Soil organic carbon, aggregation and microbial response to conservation agricultural production systems (CAPS) in a rainfed agro-ecosystem of Odisha

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(Soil Science & Agricultural Chemistry)

By

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Date

CERTIFICATE-I

This is to certify that the thesis entitled**: "Soil organic carbon, aggregation and microbial response to conservation agricultural production systems (CAPS) in a rainfed agro-ecosystem of Odisha"**submitted in partial fulfillment of the requirements for the award of the degree of **MASTERS OF SCIENCE IN AGRICULTURE (SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)** to the Orissa University of Agriculture and Technology is a faithful record of *bonafide* and original research work carried out by **Pratibha Pradhan** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

It is further certified that the assistance and help received by him from various sources during the course of investigation has been duly acknowledged.

Chairman

Advisory committee

CERTIFICATE-II

This is to certify that the thesis entitled : **"Soil organic carbon, aggregation and microbial response to conservation agricultural production systems (CAPS) in a rainfed agro-ecosystem of Odisha"** submitted by Pratibha Pradhan to the Odisha University of Agriculture and Technology, Bhubaneswar in partial fulfillment of the requirements for the degree of **MASTERS OF SCIENCE IN AGRICULTURE (SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)** has been approved by the students' advisory committee and external examiner.

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Bhubaneswar **(*Pratibha Pradhan*)**
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ABSTRACT

Conservation agriculture production system (CAPS) with the components of minimum tillage, legume based intercrops and follow up cover crop has been established in a *Fluventic Haplustepts* at Regional Research and Technology Transfer Station, OUAT at Kendujhar district of Odisha during 2011 in split plot design for sustainable management of natural resources in the degraded hilly agro-ecosystem of the tract. The impact of CAPS on BD, WSA, SOC, WSA-C, STN, soil moisture and microbial attributes across the profile (0-5, 5-10 and 10-20 cm) was assessed at the end of the 4th cropping cycle. The treatment combinations are Conventional tillage (CT) and Minimum tillage (MT) with sole Maize(M) and season and Horsegram(H), Toria (T) and no covercrop (NCC) insub-plots during dry season. Build up of SOM intercrop maize +cowpea (M+C) in main plots during wet and their retention in the soil surface under MT decreased the BD (-3.0%, -2.2%), increased the dry season moisture contents and SOC (+31.8%, +16.8%) in the top two layers. The elevated SOC in MT increased the STN (+19.4%, +11.1%), water stable macro-aggregates (+18.4%, +15.2%), their C (+12.7%, 7.6%) with concomitant decrease in micro-aggregates (-11.1%, -12.7%) in 0-5 and 5-10 in layers, indicating the low degradation rate of macro-aggregates. Loss of SOM induced by soil inversion under CT in the top layers increased the BD (+2.3%, +1.5%) and micro-aggregates (+21%, +22.1%), decreased the SOC (-6.8%, -13.2%), macro-aggregates (-5.3%, -5.7%) and their C (-6.5%, 7.1%). The elevated population of bacteria (+37.7%, + 29.6%), fungi (+22%, +19.7%), actinomycetes (+ 19.9%, + 18.4%), MBC (+85.5%, +51.4%), MBN (+70.1%, +57.3%) in the top layers in MT over CT is due to higher restoration of SOM. Dramatic changes in soil quality under cover crops were reflected with elevated status of SOC (+11.4%), Macro-aggregates (+7.9%), population of bacteria (+22.4%), fungi (+12.2%), actinomycetes (+12.4%), MBC (+20.6%) and MBN (+28.1%) in the surface layer of 0-5 cm. Soils under MT exhibited higher MBC/SOC ratio (2.04%, 1.8%), MBN/STN ratio (3.87%, 3.81%) and C/N ratio (10.4, 10.9) in the top two layers and C-stratification ratio of 1.82.SOC was identified as the most dominant soil parameter influencing soil BD ($r = -0.88^{**}$, -0.87^{**}), water stable macro-aggregates ($r = 0.90^{**}$, 0.76^{**}), soil moisture ($r = 0.85^{**}$, 0.82^{**}), MBC ($r = 0.87^{**}$, 0.97^{**}), population of bacteria ($r = 0.82^{**}$,0.83^{**}), fungi ($r = 0.86^{**}$,0.90^{**}) and actinomycetes ($r = 0.87^{**}$, 0.89^{**}) in the surface (0-5 cm) and sub-surface (5-10 cm) layers. Though the MEY of MT and CT with M+C intercrop are at par (109.1 and 106.6 q ha^{-1}), the restoration and enrichment of soil attributes reflected at the end of the 4th cropping year will enhance the productivity of soil in the long run.

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ABBREVIATION

FAO	:	Food and Agriculture Organisation
CAPS	:	Conservation Agriculture Production System
CA	:	Conservation Agriculture
CT	:	Conventional Tillage
MT	:	Minimum Tillage
SOC	:	Soil Organic Carbon
STN	:	Soil total nitrogen
HG	:	Horse gram
NCC	:	No Cover Crop
BD	:	Bulk Density
NT	:	No Tillage
WSA	:	Water Stable Aggregate
MBC	:	Microbial Biomass Carbon
MBN	:	Microbial Biomass nitrogen
Mg	:	Mega gram
µg	:	Microgram
ha	:	Hectare
CD	:	Critical Difference
SE(m)	:	Standard Error mean
SMC	:	Soil Moisture Content
NS	:	Non-significant

INTRODUCTION

The long-term sustainability and maintenance of agricultural ecosystems have emerged and only recently augmented. To achieve this interest, soil organic matter (SOM) dynamics and nutrient cycling need to be better understood and subsequently managed. In trying to further the understanding of these important dynamic soil properties, recent research focuses often on the role played by the soil matrix, the soil biota and their multiple interactions. It is this multitude of interactions that makes it a very complex research subject to be elucidated (Six *et al*., 2004).

The natural resources under rainfed agro-ecosystem is very often vulnerable to degradation through loss of fertile top soils by water erosion, poor organic matter contents, mismanagement of land resources and changing climate, resulting a decline in soil productivity. Semi-arid soils have low organic matter levels because of historical exploitation, low carbon inputs, and a climate that favors mineralization. Intensive tillage, residue removal and burning practised during the whole crop season accelerate soil erosion, environmental pollution, soil degradation and affects ecosystem functions (Srinivasan *et al*., 2012). Therefore, adoption of the rational cropping practices, such as crop residue recycling, crop rotations, conservation tillage and cover cropping, would be a century need for improving the soil quality and ecosystem function. Sustainable crop production without any degradation of natural resources can be achieved through a set of crop-nutrient-water-landscape system management practice popularly known as conservation agriculture production system.

Conservation tillage practices with minimal soil disturbance and residue retention are becoming economically and ecologically more viable option as they save energy and provide more favourable soil conditions for sustainable crop production and SOC sequestration for future posterity (Gupta Choudhury *et al*., 2014). Conservation agriculture production systems (CAPS) are tailor-fit system approaches for successful adoption and implementation of CA to specific locations (Agustin *et al*., 2012).

Alteration of soil conditions tillage operation and removal of crop residues result in an array of negative effects on the productivity of crops. Physico-chemical and biological processes in soils are largely influenced by its properties. Several studies have addressed how these properties change with tillage intensity. Ideally it is suggested to keep the soil properties at optimum, but tillage systems result in soil modification and often degradation. Excess tillage can result in soil compaction, surface sealing, crusting, reduced hydraulic conductivity, increased run-off, and erosion. Conventional tillage practices and removal of crop residues can lead to a reduction in soil organic matter due to accelerated decomposition and loss of organic matter rich top soil there by adversely affecting soil properties. Use of conservational tillage practices has increased from 15 to 38 million ha over the last decade because of the potential of this practice to reduce soil erosion, conserve soil moisture and improve soil structure (Kushwaha *et al*., 2001).

Despite these findings, conventional ploughing-based tillage systems are still dominant. However, alternative tillage systems are becoming economically and ecologically more attractive as they save energy and provide more favourable soil conditions. Besides reduced costs of machinery and working hours, more carbon is stabilized than released, giving greater C accumulation and aggregate stability (Goddard et al., 2008). This is induced by the greater microbial mass present, which has a major effect on aggregate formation and stabilization.

The moderating the effect of SOM on major soil quality indicators like SOC, BD, aggregation, moisture, microbial biomass carbon and nitrogen is well documented and the dynamics of SOM are influenced by agricultural management practices such as minimum tillage, crop residue retention and cropping systems (inter crop and cover crop), which are the basic principles of CAPS. The soil inversion reaching a maximum depth of 10 cm is defined as minimum tillage (MT). The beneficial effect of MT with cropping systems in enhancing SOM, N, aggregation and microbial density and attributes are well documented. The promising positive impact of conservation agriculture production systems (CAPS) on soils encourage the scientists world over for adaptation of this technologies, particularly in degraded rain-fed agro-ecological environments to achieve sustainable and intensive crop production.

The role of CAPS on SOM, aggregate formation and microbial diversity is poorly documented in tropical agro-ecosystems. Such information is lacking from rain-fed agro-ecosystems of Odisha, accounting for about 60% cultivated land in the state. Keeping these facts in the backdrop, a field experiment with maize based CAPS has been established at Regional Research and Technology Transfer Station, Kendujhar, Odisha, during 2011 and objectives of the present study are described below.

Objectives

The influence of maize based CAPS involving tillage practices (minimum tillage and conventional tillage), cropping systems (maize sole and maize + cowpea intercrop) and both with and without cover crops (horse gram and toria) on soil attributes across the profile at the end of 4thcropping cycle (2014-15) has been addressed through the following studies.

1. Studying the changes in soil bulk density, soil moisture contents (during dry season cover crops) and waterstable macro and micro-aggregates.

2. Monitoring the pH, organic carbon, aggregate carbon and total nitrogen status of the soils.

3. Monitoring the microbial attributes *viz*. population of bacteria, fungi, actinomycetes, microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) of the soils.

4. Assessing the impact on Maize Equivalent yield.

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REVIEW OF LITERATURE

Location specific implementation of conservation agriculture (CA) is widely known as conservation agriculture production system (CAPS), which is a set of practices specifically designed for successful adoption and implementation of conservation agriculture. Reviews on changes in soil attributes under CA, relevant to the present study "Soil organic carbon, aggregation and microbial response to conservation agriculture production systems in a rainfed agro-ecosystem of Odisha" have been presented in this chapter under the following heads.

2.1 Principles and importance of Conservation Agriculture

2.2 Effect of Conservation Agriculture Production System (CAPS) on soil properties

2.2.1 Bulk density

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2.2.3 Soil moisture content

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2.1 Principles and importance of conservation agriculture

2.1.1 Conservation agriculture

Conservation agriculture refers to a general set of practices that are focused on three main concepts-minimum tillage to reduce soil disturbance; continuous soil cover to reduce rainfall impact, suppress weeds and conserve organic matters and optimal crop rotation to maintain soil fertility and provide nutritional self-efficiency (FAO, 2010).

Conservation tillage is a widely-used terminology to denote soil management systems that result in at least 30 % of the soil surface being covered with crop residues after seeding of the subsequent crop to reduce soil erosion. (Jarecki and Lal, 2003)

Conservation agriculture (CA) can be defined as “a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment” (FAO, 2007).

2.1.2 Principles of conservation agriculture

CA is characterized by three principles which are linked to each other in a mutually reinforcing manner namely: (a) continuous no or minimal mechanical soil disturbance (b) permanent organic matter soil cover, especially by crop residues and cover crops and (c) diversified crop rotations or plant associations (Ngwira *et al*., 2012)

Conservation agriculture production system is characterized by three principles which are linked to each other (FAO, 2010), namely: (i) Continuous minimum mechanical soil disturbance, mainly through direct seeding = No tillage, (ii) Permanent organic soil cover, organic matter supply through the preservation of crop residues and cover crops = Mulching and cover cropping and (iii) Diversification of crop species grown in sequence or associations for biocontrol and efficient use of the soil = Rotation.

Cover crops are grown to provide soil cover and are killed before seeding. They have been used to augment biomass of crop residues, protect soils against erosion and promote build up of soil organic matter (Muza *et al.,* 2007). They are an integral component of CA and the main focus of this study.

Generally planned rotations involving cereals and legumes are necessary to promote nutrient recycling because of distinct rooting depths in cereal-legume systems (Tsubo *et al.,* 2003).

Reduced tillage or no-tillage is also a principal component of CA as it is designed to improve soil quality. This differs from conventional tillage by advocating minimum soil disturbance and promoting direct seeding which involves growing crops without mechanical seed bed preparations after harvesting the previous crop (Calegari, 2008).

2.1.3 Importance of conservation agriculture

Recent concerns about increasing levels of atmospheric CO_2 and consequent global warming have enhanced interest in using conservation agriculture (CA) management practices to sustain food security and enhance environmental sustainability (Dikgwatlhe *et al*., 2014).

Globally, agricultural soils are estimated to potentially sequester 0.4–0.8 Pg C per year by adopting CAPs, which represents 33.3–100% of the total potential of C sequestration in world soils. Among all CAPs options, conversion from conventional tillage (CT) to no-tillage (NT) was considered to be one of the potentially efficient strategies with the rate of C sequestration of 100–1000 kg ha^{-1} per year (Luo *et al*., 2010).

Adoption of conservation agriculture (CA) can reduce soil disturbance, retain crop and biomass as mulch and facilitate adoption of spatial and temporal crop sequencing/crop rotations for a sustainable land use (Abrol and Sagar, 2006).

Conservation agriculture production system are recommended as a general solution to the problems of rural communities facing poor agricultural productivity and declining natural resource quality (Hubbs *et al*., 2008).

Compared to conventional tillage there are several benefits from conservation tillage such as economic benefits by labour, cost and time saved, erosion protection, soil water conservation and increases of soil organic matter (Wang and Gao, 2000).

Conservation agriculture advocates the combined social and economic benefits gained from combining production and protecting the environment, hence it becomes in integration of ecology management with modern scientific agricultural production. This is compounded by the fact that yield improvement under farming takes a few years to be manifested (Hubbs *et al*., 2007).

The advantages of conservation tillage practices over crop residues to act as an insulator and reducing soil temperature fluctuation; (Uri, 1999) building up soil organic matter; conserving soil moisture (West and Post, 2002).

Conservation soil tillage technologies have been the science and research subject for decades, and over this same time period have been used in agricultural practice as a method of field crop stand establishment (Mikanova *et al*., 2009).

2.2 Effect of conservation agriculture production system (CAPS) on soil properties

2.2.1 Bulk density

Bulk density is related to natural soil characteristics such as texture, organic matter, soil structure (Chen *et al*., 1998).

While reviewing some of the studies on the effect of no-tillage on soil BD, Fengyun *et al*. (2011) observed that the lower soil bulk density when compared with the traditional methods by the end of the growing season may be derived from the more intense plant root operation, soil organism movement and the function of soil freeze and melt, as well as the well known increased soil water content and increased crop residue amounts, would also decrease bulk density in the 0 to 5 cm soil layer.

A study on long term impact of no-till on soil properties and crop productivity on Canadian prairies by Lafond *et al*. (2011) revealed that the lower soil BDs for the native soil is likely due to more aggregation and higher litter content at the soil surface. The higher soil BD on the convex areas of LTNT and STNT would have also been strongly influenced by a combination of tillage and water erosion moving soil into the concave areas, thus explaining the lower soil BD for concave areas.

The study on the effect of conservation tillage practices on soil water holding capacity in the Loess plateau, China has indicated that conservation tillage practices can increase the water and nutrient contents of the soil, reduce soil erosion, improve soil structure and increase crop yields. NTS (NT with corn straw) treatments decreased the soil bulk density and increased the soil porosity in 2008 and 2009 relative to the PT (Plough Tillage without corn straw) treatment (Liu *et al*., 2013).

Experiments on different tillage practices in sloppy terrains of North-West Tuinisia by Jemai *et al*. (2013) showed significant reduction of BD and enhancement of TP (Total Porosity) under NT 7, that may be attributed to the considerable improvement in SOM and biotic activity by residue incorporation.

The studies of Latif *et al.* (1992) revealed that legume intercrops in a conservation agriculture system significantly decreased the soil bulk density and penetration resistance.

Ekeberge and Riley (1997) found that bulk density was lower with minimum tillage than with conventional tillage at a depth of 3-7cm in a loam soil in Southeast Norway.

Kay and Vanden Bygaart (2002) observed that bulk density was lower under minimum tillage than mould board plough in the top 20cm of the soil profile with the greatest difference at 5-10cm. This was probably due to organic matter content at 0-5cm was greater under minimum tillage than mould board plough.

D’Haene *et al.* (2008) reported that bulk density was lower in 5-10cm soil layer under minimum tillage than conventional tillage on silt loam soils with crop rotations in Belgium.

Thomas *et al.* (2007) reported that bulk density was lower with minimum tillage than with conventional tillage in the top 10cm of a Luvisol in Southern Queensland, Australia.

Blanco-Canqui *et al.* (2006) reported that maize residue retention at 5 and 10 Mg/ha for a period of one year reduced bulk density in 0-5cm layer from 1.42 Mg/m^3 (control) to 1.26 Mg/m^3 and 1.22 Mg/m^3 respectively in minimum tillage system in a silt loam soil.

Hernanz *et al.* (2002) found significantly lower bulk density under minimum tillage than conventional tillage from 0-10cm with cereal mono-culture and from 0-15 cm in a wheat-vetch (*Vicia sativa l.*) rotation. But the more compacted top soil with minimum tillage had no adverse effect on crop yield with either rotation.

2.2.2 Water stable aggregate

In a long-term agricultural field experiments a decrease of macro-aggregate contents under CT in comparison with no-tillage (NT) and reduced tillage (rotary harrow to 5-8 cm depth), respectively as observed by Six *et al*. (2000b) and Jacobs *et al*. (2009).

Mikha and Rice (2004) related increased macro-aggregate contents to higher inputs of fresh organic material due to increased microbial activity and the production of microbial and fungal derived binding agents.

Conventional tillage (CT) disrupts macro-aggregates because intense soil inversion and formerly incorporated C_{org} is exposed to microbial decomposition (Balesdent *et al*., 2000; Six *et al*., 2000a; Tan *et al*., 2007; Zotarelli *et al*., 2007).

Greater aggregate stability was anticipated because the conservation management practices were expected to increase the amount of labile C available for use by microbial communities, which in turn, would produce more organic binding agents and sticky fungal hyphae as a means to stabilize soil

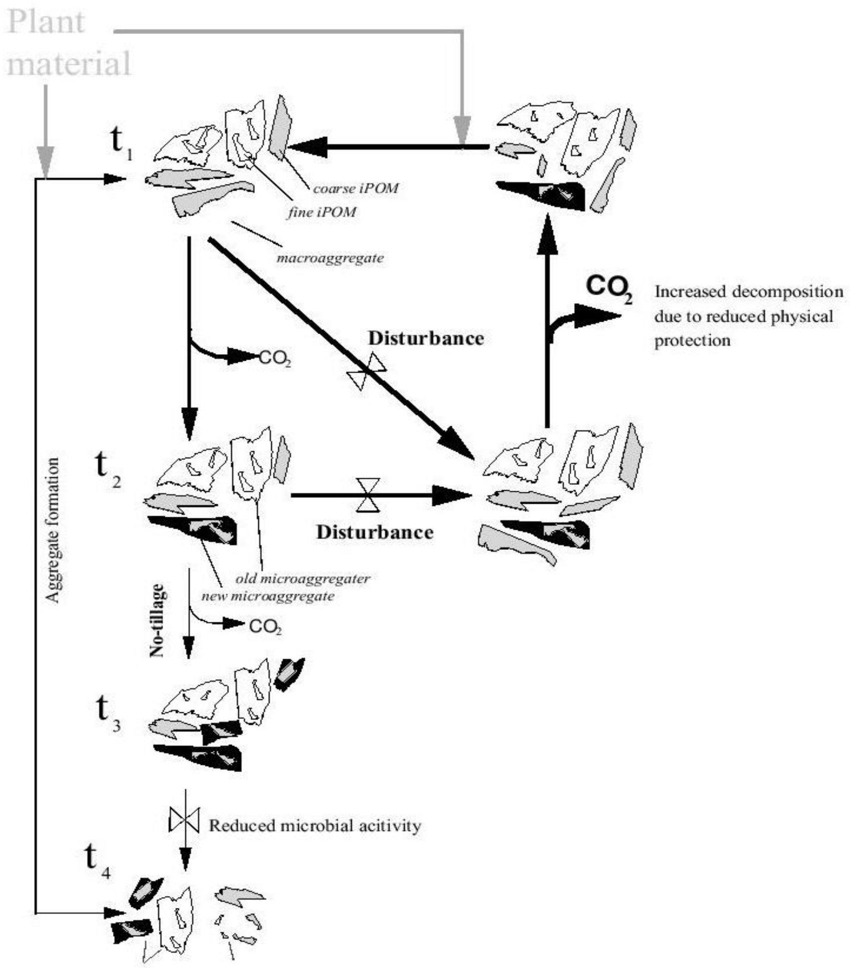


Fig. 1. Conceptual model of the 'life cycle' of a macro-aggregate (Six *et al.*, 2000a)

macro-aggregates (Roberson *et al*. 1991 ; Angers *et al*. 1992). Macro-aggregation, in turn, may increase the proportion of labile organic C that is physically protected from microbial decomposition (Boehm and Anderson 1997).

The classical theory of aggregate formation and turnover has been postulated by Six *et al*. (2000a). Following incorporation of fresh residues, soil micro-organisms utilize the more easily available C and produce mucilages (solution gum) resulting the formation of macro-aggregates around coarse (>250 µm) Intra-aggregate Particulate Organic Matter (coarse iPOM). Coarse iPOM is further decomposed and fragmented into fine iPOM. The fine iPOM and associated mucilages bind the minerals; form the organic core of a newly developed micro-aggregate within macro-aggregate. The latter process is cut short if the macro-aggregate turnover is increased by disturbance resulting in a reduced sequestration of carbon.

Six *et al*. (2000a) established that the inclusion of organic materials within soil aggregates reduces their decomposition rate. Increases in aggregation concomitant with increases in organic C have been observed in NT systems. Tillage has been found to induce a loss of C-rich macro-aggregates and a gain of C-depleted micro-aggregates However, this decrease in macro-aggregates cannot explain the total C loss associated with tillage. The increased macro-aggregate turnover under CT is a primary mechanism causing decreases of soil C. Macro-aggregate formation and degradation (i.e. aggregate turnover) is reduced under NT compared to CT and leads to a formation of stable micro-aggregates in which carbon is stabilized and sequestered in the long term.

The density fractionation and fractionation of water-stable aggregates may thus be helpful for an improved understanding of C dynamics affected by soil management, since aggregate and density fractions are more sensitive to changes in soil management than total C_{org} Water-stable macro-aggregates were enriched in younger organic material and have faster turnover times than micro-aggregates (Andruschkewitsch *et al*., 2013).

Heshmati *et al*. (2011) observed that aggregate stability in the surface soil of a sloping land is an important predictor of run-off, sediment and carbon loss through water erosion. It mainly depends on SOC which is influenced by land use practices. The contribution of coarse soil aggregate (>0.05 mm) in adsorption of SOC is more than micro aggregates (<0.05 mm), while it is damaged by improper agriculture activities (such as heavy tillage practices, burning of crop residue), grazing and forest clearance. Furthermore, the coarse soil aggregate is reduced mainly by long- term conventional tillage practices.

The study on a silty clay loam soil in China revealed that long-term (33 years) practices of this tillage resulted in reduction of 22% in coarse aggregates and increase of 34% in fine aggregates (Li and Pang, 2010).

When no tillage was continuously practiced for 4 years, 11 years and 20 years in *Typic Xerofluvents* of north east Spain, it was observed that small macro-aggregates (0.250-2.0mm) and micro-aggregates (0.053-0.250mm) increased at a depth of 0-5cm and 5-10cm. In contrast, small macro-aggregates and micro-aggregates reduced in conventional tillage (D. Plaza Bonilla *et al*, 2013).

Conventional tillage (CT) disrupts macro-aggregates (Gale *et al*., 2000). Micro-aggregates are more stable than macro-aggregates and tillage subsequently disrupts large aggregates more than smaller aggregates (Cambardella and Elliot, 1993).

In Florida, a no tillage chronosequence study of 0, 6, 10 and 15 years in commercial plots revealed that there exist a relationship between the increase in the surface soil water stable macro aggregate and the hydrolysable organic carbon with longer years under no tillage (Ochoa *et al*., 2009).

In red tropical Latosols in Brazil, it was found that no-tillage system had the best aggregation indices for the 0-20 cm layer due to the increase in the organic carbon content as reported by Castro Filho *et al*. (2002).

2.2.3 Soil moisture contents

Gicheru *et al*. (2005) reported that minimum tillage treatments produced higher maize yields than conventional tillage treatments and conserved more soil moisture in the soil. The results also indicated that minimum tillage treatments had more compact and moister soil surface than conventional tilled treatments. Overall increased crop yield under minimum tilled treatments was associated with improved soil moisture conservation.

In a seven-year study (Jones, 2000), it was found that zero tillage systems with cereal residue retention could enhance the soil moisture status.

Guto *et al*. (2012) observed that minimum tillage with vegetative barriers not only reduced soil loss though erosion, also conserved soil moisture in the dry season that was reflected in improved yields.

Daraghmeh *et al*. (2009) observed that tillage reduction in association with residue retention significantly increased the moisture contents in the surface layers mainly due to large increase in SOC in a typical Danish morainic sandy loam *Agrudalfs*.

While studying the impact on a dryland agro eco-system at BHU, Varnasi, Kushwaha *et al*. (2001) found that tillage reduction in association with residue retention significantly increased the water holding capacity in the present study, mainly due to large increase in soil organic C in residue retained treatments.

2.2.4 Soil reaction (pH)

Thomas *et al*. (2007) observed that there was a significant negative correlation between pH and organic carbon concentration ($r = -0.88$, $P < 0.01$), indicating that greater organic carbon under NT may at least partially have had an acidifying effect.

NT soils are frequently more acidic in the surface layers but less acidic in deeper layers than under CT practice as a result of an increase in organic matter and associated organic acids and changes in the proportions of cations and anions in soil under NT practice (Logan *et al*., 1991; Prasad and Power, 1991; Kern and Johnson, 1993).

Bessam and Mrabet (2003), while studying the effect of conservation agriculture on soil properties observed that increase in soil organic C and N and a slight pH decline in the seed zone under conservation agriculture practices creates a favourable environment for improvement of soil quality.

2.2.5 Soil organic carbon (SOC)

This increase in the concentration of SOC is considered to be the result of different interacting factors, such as less mixing and soil disturbance, increased residue return, reduced surface soil temperature, higher moisture content and decreased risk of erosion (Logan *et al*., 1991).

It may take a long time for soil management practices to cause measurable differences in SOC storage. In general, conversion from PT to CT can sequester 0.57 Mg C ha^{-1} yr^{-1} but a delayed response may occur in SOC accrual under CT and may reach a peak over 5–10 years (West and Post, 2002).

Synthesizing the results from 47 experiments with sampling depth deeper than 0.3 m, Angers and Eriksen-Hamel (2008) showed that NT led to significant C increase in surface soil, while full-inversion tillage (FIT) resulted in more C accumulation near or at the bottom of the plow layer (23 cm). They also showed that the greater SOC content at depth under FIT did not completely offset the gain under NT in the surface layer, leading to a higher total C stock under NT than FIT. However, results from 12 paired NT and CT experiments across three states in USA indicated that the overall change of soil C stock in the surface 60 cm of soil ranged from 22.8 to 20.3 t ha^{-1} after adopting NT for 5–23 years (Christopher *et al*., 2009).

Less soil disturbance under NT and the presence of a mulch layer caused stratification of SOC and N distribution. Furthermore, the presence of mulch may have improved soil structure by stabilizing aggregates and protecting SOM against microbial degradation and reduced the rate of SOC decomposition. Likewise, a strong SOC and N concentration gradient under NT systems from the surface to subsurface layers (0–30 cm) relative to PT systems have been reported in other studies due to isolation of residues from the soil profile. (Dikgwatlhe *et al*., 2012).

Higher SOC and N concentrations in the surface layer under NT than those under RT and PT systems can be attributed to a combination of less soil disturbance and reduced litter decomposition due to less soil/residue interaction (Du *et al*., 2010).

Tillage depth under different systems also affects the residues location, and thus influencing the depth distribution of SOC and N. The trend in SOC concentration observed for the 5 cm depth was reversed under NT for 5–30 cm depth (Puget and Lal, 2005).

Soil organic C concentration declines with depth in a logarithmic manner. Stimulation of organic matter decomposition occurs during cultivation due to frequent tillage, which releases organic matter protected in aggregates and redistributes organic matter in the soil profile where environmental conditions are more favorable for decomposition (Franzluebbers, 2005).

On a Vertisols in southern Queensland, highest concentration of organic C in the surface soil was found with a combination of NT, stubble retention and fertilizer N (Dalal, 1989) or NT and stubble retention (Thompson, 1992).

Heenan *et al*. (1995) also found greater amount of organic C in 0-10 cm depth under NT and stubble retained than under CT and stubble burned in a coarse-textured red earth with 29% clay.

The studies of Six *et al.* (2000a) and Tan *et al.* (2007) revealed that the lower physical impact of conservation tillage increases aggregate stability, leading to lower aggregate turnover rates and therefore improved physical protection of Corg from decomposition and thus higher Corg stocks in arable soils. In contrast, conventional tillage (CT) disrupts macro-aggregates and formerly incorporated Corg is exposed to microbial decomposition

When no tillage was practiced for 7 years continuously in the sloppy terrains of North-West Tuinisia, the soil organic matter was found to be more i.e. 31.0 g kg^{-1} & 24.1 g kg^{-1} at depths of 0-10 cm & 10-20 cm. But soil organic matter was much lower i.e. 20.6 g kg^{-1} & 22.4 g kg^{-1} at depths of 0-10 cm and 10-20 cm respectively when conventional tillage was practiced (Jemai *et al.*, 2013).

Long term studies on no tillage in a *Typic Xerofluvents* of North east Spain indicated that the increase in the proportion of stable macro-aggregates and the enrichment of C concentration of micro-aggregates are the main mechanisms of SOC protection when NT is maintained over time (Plaza- Bonilla *et al*., 2013).

Studies conducted under a wide range of climatic conditions, soil types, and crop rotation systems showed that soils under no-tillage and reduced tillage have significantly higher soil organic matter contents compared with conventionally tilled soils (R. Alvarez, 2005).

Havlin *et al.* (1990) determined that reducing tillage and maintaining surface residues in a long-term study increased soil organic carbon content. He conducted an experiment having three crop rotation-continuous soybean, continuous sorghum,

sorghum-soybean. These were managed for 12 years under conventional and no tillage systems (0 and 100% surface residue cover respectively). Under no tillage soil organic matter increased up to 45% as the level of residue increased from 1 to 3 t/ha/yr.

A study in eastern Paraguay about "changes in soil organic matter after land use change" showed that no tillage practices had a significant higher organic matter content compared with conventional tillage practices (Riezebos and Loerts, 1998).

In Texas, Zibilske *et al.* (2002) recorded that no tillage resulted in soil organic matter increase up to 58% in the top 4 cm of soil for no till treatment.

Balota *et al.* (2004) showed that in Brazil in 20-year experiment residue retention and minimum tillage increased organic carbon by 45% at 0-50cm depth compared with traditional tillage.

Madari *et al.* (2005) and Riley *at al*. (2005) showed that conservation tillage with residue cover had higher total organic carbon in soil aggregates than traditional tillage in Brazil. He again reported that addition of crop residues in combination with minimum tillage can yield attainable carbon accumulation rates up to 0.36 Mg C ha^{-1} yr^{-1}.

Li *et al*. (2006) conducted a 4 years no-tillage experiment and showed that active C and total organic C down to 10 cm depth were up to 5% higher in no-tillage than traditional tillage systems.

Liang *et al*. (2007) demonstrated that no tillage significantly increased the concentration of soil organic C in 5-20 cm soil layer by 5.6-5.9% on the clay loam soils after 3 years in the humid north eastern China.

Field experiment conducted in Santo Antonio de Goias, Brazil by A.S. Nascente *et al*. (2013) revealed that the use of cover crops such as millet and the no-tillage system increased C and N concentrations in each of the light fractions of the SOM. Although total SOM was little changed during the two years of this experiment, the various C fractions were significantly affected by the tillage. They concluded that SOM physical fractionation is good indicator to show significant differences caused by the soil management in the organic matter dynamics in a short period of time.

2.2.6 Aggregate carbon

The inclusion of organic materials within soil aggregates reduces their decomposition rate. Increases in aggregation concomitant with increases in organic C have been observed in NT systems. Tillage has been found to induce a loss of C-rich macro-aggregates and a gain of C-depleted micro-aggregates. However, this decrease in macro-aggregates cannot explain the total C loss associated with tillage. The increased macro-aggregate turnover under CT is a primary mechanism causing decreases of soil C (Six *et al*., 2000a).

Andruschkewitsch *et al*. (2013) observed that the fractionation of water-stable aggregates and density fractionation may thus be helpful for an improved understanding of C dynamics affected by soil management, since aggregate and density fractions are more sensitive to changes in soil management than total C_{org}. Water-stable macro-aggregates were enriched in younger organic material and have faster turnover times than micro-aggregates.

The contribution of coarse soil aggregate (>0.05 mm) in adsorption of SOC is more than micro aggregates (<0.05 mm), while it is damaged by improper agriculture activities (such as heavy tillage practices, burning of crop residue), grazing and forest clearance. Furthermore, the coarse soil aggregate is reduced mainly by long-term conventional tillage practices (Heshmati *et al*., 2011).

As a feedback mechanism, aggregation is considered as a significant mechanism of organic matter protection in soils. The incorporation of fresh crop residues in soils initiates WSA by stimulating microbial activity (Guillou *et al*., 2011).

The studies of Tisdall and Oades (1980) revealed that greater concentrations of organic C in macro-aggregates than in micro-aggregates and suggested that this is due to decomposing roots and hyphae within macro-aggregates.

Elliott (1986) suggested that macro-aggregates have elevated C concentrations because of the conversion of organic-matter-binding micro-aggregates into macro-aggregates and that this organic matter is ‘qualitatively more labile and less highly processed’ than the organics stabilizing micro-aggregates.

As compared to the conventional tillage treatments, reduced and zero tillage treatments had significantly higher amount of total aggregate associated carbon within all the aggregate size classes in surface soil depth. ZT promotes macro-aggregation as compared to CT. The macro-aggregates are highly susceptible to oxidation, but, simultaneously, they are rich conserver of SOC. Its presence in higher proportion ensures more carbon sequestration and nutrient availability by regulating proper aeration and water infiltration within the root zone (Gupta Choudhury *et al*., 2014).

Jacobs *et al.* (2009), in their study on impact of tillage on C and N storage, found that concentrations of C_{org} within water-stable aggregates decreased with decreasing size class. Overall, MT does not only improve aggregate stability but also increases the concentrations of C_{org} and N within aggregates.

2.2.7 Soil total nitrogen (STN)

In general, the TSN contents in the 0–5 cm depth were higher than the 5–10 cm or 10–20 cm depths. As compared to lower depths, a greater accumulation of TSN was observed in surface depth due to conversion of CT to NT and CRP. This indicated a stratification of crop residues and organic matter in the surface depth under NT or CRP systems. TSN contents in NP were greater than other management systems at all soil depths, while the lowest values were observed in CT and CRP soils (Purakayastha *et al*., 2009).

Retaining crop residues is important for SOM maintenance, long term soil health and the attendant increase in SOC and N storage (Salinas-Garcıa *et al*., 2002).

The influence of tillage systems on SOC and total N storage can vary with the soil depth, cropping system, site specific characteristics and climate (Mishra *et al*., 2010).

Salinas-Garcıa *et al*. (2002) observed that increased total N apparently resulted from the increased accumulation of crop residues near the soil surface with conservation tillage systems (NT and MT) and total N is known to be enhanced by increasing soil organic matter content.

While studying the effect of tillage on soil organic matter and soil hydrophobicity, Simon *et al*. (2009) observed that the total N content decreased with depth of sampling in the no and minimum tilled variants (about 10–12%). However, the total N content in the conventionally tilled variant was the same in both the 0–0.1 m and 0.1–0.3 m sampling depths.

Jacobs *et al*., (2009) reported that the surface layer of MT soils have higher total N contents and the impact of MT was more pronounced within the soil layer affected by residue input and physical impact of tillage.

Bhattacharyya *et al*. (2013) in their study have observed that soil aggregate dynamics is extremely crucial for TSN storage in a wheat based cropping system in the upper IGP. ZT-B with full residue retention had 53 kg ha^{-1} $year^{-1}$ greater TSN than the farmers' practice. Although TSN stock (on equivalent depth basis) was significantly higher under ZT plots than CT plots in the 0–5 cm soil layer, all plots had similar TSN stocks in the 0–30 cm layer.

According to the study of Corral-Fernandez *et al*. (2013) on rainfed crops of Mediterranean semi arid regions, the soil presents low OC content owing to the high mineralization of the OM and the absence of harvest residues after periods of drought. On the contrary, soils with coverage of trees or with wooded pastures show an increase in carbon (C) and nitrogen (N).

2.2.8 Microbial biomass carbon (MBC) and nitrogen (MBN)

Although soil microbial biomass represents only a small proportion of overall SOM, it is more dynamic than total SOM and a better indicator of how tillage and cropping systems impact soil health and productive capacity (Lupwayi *et al*., 1998, 1999; Campbell *et al*., 2001).

With the transition to no-tillage, MBC, microbial biomass N, and active N pools were shown to increase more rapidly in the upper soil profile than did the total pools of SOC and SON (Woods, 1989).

The greater MBC in the NP soil can be explained by the larger accumulation of labile organic C over time due to non-disturbance of the soil. In contrast, the MBC in the CT soil decreased because of low labile organic C which continuously declined due to cultivation over 100 years (Purakayastha *et al.*, 2008)

Balota *et al*. (2004) reported that CA results in more biotic diversity in the soil as a result of the mulch and less disturbance. The surface mulch also helps moderate soil temperatures and moisture, which is more favorable for microbial activity. MBC is 83% higher in MT that CT.

The MBC in CT did not vary widely at different depths which may be due to a more uniform distribution of organic C in the plow layer resulting from physical disturbance in the CT system. In contrast, there was significant stratification of MBC from the 0–5 cm to 5–20 cm depth in CRP and NT soils, with the lower depths being similar. The CT soil had significantly more MBC than NT4, NT28 and CRP in the 5–10 cm depth but similar amounts in the 10–20 cm depth which may have been due to soil mixing during repeated tillage under cropping (Purakayastha *et al*., 2009).

Singh and Singh (1993) stated that microbial growth due to the application of organic matter such as straw is mainly dependent on the availability of C in the soil; they reported 77% increases for MBC and MBN under straw C fertilizer, and 51 and 84% increases under straw treatment for MBC and MBN, respectively.

Salinas-Gracia *et al*. (1997) reported that use of minimum and zero tillage retained more crop residue C as soil organic C and soil MBC compared to conventional tillage.

Alternation to no tillage or increased cropping intensity increases microbial biomass C (MBC) in response to increase nutrient reserves and improved soil structure and water retention (Biederbeck *et al*., 2005).

Results on impact of tillage and residue incorporation on soil microbial biomass C and N in dry land farm (*Inceptisols*) of BHU by Kushwaha *et al*. (2001) indicated that when flushes of C are supplied to the soil in the form of crop residues, the microbial biomass increases in size until the substrate is depleted. In the present study, residue retention and tillage reduction both increased the level of soil MBC and MBN, the maximum effect on microbial biomass being recorded in MT with residues.

Alvear *et al*. (2004) suggest the use of microbial biomass and enzyme activity as indicators of soil quality because of their relationship to soil biology, the ease of measurement, the rapid response to changes in soil management, and the high sensitivity to temporary soil changes caused by both management and environmental factors.

Soil microbial biomass C and N in the surface layer were 25–50% greater with the NT and MT treatments than with disk plowing. At lower depths, soil microbial biomass C and N were generally not significantly different and decreased with depth in all tillage treatments. This decrease, however, was least evident in plowed soils and probably resulted from the incorporation and mixing of crop residues within the plowing layer. In contrast, higher surface soil microbial biomass concentrations with NT and MT may be due to the accumulation of crop residues at the soil surface (Salinas-Garcıa *et al*., 2002).

2.2.9 Soil quality indicators (SOC stratification ratio, MBC/SOC ratio, MBN/STN ratio, C/N ratio)

2.2.9.1 SOC stratification ratio

Plant residue placement is of importance to the depth distribution of SOM in the soil profile, because plant residues contribute greatly to subsequent SOM formation. Therefore, stratification of SOM fractions has been suggested as an indicator of soil quality in different agroecological zones, because surface SOM is essential to erosion control, conservation of nutrients, water infiltration, and other important soil functions (Franzluebbers, 2002).

The degree of stratification of SOC and N pools with depth, expressed as a ratio (stratification ratio, SR), can indicate soil ecosystem functioning and SR values for SOC may range from 1.1 to 1.8, and 1.8 to 3.2 under PT and CT, respectively (Sá and Lal, 2009).

In general, and irrespective of soil and climatic conditions, a high stratification ratio (relation between surface and deeper layer concentrations of SOM) would indicate good soil quality, as ratios (>2) are not frequently found in degraded soils (Franzluebbers, 2002).

The lack of strong difference in stratification ratio could reflect some C and N accumulation in the sub-surface layer under CT derived from inversion of soil with tillage and under NT from the self-tilling characteristic of this high-clay content in Vertisol (Melero *et al*., 2012).

The SR (stratification ratio) of SOC in Cambisols for surface (0–20.9 cm) to depth (20.9–55.5 cm) was greater under OT (organic tillage) with 1.3 to 1.6 than under CT (conventional tillage) with 1.25 to 1.42, which was related to higher SR of SOC in OT than in CT is a consequence of the accumulation of surface SOC due to straw soil surface coverage and root distribution change in OT (Corral-Fernandez *et al*., 2013).

Soil organic carbon was relatively uniformly distributed within the surface and sub-surface soil after five years of conventional tillage with transplanted rice. In contrast, zero tillage management resulted in a higher stratification ratio (1.5) of SOC, which depicted the presence of higher SOC in the surface soil than the sub-surface (Gupta Choudhury *et al*., 2014).

2.2.9.2 MBC/SOC ratio and MBN/STN ratio

The ratio of biomass C to total organic C is a measure of C availability, where a high ratio indicates an anticipated accumulation of organic matter, long before the actual accumulation can be measured (Stockfisch *et al*., 1999)

In the top 10 cm of MT and the uppermost 0-30 cm layer of CT the ratio of MBC/SOC is much higher, which suggests C availability to be higher (Stockfisch *et al*., 1999). Quite similar relations with microbial biomass C in contrasting tillage systems were reported from central USA (Staley *et al*., 1988) and from Prince Edward Island, Canada (Carter, 1991).

Kushwaha *et al*. (2001) while studying in a dryland agro-ecosystem at Varnasi, UP, observed that the higher MBC/SOC and MBN/STN in MT soils with residue are due to higher C and N availability to microbes as a result of higher residue retention.

An increased substrate availability can be demonstrated by a high C_{mic}:C_{org} ratio (Stockfisch *et al*., 1999). Jacobs *et al*., (2009), in their study, found that the C_{mic}:C_{org} ratio increased with depth in CT and decreased in MT indicating that C-availability to microorganisms was the best in the soil layer which received the highest residue input.

Elcio *et al*. (2003) and Roldan *et al*. (2005) included crop rotation systems of maize with soybean and beans, respectively, in their studies suggesting that the residues from these legume crops maintained more labile organic substrates in the soil, which allows a higher microbial biomass C per unit of soil organic C. Generally, if a soil is being degraded, the microbial C pools will decline at a faster rate than the organic matter, and the proportion of organic C as MBC will decrease as well. This might allow for a calibrated soil quality indicator to predict whether soils are accumulating or losing C.

2.2.9.3 C/N ratio

The soil C:N ratio is a soil fertility indicator due to the close relationship between SOC and total nitrogen (TN). The soil C:N ratio is often influenced by many factors such as climate, soil conditions, vegetation types and agricultural management practices (Corral-Fernandez *et al*., 2013).

Tillage and residue management can greatly influence soil C:N ratio. The latter is an important soil quality indicator which reflects the soil C:N interaction and is also affected by soil management (Lou *et al*., 2012).

In general, the C:N ratio is directly affected by the amount of residue retention, fertilizer rate and type, and the decomposition rate of the residue. Therefore, farm operations (e.g., tillage, residue management, fertilizer) also impacts the C:N ratio. The specific trend observed in the C:N ratio under tilled systems may be attributed to tillage intensities due to soil structural distortion and to higher SOM mineralization (Ussiri and Lal, 2009).

The mechanisms behind the lower C:N ratios for CT and NP soils are different. The CT soil has reduced C concentrations from oxidation of labile SOM due to tillage. But fertilizer N inputs to CT soil that results in an apparent low soil C:N ratio, whereas, the NP soil has built up C reserves and has increased the soil N two fold thus reducing the soil C:N ratio (Purakayastha *et al*., 2009).

The comparatively high ratio of organic C to N in the top 5 cm of MT may be the consequence of a less advanced decomposition of organic matter (Stockfisch *et al*., 1999).

2.2.10 Soil microbial properties (population of bacteria, actinomycetes and microbial biomass carbon)

Conservation soil technologies with reduced tillage increase SOM content in superficial layer, which is the major source for soil biota. More microorganism classes and a higher diversity were found in non-tilled soils, compared with conventional tillage. In favourable conditions and under available soil biota composition, nutrients are gradually released from SOM, thereby made accessible for the plants to be utilized for yield formation (Simon *et al*., 2009).

Soil organic matter (SOM) also plays a key role in soil quality The size of the microbial community is directly proportional to SOM content and soil microbes are the principal mediators of nutrient cycling (Hamel *et al*., 2006).

The fungal component of the microbial community was greater at less than 10 cm depth in the ZT and MT treatments, but not in the CT and DP treatments, whereas the bacteria showed much less variation with depth. An increase in the proportion of microbial biomass attributable to fungi was also found in reduced tillage and no tillage systems (Sun *et al*., 2011).

After 5 years of NT maize in Mexico, soil wet aggregate stability had increased over conventional tillage (TT) as had soil enzymes, soil organic carbon (SOC) and microbial biomass (MB). They conclude that NT is a sustainable technology (Roldan *et al*. 2003).

Although fungal dominance is commonly assumed in no-till soils, the relative abundance of fungi over bacteria is not consistently greater in the Northern Great Plain soils under long-term no-till practices compared with intensive tillage (Helgason *et al*., 2009).

Using NT and/or cover crop systems can alter enzymatic activity (Bandick and Dick 1999; Dick 1994), microbial biomass (Linn and Doran 1984; Wagner *et al*., 1995; Kirchner *et al*., 2003; Zablotowicz *et al*., 1998a), microbial community structure (Lupwayi *et al*., 1998; Feng *et al*., 2003), and macroflora diversity (Gaston *et al*., 2003; Reeleder *et al*., 2006).

Results of many researchers indicated the importance of reducing tillage as a means of increasing soil biological activity of the topsoil. (Zibilske & Bradford, 2003; Mijangos, *et al.*, 2006; M¸ler *et al*., 2009). Authors have shown that even a reduction in tillage leads to increased microbial activity and biomass in contrast to surface soil under conventional tillage (Von Lu zow *et al*., 2002).

The microbial diversity, measured by the Shannon diversity index (SDI), was significantly higher in samples from no-tillage system plots in four taxonomic levels (order, family, genus and species), which agree with Ceja-Navaro *et al*. (2010), who found that soils under no-tillage had the highest levels of microbial diversity compared to the conventional tillage system.

MATERIALS AND METHODS

The potential benefits of conservation agriculture on soil health are well documented world over with varying results depending on climate, soil type, cropping system, residue management. A long term field experiment with conservation agriculture production system (CAPS) has been established at the Regional Research and Technology Transfer Station (RRTTS) of OUAT, Kendujhar located under the rainfed agro-ecosystem of the North Central Plateau zone of Odisha (Fig.3.1) during 2011. The study is a joint collaboration programme of Orissa University of Agriculture and Technology (India), University of Hawaii (USA), and Japan Science and Technology (Japan) under the name 'SMARTS' 2 (Sustainable Management of Agricultural Resources for Tribal Societies 2). The impact of (CAPS) on soil attributes and productivity was assessed at the end of 4th cropping cycle with the following materials and methods.

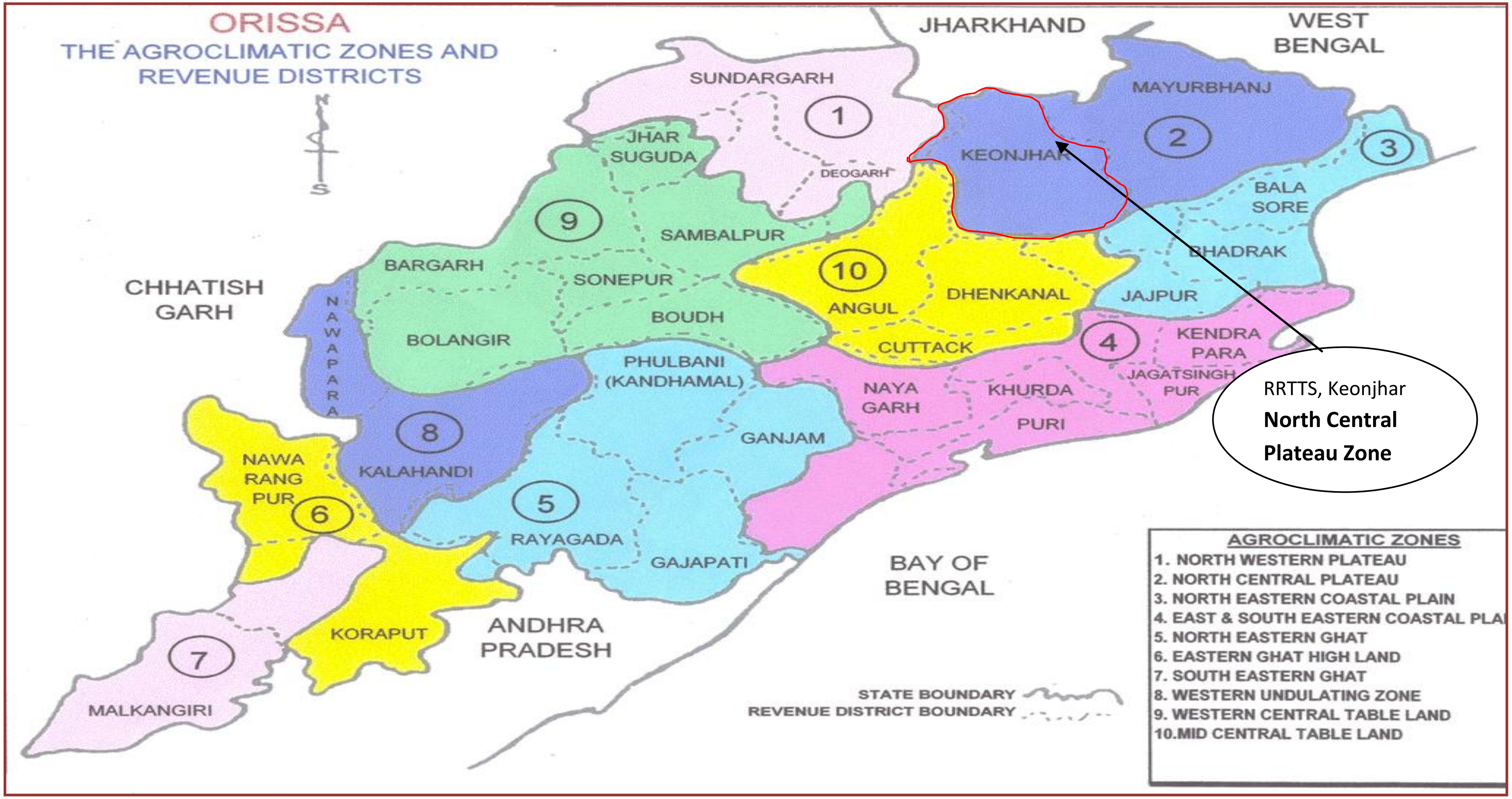
3.1. MATERIALS

3.1.1 Description of the study area

The study area is located in 'B' block of RRTTS Kendujhar (Fig. 3.2) with the geo-codes of 85˚ 34' 30.61" E, 20˚ 50' 50.38"N, 499m above MSL. The tract is predominantly a rainfed agro-ecosystem under Agro Ecological Sub-region (AESR) 12.3 and North Central Plateau Agro-climatic zone of Odisha. The soils developed from colluvial-alluvial deposits in a piedmont plain, with sandy clay loam to sandy loam texture, belong to *Fluventic Haplustepts*.

3.1.2 Climate of the study area

The climate of the study area is characterized by hot, moist, sub-humid type with mean annual rainfall of 1527.3 mm, of which more than 75% is received in the months from May to September. The mean maximum and minimum temperatures are 31.3˚C and 19.5˚C, respectively and the afternoon relative humidity varies from 34.7% in March to 87.5% in September.



RRTTS, Keonjhar

North Central Plateau Zone

Fig.3.1. Agroclimatic zones of Odisha

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Study area with profile site and external land features

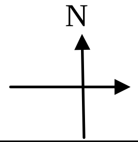
The weather parameters during growing season of the study year are presented in Table 3.1.

Table 3.1 Mean monthly meteorological data during the cropping season (2014 –2015)

Month	Mean Monthly Rainfall (mm)	Rainy Days	Mean monthly Temperature (^{0}C)		Mean Monthly Relative Humidity (%)	
			Max.	Min.	FN	AN
2014						
April	26.3	4	38.07	20.37	66.83	15.93
May	44.9	5	38.41	22.25	72.9	24.51
June	320.7	15	35.43	22.36	78.9	39.33
July	495.9	19	30.39	20.90	85.22	55.32
August	390.9	14	30.54	20.87	90.12	61.16
September	283.3	15	30.73	20.16	90.03	59
October	124.8	15	30.12	17.06	87.78	51.16
November	0	0	29	14.36	78.8	36.73
December	0.81	0	25.97	10.41	61.64	29.8
2015						
January	0.3	0	25.61	10.64	66.68	38.97
February	14.8	3	30.14	14.28	69.34	21.18
March	14.8	2	33.49	18.49	97.93	20.83

3.1.3 Experimental design and Treatment details

The experimental designis split-plot with three replications. The treatment details are conventional tillage (CT) and minimum tillage (MT) with sole maize (M)



RI		RII		RIII	
CT-M-NCC	MT-M+C-T	MT-M-H	MT-M+C-H	CT-M-T	CT-M+C-NCC
CT-M-H	MT-M+C-NCC	MT-M-NCC	MT-M+C-T	CT-M-H	CT-M+C-T
CT-M-T	MT-M+C-H	MT-M-T	MT-M+C-NCC	CT-M-NCC	CT-M+C-H
MT-M-NCC	CT-M+C-H	CT-M-T	CT-M+C-NCC	MT-M-T	MT-M+C-H
MT-M-H	CT-M+C-NCC	CT-M-H	CT-M+C-T	MT-M-H	MT-M+C-NCC
MT-M-T	CT-M+C-T	CT-M-NCC	CT-M+C-H	MT-M-NCC	MT-M+C-T

Fig.3.3 Layout plan of the experiment

Experimental Design:Split plot
Number of treatments:12
Number of replication:03
Individual plotsize:10.2m x 7.2m

Main plot (Kharif)

CT-M -Conventional tillage with sole maize
CT-M+C -Conventional tillage with maize+cowpea inter crop
MT-M -Minimum tillage with sole maize
MT-M+C -Minimum tillage with maize+cowpea inter crop

Sub plot (Rabi)

NCC- No cover
H- Horsegram
T- Toria mustard

and maize cowpea intercrop (M+C) in main plots during wet season (*Kharif*) and no cover crop (NCC), horse gram (H) and toria mustard (T) in sub-plots during dry season (*Rabi*), resulting a total of twelve different combinations. The treatment details and layout design are depicted in Table3.2 and Figure3.5, respectively.

Table3.2 Treatment details

Treatment	**Descriptions**
Mainplot (*Kharif* season)	
CT-M	Conventional tillage with sole maize
CT-M+C	Conventional tillage with maize+cowpea inter crop
MT-M	Minimum tillage with sole maize
MT-M+C	Minimum tillage with maize+cowpea inter crop
Sub-plot (*Rabi* season)	
NCC	No cover crop
H	Horsegram as covercrop
T	Toria mustard as covercrop

3.1.4 Field preparation

Three mould board ploughing was advocated up to a depth of 20-25 cm in conventional tillage (CT) without residue incorporation and in minimum tillage (MT), one shallow disking is done up to a depth of 10 cm with addition of chopped main crop (maize, cowpea) and cover crop (horsegram, toria) biomass as surface residues

3.1.5 Crop management

The crop varieties used in the experiment, their duration, date of sowing as well as harvesting is given below.

Table 3.3 Crop varieties and their duration

Crops	**Variety**	**Duration**
Maize	Pioneer30R-77	90-100days
Cowpea	Utkal Manika	75days
Horsegram	Athagarh local	100days
Toria (Mustard)	Anuradha	75-80days

3.1.6 Fertilizer management

The recommended chemical fertilizers applied to Maize, Cowpea, Toria and Horsegram were indicated in the Table 3.4. The fertilizer applied for Maize + Cowpea was based on additive series, taking into consideration 100 per cent plant population of maize and 50 percent plantpopulationof cowpea. The fertilizers were applied in line basally for the crops except maize where nitrogen was applied in three split viz. 25% basal, 50% at first earthing up and rest 25% at second earthing upstage.

Table3.4 Fertilizer dose for different experimental crops grown

Crops	**Fertilizer Dose (kg ha^{-1})**		
	N	**P_2O_5**	**K_2O**
Maize	80	40	40
Cowpea	20	40	20
Mustard	40	20	20
Horsegram	20	40	20

3.1.7 Sowing, seed rate and spacing

During kharif season, for sole maize, spacing of 60cmx30cm was adopted for which a seed rate of 15kg ha^{-1} was required. But, maize+ cowpea as intercrops were sown in 1:1 ratio at a uniform spacing of 30cm. The spacing adopted for cowpea was 15cm from plant to plant within the row. A seed rate of 10 kg ha^{-1} was required taking into consideration that the cowpea plant population was 50%of normal sole cowpea. In Minimum tillage practice, Maize and Cowpea seeds were sown by dibbling inline. In Conventional tillage practice, line sowing of seeds was done and the seeds were covered with soil after sowing. A seed rate of 7.5kg and 25 kg ha-^{1} was required for toria and horse gram, respectively.

3.2 METHODS

3.2.1 Collection and processing of soil samples

Soil samples were collected after harvest of the cover crops (at the end of 4th cropping cycle) in the month of February, 2015.

Soil samples from each plot consisted of composite samples that were collected with a narrow spade and divided into segments of 0-5, 5-10 and 10-20cm, placed in plastic bags and brought to the laboratory immediately for analysis. Field moist samples were gently passed through a 10mm sieve and dried at 40˚C for 48 hours and 100g of dry soil samples were used for determining water stable aggregates. A portion of fresh soil samples were sieved through a 2mm sieve and stored at 4˚C for analysis of various microbiological tests. Another portion of the sieved soils were air dried (2-3 days) and used for determination of organic carbon and pH. Undisturbed core samples from each layer were collected with a core sampler (5.0cm diameter) for determination of soil bulk density. Soil cores from each depth were also collected during sowing, flowering and harvesting of dry season cover crops for determination of gravimetric moisture content.

3.2.2 Methods of Soil Analysis

a) Physical analysis

3.2.2.1 Bulkdensity

The bulkdensity of the soils from the experimental plots was analysed by core method (Blake, 1965).

3.2.2.2 Waterstable aggregates (WSA)

The WSA in the soils were determined using 250µm and 53µm mesh sieve by wet sieving method (Kemper and Rosenau, 1986). A sample of 100g air-dried (8-mm sieved) soil was placed onthe top of a 2 mm sieve and submerged for 5 min indeionized water at room temperature to allow slaking. Sieving was manuallydone (when the sample was submerged) by moving thesieves up and down 3 cm, 50 times in 2 min to achieveaggregate separation. A series of two sieves (0.25 and 0.053 mm) was used to obtain the two aggregatefractions: (1) 0.25–2-mm (macro-aggregates), (2) 0.053–0.25-mm (micro-aggregates). Soil aggregate fractionsretained on different sieves, were oven dried (50^0C), weight expressed in percentages.

3.2.2.3 Soil Moisture Content (SMC)

The SMC in the soils were determined by gravimetric method. The soil samples are collected and dried in the hot air oven at 105˚C for 24 hours. Moisture content is determines by measuring moist weight and dry weight of the soil. It is expressed as percentage of moisture content per weight of dry soil (Dastane, 1972).

b) Chemical analysis

3.2.2.4 Soil pH

The pH of soil samples of the experimental plots was determined in 1:2.5 soil:water suspension (Jackson, 1973) after equilibration for half an hour with intermittent stirring using the glass electrode digital pH meter, 'SYSTRONICS' (model M.K.VI).

3.2.2.5 Soil organic carbon (SOC)

The soil organic carbon (SOC) was determined by modified Walkley and Black's rapid titration method (Jackson,1973) using ferroin indicator (Chopra and Kanwar,1986).

3.2.2.6 Aggregate Carbon

The carbon content of both macro and micro aggregates was determined by taking a known weight of aggregate fraction for wet oxidation as per the procedure outlined by Walkley and Black modified by Mebius (1960). The modification consists of extensive heating of the sample during digestion, boiling the sample at 150^0C for 30 minutes to increase the digestion of organic carbon.

3.2.2.7 Soil Total Nitrogen (STN)

The soil total nitrogen (STN) were analysed by digestion distillation methods with help of a PELICAN N auto analyser. The soils were digested in sulphuric acid with sodium thiosulphate and salicylic acid in presence of digestion mixture, followed by distillation and titration (Page *et al.*,1982).

c) Microbial analysis

3.2.2.8 Microbial Biomass Carbon (MBC)

Microbial biomass carbon was estimated employing fumigation and extraction procedure as described by Vance *etal.* (1987). The process involved collection of filtrate using Whatman filter paper no.2 by shaking unfumigated soil(20g) with $0.5MK_2SO_4$

for 30minutes. Similarly another set of filtrate was collected using fumigated soil exposed to ethanol free chloroform for 24 hours. Organic carbon in both the extract was analysed using the method of digestion titration. For digestion of organic carbon 10 ml of filtrate was transferred into aconical flask and 10 ml of $K_2Cr_2O_7$ followed by 20ml of conc.H_2SO_4 were added and the entire content was digested for 30 minutes at 170^0C. After the content in the flask cooled down, 25ml distilled water and 5ml, ortho-phosphoricacid were added to the digested material and titrated against 0.04M ferrous ammonium sulphate with ferroin as the indicator.

$$\text{MBC} = \frac{\text{EC fumigated soil - EC of unfumigated soil}}{\text{Kc}}$$

Where, EC = Extractable carbon

Kc = 0.379 (Kc is the K_2SO_4 extract efficiency factor, Hu and Cao, 2007)

3.2.2.9 Microbial Biomass Nitrogen (MBC)

With the same K_2SO_4 soil extracts, microbial biomass nitrogen (MBN) was determined as total N using Kjeldahl digestion procedure (Brookes *et al*., 1985). The flush of total N (K_2SO_4 extractableN from non-fumigated soil subtracted from that of fumigated soil) was divided by a K_N (fraction of biomassN extracted after chloroform fumigation) value of 0.54(Brookes *et al*., 1985). All the results are expressed onoven dry soil (105^0C) basis.

$$\text{MBN}= \frac{E_N \text{ fumigated soil - } E_N \text{ of unfumigated soil}}{K_N}$$

where, E_N = Extractable nitrogen

K_N = 0.54(K_N is the K_2SO_4 extract efficiency factor)

3.2.2.10 Enumerationofsoilmicrobialpopulation

Soil microbial population was determined by serial dilution and spread plate technique. One gram of the soil sample was added to test tube containing 9ml of distilled water, serially diluted (Dhingra and Sinclair, 1993) spread over Nutrient Agar, Actinomycetes Isolation Agar and Potato Dextrose Agar for enumeration of bacteria, actinomycetes and fungi, respectively. The plates were incubated at30°C for 24 hours for bacterial isolation and at 30°C for 48 hours for actinomycetes and fungal isolation.

Calculation

The following mathematical deduction was followed for enumeration of the microbial colony and expressed as CFU per gram of soil.

$$\text{CFU/ml} = \frac{\text{No. of colony} \times \text{Inverse of dilution taken}}{\text{Volume of inoculum taken}}$$

3.2.2.11 Maize-equivalentyield

Maize equivalent yield (MEY) was calculated by the formula as follows :

$$\text{MEY (q/ha)} = \frac{\text{Yield of other crop produce (q ha}^{-1}\text{)} \times \text{price of that produce(Rs q}^{-1}\text{)}}{\text{Price of maize grain (Rs q}^{-1}\text{)}}$$

The maize equivalent yield of the cropping system was obtained by addition of yield of maize component and the maize equivalent yield of other component crop taken in intercropping and the *Rabi* crop if any (Toria and Horse gram).

3.2.2.12 Statistical analysis

Data in respect of soil physical and chemical properties for various treatments were subjected to analysis of variance following standard statistical procedure (Gomez and Gomez, 1984).

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RESULTS

Alteration of soil conditions by tillage (minimum and conventional) and cropping systems (intercrop and cover crop) can significantly affect productivity and sustainability through influences on depth distribution of major key soil parameters. In the present study, the impact of conservation agricultural production system (CAPS) on soil properties has been assessed at the end of 4^{th} cropping cycle and the results are described in the following section.

4. Soil parameters of the experiment

4.1 Soil physical parameters

4.1.1 Soil bulk density

The magnitude of change in soil bulk density depends upon depth and intensity of tillage operation and quantum of organic matter build up in the soil. Tillage methods and cropping systems influence the soil BD significantly across the depths (table 4.1) at the end of the 4^{th} cropping year. Minimum tillage (MT) reduced soil BD in the tune of 3% and 2.2% over the initial status (1.32 and 1.37 mg m^{-3}) in 0-5cm and 5-10 cm layers, respectively. Conventional tillage, on the other hand registered higher bulk density (+2.3%, +1.5%) in the top two layers. Growing of cover crops (Horse gram, Toria) also lowered the bulk density by 0.8% and 0.7% over fallow (NCC) in the depth ranges of 0-5cm and 5-10cm respectively. Tillage and cropping systems could not change the soil bulk density much in the layer of 10-20cm.

4.1.2 Water stable aggregates

Aggregates not only physically protect soil organic matter, but also regulate water and air flow and reduce run-off and erosion.

Table 4.1Soil BD (mg m^{-3}) as influenced by tillage and cropping systems

0-5 cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	1.39	1.36	1.37	**1.37**
CT-M+C	1.35	1.33	1.33	**1.34**
MT-M	1.30	1.28	1.29	**1.29**
MT-M+C	1.29	1.27	1.28	**1.28**
Mean	**1.33**	**1.31**	**1.32**	
Initial	1.32			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.009	0.004	0.011	0.007
CD (0.05)	0.032	0.01	NS	NS

5-10cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	1.41	1.40	1.40	**1.40**
CT-M+C	1.40	1.38	1.39	**1.39**
MT-M	1.36	1.34	1.35	**1.35**
MT-M+C	1.35	1.33	1.34	**1.34**
Mean	**1.38**	**1.36**	**1.37**	
Initial	1.37			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.006	0.003	0.009	0.007
CD (0.05)	0.022	0.01	NS	NS

10-20cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	1.46	1.45	1.45	**1.45**
CT-M+C	1.45	1.44	1.44	**1.45**
MT-M	1.46	1.45	1.44	**1.45**
MT-M+C	1.45	1.43	1.44	**1.44**
Mean	**1.45**	**1.44**	**1.44**	
Initial	1.44			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.005	0.005	0.01	0.01
CD (0.05)	NS	NS	NS	NS

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4.1.2.1 Macro-aggregate (>0.25 mm)

The depth wise distribution of macro-aggregates of soils under different tillage and cropping systems are presented in table 4.2a and fig.4.1a. Soils under MT exhibited increase in proportion of macro aggregates in 0-5 cm and 5-10 cm layers and the gain was in the tune of 18.4% and 15.2%, respectively over initial (58.2% and 52.8%) and 28.5% and 29.4% over CT (53.6% and 47.0%). Practice of CT over the years reduced the quantity of macro aggregates in the top two layers by 7.9% and 11.0%. Soils under cover crops are also enriched with macro aggregates and the increase was in the tune of 7.9% and 5.4% in the top two layers over NCC (58.2% and 52.0%). There was no significant change in the proportion of macro aggregates among treatments in 10-20 cm layer.

4.1.2.2 Micro aggregate (0.053-0.25mm)

Intensive tillage and low residue inputs increase the proportion of micro aggregates in the soil because of rapid macro aggregate turnover rate. The soils under MT showed a remarkable decrease in the proportion of micro aggregate in 0-5cm and 5-10 cm depths (Table 4.2b and fig. 4.1b) that was in the tune of 11.1% and 12.7%, respectively over the initial status(16.2% and 18.1%). The concomitant increase of micro aggregates in the soils under CT was 21.0% and 22.1% for the top two layers. Soils under cover crops and the bottom layer (10-20 cm) of both MT and CT exhibited no noticeable variation in the proportion of micro aggregates.

Table 4.2a. Effect of tillage and cropping systems on water stable macro-aggregates (>0.25mm) (%)

0-5cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	50.13	54.83	53.10	**52.69**
CT-M+C	52.20	56.50	55.03	**54.58**
MT-M	63.53	69.60	67.33	**66.82**
MT-M+C	66.80	74.07	72.23	**71.03**
Mean	**58.17**	**63.75**	**61.93**	
Initial	58.22			
	M	**S**	**M within S**	**S within M**
SEm(±)	1.120	1.029	2.019	2.058
CD (0.05)	3.88	3.09	NS	NS

5-10cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	43.33	47.60	46.77	**45.90**
CT-M+C	45.77	49.83	48.47	**48.02**
MT-M	58.90	61.10	60.60	**60.20**
MT-M+C	60.17	62.43	61.73	**61.44**
Mean	**52.04**	**55.24**	**54.39**	
Initial	52.82			
	M	**S**	**M within S**	**S within M**
SEm(±)	1.199	0.961	1.976	1.923
CD (0.05)	4.15	NS	NS	NS

10-20cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	41.20	44.77	43.77	**43.24**
CT-M+C	43.70	45.23	44.60	**44.51**
MT-M	43.33	46.77	45.20	**45.10**
MT-M+C	43.80	46.50	45.57	**45.90**
Mean	**43.01**	**45.82**	**44.78**	
Initial	44.72			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.832	1.148	2.052	2.298
CD (0.05)	NS	NS	NS	NS

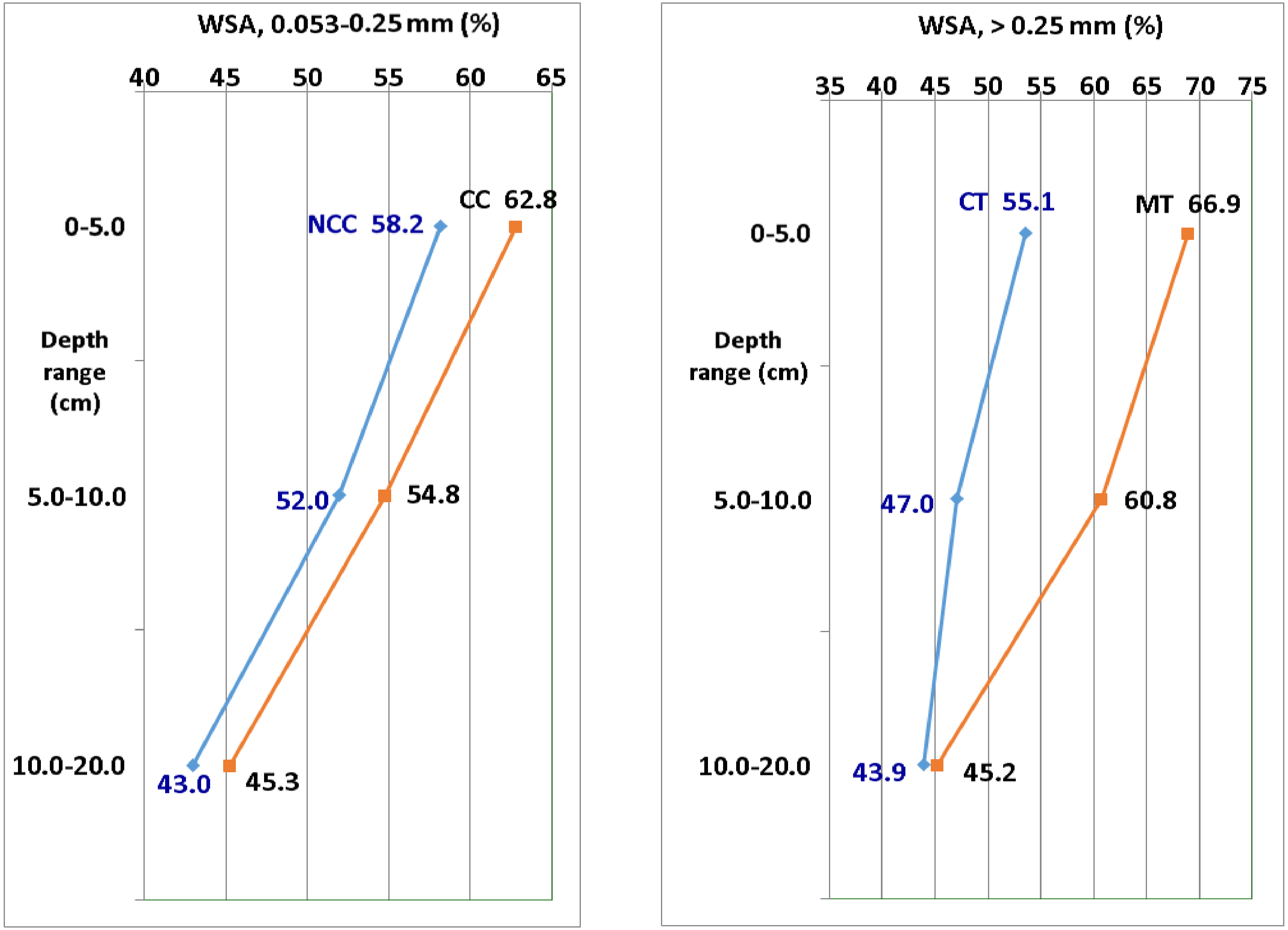

Fig. 4.1a. Dcpth wise graph showing the distribution of WSA (micro- aggregate) under different tillage systems

Table 4.2b Effect of tillage and cropping systems on water stable micro-aggregates (0.053-0.25 mm)

0-5cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	21.87	19.27	20.80	**20.64**
CT-M+C	19.33	17.90	18.43	**18.56**
MT-M	15.67	14.93	15.20	**15.27**
MT-M+C	14.20	13.10	13.30	**13.53**
Mean	**17.77**	**16.30**	**16.93**	
Initial	16.16			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.435	0.612	1.09	1.225
CD (0.05)	1.506	NS	NS	NS

5-10cm layer				
Particulars	**NCC**	**H**	**T**	**MEAN**
CT-M	25.13	21.30	23.27	**23.23**
CT-M+C	21.53	20.20	21.00	**20.91**
MT-M	17.27	15.67	16.30	**16.41**
MT-M+C	15.90	14.60	15.20	**15.23**
Mean	**19.96**	**17.94**	**18.94**	
Initial	18.10			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.38	0.599	1.05	1.199
CD (0.05)	1.315	NS	NS	NS

10-20cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	24.53	23.43	24.00	**23.99**
CT-M+C	23.00	21.23	22.83	**22.36**
MT-M	21.90	21.40	21.60	**21.63**
MT-M+C	21.20	20.47	21.07	**22.22**
Mean	**22.66**	**21.63**	**22.38**	
Initial	19.60			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.704	0.659	1.286	1.319
CD (0.05)	NS	NS	NS	NS

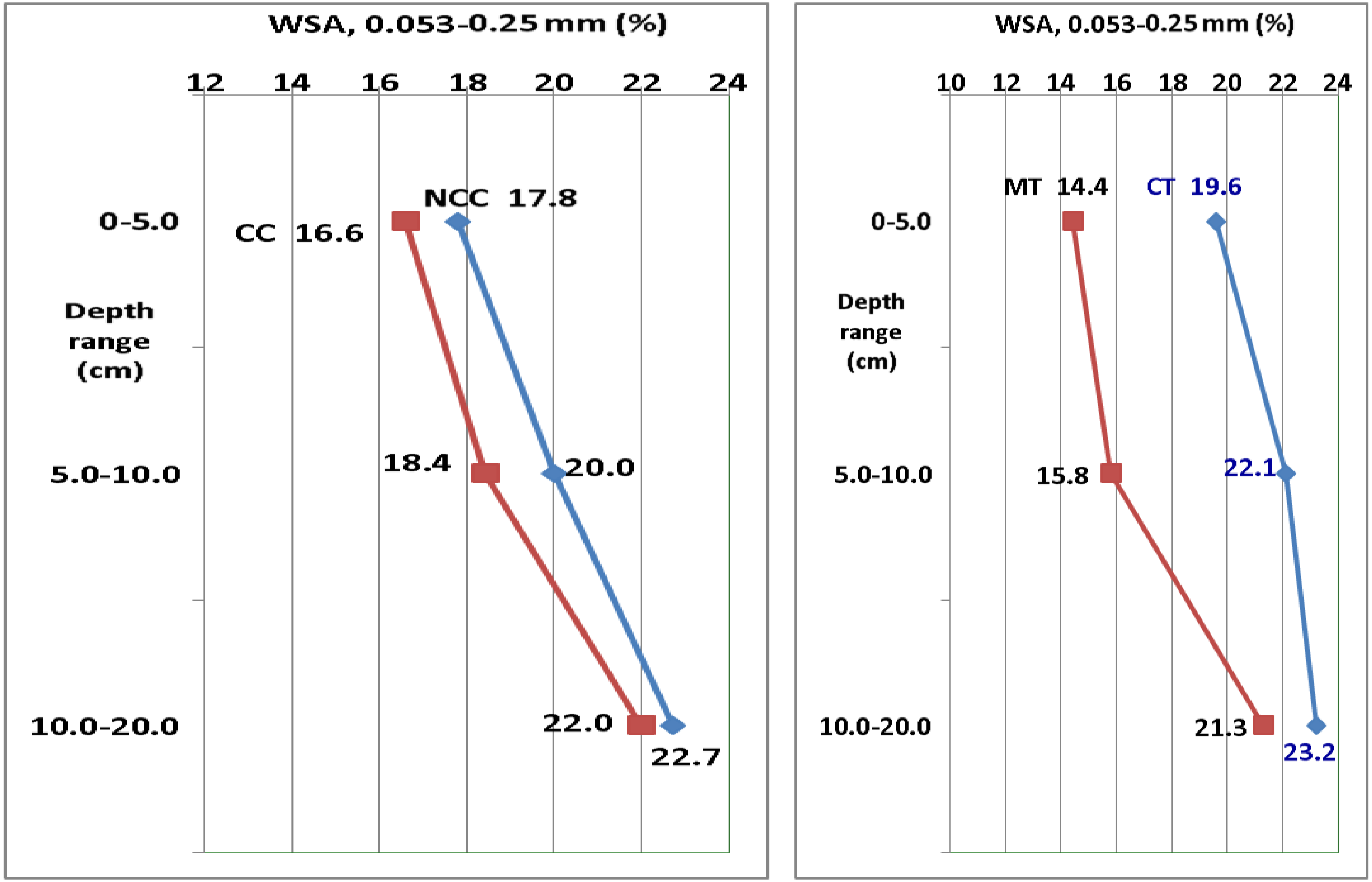

Fig. 4.1b. Depth wise graph showing the distribution of WSA (micro- aggregate) under different tillage systems

4.1.3 Soil moisture content

The soil moisture content of different layers during cover crops (Rabi season) changed conspicuously among sampling times, showing higher contents at sowing and lower contents at harvesting. The soils of top layers (0-5cm) under MT exhibited significantly higher moisture content both at sowing (+13.3%) and flowering (+14.1%) over soil moisture contents of14.89% and 10.61% under CT, respectively (Table 4.3a) The moisture content of top layers did not show any changes at harvesting. The moisture content of deeper layers (5-10cm and 10-20cm) did not change remarkably among treatments and sampling time, even though an increase in overall moisture contents across the Profile was observed at the end of the fourth cropping cycle.

4.2 Soil chemical parameters

4.2.1 Soil Reaction (pH)

Soil reaction is considered as one of the key soil quality indicator as it influences the nutrient dynamics and microbial profile within the soil system.

The depth wise status of soil pH is presented in table 4.4. Practice of Conservation agriculture did not influence the soil pH remarkably even after four cropping years except the top layers (0-5cm). The soil pH in the top layers under MT was reduced by 3.7% and 1.5% over initial pH of 7.34 and CT soil pH of 7.17, respectively. A declining trend of soil soil pH was observed in deeper layers over the initial status, through the variation among the treatments were not significant.

Table4.3a Effect of tillage and cropping systems on soil moisture content (%) at 0-5cm depth

Sowing				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	14.49	15.18	14.79	**14.82**
CT-M+C	14.71	15.26	14.91	**14.96**
MT-M	16.02	16.93	16.62	**16.53**
MT-M+C	16.87	17.51	17.21	**17.20**
Mean	**15.52**	**16.22**	**15.88**	
Initial	14.33			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.428	0.211	0.551	0.423
CD (0.05)	1.48	NS	NS	NS

Flowering				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	10.36	10.71	10.57	**10.54**
CT-M+C	10.42	10.88	10.72	**10.68**
MT-M	11.82	12.26	12.07	**12.05**
MT-M+C	11.92	12.36	12.23	**12.17**
Mean	**11.13**	**11.55**	**11.40**	
Initial	10.2			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.382	0.14	0.445	0.28
CD (0.05)	1.32	NS	NS	NS

Harvesting				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	7.20	7.60	7.40	**7.40**
CT-M+C	7.41	7.71	7.59	**7.57**
MT-M	7.68	8.01	7.88	**7.86**
MT-M+C	7.59	8.06	8.14	**7.93**
Mean	**7.47**	**7.85**	**7.75**	
Initial	7.27			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.358	0.23	0.519	0.495
CD (0.05)	NS	NS	NS	NS

Table 4.3b Effect of tillage and cropping systems on soil moisture content (%) at 5-10cm depth

Sowing

Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	14.98	15.83	15.86	**15.56**
CT-M+C	15.52	15.88	15.85	**15.75**
MT-M	16.88	17.13	17.06	**17.02**
MT-M+C	16.96	17.46	17.40	**17.28**
Mean	**16.08**	**16.58**	**16.54**	
Initial	14.96			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.53	0.159	0.59	0.317
CD (0.05)	NS	NS	NS	NS

Flowering

Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	10.77	11.22	11.20	**11.03**
CT-M+C	11.06	11.38	11.28	**11.24**
MT-M	12.33	12.72	12.53	**12.53**
MT-M+C	12.35	12.82	12.74	**12.64**
Mean	**11.63**	**12.03**	**11.92**	
Initial	10.73			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.454	0.149	0.515	0.298
CD (0.05)	NS	NS	NS	NS

Harvesting

Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	7.56	8.18	7.87	**7.87**
CT-M+C	7.69	8.01	7.88	**7.86**
MT-M	8.29	8.04	8.57	**8.50**
MT-M+C	8.22	9.07	8.87	**8.72**
Mean	**7.94**	**8.48**	**8.30**	
Initial	7.55			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.335	0.164	0.43	0.329
CD (0.05)	NS	NS	NS	NS

Table 4.3c. Effect of tillage and cropping systems on soil moisture content (%) at 10-20 cm depth

Sowing				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	16.07	16.72	16.59	**16.46**
CT-M+C	16.27	16.84	16.67	**16.59**
MT-M	16.74	17.75	17.68	**17.39**
MT-M+C	17.20	17.94	17.72	**17.62**
Mean	**16.57**	**17.31**	**17.17**	
Initial	15.96			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.293	0.269	0.528	0.539
CD (0.05)	NS	NS	NS	NS

Flowering				
Particulars	**NCC**	**HG**	**TORIA**	**Mean**
CT-M	11.62	12.14	11.88	**11.88**
CT-M+C	11.93	12.36	12.18	**12.15**
MT-M	12.51	13.02	12.81	**12.78**
MT-M+C	12.60	13.07	12.91	**12.86**
Mean	**12.17**	**12.65**	**12.45**	
Initial	11.52			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.315	0.214	0.471	0.429
CD (0.05)	NS	NS	NS	NS

Harvesting				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	7.88	8.37	8.20	**8.15**
CT-M+C	7.90	8.35	8.26	**8.17**
MT-M	8.84	9.19	9.07	**9.03**
MT-M+C	9.08	9.35	9.26	**9.23**
Mean	**8.42**	**8.81**	**8.70**	
Initial	7.79			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.295	0.212	0.454	0.424
CD (0.05)	NS	NS	NS	NS

Table 4.4 Effect of tillage and cropping systems on Soil pH (1:2.5)

0-5cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	7.21	7.16	7.16	7.18
CT-M+C	7.19	7.13	7.14	7.16
MT-M	7.09	7.06	7.08	7.08
MT-M+C	7.08	7.01	7.02	7.04
Mean	7.14	7.09	7.10	7.11
Initial	7.34			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.03	0.03	0.05	0.06
CD (0.05)	0.09	NS	NS	NS

5-10cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	7.54	7.51	7.52	7.52
CT-M+C	7.55	7.48	7.49	7.51
MT-M	7.51	7.45	7.46	7.48
MT-M+C	7.51	7.44	7.46	7.47
Mean	7.53	7.47	7.48	7.49
Initial	7.46			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.03	0.03	0.06	0.06
CD (0.05)	NS	NS	NS	NS

10-20cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	7.58	7.57	7.57	7.57
CT-M+C	7.60	7.59	7.60	7.60
MT-M	7.59	7.49	7.49	7.52
MT-M+C	7.52	7.56	7.55	7.54
Mean	7.57	7.56	7.55	7.56
Initial	7.51			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.026	0.013	0.034	0.026
CD (0.05)	NS	NS	NS	NS

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4.2.2 Soil organic carbon (SOC)

Restoration of SOC is influenced most by tillage regimes, cropping systems, soil types and climate. Depth distribution of SOC under different tillage and cropping systems are depicted in table 4.5 and fig 4.2. Practice of MT over the years elevated the SOC contents significantly (+31.8% and +16.8%) over the initial contents of 6.82 and 6.44 g kg $^{-1}$ in the top two layers. The SOC contents under CT showed a declining trend, registering a decrease of 6.8% and 13.2% over the initial for the corresponding layers. The bulid up of SOC in the top two layers under MT was in the tune of 2.86 and 1.93 g kg $^{-1}$ over CT (6.13 and 5.59 g kg $^{-1)}$ after 4th year of CAPS establishment. The SOC pool under cover crops were also enriched in the tune of 11.4% and 10.1% over NCC (6.96 and 6.14 g kg $^{-1)}$ in the layers of 0-5cm and 5-10cm, respectively. The SOC contents of the deeper layer (10-20cm) exhibited no significant variations under different tillage and cropping system combinations.

4.2.3 Aggregate carbon

Enhanced carbon concentrations in water stable aggregates is the main mechanism of SOC protection in reduced tillage. The distribution of water stable macro aggregate carbon across the profile is presented (Table 4.5 and fig 4.3a). Adoption of MT increased the macro aggregate carbon by 12.4% and 7.6% over the initial status (13.9 and 11.5 g kg $^{-1}$) in the depth ranges of 0-5 cm and 5-10 cm, respectively. The concomitant decrease in macro aggregate carbon in the top two layers under CT were 6.5 % and 7.1%. Growing of cover crops could enhance the macro aggregate carbon only in 0-5 cm layer and the gain was in the tune of 12.1% over NCC (13.2 g kg $^{-1)}$. No significant changes in macro aggregate carbon was observed in the deeper layer of 10-20 cm.

The micro aggregate carbon contents across the profile is depicted (Table 4.6a and fig 4.3b) Soils under MT are characterized by higher micro aggregate carbon as compared to the initial status (9.2 g kg $^{-1}$) and the increase was 7.6% for 0-5 cm layer and 12% for 5-10 cm layer. A decreased in micro aggregate carbon (4.0-4.3%) was observed in the top two layers of the soils under CT. Cover cropping could be able to elevate the micro aggregate carbon (+10.3%) over NCC (8.7 g kg $^{-1}$) in surface layer (0-5 cm) only.

Table 4.5 **Soil organic carbon (g kg^{-1}) as influenced by tillage and cropping systems**

0-5cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	5.16	6.23	5.81	**5.74**
CT-M+C	6.33	6.76	6.48	**6.52**
MT-M	7.81	9.24	8.56	**8.53**
MT-M+C	8.55	10.32	9.45	**9.44**
Mean	**6.96**	**8.14**	**7.58**	
Initial	6.82			
	M	**S**	**M within S**	**S within M**
SEm (±)	0.115	0.097	0.195	0.194
CD(0.05)	0.40	0.28	NS	NS

5-10cm layer				
Particulars	**NCC**	**H**	**T**	**MEAN**
CT-M	4.91	5.56	5.43	**5.30**
CT-M+C	5.65	6.06	5.91	**5.87**
MT-M	6.75	7.57	7.26	**7.19**
MT-M+C	7.24	8.25	8.03	**7.84**
Mean	**6.14**	**6.86**	**6.66**	
Initial	6.44			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.127	0.096	0.202	0.192
CD (0.05)	0.44	0.28	NS	NS

10-20cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	5.03	5.21	5.10	**5.11**
CT-M+C	5.16	5.26	5.17	**5.20**
MT-M	4.76	4.93	4.89	**4.86**
MT-M+C	4.86	5.06	5.03	**4.98**
Mean	**4.95**	**5.11**	**5.05**	
Initial	4.72			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.0841	0.05	0.117	0.1
CD (0.05)	NS	NS	NS	NS

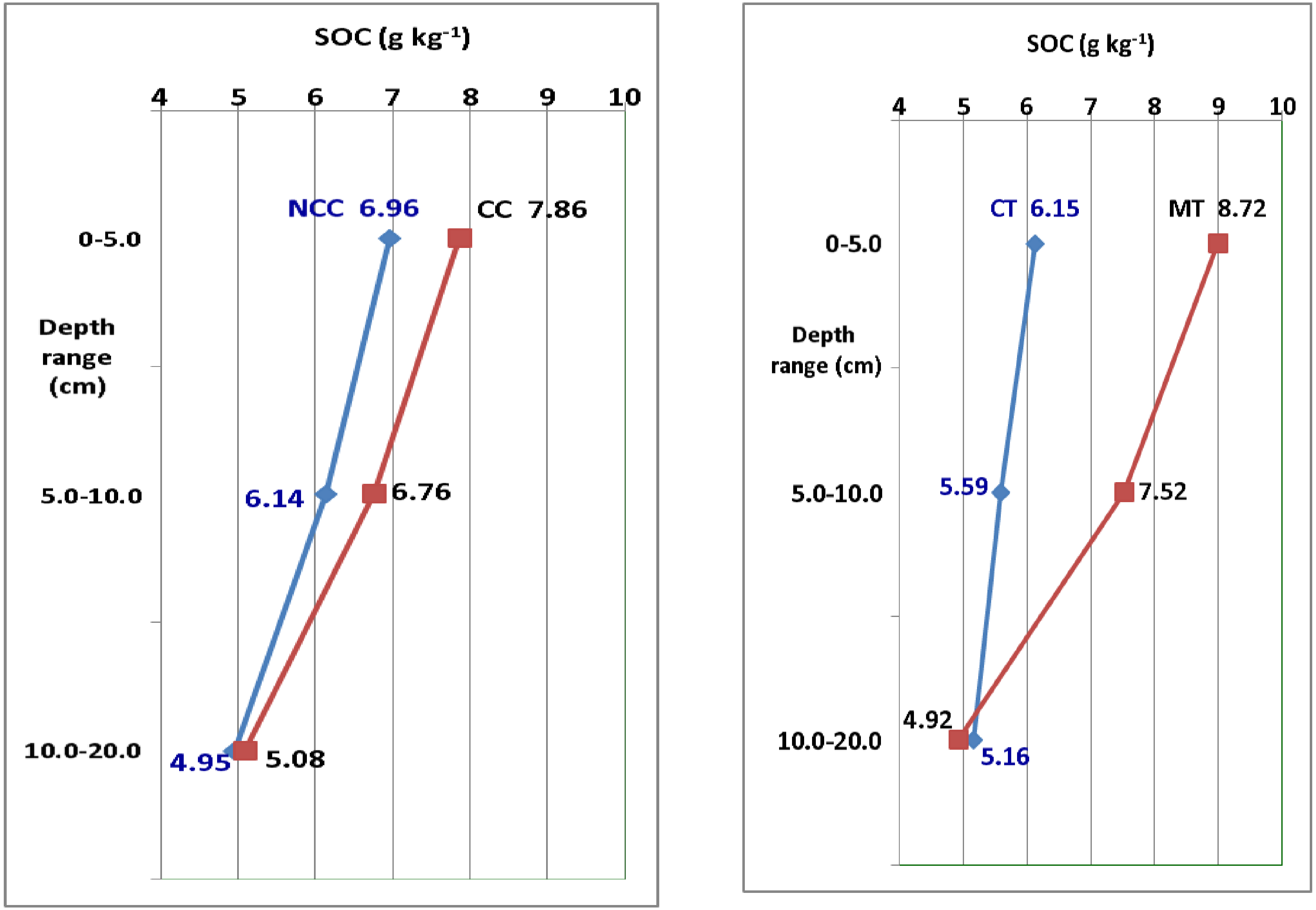


Fig. 4.2 Depth wise showing the distribution of SOC under different tillage systems

Table 4.6a. Effect of tillage and cropping systems on water stable macro-aggregate (>0.25mm) carbon (g kg^{-1})

0-5cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	11.40	13.20	12.43	**12.34**
CT-M+C	12.80	14.40	13.70	**13.63**
MT-M	13.80	19.20	15.60	**15.20**
MT-M+C	14.73	16.90	16.13	**15.92**
Mean	**13.18**	**15.18**	**14.47**	
Initial	13.88			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.375	0.232	0.533	0.464
CD (0.05)	1.30	0.68	NS	NS

5-10cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	10.27	10.70	10.60	**10.52**
CT-M+C	10.37	11.03	10.97	**10.79**
MT-M	12.00	12.50	12.43	**12.31**
MT-M+C	12.17	12.63	12.50	**12.43**
Mean	**11.20**	**11.72**	**11.63**	
Initial	11.52			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.45	0.163	0.528	0.326
CD (0.05)	1.58	NS	NS	NS

10-20cm layer				
Particulars	**NCC**	**HG**	**TORIA**	**Mean**
CT-M	10.77	11.20	11.00	**10.99**
CT-M+C	11.07	11.50	11.27	**11.28**
MT-M	10.53	10.80	10.60	**10.64**
MT-M+C	10.77	10.87	10.80	**10.81**
Mean	**10.78**	**11.09**	**10.92**	
Initial	10.94			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.284	0.228	0.469	0.457
CD (0.05)	NS	NS	NS	NS

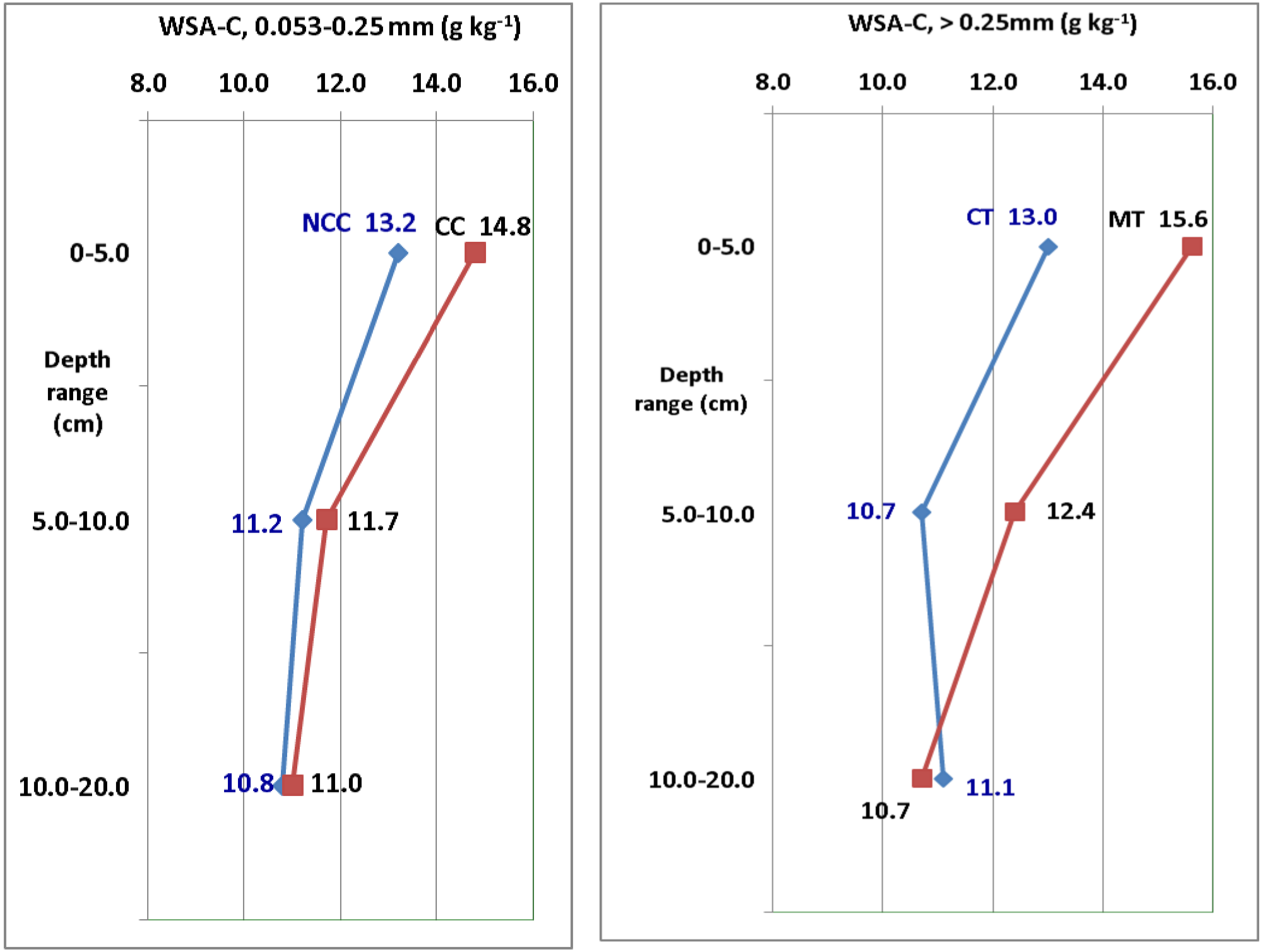


Fig. 4.3a Depthwise graph distribution of WSA-C (micro-aggregate) under different tillage systems

Table 4.6b. Effect of tillage and cropping systems on water stable micro-aggregate (0.053-0.25mm) carbon (g kg-1)

0-5cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	7.90	9.20	8.60	**8.57**
CT-M+C	8.43	9.50	9.00	**8.98**
MT-M	9.20	10.27	9.60	**9.69**
MT-M+C	9.40	10.80	10.20	**10.13**
Mean	**8.73**	**9.94**	**9.35**	
Initial	9.22			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.32	0.173	0.424	0.346
CD (0.05)	1.11	0.51	NS	NS

5-10cm layer				
Particulars	**NCC**	**H**	**T**	**MEAN**
CT-M	7.73	8.00	7.87	**7.87**
CT-M+C	7.80	8.20	8.13	**8.04**
MT-M	8.93	9.37	9.23	**9.18**
MT-M+C	9.07	9.77	9.60	**9.48**
Mean	**8.38**	**8.83**	**8.71**	
Initial	8.33			
	M	**S**	**M within S**	**S within**
SEm(±)	0.36	0.134	1.422	0.269
CD (0.05)	1.25	NS	NS	NS

10-20cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	7.70	7.90	7.83	**7.81**
CT-M+C	7.77	8.10	8.00	**7.96**
MT-M	6.70	7.00	6.90	**6.87**
MT-M+C	6.90	7.13	7.00	**7.01**
Mean	**7.27**	**7.53**	**7.43**	
Initial	7.48			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.227	0.192	0.387	0.384
CD (0.05)	0.78	NS	NS	NS

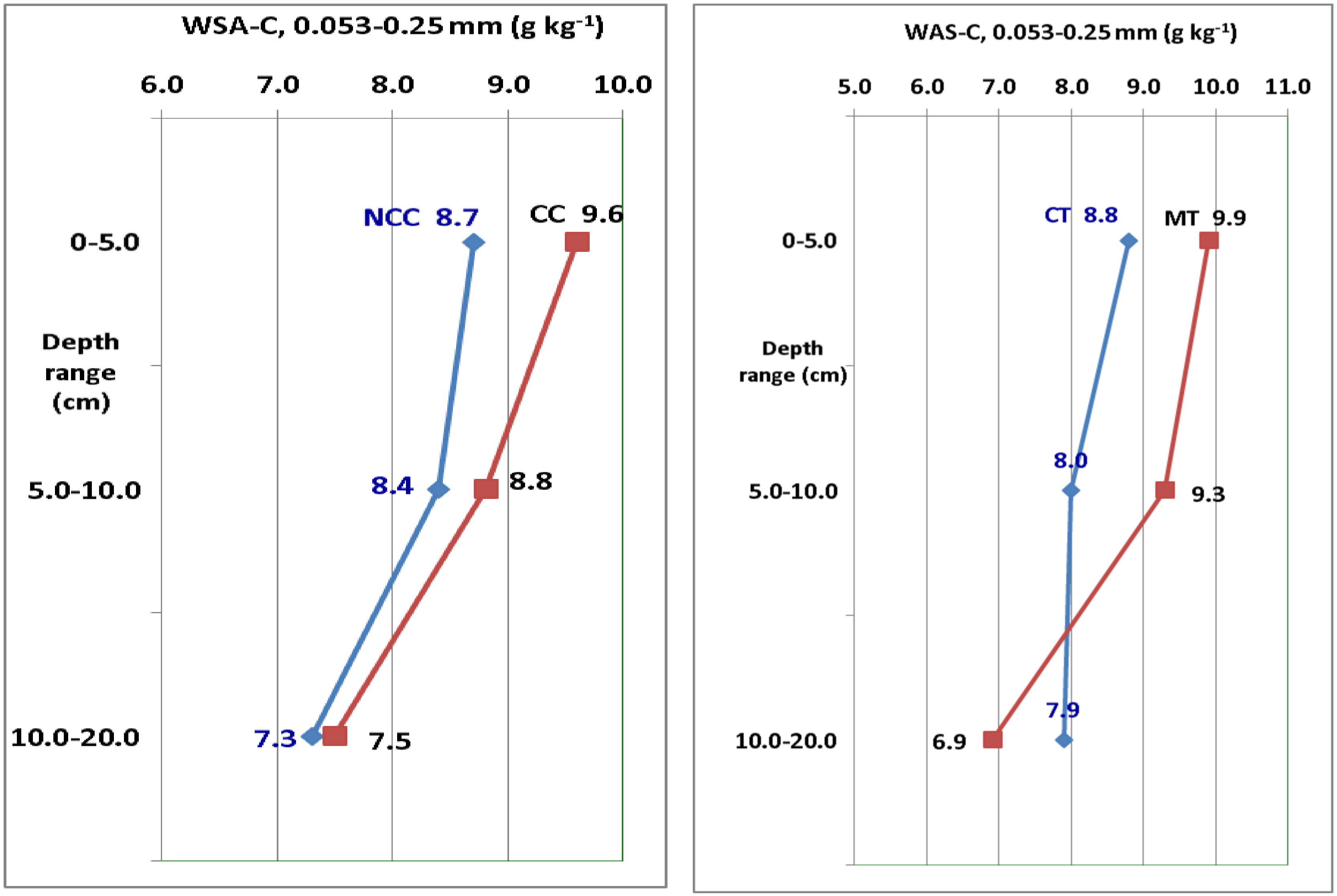


Fig. 4.3b. **Depth wise graph showing the distribution of WSA-C (micro-aggregate) under different tillage systems**

4.2.4 Soil total nitrogen (STN)

Within a short time, reduced tillage in association with residue inputs imparted a significant variation in soil total nitrogen (STN) across the profile date pertaining to the distribution of STN are depicted in table 4.7and fig. 4.4. In the top two layers, MT elevated the STN to the tune of 19.4% and 11.1% over the initial status of 0.72 and 0.63 g kg^{-1} respectively. The concomitant decreased in the soils under CT were by 12.5% and 11.1% .cover cropping with horse gram and toria mustard also enhanced the STN by 10% and 8.3% as compared to NCC (0.7and 0.6 g kg^{-1}). Soils under CT, however, exhibited significantly higher STN (+13.3%) over MT (0.45 g kg^{-1}). Effect of tillage and cropping systems on soil total nitrogen (g kg-1).

4.3 Soil microbial attributes

4.3.1 Microbial population

4.3.1.1 Bacteria

The soils of the study area exhibited an elevation in bacterial population over the initial status (Table 4.8a) irrespective of different layers. Soils under MT and CT registered an increase of 71.7% and 26.5%, respectively. Over the initial population of 17.6 x 10^{6}cfu g^{-1} in 0-5cm layer. The corresponding increase in 5-10cm layer were 79.8% and 38.7%. Accumulation of litter inputs in MT soils enhanced the bacterial abundance significantly to the tune of 35.7% and 29.6% over CT soils in the top two layers 0-5cm and 5-10cm (Table 4.8b and 4.8c). Cover cropping also enhanced the bacterial population by 22.4% and 20% over NCC (22.8 and 20.6x10^{6}cfu g^{-1}) in the top two layers.

4.3.1.2 Fungi

Variable contents of SOC among treatment influenced the population of fungi in different soil layers (Table 4.8b). The MT soils exhibited the maximum fungal population and the increase was in the tune of 42% and 35.2% over the initial status (11.8 and 9.4x10^{4} cfu g^{-1}) in the layers of 0-5cm and 5-10cm, respectively.

Table 4.7 Effect of tillage and cropping systems on Soil total nitrogen (g kg^{-1})

0-5cm layer				
Particulars	**NCC**	**HG**	**TORIA**	**Mean**
CT-M	0.56	0.64	0.60	**0.60**
CT-M+C	0.65	0.68	0.66	**0.66**
MT-M	0.77	0.88	0.84	**0.83**
MT-M+C	0.83	0.95	0.89	**0.89**
Mean	0.70	0.79	0.75	
Initial	0.72			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.021	0.011	0.028	0.023
CD (0.05)	0.07	0.03	NS	NS

5-10cm layer				
Particulars	**NCC**	**HG**	**TORIA**	**Mean**
CT-M	0.51	0.56	0.55	**0.54**
CT-M+C	0.57	0.60	0.59	**0.59**
MT-M	0.66	0.71	0.69	**0.69**
MT-M+C	0.68	0.75	0.73	**0.72**
Mean	**0.60**	**0.65**	**0.64**	
Initial	0.63			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.020	0.009	0.025	0.018
CD (0.05)	0.07	0.03	NS	NS

10-20cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	0.49	0.51	0.50	**0.50**
CT-M+C	0.51	0.53	0.52	**0.52**
MT-M	0.45	0.46	0.45	**0.45**
MT-M+C	0.45	0.45	0.45	**0.45**
Mean	**0.47**	**0.48**	**0.48**	
Initial	0.48			
	M	**S**	**M within S**	**S within M**
SEm(±)	0013	0.009	0.02	0.02
CD (0.05)	0.05	NS	NS	NS

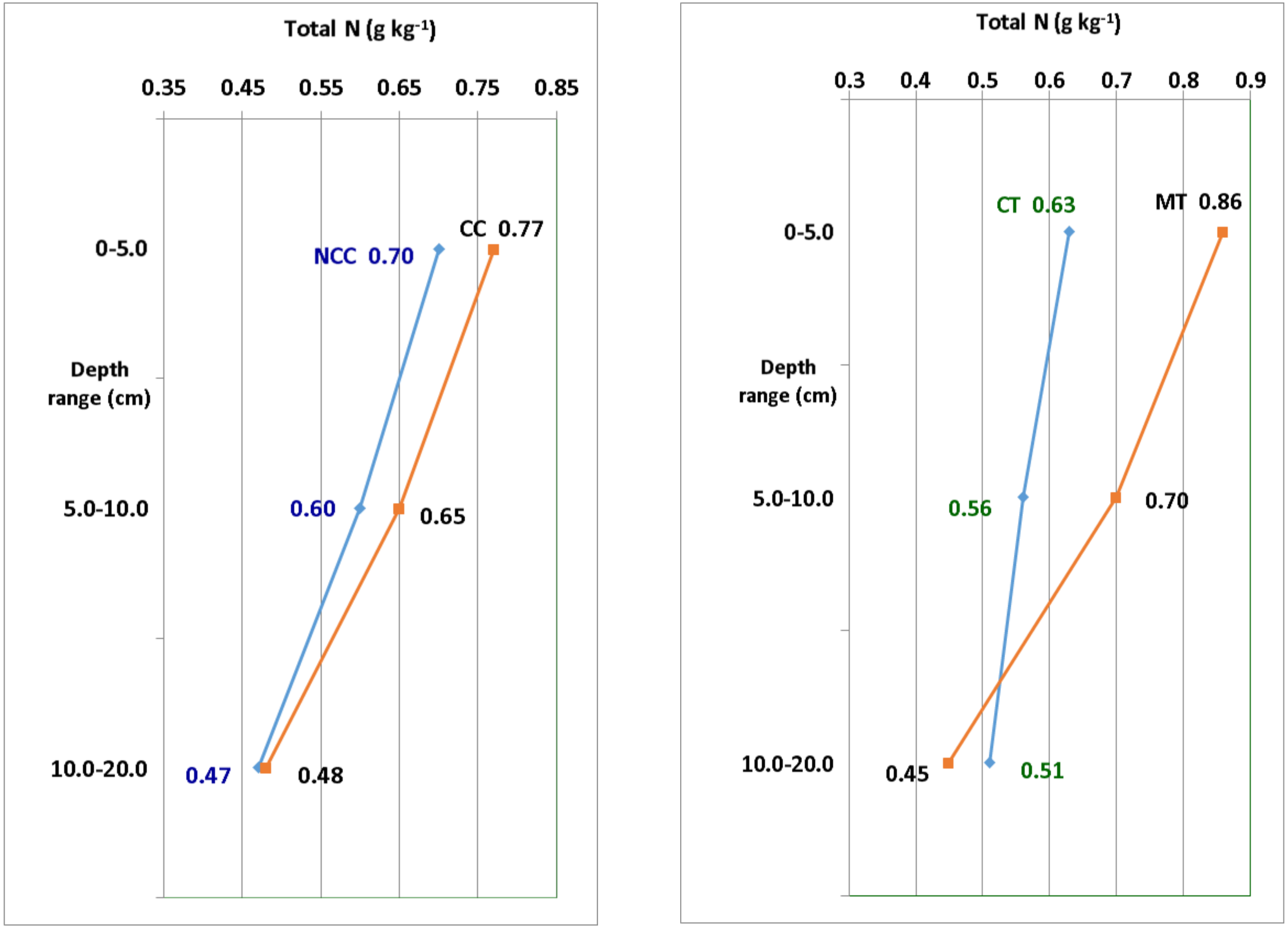


Fig . 4.4 Depth wise graph showing the distribution of Total N (g kg^{-1}) under different tillage systems

Table 4.8a **Bacterial population (×10^6cfu g^{-1}) as influenced by tillage and cropping systems**

0-5cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	17.57	21.73	21.17	**20.16**
CT-M+C	22.07	26.63	24.17	**24.29**
MT-M	24.10	31.00	30.07	**28.39**
MT-M+C	27.43	35.13	33.20	**31.92**
Mean	**22.79**	**28.63**	**27.15**	
Initial	17.56			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.512	0.436	0.876	0.871
CD (0.05)	1.77	1.27	NS	NS

5-10cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	15.10	20.10	19.00	**18.07**
CT-M+C	20.93	23.70	23.20	**22.61**
MT-M	22.47	26.27	24.93	**24.56**
MT-M+C	23.90	30.90	29.70	**28.17**
Mean	**20.60**	**25.24**	**24.21**	
Initial	14.66			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.679	0.679	1.301	1.358
CD (0.05)	2.35	1.98	NS	NS

10-20cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	14.40	15.73	15.33	**15.16**
CT-M+C	14.93	16.70	16.63	**16.09**
MT-M	15.40	16.60	16.23	**16.08**
MT-M+C	16.50	16.93	16.70	**16.71**
Mean	**15.31**	**16.49**	**16.23**	
Initial	12.94			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.297	0.477	0.833	0.953
CD (0.05)	NS	NS	NS	NS

The organic matter enriched MT soils registered significantly higher fungal abundance over CT soils in the top two layers (+22% and + 19.7%). The fungal population were also higher in soils under CC (+12.2% and 13.8%) as compared to NCC soils (13.9 and 10.74 X 10^4 cfu g^{-1}) in the top two layers. In the deeper layers (10-20 cm), no noticeable population changes were observed among treatments.

4.3.1.3 Actinomycetes

The actinomycetes population of soils across the profile is presented (Table 4.8c) Build up of organic matter in soils under MT, elevated the actinomycetes abundance by 39.6% and 31.5% over the initial status (12.56 and 10.77x10^6cfu g^{-1}) in 0-5 cm and 5-10cm layers ,respectively. MT soils of these two layers also registered significantly higher actinomycetes population (+19.9% and 18.4%) over CT soils. Cover cropping also enhanced the actinomycetes population in the tune of 12.4% and 8.6% over NCC (14.86 and 12.35x10^6 cfu g^{-1}) in the top two layers .The soils in 10-20 cm layers did not exhibit any significant variation in actinomyctes population.

4.3.2 Microbial biomass carbon (MBC)

Tillage reduction and residue retention elevates the microbial biomass carbon much more rapidly and the increase is much more conspicuous in top few cms of the surface layer. The MBC of soils across the depth are presented in table 4.9 and fig.4.5. Conversion to MT systems over the years enhanced the MBC of soils by 123.6% and 72.4% over the initial status of 82.3 and 78.6 µg C g^{-1} in the depth ranges of 0-5cm and 5-10cm, respectively and the corresponding increase over CT (99.2 and 89.5 µg C g^{-1}) were 85.5% and 51.4%. Cover cropping also enhanced the MBC status of the soils by 20.6% and 14.3% as compared to NCC (124.5 and 102.7 µg C g^{-1}) in the top two layers. A decreasing trend in soil MBC was observed from surface to down the depths and no remarkable changes could be observed in the deeper layers (10-20 cm).

Table 4.8b **Population of fungi (× 10^4 cfu g^{-1}) as influenced by tillage and cropping systems**

0-5cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	11.73	14.13	13.70	**13.19**
CT-M+C	12.80	15.33	14.53	**14.22**
MT-M	15.17	17.40	16.50	**16.36**
MT-M+C	15.83	18.07	17.27	**17.06**
Mean	**13.88**	**16.23**	**15.50**	
Initial	11.77			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.320	0.367	0.681	0.736
CD (0.05)	1.11	1.07	NS	NS

5-10cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	9.67	10.77	10.50	**10.31**
CT-M+C	10.40	11.40	11.27	**11.02**
MT-M	11.00	13.00	12.60	**12.20**
MT-M+C	11.87	14.30	13.83	**13.33**
Mean	**10.73**	**12.37**	**12.05**	
Initial	9.44			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.380	0.183	0.484	0.366
CD (0.05)	1.32	0.54	NS	NS

10-20cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	8.73	8.83	8.79	**8.79**
CT-M+C	9.13	9.73	9.60	**9.49**
MT-M	9.27	9.73	9.53	**9.51**
MT-M+C	9.57	10.47	10.40	**10.14**
Mean	**9.18**	**9.69**	**9.58**	
Initial	8.37			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.309	0.231	0.487	0.462
CD (0.05)	NS	NS	NS	NS

Table 4.8c Population of actinomycetes (× 10^6cfu g^{-1}) as influenced by tillage and cropping systems

0-5cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	12.77	15.20	14.23	**14.23**
CT-M+C	13.87	15.77	15.43	**15.02**
MT-M	16.23	17.93	17.70	**17.29**
MT-M+C	16.57	18.63	18.17	**17.79**
Mean	**14.86**	**16.88**	**16.51**	
Initial	12.56			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.306	0.310	0.592	0.620
CD (0.05)	1.06	0.91	NS	NS

5-10cm layer				
Particulars	**NCC**	**HG**	**TORIA**	**Mean**
CT-M	10.83	12.17	11.90	**11.63**
CT-M+C	11.53	12.77	12.53	**12.28**
MT-M	13.27	14.27	14.03	**13.86**
MT-M+C	13.77	14.97	14.67	**14.47**
Mean	**12.35**	**13.54**	**13.28**	
Initial	10.77			
	I	**T**	**I within T**	**T within I**
SEm(±)	0.519	0.217	0.628	0.434
CD (0.05)	1.80	0.63	NS	NS

10-20cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	9.73	10.07	9.83	**9.88**
CT-M+C	10.20	10.60	10.37	**10.39**
MT-M	10.10	10.90	10.83	**10.61**
MT-M+C	10.67	11.30	11.03	**11.00**
Mean	**10.18**	**10.72**	**10.52**	
Initial	9.43			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.351	0.231	0.516	0.463
CD (0.05)	NS	NS	NS	NS

Table 4.9 Impact of tillage and cropping systems on soil MBC (μg C g^{-1})

0-5cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	78.43	101.47	94.47	**91.46**
CT-M+C	98.57	114.50	107.90	**106.99**
MT-M	153.23	185.10	171.10	**169.81**
MT-M+C	167.57	225.63	201.23	**198.14**
Mean	**124.45**	**156.68**	**143.68**	
Initial	82.3			
	M	**S**	**M within S**	**S within M**
SEm(±)	3.118	3.122	5.976	6.244
CD (0.05)	10.79	9.11	NS	NS

5-10cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	76.90	90.90	88.23	**85.34**
CT-M+C	89.90	96.43	94.43	**93.59**
MT-M	116.90	138.23	131.23	**128.79**
MT-M+C	127.23	153.43	145.90	**142.19**
Mean	**102.73**	**119.75**	**114.95**	
Initial	78.6			
	M	**S**	**M within S**	**S within M**
SEm(±)	3.041	1.497	3.901	2.993
CD (0.05)	10.52	4.37	NS	NS

10-20cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	79.2	82.2	81.1	**78.0**
CT-M+C	82.1	84.1	81.1	**80.9**
MT-M	73.6	75.8	76.8	**72.5**
MT-M+C	75.1	82.3	80.6	**76.5**
Mean	**77.5**	**81.1**	**79.9**	
Initial	74.7			
	M	**S**	**M within S**	**S within M**
SEm(±)	1.876	1.254	2.777	2.509
CD (0.05)	NS	NS	NS	NS

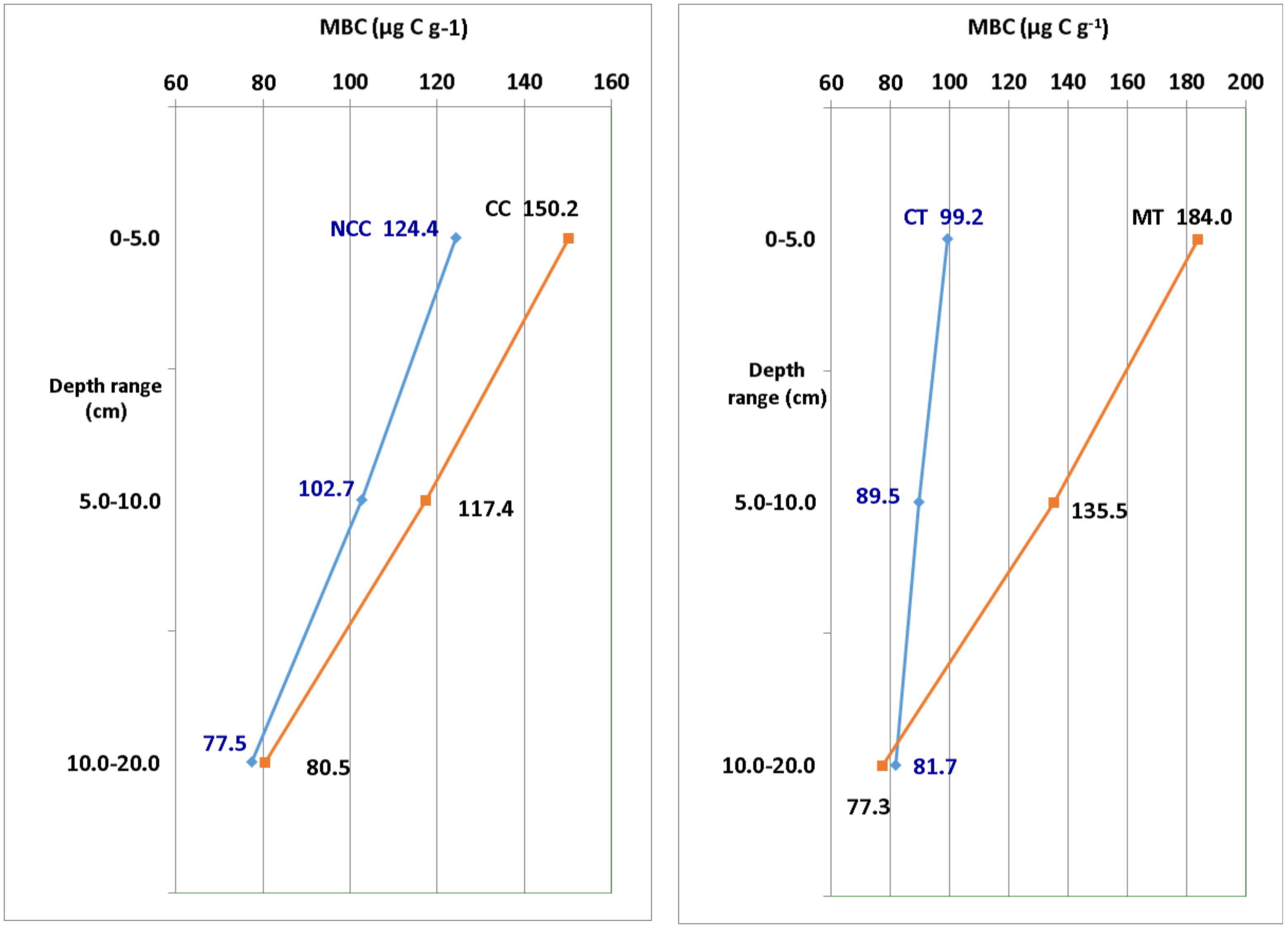


Fig. 4.5 Depth wise graph showing the distribution of MBC (µg C g^{-1}) under different tillage systems

4.3.3 Microbial biomass nitrogen

Microbial biomass nitrogen (MBN) very often responds to the alteration of soil condition through tillage and cropping system. The profile distribution of MBN are presented in Table 4.10 and fig. 4.6 Practice of MT over the years, significantly increased the MBN of top two soil layers over initial contents and the gain was in the tune of +58.5% and 53.2% for 0-5cm and 5-10cm depth ranges, respectively over initial (21.1 and 17.6 µg N g^{-1}). The decrease of MBN for the corresponding layers under CT were 6.8% and 2.6%. Soils under cover crops exhibited an increase in MBN by 28.1% and 20.1% over NCC (22.4 and 19.4 µg N g^{-1}) in the top two layers. A reversal trend in the status of MBN was observed in 10-20cm layer where the soils under CT registered a gain of MBN by +9.8% over initial (14.3 µg N g^{-1}) and +18% over MT (13.3 µg N g^{1}).

4.4 C/N ratio

The C/N ratio is an indicator of mineralization of organic matter, nitrogen availability in soil and immobilization. The C/N ratio under different tillage and cropping systems are depicted in Table 4.11 and fig. 4.7 The soils under MT registered higher C/N ratio in all the layers with value of 10.43, 10.68 and 10.87 for 0-5 cm, 5-10 cm and 10-20 cm, respectively over CT (9.77,9.11 and 10.11). Similarly, the soils under CC registered higher C/N ratio of 10.17, 10.39 and 10.54 for the layers from surface to downwards as compared to the soils under NCC (9.97, 10.1 and 10.39).

4.5 SOC stratification ratio

The degree of stratification of SOC depends upon pools with soil depth , expressed as ratio, indicate the function of soil ecosystem . In this study, the SOC stratification ratios were calculated from SOC stocks at 0-5 cm divided by these at 10-20 cm, which are depicted in table 4.12 and fig. 4.8. Practice of MT four years in succession elevated the SOC stratification ratio to 1.82 as compared to the soils under CT(1.19).The SOC stratification ratio is also higher in soils under CC(1.55) than those under NCC (1.76).

Table 4.10 Impact of tillage and cropping systems on soil MBN (μ g N g^{-1})

0-5cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	15.73	19.86	18.28	**17.96**
CT-M+C	18.88	23.93	21.69	**21.50**
MT-M	25.73	34.91	32.88	**31.17**
MT-M+C	29.31	40.66	37.30	**35.76**
Mean	**22.41**	**29.84**	**27.54**	26.60
Initial	21.13			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.68	0.61	0.20	0.22
CD (0.05)	2.34	1.79	NS	NS

5-10cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	14.09	17.08	16.29	**15.82**
CT-M+C	16.33	19.73	18.89	**18.32**
MT-M	21.64	27.33	26.10	**25.02**
MT-M+C	25.50	31.01	29.70	**28.73**
Mean	**19.39**	**23.79**	**22.74**	21.97
Initial	17.6			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.71	0.28	0.84	0.55
CD (0.05)	2.45	0.81	NS	NS

10-20cm layer				
Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	14.30	15.70	14.98	**14.99**
CT-M+C	15.88	16.89	16.30	**16.35**
MT-M	12.99	13.30	13.12	**13.14**
MT-M+C	13.22	13.60	13.43	**13.42**
Mean	**14.10**	**14.87**	**14.46**	
Initial	0.71			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.42	0.25	0.58	0.49
CD (0.05)	1.44	NS	NS	NS

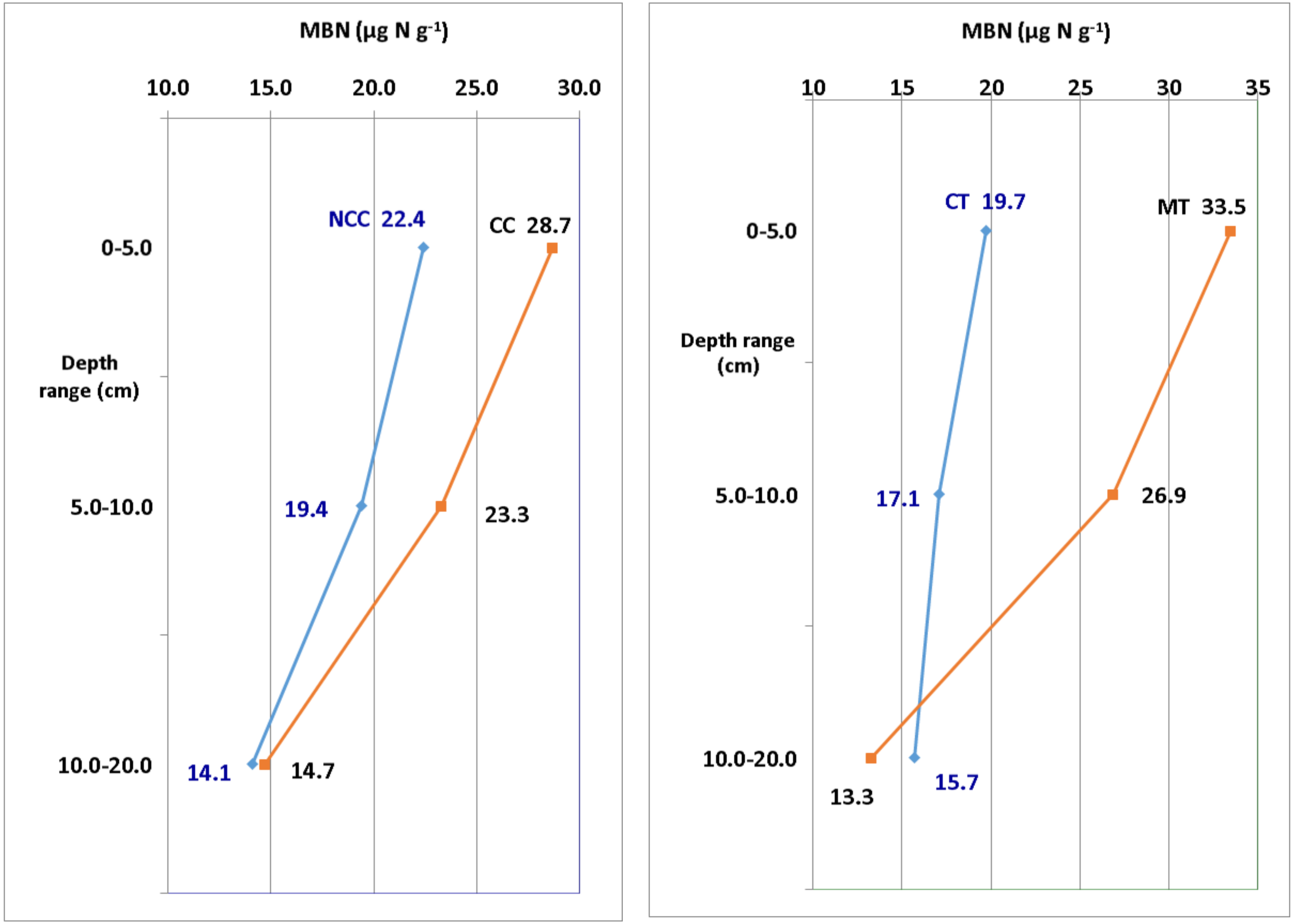


Fig. 4.6 Depth wise graph showing the distribution of MBN (µg N g^{-1}) under different tillage systems

Table 4.11effects of tillage and cropping systems of C/N ratio

MAIN PLOT			
Particulars	**NCC**	**H**	**T**
CT-M	9.72	9.81	10.23
CT-M+C	9.83	10.01	9.99
MT-M	10.28	10.47	10.65
MT-M+C	10.59	10.88	11.08
SUB-PLOT			
NCC	9.97	10.10	10.39
H	10.26	10.43	10.52
T	10.08	10.35	10.55

Table 4.12 SOC Stratification ratio as influenced by tillage and cropping systems

Particulars	NCC	H	T	Mean
CT-M	1.03	1.20	1.14	**1.12**
CT-M+C	1.23	1.29	1.25	**1.26**
MT-M	1.64	1.87	1.75	**1.75**
MT-M+C	1.76	2.04	1.88	**1.89**
Mean	**1.42**	**1.60**	**1.51**	

4.6 MBC/SOC ratio

The ratio of MBC/ SOC (expressed as %) is very often used as quality soil indicator for assessing soil health. The MBC/SOC ratio from the soil across the depth are presented (Table 4.13 and Fig. 4.8). The ratio was observed higher in the soils under MT with a value of 2.04% and 1.8% in the top two layers, where as in soils under CT, the ratio was 1.62% and 1.6% for the corresponding layers. The MBC/SOC ratio exhibited a declining trend down the depth and almost remained unchanged in the deeper layers. Soils under cover crops also registered higher MBC/SOC ratio of 1.87 and 1.72% as compared to soils under NCC (1.75 and 1.66%) in the layers of 0-5 cm and 5-10 cm, respectively.

Table 4.13 MBC/SOC ratio (%) as influenced by tillage and cropping systems

Main plot			
Particulars	**NCC**	**H**	**T**
CT-M	1.59	1.61	1.58
CT-M+C	1.64	1.59	1.59
MT-M	1.99	1.79	1.55
MT-M+C	2.09	1.81	1.59
Sub-plot			
NCC	1.75	1.66	1.57
H	1.88	1.73	1.59
T	1.86	1.72	1.58

4.7 MBN/STN ratio (%)

The MBN/STN ratio (%) across the depth is often used to indicate soil health under altering land management practices. The MBN/STN ratio in different depth ranges are presented in table 4.14 and fig. 4.9. The ratio is higher in soils under MT with value of 3.87 for 0-5 cm layer and 3.81 for 5-10 cm layer. In deeper layer (10-20 cm), however soil under CT registered higher ratio (3.07) as compared to MT (2.94). Similarly soils under cover crops exhibited higher MBN/STN ratio of 3.66 and 3.54 in the top two layers as compared to NCC (3.15 and 3.16).

Table 4.14 MBN/STN ratio (%) as influenced by tillage and cropping systems

Main plot			
Particulars	**NCC**	**H**	**T**
CT-M	2.99	2.92	3.00
CT-M+C	3.24	3.11	3.15
MT-M	3.74	3.63	2.90
MT-M+C	4.00	3.98	2.98
Sub-plot			
NCC	1.75	1.66	2.97
H	1.88	1.73	3.05
T	1.86	1.72	3.01

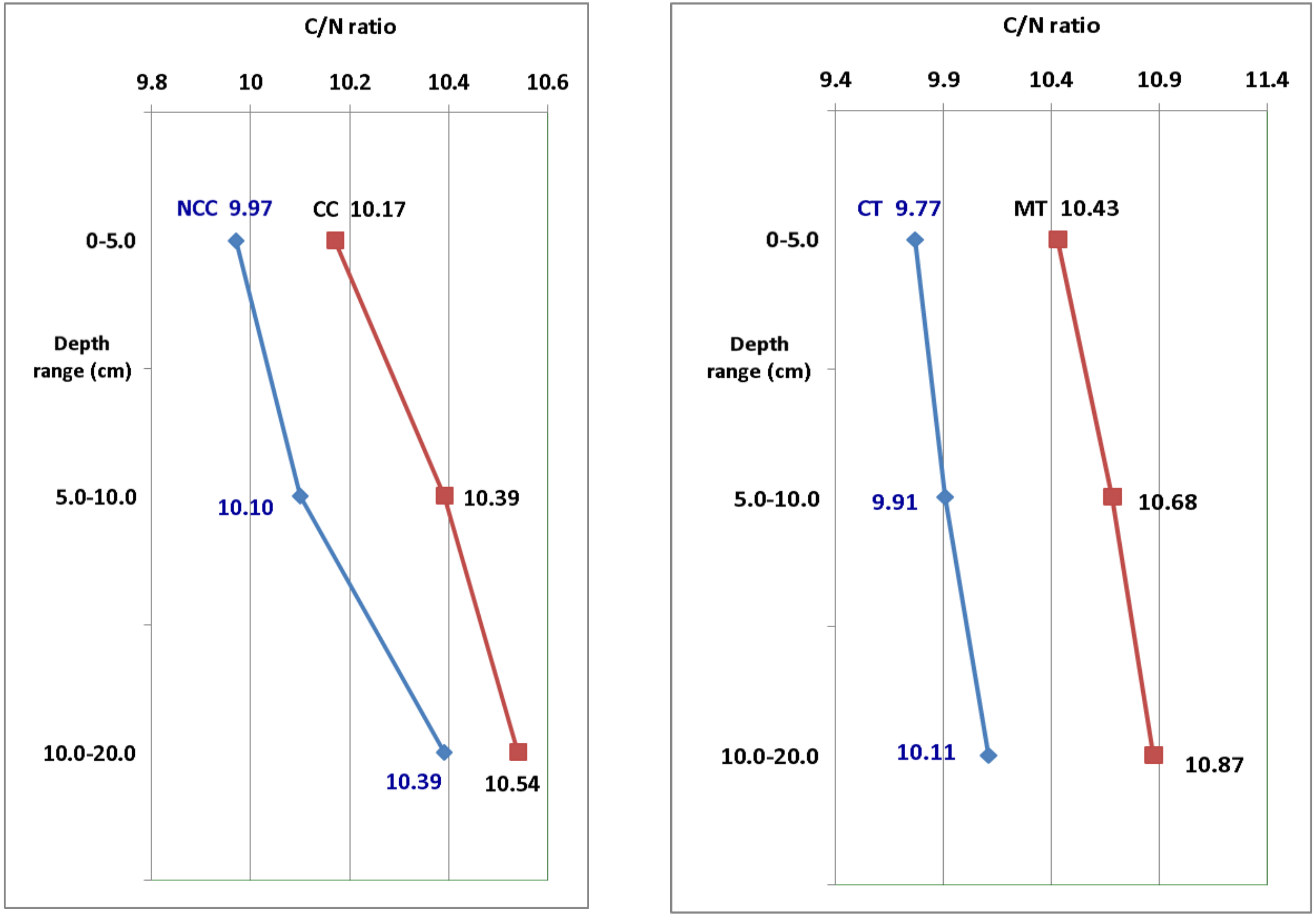


Fig. 4.7. Depth wise graph showing the distribution of C/N under different tillage systems

4.8 Maize equivalent yield (MEY)

The maize equivalent yield (MEY) of different tillage and cropping systems treatments is presented in table 4.15. Growing of maize + cowpea intercrop registered the significantly higher MEY with values of 109.1 q/ha^{-1} in MT and 106.6 q/ha^{-1} in CT as compared to sole maize for the corresponding tillage methods (61.9 and 63.9 q/ha). Cropping systems (maize sole or Maize + cowpea intercrop) within different tillage systems could not influence the MEY significantly. Inclusion of horse gram (H) and toria mustard (T) as cover crops enhanced the MEY significantly (+19.6% and 30.5%) over NCC (72.88 q/ha$^{-1)}$. The maximum MEY of 118.14 q/ha^{-1} was obtained from MT-M+C-T combination.

Table 4.15 Effect of tillage and cropping systems on maize equivalent yield (qha^{1})

Particulars	**NCC**	**H**	**T**	**Mean**
CT-M	50.11	68.69	73.05	63.95
CT-M+C	92.82	109.70	117.25	106.59
MT-M	49.15	64.41	72.14	61.90
MT-M+C	99.42	109.78	118.14	109.11
Mean	72.88	88.14	95.14	85.39
	M	**S**	**M within S**	**S within M**
SEm(±)	1.89	0.88	2.3	1.8
CD (0.05)	6.19	2.55	NS	NS

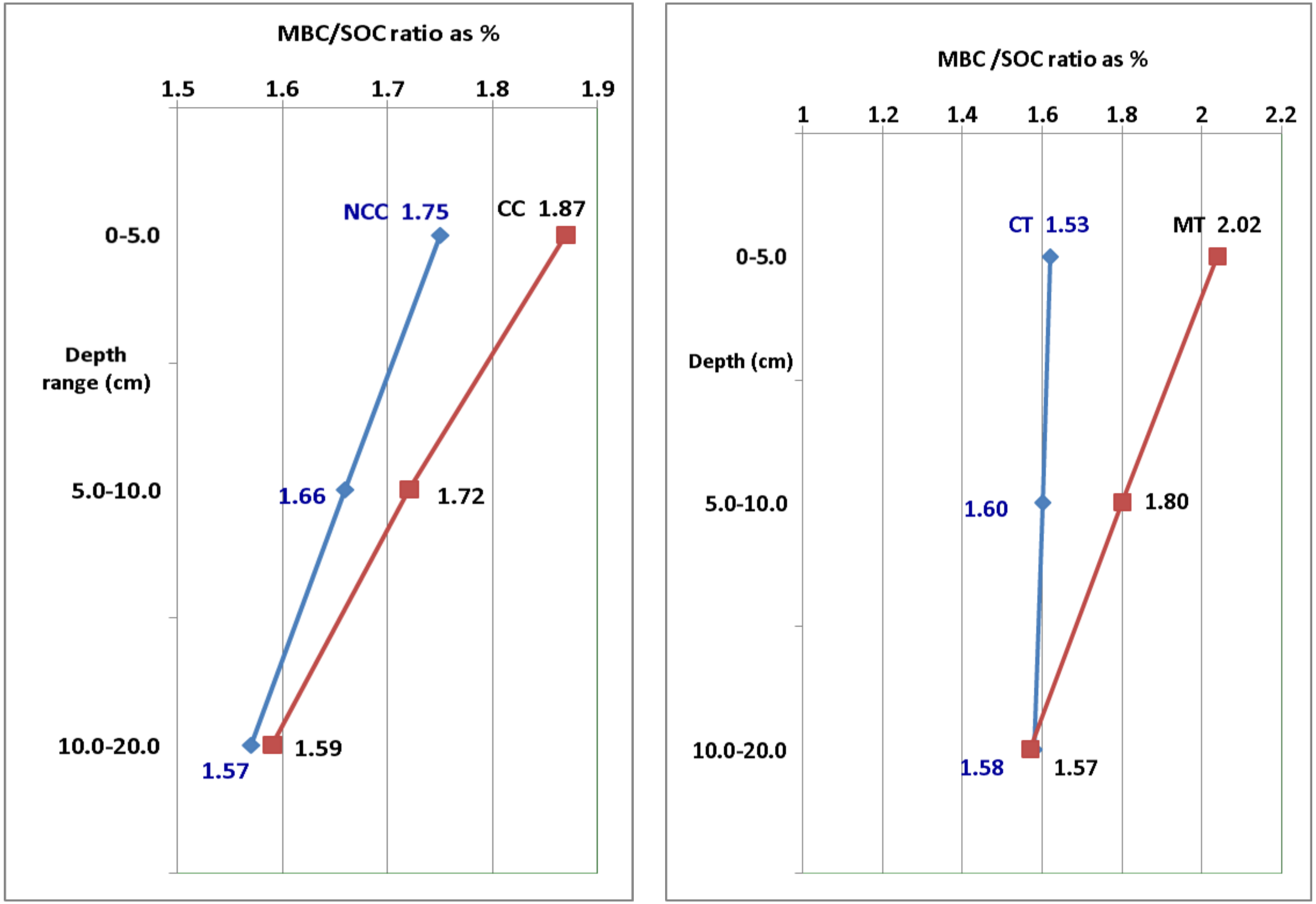


Fig. 4.8. Depth wise graph showing the distribution of MBC/SOC ratio under different tillage systems

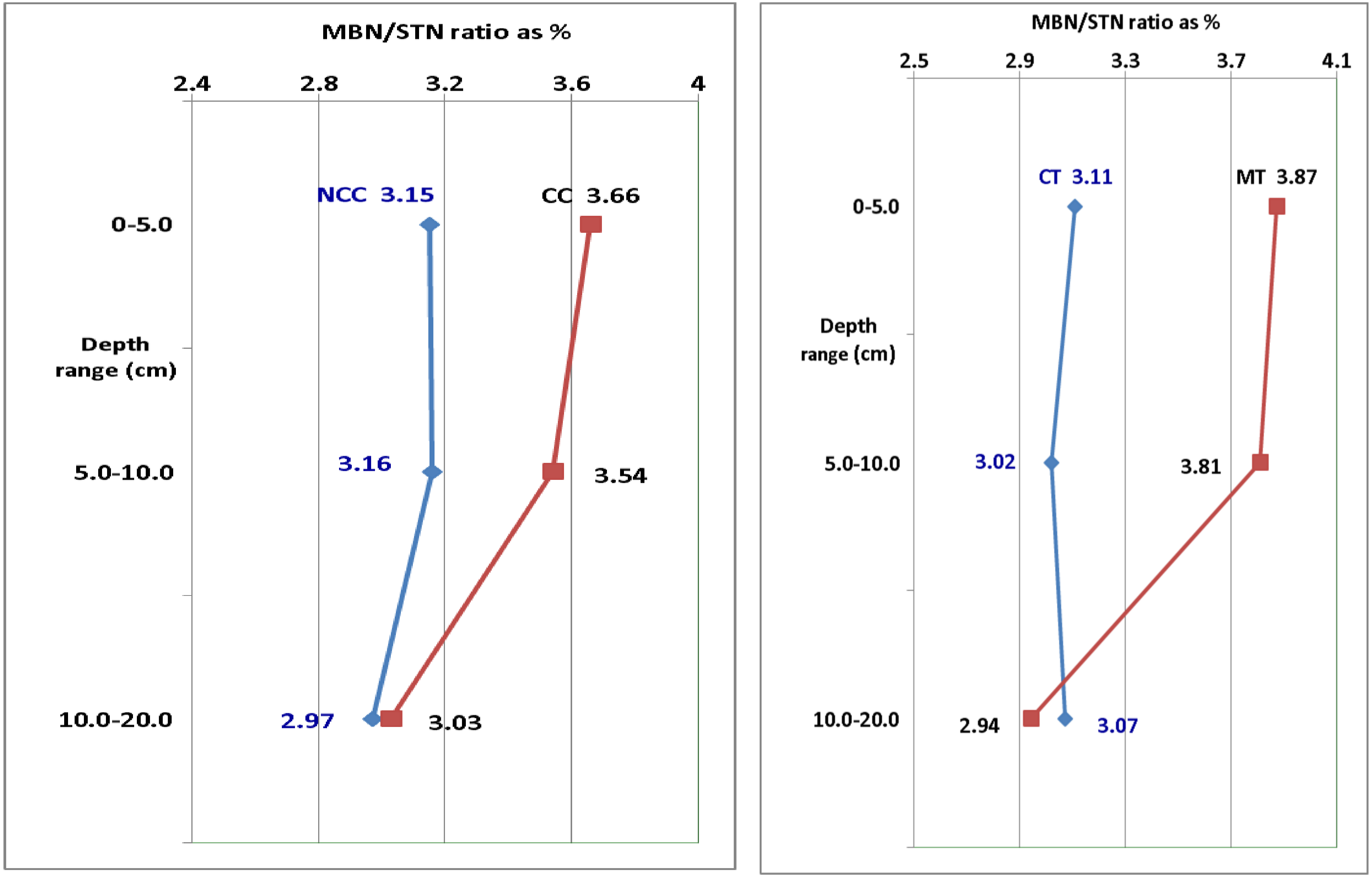


Fig. 4.9. Depth wise graph showing the distribution of MBN/STN ratio under different tillage systems

Fig.4. 9 Sole Maize and Maize + Cowpea intercrop in the wet (*Kharif*) season

Fig. 4.10 Treatments of NCC, Horse gram and Toria mustard in dry (*Rabi*)season

DISCUSSION

The positive effect of Conservation Agriculture Production System (CAPS) on soil health is well-established world over. Tillage reduction in association with residue retention under CAPS has influenced some promising and interesting changes in different soil attributes that have been discussed below.

5.1 Soil Bulk Density

The remarkable decrease of soil BD in MT with cropping systems in the top two layers of 0-5 cm and 5-10 cm is likely to be a reflection of dramatic increase in SOM contents due to continuous deposition of litter inputs on the soil surface over the years. The results are in agreement with Arvidson (1998) and Fengyan *et al.*, (2011). The reduction in BD in MT soils is often associated with increased aggregation and permanent pore development by considerable improvement in SOM and biotic activity by residue incorporation (Jemai *et al.*, 2013). The increased BD in the top layers under CT soils may be related to the loss of finer particles induced by water erosion and low SOM leading to less aggregation (Lafond *et al.*, 2011). The BD of deeper layers (10-20 cm) remained unaffected due to lack of changes in SOM status. The favourable influence of SOC on Soil BD is justified by the significant negative correlation of SOC with BD with ‘r’ of - 0.88^{**} and - 0.87^{**}in the layers the top two layers (fig.5.1).

5.2 Water Stable Aggregates

Aggregation is considered as a significant mechanism of organic matter protection in soils (Balesdent *et al.,* 2000). Aggregation stability is a measure of soil structure, which is a key indicator in edaphic systems and the ability of the soil to sustain the biota. The central nucleus in aggregate formation is SOM whereas organic binding products from biota contribute to their development (Sandoval *et al*., 2008).

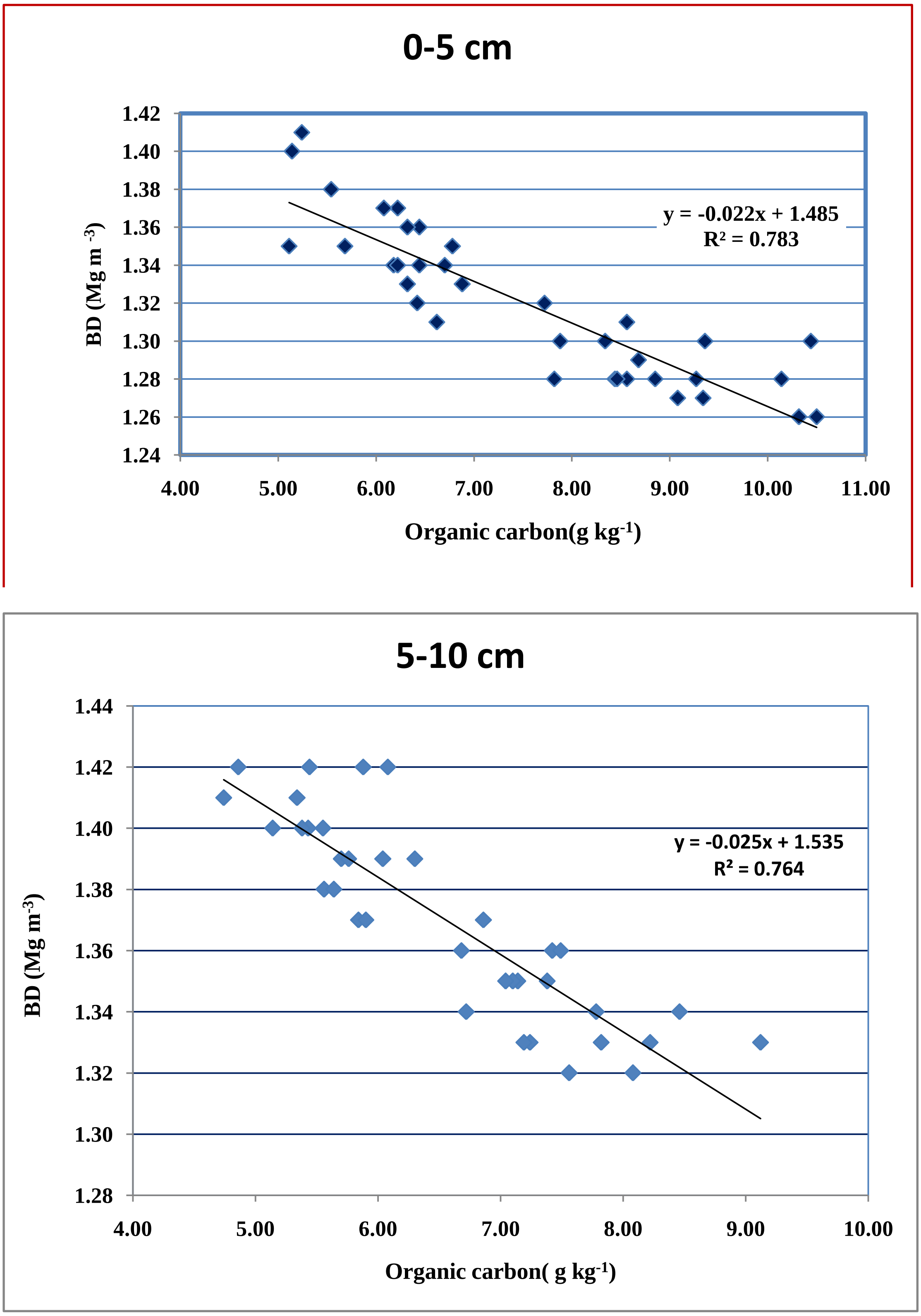
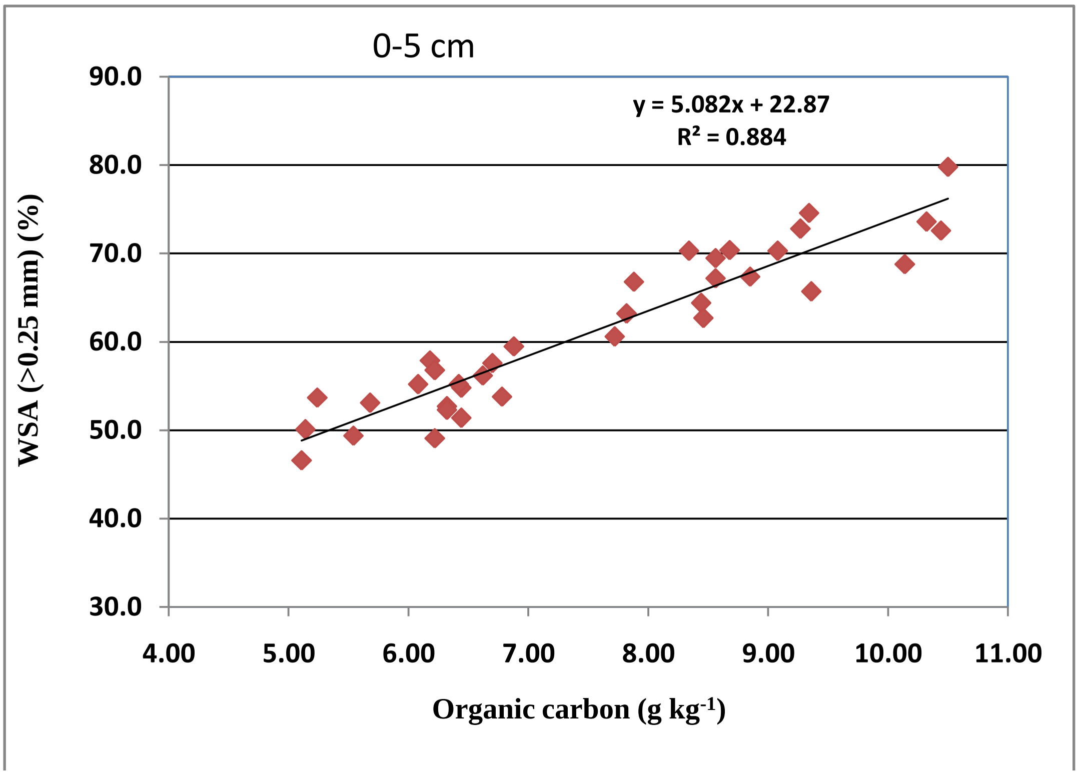


Fig.5.1Correlation of SOC with BD

The enrichment of macro-aggregates (>0.25mm) in the surface (0-5 cm) and subsurface (5-10 cm) soils under MT and concomitant decrease in micro-aggregates (0.053-0.25mm) may be attributed to reduced physical impact leading to lower turnover rates. Repeated inversion of soils in the surface layers under CT, in contrast, disrupts macro-aggregates (Zotarelli *et al.*, 2007). The incorporation of higher amount of fresh crop residues in soils under cover crops initiated formation of significant proportion of macro-aggregates by stimulating microbial activity in the top two layers (Guillou *et al.*, 2011). The status of soil aggregates in deeper layers (10-20 cm) under both tillage systems were related to the contents of organic matter rather than tillage methods. Similar trends have also been reported by Zhou Hu *et al.*, 2007. The significant positive correlation ($r = 0.94^{**}$ and 0.87^{**}) of SOC with macro-aggregates in the layers of 0-5 cm and 5-10 cm indicates the contribution of SOC in formation of macro-aggregates (Fig.5.2). Depletion of SOC with rapid turnover rates of macro-aggregates induced by tillage is reflected by the negative correlation ($r = -0.86^{**}$and -0.85^{**}) of SOC with micro-aggregates (Fig.5.3).

5.3 Soil Moisture Content

Favourable influences of organic matter maintenance on the soil surface under conservation tillage include increased water conservation and soil aggregation (Hubbard *et al.*, 2013). Irrespective of tillage practices, the soil moisture content reduces gradually in the dry season after cessation of rainfall. Residue retention in association with tillage reduction in MT significantly increased the soil water contents in the surface layers (0-5 cm and 5-10 cm) at sowing and flowering time of cover crops mainly due to considerable buildup of SOC. Similar trends on soil moisture contents under MT systems have also been reported by Pankhurst *et al.*, 2002, Daraghmeh *et al.*, 2009. Lower stable pore system and pore aggregate development due to soil inversion in CT system reduce soil moisture contents and CT also enhances direct evaporation of water from soil surface (Guto *et al.*, 2012). The effect of SOC on soil moisture contents in the surface layers are justified by its strong correlation with the later during sowing ($r = 0.85^{**}$) and flowering ($r = 0.82^{**}$) (fig. 5.4).The water contents in the deeper layers remain unaffected by tillage methods due to lack of variations in SOC.



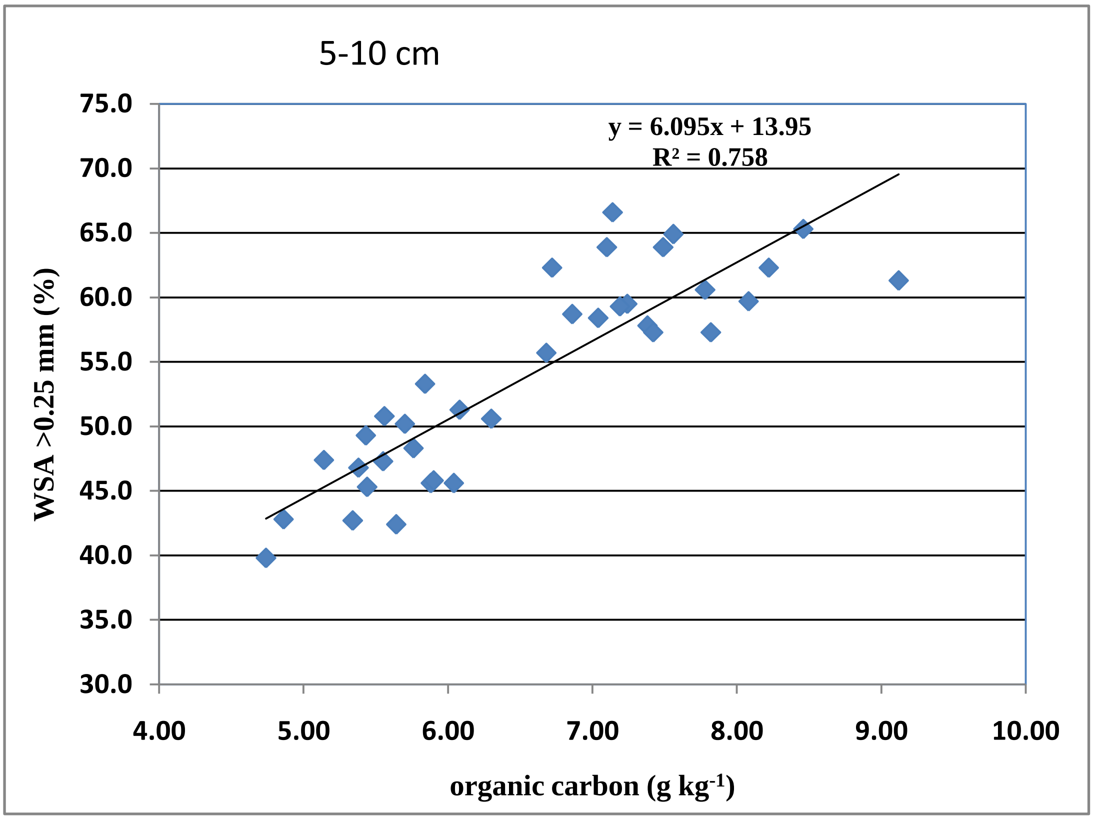


Fig 5.2Correlation of SOC with water stable macro-aggregates

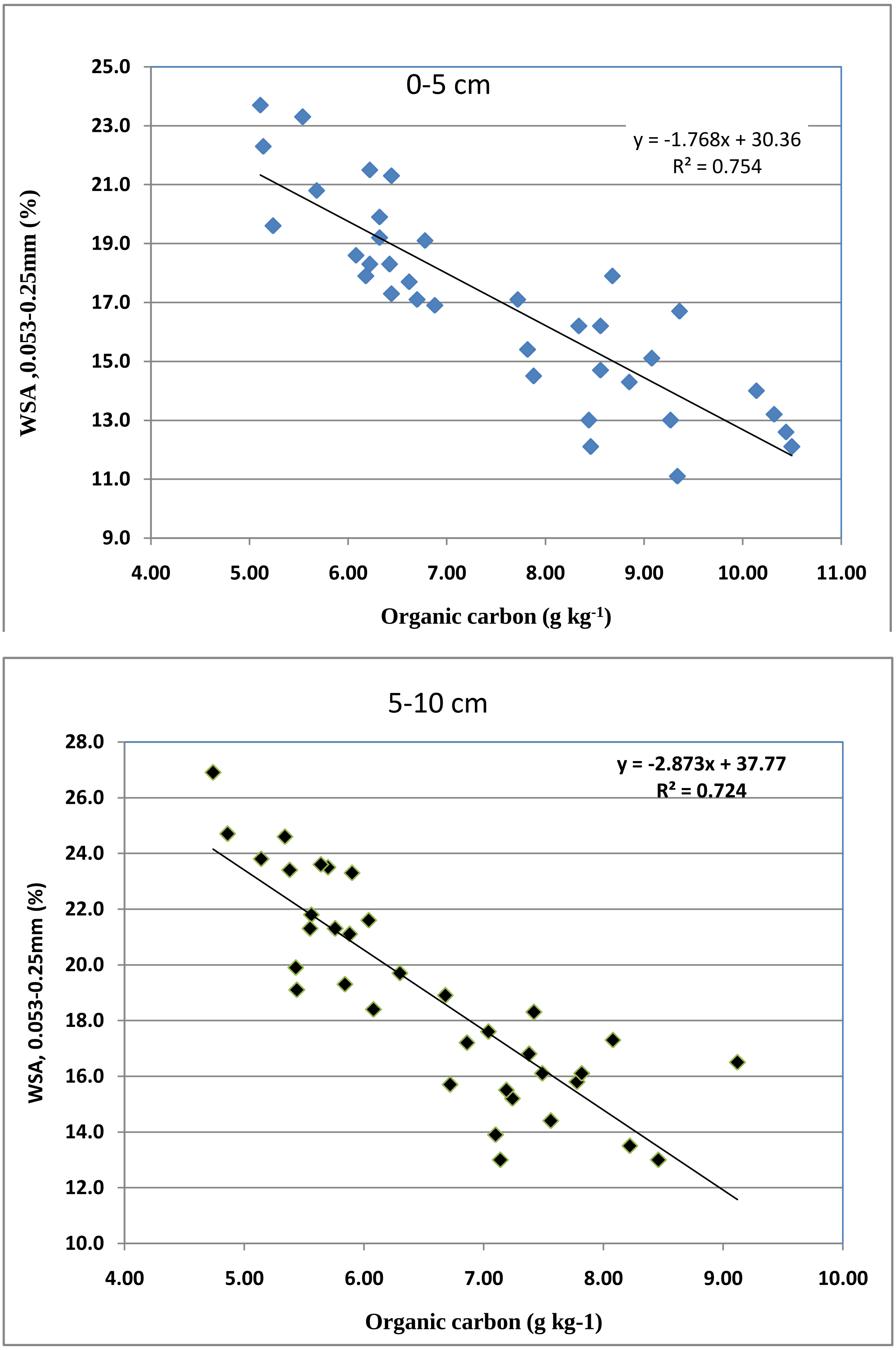
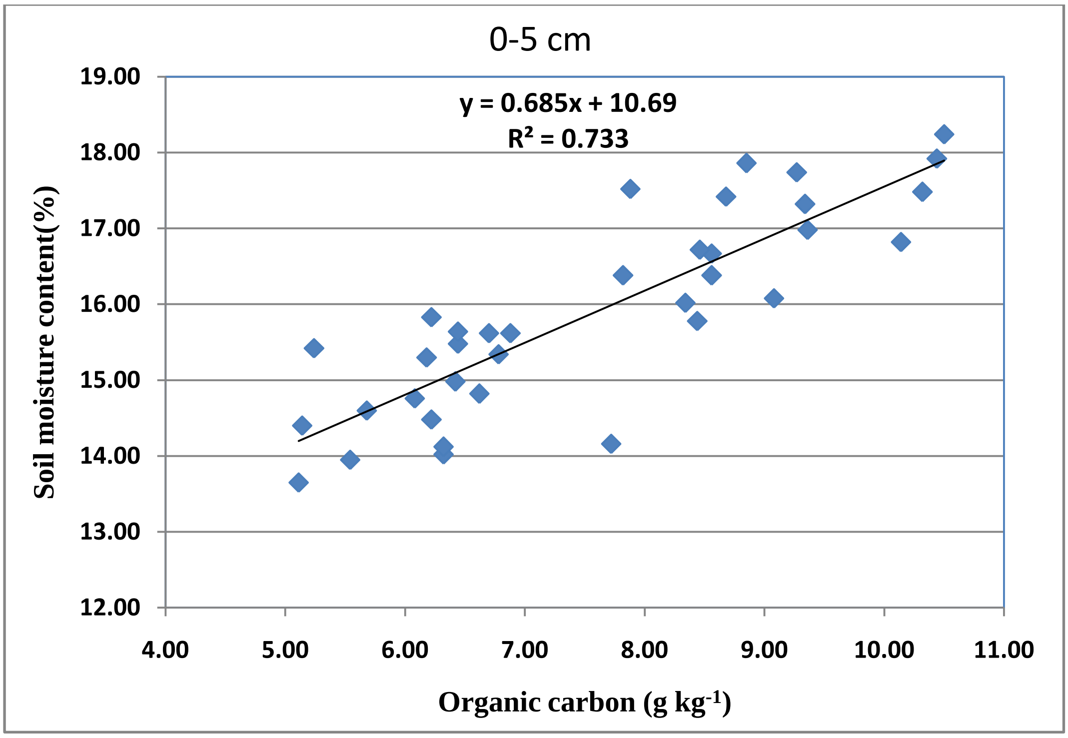


Fig.5.3 Correlation of SOC with water stable micro-aggregates



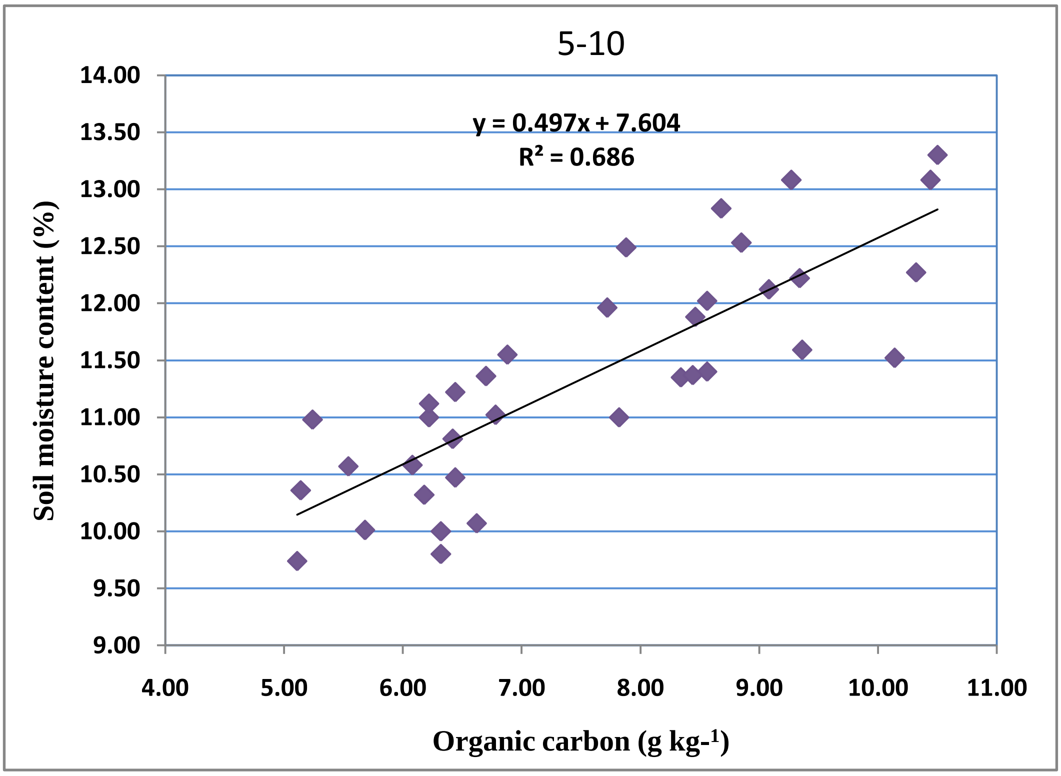


Fig.5.4 Correlation of SOC with soil moisture content at sowing and flowering at 0-5cm soil depth

5.4 Soil Reaction (pH)

The reduced pH in the surface layer (0-5 cm) under MT might be due to production of organic acids as a result of greater microbial decomposition of organic matter as these layers are enriched with higher litter inputs. Similar reasons for lower pH in MT soils have also been reported by Logan *et al*., 1991 and Kern *et al*., 1993. The SOM induced acidifying effect on MT soils was also observed Thomas *et al*., 2007. These findings are justified by the significant negative correlation ($r = 0.62^{**}$) obtained between SOC and soil pH in the top soil layer (fig.5.5).

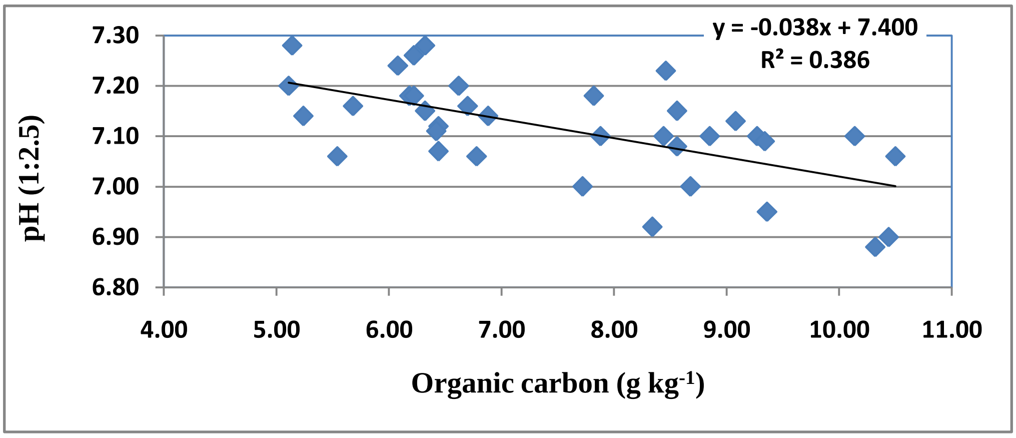


Fig 5.5 Correlation of SOC with pH(0-5cm)

5.5 Soil Organic Carbon (SOC)

As the changes of agricultural practices, such as tillage and crop types, influence C input (Martinez et al., 2008), SOC distribution and their decomposition processes (Six et al., 1999) in different soil layers, SOC status in all affected soil depth, rather than only the surface soil, were investigated in the present study.

Significant elevation of SOC in soils under MT with cropping systems in the top two layers is attributed to greater buildup of residue input (6.0 to 6.5 t $ha^{-1}$of biomass) as well as lower biological oxidation due to less tillage induced soil inversion. Higher SOC contents due to absence of soil redistribution were also observed by Hel *et al*.,2009 and Jemai *et al*., 2013. Again reduced physical impacts in MT increased the aggregate stability resulting in lower aggregate turn over, therefore improved physical protection of aggregate SOC from decomposition and thus higher SOC stocks. The soils under CT, in contrast, exhibited higher degradation of macro-aggregate induced by intense soil disturbances exposing the formerly incorporated SOC stocks to microbial decomposition (Tan *et al*., 2007) in the top layers. Protection of SOC because of higher proportion of macro-aggregates under MT systems also corroborates the findings of Plaza-Bonilla *et al*., 2013. Kushwaha *et al*., 2001, reported that the combined effect of MT and residue retention or the accumulation of SOC is greater than the effects of either MT or residue retention alone. In MT, the organic matter is incorporated faster in the top few centimeters of soil than in CT, where it is redistributed up to a depth of 20 cm. In addition, residues on the ground surface under MT can cause decrease in soil temperature in the top soil in summer, therefore lead to reduced SOC decomposition It can also increase moisture through reduced evaporation in the top soil, leading to changes in crop root growth and other soil processes related to SOC decomposition in the top soil layer (Luo *et al*., 2010)..The effect of surface accumulated residues on SOC is negligible in the deeper layers under MT and soil redistribution in CT results an even SOC distribution.

5.6 SOC stratification ratio

Plant residue placement is of importance to the depth distribution of SOM in the soil profile, because plant residues contribute greatly to subsequent SOM formation. Therefore, stratification of SOM fractions has been suggested as an indicator of soil quality in different agro-ecological zones, because surface SOM is essential to erosion control, conservation of nutrients, water infiltration, and other important soil functions (Franzluebbers, 2002). In general, and irrespective of soil and climatic conditions, a high stratification ratio (relation between surface and deeper layer concentrations of SOC) would indicate good soil quality, as ratios (>2) are not frequently found in degraded soils (Franzluebbers, 2002). In the present study, higher SOC stratification ratio observed in the soils under MT and cover crops indicate the effectiveness of MT in improving SOM accumulation and biological status of the surface layers, whereas the lower stratification ratio in CT soils are related to even depth distribution of SOC as a result of soil redistribution. The results are in agreement with the findings of Melero *et al*. (2012).

5.7 Water Stable Aggregate Carbon

It has been established that the inclusion of organic matter within soil aggregates reduce their decomposition rates and tillage has been found to induce a loss of C-enriched macro-aggregates and a C-depleted micro-aggregates (Six *et al.*, 2000a). The elevated macro-aggregate C in soils under MT, in the current study, is related to the physical protection of labile SOC within macro-aggregates from microbial decomposition due to higher litter inputs and lower soil disturbances. The enrichment of C concentration in macro-aggregates in soils under MT has also been reported by Plaza-Bonilla *et al.* (2013). The higher micro-aggregate C in MT soils are also related to greater buildup of SOM that facilitates more organic matter binding micro-aggregates. Elliott (1986) suggested that macro-aggregates have elevated C concentrations because of the conversion of organic-matter-binding micro-aggregates into macro-aggregates and that this organic matter is 'qualitatively more labile and less highly processed' than the organic stabilizing micro-aggregates. Intense physical impacts in CT soils disrupt the C enriched macro-aggregates and expose them for microbial decomposition. Influence of SOC on aggregate C was evidenced by significant positive correlation of SOC with macro-aggregates (r = 0.91**, 0.85**)(Fig 5.6) and micro-aggregates (r =0.81**.0.87**) in the top two layers (Fig. 5.7).

5.8 Microbial Biomass Carbon (MBC)

Although soil microbial biomass represents only a small proportion of overall SOM, it is more dynamic than total SOM and a better indicator of how tillage and cropping systems impact soil health and productive capacity (Campbell *et al.*, 2001).The greater MBC in the top layers under MT system can be explained by the larger accumulation of labile organic Cover time due to non-disturbance of the soil. In contrast, the MBC in the CT soil decreased because of low labile organic C which continuously declined due to cultivation over years. Accumulation of concentrate C input in the top few centimeters in MT and CC soils result an increase in MBC near the soil surface and it increases much more readily due to changes in tillage system or residue supply than SOC. (Stockfisch *et al.*, 1999). Greater MBC in surface soils under reduced tillage has been reported by Balota *et al.* (2004) and Purakayastha *et al.* (2009). Marginally higher MBC in the CT soils in the 10–20 cm depth might have been due to soil mixing during repeated tillage under cropping. From the contrasting profiles of MBC observed in MT and CT systems, it may be deduced that the high SOC near the soil surface is maintained or that the enrichment will be even continued. The effect of SOC on MBC is evidenced by strong positive correlation (r = 0.87^{**} and 0.97^{**}) in top two layers (Fig.5.8).

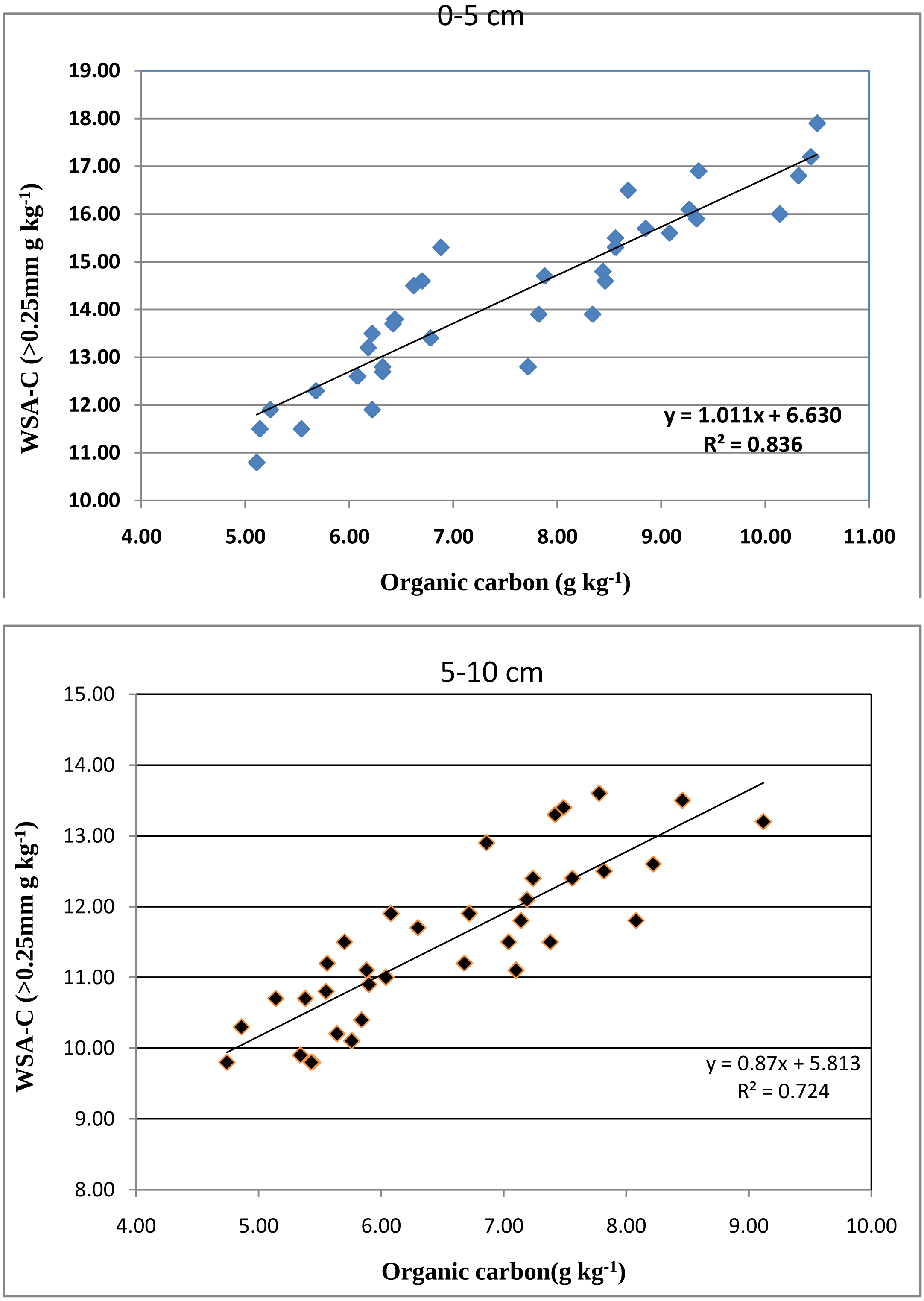


Fig.5.6 Correlation of SOC with water stable macro-aggregates carbon

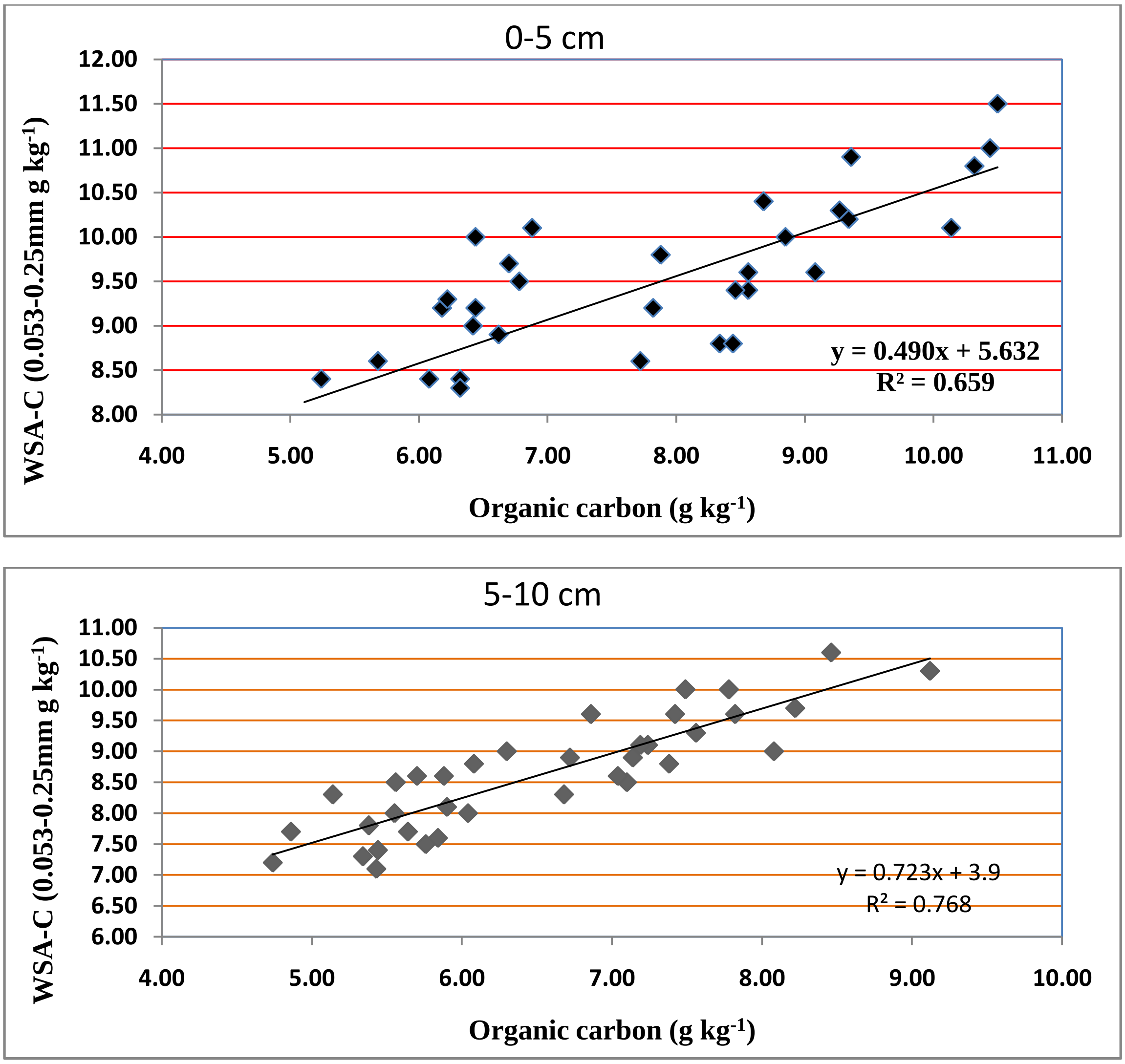


Fig.5.7 Correlation of SOC with water stable micro-aggregate carbon

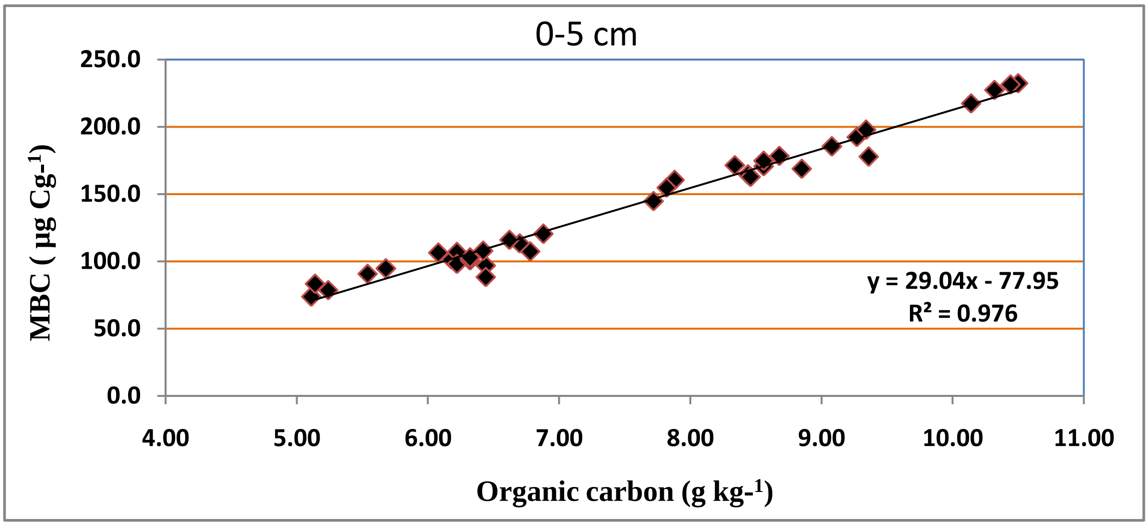


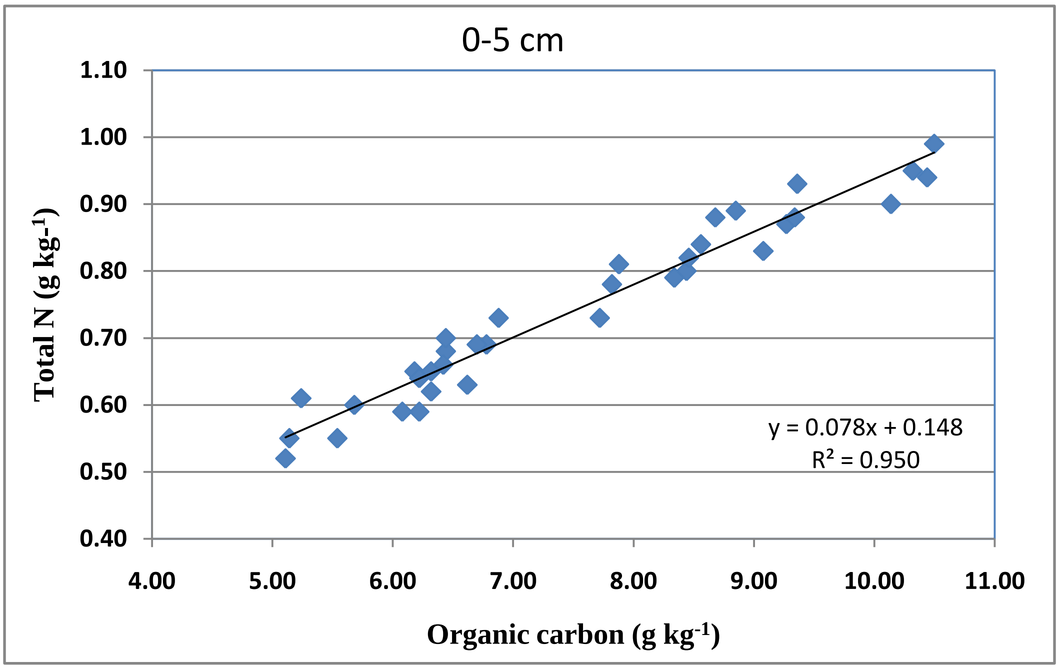
Fig 5.8 Correlation of SOC with MBC of the soils

5.9 MBC/SOC ratio (Microbial Quotient)

The microbial quotient or SOC ratio is very often used as a calibrated soil quality indicator to predict whether soils are accumulating or losing C. It serves as a measure of C availability to microorganisms. Higher MBC/SOC ratio in the top two layers under MT suggest that accumulated crop residues maintained more labile organic substrates in the soil, which allows a higher MBC per unit of SOC. The lower ratio for the same layers under CT indicates that the microbial C pools decline at a faster rate than the organic matter resulting a decrease in proportion of SOC as MBC. Similar findings have been corroborated by Elcio *et al*. (2003) in their study on microbial biomass in soils under different tillage and cropping systems and Jacobs *et al*. (2009) working on C and N storage in reduced tillage.In deeper layers (10-20cm) of MT, the microbial quotient is relatively low indicating ongoing decline in SOM concentration (Stockfisch *et al*., 1999).

5.10 Soil Total Nitrogen (STN)

Carbon (C) is an indispensable necessity for soil fertility; it is strongly correlated with nitrogen (N) and fuels the microbial engine that drives the nitrogen cycle (Korschens, 1998). The elevated STN concentration in the surface layers under MT than those under CT systems can be attributed to a combination of less soil disturbance and reduced litter decomposition due to less soil residue interaction (Du *et al*. 2010). The greater accumulation of STN in the surface layer as compared to lower depths in MT indicates a stratification of crop residues and organic matter in the top soil layers. This hypothesis is agreement with the findings of Purakayastha *et al*. (2009). Significant positive correlation exists between SOC and STN (Fig.5.9) in the layers of 0-5 cm (r = 0.97**) and 5-10 cm (r = 0.94**).



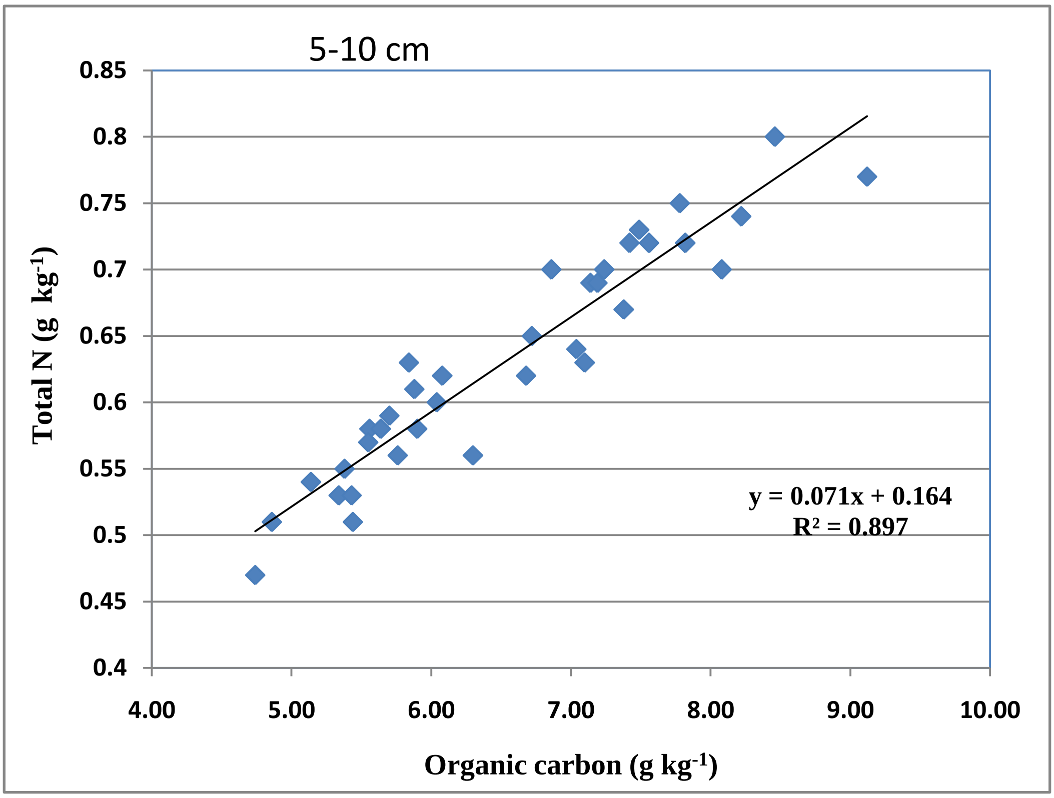


Fig 5.9 Correlation of SOC with STN of the soils

5.11 Microbial biomass nitrogen (MBN)

Microbial biomass nitrogen (MBN) has been advanced as a sensitive biological indicator because it is strongly influenced by management practices and system perturbations The MBN of soils depends on microbial abundance. When flushes of C are supplied to the soil in the form of crop residues, the microbial biomass increases in size until the substrate is depleted. In the present study, residue retention and tillage reduction both increased the level of MBN, the maximum effect on MBN being recorded in the top layers under MT (Kushwaha *et al*., 2001). Singh and Singh (1993) stated that microbial growth due to the application of organic matter mainly dependent on the availability of C in the soil; which is responsible for elevated MBC and MBN. CT soils on the other hand exhibited lower MBN because of lower SOM and thus lower microbial density. Favourable impact of SOC on MBN is reflected in their strong correlation (r = 0.966**,0.97**) in the top two soil layers (Fig.5.10).

5.12 MBN/STN ratio

Microbial biomass-based indicators of soil quality are believed to be more dynamic than those based on physical and chemical properties, and therefore, have the advantage of serving as early signals of soil degradation or soil improvement (Powlson *et al*., 1987). Higher MBN due to abundance of microorganisms thriving on concentrated C inputs in the surface layers under MT is the main reason for higher MBN/STN ratio. Higher MBN/STN ratio in 0-10 cm soil depth under MT with residues has been reported by Kushwaha *et al*. (2001).Rapid decline in microbial N pools as compared to STN results lower MBN/STN ratio in CT soils. Decline in MBN and STN concentration in deeper layers due to lack of residue retention is indicated by lower MBN/STN ratio.

5.13 C/N ratio

In general, the C/N ratio is directly affected by agricultural operations like tillage, residue management and decomposition rates of the residues. In the present study, marginally higher C/N ratio in the soils under MT might be an indication of higher concentration of less decomposed residues due to surface placement where less mineralization occurs (Lou *et al*., 2012). Comparatively higher C/N ratio in the top soil with conservation tillage as compared to CT has also reported by Wood *et al*. (1991).

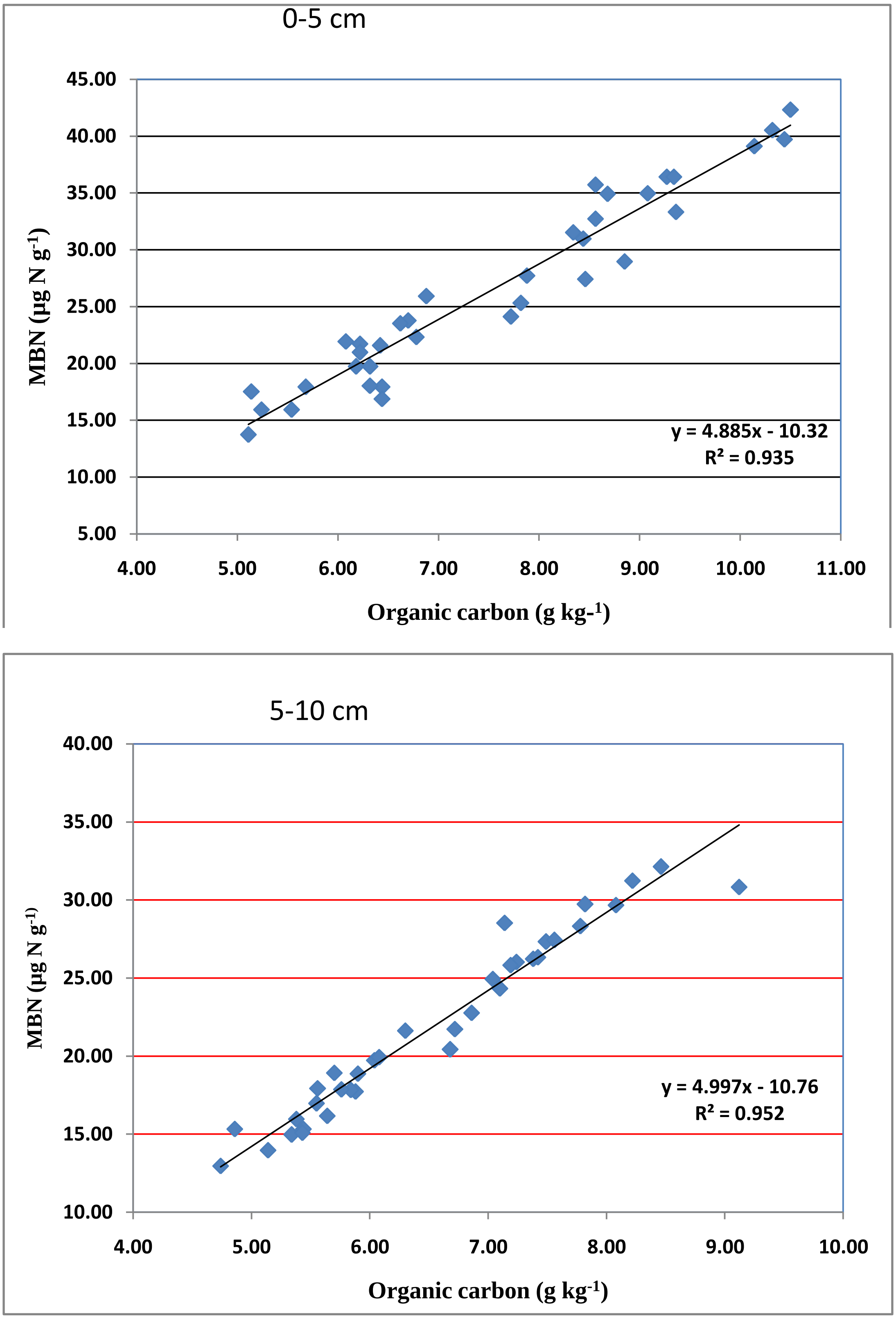


Fig 5.10Correlation of SOC with STN of the soils

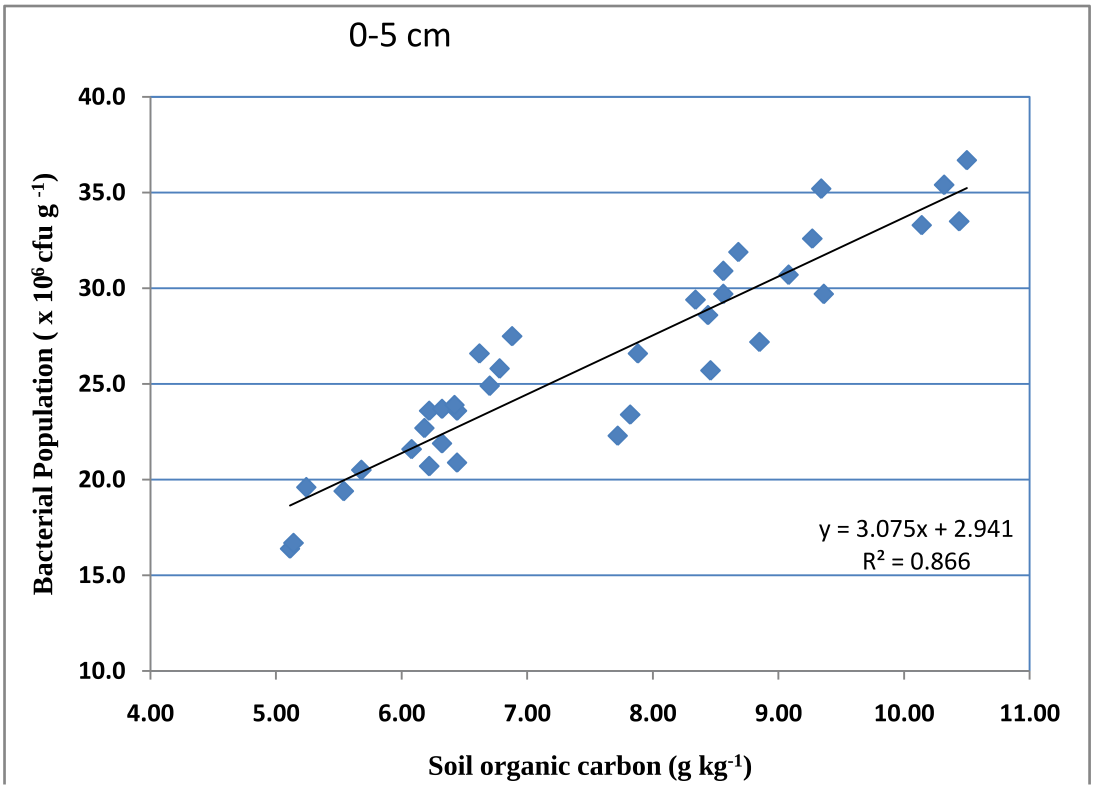
The mechanism behind the lower C/N ratio in CT soils is that these soils have reduced C concentration from oxidation of SOM due to tillage. Slightly amplified C/N ration in the deeper layers indicate unusually lower concentration of N relative to SOC (Dikgwatlhe *et al*., 2014).

5.14 Microbial population

Soil biota is more dynamic than total SOM and a better indicator of how tillage and cropping systems impact soil health and productivity (Hamel *et al*., 2006). Considerable buildup of SOM in association with reduced soil disturbance enhanced the population of bacteria, fungi and actinomycetes in the top two layers (0-5 cm and 5-10 cm) under MT, which might be due to availability of higher amounts of substrates for microorganisms. Higher microbial abundance in MT surface soils has been observed by Sun *et al*., (2011). Lack of variation in microbial density in deeper layer under both MT and CT is due to lower and even distribution of SOC (Balota *et al*., 2004). The favourable influence of SOC on these microbial community in the top layers (0-5 and 5-10cm) is reflected by the significant positive correlations (Fig.5.11) of SOC with bacteria (r = 0.82**, 0.83**), fungi (r = 0.86**, 0.90**)(fig.5.12) and actinomycetes (r = 0.87**,0.89**).(fig. 5.13).

5.15 Maize Equivalent Yield (MEY)

Though the cropping systems of either maize sole or maize + cowpea intercrop among MT and CT could not change the MEY significantly, marginal increase of MEY in MT may be related to considerable buildup of SOM that moderates the aggregation, moisture retention, microbial profile and the dynamics of nutrient mobility at the end of 4thcropping cycle. The intercrop of maize and cowpea under both MT and CT systems increased the MEY over sole maize because of higher productivity, improved soil conditions and additional gain from cowpea. The higher selling price of toria mustard is the reason for the elevated MEY with inclusion of toria mustard as cover crop.



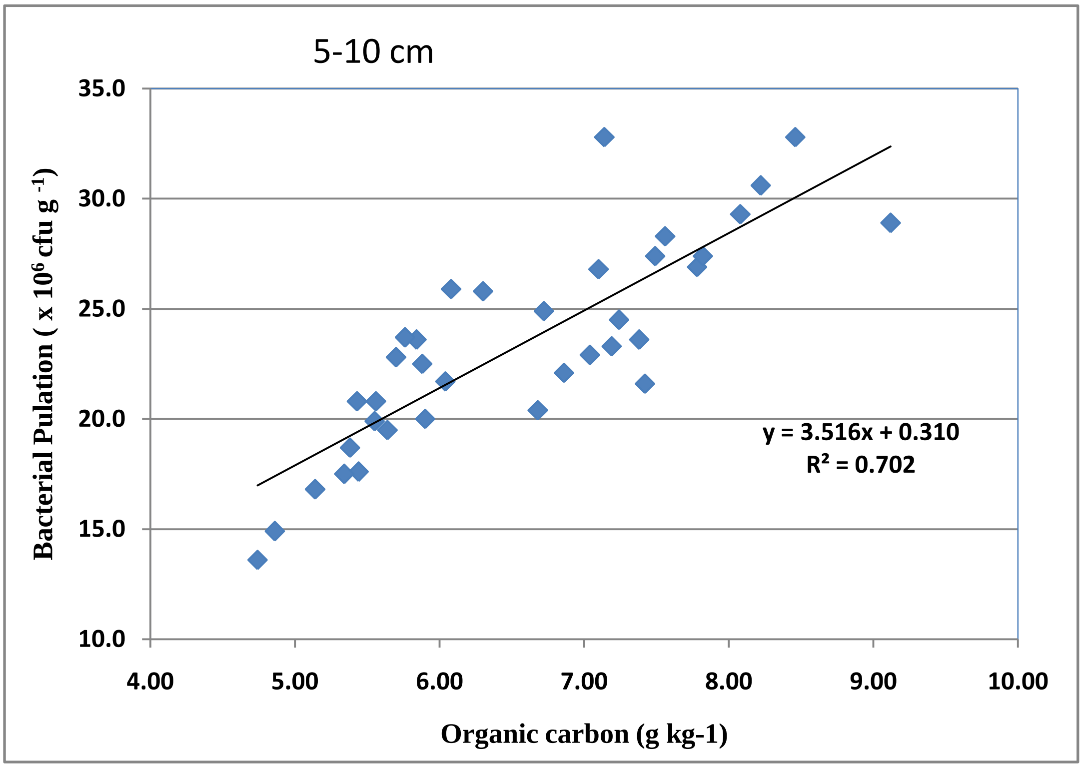
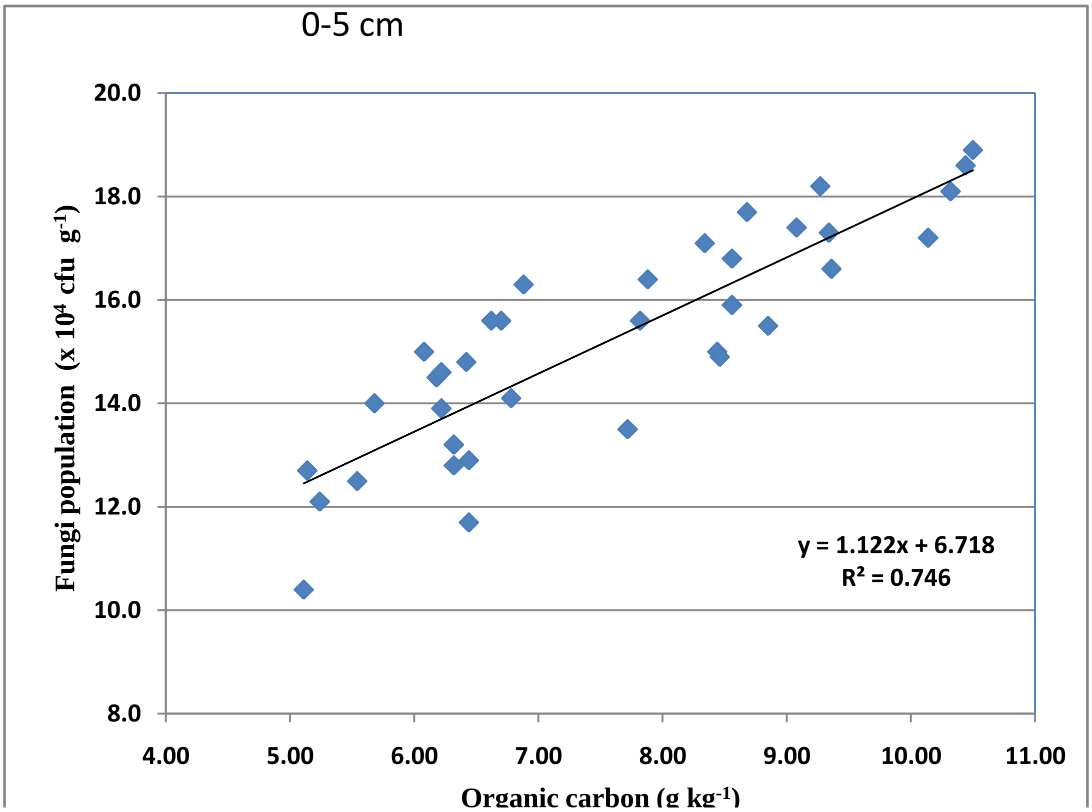


Fig 5.11Correlation of SOC with bacterial population of the soils



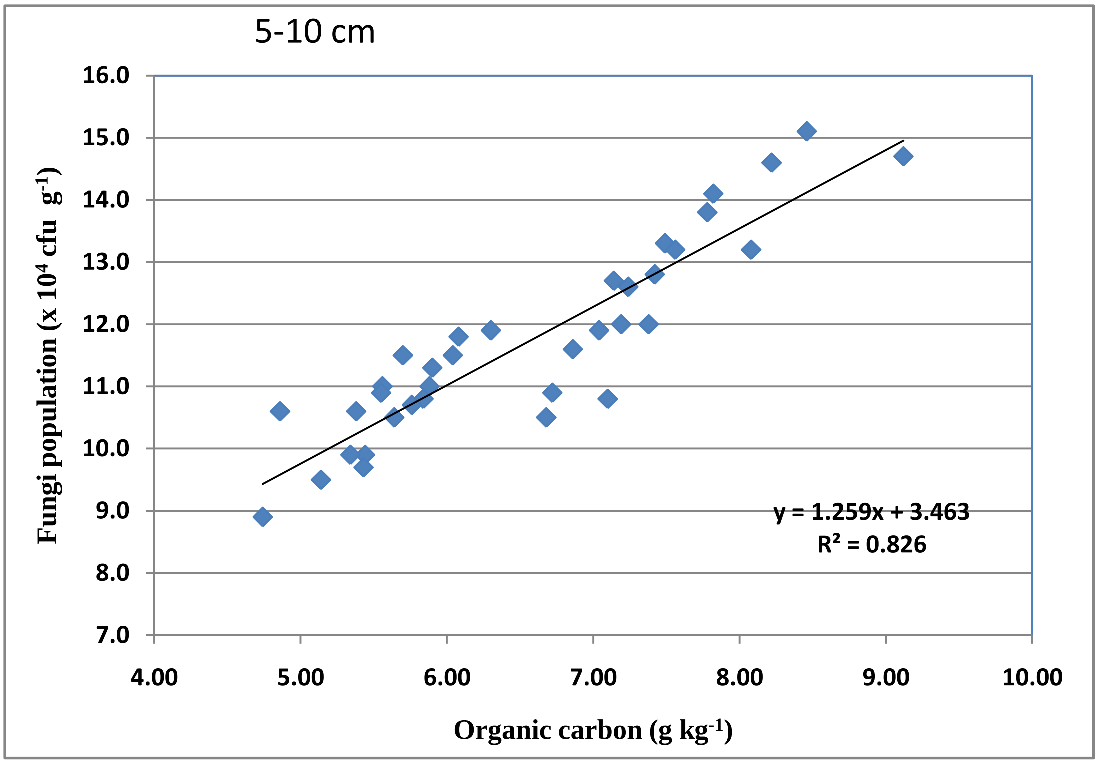
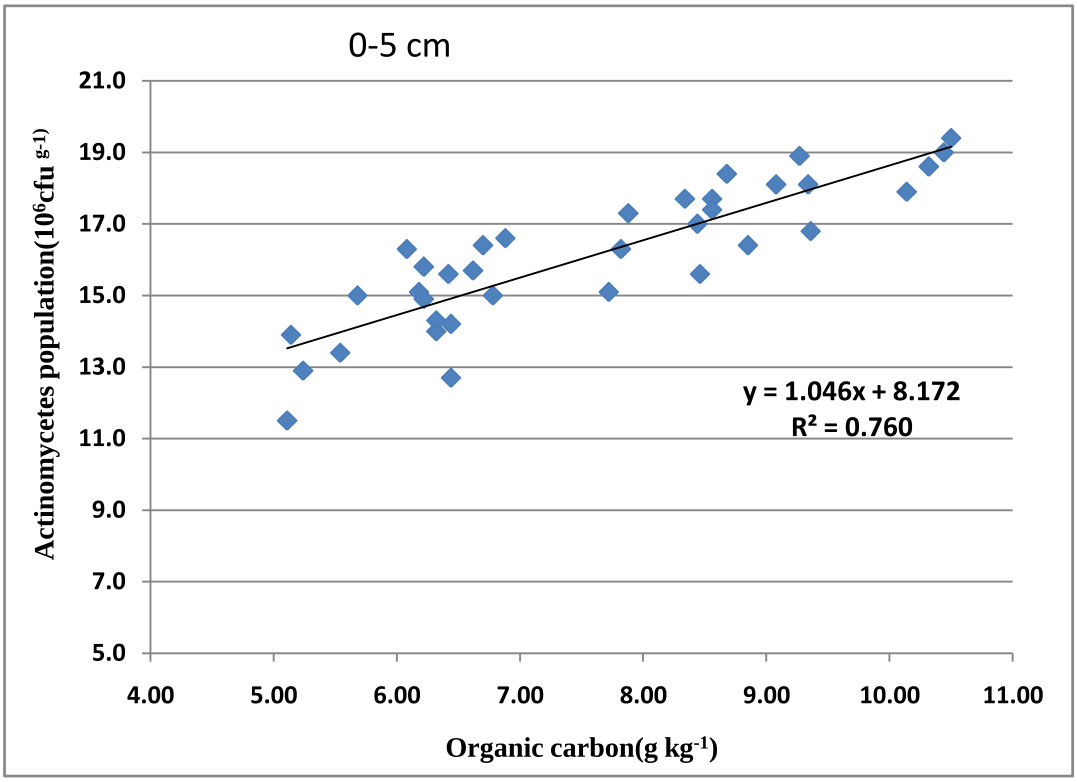


Fig.5.12 Correlation between SOC with fungal population of the soils



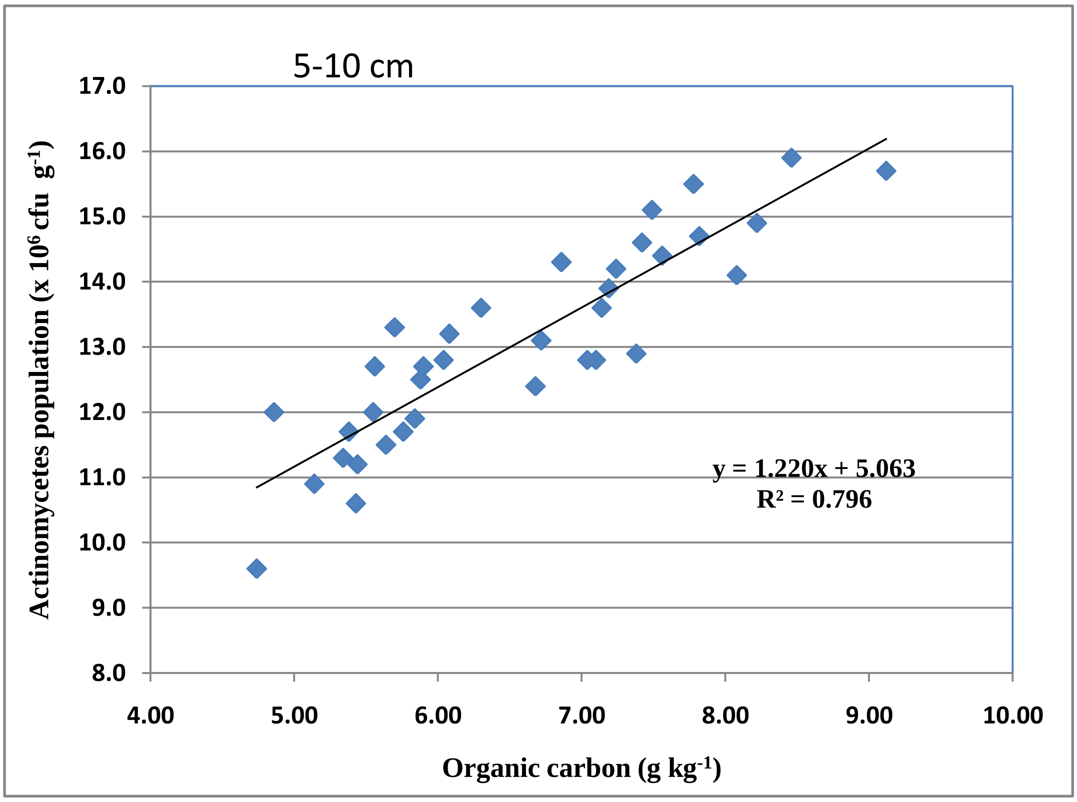


Fig.5.13Correlation between SOC with actinomycetes population of the soils

SUMMARY AND CONCLUSION

Loss of fertile top soils through water erosion coupled with intensive tillage practice and mono-cropping have rendered the soils of North Central Plateau zone in Kendujhar district of Odisha unproductive. Conservation agriculture production system (CAPS) with the components of minimum tillage, legume based intercropping and follow up cover crop has been established at RRTTS (OUAT),Kendujhar located in the degraded rainfed agro-ecosystem, during 2011, in split plot design, with an objective to conserve the natural agro eco-systems sustainably. The treatment details are Conventional tillage (CT) and Minimum tillage (MT) with sole Maize (M) and inter crop ofMaize + Cowpea (M+C) in main-plots during wet season, Horsegram(H), Toria mustard(T) and no cover crop (NCC) in sub-plots during dry season. The impact of CAPS on soil attributes is assessed after completion of the 4thcropping cycle in the present study “Soil organic carbon, aggregation and microbial response to conservation agricultural production systems in a rainfed agro-ecosystem of Odisha” and the salient findings are as follows:

- Residue retention in association with tillage reduction (MT) lowered the soil BD in the tune of 3.0% and 2.2% over the initial status (1.32 and 1.37 Mg m^{-3}) in 0-5 and 5-10cm layers, respectively, whereas CT soilsregistered higher BD (+2.3%, +1.5%). Soils under CC also reduced the BD by 0.8% and 0.7% over NCC (1.33 and 1.38 Mg m^{-3}) in the top two layers.

- Both top layers under MT registered higher proportion of water stable macro-aggregates (+18.4%, +15.2%) over initial contents (58.2, 52.8%) and the decrease for the corresponding layers in CT soils are in the tune of -7.9% and -11.0%, respectively. The proportion of micro-aggregateson the other hand exhibited a reverse trend with the higher values in CT (+21%, +22.1%) than those of MT (-11.1%, -12.7%) over the initial contents of 16.2% and 18.1% in the top two depth ranges.

- The soils under MT exhibited higher water contents at sowing (16.9%) and flowering (12.1%) during dry season cover crops as compared to CT systems (14.9% and 10.6%) in the surface layer.

- In the surface layer, soil pH under MT systems was reduced by 3.8% and 1.5% over the initial status (7.34) and CT systems (7.17) respectively.

- The status of SOC in MT soilsincreased considerably (+31.8% and 16.8%) over the initial status of 6.82 g kg^{-1} and 6.44 g kg^{-1} in the top two layers, whereas a reduction of SOC (-6.8%, and -13.2%) was observed in CT soils. Cover cropping also enhanced the SOC of soils by 11.4% and 10.1% over NCC (6.96 and 6.14 g kg^{-1}) in the 0-5 cm and 5-10 cm layers.

- Macro-aggregate C under MT increased by 12.4% and 7.6% in two top layers over initial status of 13.9 and 11.5 g kg^{-1}, respectively. The concomitant decrease in CT soils was 6.5% and 7.1%. Soil under CC also registered more macro-aggregate C (+12.1%) over NCC (13.2 g kg^{-1}) in the surface layer.

- Elevation of micro-aggregate C in top layers under MT was by 7.6% and 12% over initial values (9.2 and 8.3g kg^{-1}) and corresponding decrease in CT soils were 4% and 4.3%.

- Conversion to MT systems over the years enhanced the MBC of soils by 123.6% and 72.4% over the initial status of 82.3 and 78.6 µg C g^{-1} in the top two layers. Cover cropping also enhancedthe MBC by 20.6% and 14.3% over NCC (124.5 and 102.7 µg C g^{-1}) in the same soil layers.

- A higher microbial quotient (MBC/SOC) was observed in the top two layers under MT (2.04% and 1.8%) as compared to CT (1.62% and 1.6%).

- In the top two layers, MT elevated the STN by 19.4% and 11.1% over the initial contents of 0.72 and 0.62 g kg^{-1}, respectively. The concomitant decrease in CT soils was by 12.5% and 11.1%.

- Practice of MT increased the MBN of top two layers by 58.5% and 53.2% over the initial values of 21.1 and 17.6 µg N g^{-1}. The corresponding decrease in CT soils was by 6.8% and 2.6%. Soils under CC exhibited a gain in MBN by 28.1% and 20.1% over NCC (22.4 and 19.4 µg N g^{-1}) in 0-5 cm and 5-10 cm layers.

- A higher MBN/STN ratio was observed in MT soils (3.87, 3.81) as compared to CT (3.11, 3.02) in both surface layers.

- The soils under MT registered higher C/N ratio in all the layers with the values of 10.43, 10.68 and 10.87 for 0-5 cm, 5-10 cm and 10-20 cm, respectively over CT (9.77, 10.1 and 10.11).

- Soils under MT registered higher SOC stratification ratio of 1.82 as compared to CT (1.19).

- Accumulation of litter inputs in MT soils enhanced the abundance of bacteria (+35.7%, 29.6%), fungi (+22%, +19.7%) and actinomycetes (+19.9%, +18.4%) remarkably over CT soils in the layers of 0-5cm and 5-10cm. Cover cropping also increased the bacterial (+22.4%, +20%), fungal (+12.2%, +13.8%) and actinomycetes (+12.4%, +8.6%) population over NCC in the surface layers of 0-5 cm and 5-10 cm.

- Cropping systems either sole maize or with maize + cowpea intercrop among tillage methods (MT, CT) did not vary the MEY significantly. Cover crops of horsegram and toria increased the MEY by 19.6% and 30.5%, respectively over NCC. The maximum MEY of 118.14 q ha^{-1} was produced from the treatment ofmaize cowpea intercropping in minimum tillage followed by toria mustard as cover crop (MT-M + C-T).

CONCLUSION

The study clearly showsthe temporal effects of different tillage and residue management systems on stratification and distribution of SOM and its' related properties across the profile in arainfed agro-ecosystem. The concentrations of SOC and STN were higher in soil under MT with cropping systems in the surface layers (0–10 cm depth) compared with uniform distribution in those under CT in the plow layer exhibiting a distinct SOC stratification. The decrease in soil BD, low turnover rate of macro aggregates, high aggregate C, high soil moisture content and elevated ratios of MBC/SOC, MBN/STN, C/Nand microbial diversity are directly related to buildup of SOC through surface accumulation of litter inputs promoted by MT. Faster decomposition of SOC due to intense soil inversion in CT imparted an adverse effect on these soil attributes. MT with cropping systems are thus creating a more favorable soil environment with time and can be an adoptable intervention for restoration of soil health and productivity in the degraded rainfed agro-ecosystems under North Central Plateau zone of Odisha. Further, studies are necessary to clarify the effects of soil moisture characteristics, soil respiration and carbon sequestration to fully evaluate the functioning of CAPS ecosystem in agricultural fields.

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