतरी हुई जबकि इन्सेप्टिसॉल एवं वर्टिसोल में 50% एन पी के+ 50% ऐन- जी एम में क्रमशः 30% एवं 70% की वृद्धि हुई। मॉलिसोल में टी एस सी की बढ़ोतरी सर्वाधिक थी उसके बाद वर्टिसोल अल्फ़ीसोल तथा इन्सेप्टिसॉल में बढ़ोतरी हुई। 50% एन पी के+ 50% ऐन- एफ वाई एम के अंतर्गत एम बी सी की मात्रा सभी मृदा वर्गो में अधिक पायी गई सिवाय इन्सेप्टिसॉल जिसमे की सर्वाधिक एम बी सी की मात्रा 50% एन पी के+ 50% ऐन- जी एम उपचार में पाई गई। सभी मृदा वर्गों में पी ओ एम सी, डी ओ सी एवं केएमऐनओ-4 सी, दूसरे उपचारों की तुलना में 50% एन पी के+ 50% ऐन- एफ वाई एम में उल्लेखनीय पाया गया। मॉलिसोल में सहसम्बन्ध गुणांक का मान अस्थिर कार्बन में जैसे कि डी ओ सी एवं केएमऐनओ-4 सी के साथ एस ओ सी (आर = 0.70**, 0.89**) एवं एम बी सी के साथ एस ओ सी (आर= 0.73**) में उच्चतम पाया गया। हालाँकि मॉलिसोल में किसी भी मापदंड का खनिजन कार्बन के साथ उल्लेखनीय सहसम्बन्ध गुणांक नहीं पाया गया जो यह सूचित करता है कि इन अंशों के अलावा, कार्बन के अन्य अंशों ने कार्बन की खनिजन में योगदान किया। यह कहना उचित होगा कि अन्य मृदा वर्गों में कार्बन खनिजन का, ज्यादातर अस्थिर कार्बन के अंशों के साथ उल्लेखनीय रूप से सहसम्बन्ध था, जो कि उनका कार्बन खनिजन में अधिक योगदान को दर्शाता है। इन्सेप्टिसॉल एवं अल्फ़ीसोल में 100% एन पी के, 50% एन पी के+ 50% ऐन- एफ वाई एम एवं 50% एन पी के+ 50% ऐन-स्ट्रॉ में कार्बन उपयोग दक्षता अधिक पाया गया जबकि मॉलिसोल एवं वर्टिसोल में कार्बन उपयोगिता दक्षता 50% एन पी के+ 50% ऐन- एफ वाई एम में अधिक रहा। मृदा वर्गों की निरपेक्ष कार्बन उपयोगिता दक्षता की मात्रा ढैंचा अवशेष में सबसे अधिक पायी गयी, उसके बाद मक्का अवशेष एवं सबसे कम गेंहू अवशेष में पाई गई। 15 दिन में कार्बन उपयोगिता दक्षता की मात्रा वर्टिसोल (~0.63) एवं मॉलिसोल (~0.62) में सर्वाधिक थी, उसके बाद अल्फ़ीसोल (~0.29) एवं इन्सेप्टिसॉल (~0.15) में रही। प्राइमिंग का प्रभाव 50% एन पी के+ 50% ऐन-एफ वाई एम उपचार के तहत , इन्सेप्टिसॉल(50%), मॉलिसोल (27%) एवं अल्फ़ीसोल (47%) में न्यूनतम पाया गया जबकि 50% एन पी के+ 50% ऐन-स्ट्रॉ के उपचार के तहत, वर्टिसोल में न्यूनतम रहा। सामान्यतः मूल एस ओ सी पर प्राइमिंग का प्रभाव ढैंचा अवशेष में न्यूनतम अभिलिखित हुआ और उसके बाद मक्का अवशेष एवं गेंहू अवशेष में रहा। सभी मृदा वर्गों के मध्य 15 दिनों में इन्सेप्टिसॉल में एस ओ सी पर प्राइमिंग का प्रभाव सर्वाधिक था (55%),उसके बाद अल्फ़ीसोल (48%), वर्टिसोल (40%) और न्यूनतम प्रभाव मॉलिसोल (31%) में था। 15 से 45 दिनों के ऊष्मायन काल के दौरान कार्बन उपयोगिता दक्षता तथा प्राइमिंग के प्रभाव में कमी पाई गई। सभी पोषक प्रबंधन के मध्य चारों मृदा वर्गों के अंतर्गत , 50% एन पी के+ 50% ऐन-एफ वाई एम/ 50% एन पी के+ 50% ऐन- जी एम, सर्व श्रेष्ठ प्रबंधन पाया गया। सारे मृदा वर्गों के मध्य एस ओ सी का संरक्षण (न्यूनतर प्राइमिंग प्रभाव एवं उच्चतर सी यू ई) मॉलिसोल में सर्वाधिक पाया गया, उसके बाद वर्टिसोल, अल्फ़ीसोल एवं इन्सेप्टिसॉल में रहा। समान क्रम में, इन चारों मृदा वर्गों में इस प्रचलन का, उच्चतर सी यू ई एवं न्यूनतर प्राइमिंग प्रभाव के द्वारा पूरी तरह से व्याख्या किया जा सकता है।

CHAPTER 8

Bibliography

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ANNEXURE

Following abbreviations have been used in the thesis. The expanded form of the abbreviations is given in the following.

Abbreviations

ANOVA : Analysis of variance
C_{min} : Carbon mineralization
CH_4 : Methane
CR : Crop residue
CO_2 : Carbon dioxide
CUE : Carbon utilization efficiency
DOC : Dissolved organic carbon
GHGs : Green house gases
GM : Green manure
HCl : Hydrochloric acid
FYM : Farm yard manure
$KMnO_4$: Potassium permanganate
LTFE : Long term fertilizer experiment
MBC : Microbial biomass carbon
MQ : Microbial quotient
MMQ : Microbial metabolic quotient
MR : Maize residue
MRT : Mean residence time
NaOH : Sodium hydroxide
N_2O : Nitrous oxide
NPK : Nitrogen, phosphorous, potassium
PE : Priming effect
PMC : Potentially mineralizable carbon
POC : Particulate organic carbon
POM-C : Particulate organic matter carbon
SIC : Soil inorganic carbon
SOC : Soil organic carbon
SOM : Soil organic matter
SR : Sesbania residue
TSC : Total soil carbon
WEOC : Water extractable organic carbon
WR : Wheat residue