ASSESSMENT OF MAIZE BASED CONSERVATION AGRICULTURE PRODUCTION SYSTEM (CAPS) ON SOIL HEALTH IN THE HILLY TERRAINS UNDER NORTH CENTRAL PLATEAU ZONE OF ODISHA

A THESIS SUBMITTED TO
THE ORISSA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
BHUBANESWAR
IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

MASTER OF SCIENCE IN AGRICULTURE
(SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)

By

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THESIS ADVISOR: **DR. K. N. MISHRA**

With the Benedictions of my Parents as
well as my Adorable Chairman
Dr. K. N. Mishra Sir this thesis is

Dedicated to
Dr. Manoranjan Kar
Dr. K. K. P
&
My Dear Papa

Dr. K. N. Mishra
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CERTIFICATE

This is to certify that the thesis entitled "**ASSESSMENT OF MAIZE BASED CONSERVATION AGRICULTURE PRODUCTION SYSTEM (CAPS) ON SOIL HEALTH IN THE HILLY TERRAINS UNDER NORTH CENTRAL PLATEAU ZONE OF ODISHA"** submitted in partial fulfilment of the requirements for the award of the degree of **MASTER OF SCIENCE IN AGRICULTURE (SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)** of the Orissa University of Agriculture and Technology, Bhubaneswar is a faithful record of *bona fide* research work carried out by **Ayesha Mohanty** under my guidance and supervision. No part of the thesis has been submitted for the award of any other degree or diploma.

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

Bhubaneswar
Date :

(K. N. Mishra)

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ABSTRACT

A field experiment has been initiated on a Fluventic Haplustepts at Regional Research and Technology Transfer Station, OUAT, in Kendujhar district located under the hilly terrains of North Central Plateau Zone, Odisha, during 2011-2012, in split plot design to assess the impacts of Conservation Agriculture Production System (CAPS) on soil health. The treatment combinations are Conventional tillage (CT) and Minimum tillage (MT) with sole Maize (M) and inter crop Maize+Cowpea (M+C) in main-plots during wet season and Horsegram (H), Mustard (M) and no cover crop (NCC) in sub-plots during dry season. Practice of MT increased the water stable macro-aggregates (+8.7%) with concomitant decrease in water stable micro-aggregates (-13.4%) over the initial status. CT increased the BD by 0.03 Mg m^{-3} whereas, it remained unchanged under MT. The accumulation and preservation of organic matter in MT elevated the SOC (+17%), CEC (+15.3%), Ca^{++} (+20.4%) ,Mg^{++} (+20.3%), K^{+} (+10.1%), base saturation (+3.8%) over the initial contents at the end of second cropping cycle. Physical protection of SOM due to less soil disturbances in MT resulted in higher available N (305 kg ha^{-1}), P(17 kg ha^{-1}) and K (364 kg ha^{-1}). The elevated SOM in MT enhanced the population of bacteria (+10.8%), actinomycetes (+14.6%) and MBC (+13.6%) over initial. The inclusion of cover crops in CAPS significantly enhanced the SOC (+6.8%), available N (+7.5%), P (+8.6%), actinomycetes (+6.4%) and MBC (+5.8%) over the soils with NCC. Considerable buildup of SOM due to residue incorporation and its protection under MT contributed significantly in improving the status of macro-aggregates (R=0.92**), BD (R= -0.87**), CEC (R=0.89**), base saturation (R-0.86**), available N (R=0.96**), P (R=0.66*), K (R=0.93**), population of Bacteria (R=0.93**), actinomycetes (R=0.92**) and MBC (R=0.87**). Though the system yield of MT-M+C-CC was marginally lower than CT at the end of second cropping cycle, the positive influence on soil health will be reflected in yield in the long run.

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ABBREVIATION

CAPS : Conservation Agriculture Production System
CA : Conservation Agriculture
MT : Minimum Tillage
H : Horsegram
NCC : No Cover Crop
CC : Cover Crop
SOC : Soil Organic Carbon
CEC : Cation Exchange Capacity
POC : Particulate Organic Carbon
BD : Bulk Density
GC : Gravel Content
TP : Total Porosity
SOM : Soil Organic Matter
SBD : Soil Bulk Density
WSA : Water Stable Aggregates
OC : Organic Carbon
NTS : No Till System
NT : No Tillage
MBC : Microbial Biomass Carbon
MBN : Microbial Biomass Nitrogen
Mg : Megagram
ha : Hectare

INTRODUCTION

In India, growing population of the country may stabilize around 1.4 billion by 2025 and 1.6 billion in the year 2050 calling for 380 and 480 metric tonne food grain production per annum respectively. Rising population per capita income is pushing up demand which needs to be met through enhancing productivity per unit area input and time. Although green revolution was highly successful and resulted in dramatic yield increase, conservation efforts to protect soil resources were not always given appropriate attention.

As soil is the most vital resource for providing food to the ever increasing population, it is mandatory that wide spread soil degradation is brought to a halt. Soil should be used rationally and conserved properly for realizing agricultural productivity on a sustainable basis. So to achieve this sustainable production without any degradation of natural resource base and environment a set of crop-nutrient-water-landscape system management practice popularly known as conservation agriculture production system has been identified as one of the immediate and long term solutions.

Conservation agriculture (CA) can be defined by a statement "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).

The Food and Agricultural Organization of the United Nations has determined that CA has three key principles that producers (farmers) can proceed through in the process of CA. These three principles outline what conservationists and producers believe can be done to conserve what we use for a longer period of time.

The first key principle in CA is practicing minimum mechanical soil disturbance which is essential to maintaining minerals within the soil, stopping erosion, and preventing water loss from occurring within the soil. In the past agriculture has looked at soil tillage as a main process in the introduction of new crops to an area. It was believed that tilling the soil would increase fertility within the soil through mineralization that takes place in the soil. Also tilling of soil can cause severe erosion and crusting which will lead to a decrease in soil fertility. Today tillage is seen as a way as destroying organic matter that can be provided within the soil cover. No-till farming has caught on as a process that can save soils organic levels for a longer period and still allow the soil to be productive for longer periods (FAO 2007).

When no-till practices are followed, the producer sees a reduction in production cost for a certain crop. Tillage of the ground required more money due got fuel for tractors or feed for the animals pulling the plough. The producer sees a reduction in labor because he or she does not have to be in the fields as long as a conventional farmer.

The second key principle in CA is much like the first in dealing with protecting the soil. The principle of managing the top soil to create a permanent organic soil cover can allow for growth of organisms within the soil structure. This growth will break down the mulch that is left on the soil surface. The breaking down of this mulch will produce a high organic matter level which will act as a fertilizer for the soil surface. If the practices of CA were being done for many years and enough organic matter was being built up at the surface, then a layer of mulch would start to form. This layer helps prevent soil erosion from taking place and ruining the soils profile or layout.

The third principle is the practice of crop rotation with more than two species. According to an article published in the *Physiological Transactions of the Royal Society* called “The role of conservation agriculture and sustainable agriculture,” crop rotation can be used best as a disease control against other preferred crops (Hubbs *et al*. 2007). This process will not allow pests such as insects and weeds to be set into a rotation with specific crops. Rotational crops will act as a natural insecticide and herbicide against specific crops. Not allowing insects or weeds to establish a pattern will help to eliminate problems with yield reduction and infestations within fields (FAO 2007). Crop rotation can also help build up a soils infrastructure. Establishing crops in a rotation allows for an extensive build up of rooting zones which will allow for better water infiltration (Hubbs *et al*. 2007).

Conservation agriculture production system (CAPS) is tailor-fit system approaches for successful adoption and implementation of CA to specific locations. CAPS are underpinned by a “basket” of agricultural, marketing, local government policy practices or a tool box of practices that promote CA (Agustin *et al*., 2012).As a whole, this systematic approach encourages soil and water conservation while providing potential for reduced labour of tillage and weeding (Bishop-Sambrook, 2003).

The major categories of land degradation (NRSC, ISRO, 2011) in the undulating hilly terrains of Kendujhar district under North Central Plateau Zone of Odisha are underutilized or degraded forest (246 million hectare), gullied and ravenous land (57 million hectare) and shifting cultivation (10.3 million hectare). These factors coupled with growing exhaustive crop of maize with intense tillage by the tribal farmers resulted poor quality soils, which ultimately not only affects optimum crop production but also the livelihood options and environmental quality of the region. Conservation agricultural production system (CAPS) with the components of minimum tillage, erosion resistant legume intercrop and a succeeding cover crop is thought up to be the best possible option for this tract for maintenance of the quality of agro-ecosystem sustainably.

Studies on conservation agriculture in sloppy, erosion prone hilly tracts are scanty. Keeping these facts in view, a field experiment has been initiated at Regional Research Technology Transfer Station, Kendujhar under North Central Plateau zone of Odisha during 2011-12 with the following objectives

Objectives

The objectives of the study is to assess the impact of the maize based conservation agriculture production system (CAPS) involving tillage practices (minimum tillage and conventional tillage) and cropping systems (maize sole and maize cowpea intercrop, both with or without follow up cover crops) before and at the end of the 2nd cropping cycle (2012-13) on some basic soil attributes as follows:

1. Determination of soil BD and water stable aggregates
2. Monitoring the pH , EC and organic carbon status of the soils
3. Determination of CEC, exchangeable bases and base saturation percentage of the soils
4. Monitoring the available indices *viz*. N,P and K of the soils
5. Monitoring the microbial attributes *viz*. population of bacteria, actinomycetes and microbial biomass carbon (MBC) of the soils
6. Assessing the impact on Maize Equivalent Yield (MEY)

REVIEW OF LITERATURE

The earlier research findings relevant to the present study “Assessment of maize based conservation agriculture production system (CAPS) on soil health in the hilly terrains under North Central Plateau Zone of Odisha” have been thoroughly reviewed and presented in this chapter under the following heads.

2.1 Conservation Agriculture Production System (CAPS), Definition, Principles and Importance.

2.2 Impacts of Conservation Agriculture Production System (CAPS) on soil health

2.2.1 Soil physical properties
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2.2.3 Soil microbial properties (population of bacteria, actinomycetes and microbial biomass carbon)

2.3 Conservation Agriculture Production System (CAPS) -Yield

2.1 Conservation Agriculture Production System (CAPS), Definition, Principles and Importance.

2.1.1 Definition of conservation agriculture

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).

"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 ;Uri, 1999).

2.1.2 Principles of conservation agriculture

Conservation agriculture makes use of soil biological activity and cropping systems to reduce the excessive disturbance of the soil and to maintain the crop residues on the soil surface in order to minimize damage to the environment and provide organic matter and nutrient.

Conservation agriculture production system is characterized by three principles which are linked to each other (FAO, 2010), namely:

1. Continuous minimum mechanical soil disturbance, mainly through direct seeding = No-tillage

2. Permanent organic soil cover, organic matter supply through the preservation of crop residues and cover crops = Mulching and Cover cropping

3. Diversification of crop species grown in sequence or associations for biocontrol and efficient use of the soil = Rotation

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 seedbed preparations after harvesting the previous crop (Calegari, 2008).

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).

Sustainable soil management can be practiced through conservation tillage (including no-tillage), high crop residue return, and crop rotation. (P. R. Hubbs, K. Sayre, and R. Gupta,2008)

2.1.3 Importance of conservation agriculture

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).

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 (Derpsch, 2003; Hubbs, 2007; Hubbs *et al.*, 2008).

Conservation Agriculture can support intensification of agricultural production in the face of a shrinking land base without compromising soil quality reducing production per unit of available water (FAO,2007).

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 (Uri *et al*.1998; Wang and Gao, 2000)

2.2 Impacts of Conservation Agriculture Production System (CAPS) on soil health

Doran and Parkin (1994), Doran and Safley (1997) initially distinguished between “soil quality” and “soil health” before inclusively using the term “soil health” and defining it as “the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, promote the quality of air and water environments, and maintain plant, animal and human health”

However, the general perception of a healthy or high-quality soil is one that adequately performs functions, which are important to humans, such as providing a medium for plant growth and biological activity, regulating and partitioning water flow and storage in the environment and serving as an environmental buffer in the formation and destruction of environmentally hazardous compounds.

Reeves (1997) noted that “SOC is the most often reported attribute from long-term agricultural studies and is chosen as the most important indicator of soil quality and agronomic sustainability because of its impact on other physical, chemical and biological indicators of soil quality”.

For example, the humic fraction is considered the principal pool in contributing to the soil’s CEC, whereas soil structure is provided and maintained by both the humic and particulate organic carbon (POC) fractions. Here, the POC fraction plays a greater role in sandy soils as a means of physically binding particles together In turn, this means that with an increase in SOC content, there is increased aggregation and decreased D_b, which tend to increase the total pore space as well as the number of small pore sizes (Haynes and Naidu, 1998).

Over a long period, improved organic matter under the practice of Conservation Agriculture promoted good soil structure and macro-porosity. Water infiltrates easily, similar to forest soils (Machado, 1976).

Tillage and residue management increased soil profile water content. (Nicou and Chopart, 1979) Unger (1991) and Bruce *et al.* (1995) reported that soil nutrients become stratified when no-till management is employed.

Cover crop residues remaining on the surface can reduce evaporation, thus conserve soil moisture, lower soil surface temperatures, provide a certain degree of weed control, and minimize erosion (Liebl *et al.*, 1992).

Reducing tillage affects several aspects of the soil. With time, conservation tillage improves soil quality indices (Dick, 1983; Lal *at al*., 1998), including soil organic C storage (Dick, 1983; Lamb *at al*., 1985; Unger, 1991; Bruce *et al*.,1995; Potter *et al*., 1998).

Conservation tillage is an effective practice to control soil degradation on intensively farmed cropland (Larney and Kladivko, 1989; Grant and Lafond,1993) and to increase soil water storage (Dao, 1993).

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

No-tillage is a sustainable cropping management system that protects soil, water, air, and biodiversity (Hubbs, P.R.; Sayre, K.; Gupta, R, 2007; Campbell, C.A.; McConkey, B.G.; Zentner, R.P.; Dyck, F.B.; Selles, F.; Curtin, D.,2006, Calegari, A.; Hargrove, W.L.; Rheinheimer, D.D.; Ralisch, R.; Tessier, D.; de Tourdonnet, S.; Guimaraes, M.D. *Agron. J.* 2008).

Soils managed using reduced tillage generally have more surface plant residues, higher moisture content, and better structure and aggregation compared to soils managed under Conventional tillage. (Reeves 1997)

Crop residues left on the soil surface lead to improved soil aggregation and porosity, and an increase in the number of macro-pores, and thus to greater infiltration rates. On bare soil, runoff and thus soil erosion is greater than when the soil is protected with residue cover (Ruedell, 1994).

No tillage retained the highest moisture followed by minimum tillage, raised bed and conventional tillage in inceptisols under semi- arid regions of India. (Sharma *et al.*, 2011).

Karlen *et al.* (1994) showed that normal rates of residue combined with zero-tillage resulted in better soil surface aggregation, and that this could be increased by adding more residues.

Surface (0–30 cm) soil in a no-till system was shown to contain more moisture and to be cooler than a comparable plough tillage soil (Doran *et al.,*1998).

Conservation tillage can usually lead to greater accumulation of surface nutrients, compared to traditional tillage, with soil ploughing (Franzluebbers and Hons, 1996; Holanda *et al.*, 1998).

Residue retention and direct seeding have a major influence on improving water infiltration, organic matter content and fertility of a soil (Wall,1999).

Bissett and O'Leary (1996) showed that infiltration of water under long term (8–10 years) conservation tillage (zero and subsurface tillage with residue retention) was higher compared to conventional tillage (frequent ploughing plus no residue retention) on a grey cracking clay and a sandy loam soil in south- eastern Australia.

No-tillage practices featuring residue cover and less soil disturbance have been shown to reduce runoff by 52.5% and reduce erosion by 80.2% compared to traditional tillage (Wang, 2000). Landers (2001) concluded an improvement of the infiltration capacity under NT farming.

Trials conducted in the higher potential areas of Zimbabwe between 1988 and 1995 indicated that mulching significantly reduced surface runoff and hence soil loss (Erenstein, 2002).

Experiments conducted by *Liu (2004)* showed that conservation tillage systems can increase organic matter, nitrogen, phosphorus, and potassium in the topsoil layer.

Luo *et al.* (2005) reported that conservation tillage can improve soil physical properties and soil fertility in northern China.

Bescanca *et al.* (2006) reported that Conservation tillage leads to positive changes in the physical, chemical properties of a soil.

Bolliger *et al.* (2006) observed that positive changes on soil physical and chemical properties occur only after several years of practicing conservation agriculture. NT has positive effects on soil properties, yields and prevents erosion (Derpsch, 2006).

Conservation agriculture improve soil quality such as improved sequestration of organic carbon and improved soil fertility reported by (Hobbs and Gupta, 2004).

2.2.1 Soil physical properties

2.2.1.1 Bulk density

Bulk density is related to natural soil characteristics such as texture, organic matter, soil structure (Chen *et al*., 1998) and gravel content (GC) (Franzen *et al*., 1994)

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 5cm soil layer.

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.

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 SBDs for the native soil is likely due to more aggregation and higher litter content at the soil surface. The higher SBDs 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 SBDs 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)

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 mouldboard 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 mouldboard 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.

Hernanz *et al.*(2002) found significantly lower bulk density under minimum tillage than conventional tillage from 0-10cm with cereal monoculture 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.

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.

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.

2.2.1.2 Water stable aggregate

Several researchers 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 (Mikha and Rice, 2004).

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; Blevins and Frye, 1993).

Six *et al.* (2000b) and Jacobs *et al.* (2009) found for 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.

In contrast, conventional tillage (CT) disrupts macro-aggregates and formerly incorporated Corg 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 macroaggregates (Roberson *et al*. 1991 ; Angers *et al*. 1992). Macroaggregation, in turn, may increase the proportion of labile organic C that is physically protected from microbial decomposition (Boehm and Anderson 1997)

It has been 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 macroaggregates and a gain of C-depleted microaggregates However, this decrease in macroaggregates cannot explain the total C loss associated with tillage. The increased macroaggregate turnover under CT is a primary mechanism causing decreases of soil C. Macroaggregate formation and degradation (i.e. aggregate turnover) is reduced under NT compared to CT and leads to a formation of stable microaggregates in which carbon is stabilized and sequestered in the long term(Six *et al.*, 2000).

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 Corg Water-stable macro-aggregates were enriched in younger organic material and have faster turnover times than micro-aggregates (Andruschkewitsch *et al.*, 2013).

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 (Heshmati *et al*., 2011).

The study of Li and Pang (2010) 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, G.L. and X.M. 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) & 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 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. , Castro Filho *et al.* (2002).

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).

2.2.2 Soil chemical properties

2.2.2.1 Soil reaction (pH)

Soils under NT practice 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).

Increase in soil organic C and N and a slight pH decline in the seed zone under conservation agriculture practices improves the soil quality (Bessam and Mrabet, 2003; Mrabet *et al.*, 2001a, 2001b).

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 atleast partially have had an acidifying effect. (Thomas *et al.*, 2007).

2.2.2.2 Organic carbon and organic matter

On a Vertisol 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 (Lixisol) (29% clay).

The SOM increases resulting from conservation tillage are attributed to the greater straw input and reduced biological oxidation associated with less soil disturbance by tillage (Chan *et al.*, 2002).

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 C_{org} from decomposition and thus higher C_{org} stocks in arable soils. In contrast, conventional tillage (CT) disrupts macro-aggregates and formerly incorporated C_{org} is exposed to microbial decomposition

When no tillage was practiced for 7 years continuously in the slopy 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 (D. Plaza-Bonilla *et al.,* 2013).

Studies conducted under a wide range of climatic condi-tions, 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).

Significant increases in soil N, organic C and SOM fraction was found with no-tillage system, while conventional tillage had deleterious impact on soil microbial biomass and also reduced SOC. [Wang, Y.; Tu, C.; Cheng, L.; Li, C.; Gentry, L.F.; Hoyt, G.D.; Zhang, X.; Hu, S., 2011]

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).

Bayer *et al.* (2000) stated that minimum tillage is a promising strategy to maintain or even increase soil organic carbon by minimizing loss of organic matter. He said that a no-till system (NTS) is a soil management technique that reduces soil disturbance, increases soil organic matter (SOM) accumulation and can increase crop yields.

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

Six *et al*. (2002) concluded that there is an increase in soil organic matter after doing a literature review about soil organic matter dynamics in tropical and temperate countries under the NT system. He concluded that in the upper 40 cm the soil organic matter increases after 6-8 years.

Balota *et al.* (2004) showed that in Brazil in a 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 reported that addition of crop residues in combination with minimum tillage can yield attainable carbon accumulation rates up to 0.36Mg 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.

2.2.2.3 Available nutrients (N, P and K)

When NT is associated with a crop rotation with more than one crop per year and fertilizer applications, it may lead to a higher input of residues and nutrients. It is possible that NT, which is associated with the maintenance of plant residues in the soil surface, caused improved P cycling, leading to an increase in available P stocks with increasing time under NT. Under NT, improved nutrient cycling due to higher crop residue inputs, periodic fertilizer application and the soil acidity correction associated with lower nutrient losses could be responsible for the increase in soil nutrient stocks, especially in NT. CEC increased simultaneously, indicating an increased proportion of base cations at the SOM exchange sites under NT.(João Luís Nunes Carvalho; Carlos Eduardo Pelegrino Cerri; Brigitte Josefine Feigl; Marisa de Cássia Píccolo; Vicente de Paula Godinho; Uwe Herpin5; Carlos Clemente Cerri. 2009.)

Dalal *et al.* (1991) and Thompson (1992) recorded highest total N recorded with combination of NT, stubble retention and N fertilizer application on a Vertisol in southern Queensland. NT reduced total soil N loss compared to CT, as observed by Dalal (1992), possibly due to immobilisation as organic N from stubble retention and placement near the soil surface.

Greater soil NO_3-N accumulation in the top 30 cm depth under NT with stubble removed may have been due to less immobilization of N in the absence of stubble. Dalal (1989) and Radford *et al.* (1992) also found higher NO_3-N under NT when stubble was either burned or removed than when stubble was retained.

Significant increase in soil N, was found with no-tillage system, while conventional tillage had deleterious impact on soil microbial biomass and also reduced SOC. (Wang, Y.; Tu, C.; Cheng, L.; Li, C.; Gentry, L.F.; Hoyt, G.D.; Zhang, X.; Hu, S. 2011).

Total nitrogen in the surface soil (0-5 cm) in the Douglas-Daly experiment was 33% higher under no-tillage than under conventional tillage, and at Pinnerand it was 33% higher under no-tillage compared with reduced tillage.(Thiagalingam *et al.* 1994*)*.

Crops intercropped with legumes can improve soil nitrogen status *(*Chalk, 1998) when reducing till- age with crop residue retention conserved soil moisture and increased crop yields *(*Lal, 1989*)*.

Bayer *et al.* (2000) also pointed out that conservation tillage produced higher N content than MT, which was probably the cause of result the lowest soil organic matter losses (due to erosion and oxidation) and the highest addition of crop residues.

Dao (1993) stated that surface mulch reduce water losses from the soil by evaporation and also helps moderate soil temperature. This enhances available N especially in the surface layers.

Astier *et al.* (2006) and Govaerts *et al.* (2007c) observed a significantly higher total nitrogen under minimum tillage than conventional tillage in the highlands of Mexico. Similar results were obtained by Borie *et al.* (2006) and Atreya *et al.* (2006) in other agro-ecological regions.

Where crop residues are returned to the soil, an increase in P availability may occur by decreasing the adsorption of P to mineral surfaces (Ohno and Erich, 1997)

Standley *et al*. (1990) and Hunter and Cowie (1989) also found available P concentration to be greater in the surface soil layer (0–7.5 cm) under NT than under CT on a Vertisol in central Queensland.

Greater available P values in the upper layers of NT soils are apparently due to reduced mixing of fertilizer P, possibly increased quantities of organic P, and shielding of P adsorption sites (Schomberg *et al*., 1994).

Olsen's P at 0–5 cm increased under no tillage and reduced tillage systems due to the effect of higher SOM accumulation.(Wang *at al*., 2008).

Franzluebbers and Hons (1996), Du Preez *et al*. (2001) reported higher extractable phosphorus levels in minimum tillage than in tilled soil largely due to reduced mixing of the phosphorus fertilizer with the soil leading to lower P- fixation. Surface accumulation of phosphorus, magnesium, zinc and copper and a lower rate of acidification were reported under no-tillage (Lal 1989*)*.

Hunter and Cowie (1989) also found greater concentration of K in the top 5 cm of soil under NT than under CT on a Vertisol in central Queensland.

Surface 0–5 cm layer of the plots under NT and ZT exhibited similar stocks of K with plots under CT showing the minimum value. In general, effects of tillage practices on available K were less than that of soil depth and this supported results presented by others (Lal *et al*., 1990; Asghar *et al*., 1996; Thomas *et al*., 2007).

Most of the nutrients in SOM are derived from the mineralisation of SOM and become available for plant uptake during decomposition and for this reason, the particulate organic matter fraction is often considered the most important proportion of SOM in providing nutrients to plants (Wolf and Snyder, 2003).

Qin *et al*. (2007) demonstrated that soil organic matter and available P and K down to 10 cm depth were up to 10% higher in no-tillage than traditional tillage after 4 years in semiarid Inner Mongolia.Qin *et al.* (2007) in Inner Mongolia recorded that after 4 years the SOM, total N and Olsen's P to 5 cm depth under no-tillage was only 17, 8 and 1% more than for traditional tillage, respectively.

Follett and Peterson (1988) observed either higher or similar extractable potassium levels in minimum tillage compared to mouldboard tillage. Standley *et al.* (1990) also observed higher extractable potassium levels in top soil when sorghum stubble was retained than when the stubble was removed.

Franzluebbers and Hons (1996) reported that minimum tillage conserves and increases availability of nutrients like potassium near the soil surface where crop roots proliferate.

2.2.2.4 CEC, exchangeable bases and base saturation

Higher SOC in MT and dominance Ca^{++} in the exchange complex is related to increased CEC and BS in these soils.Most studies show a linear correlation between SOC and CEC . SOM contributes mostly to an increase in the variable-charge CEC (CEC_v). Functional groups (e.g. carboxylic acids) of SOM are believed to be one of the main contributors to CEC_v as they provide negatively charged sites (Odaes *et al*., 1989).

Positive Correlations between C stock and CEC in NT1 (r=0.88**), NT3 (r=0.77**) and C stock with Base Saturation in NT1 (r=0.86*) and NT3 (r=0.77*) in Typic Hapludox soils of Brazil indicates the contribution of SOM to the CEC and exchangeable cations (J. L. N. Carvalho *et al*, 2009) .

Sidiras and Pavan (1985) found increased available calcium, magnesium concentrations from surface to 60 cm depth in both Oxisol and Alfisol in Brazil under minimum tillage. Similar results have also been observed by Edwards *et al.*, (1992) and Motta *et al.*,(2002).

Eshetu *et al*. (2004) also noted that in forest soils of Philippines, there was a strong linear correlation between total CEC, SOC content and exchangeable and total Ca and that SOC content accounted for most of the variability : CEC = 144 + 18.3 and SOC ($R^2 = 0.93^{**}$).

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

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 . (Balota, E.L., A.C. Filho, D.S. Andrade, and R.P. Dick. 2004.)

Roldan *et al*. (2003) showed that 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 (MBM). They conclude that NT is a sustainable technology

The effect of tillage practices on microbial attributes has been studied by Mathew *et al.* (2012) in silt loam Rhodic Paleudults of Alabama, USA. The observed changes in soil microbial communities can be attributed to favourable physical and chemical conditions under the no-tillage system for microbial activities. In no-till soils, the accumulation of crop residues on the soil surface results in enrichment of soil organic matter in the surface layer and as a consequence increased abundance of microorganisms.

Studies 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 microbial biomass, the maximum effect on microbial biomass being recorded in MTCR, either alone or in combination.

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

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 *at al*., 2006).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).

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, Walley, and Germida, 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; Müler *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, M.; Leifeld, J.; Kainz, M.; Kogel-Knabner, I.; Munch, J.C., 2002).

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, V.O.M R.P. Zentner. and C.A. Campbell, 2005).

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.

2.2 Conservation agriculture production system (CAPS) - Yield

In the Douglas-Daly and Katherine districts of the Northern Territory, dryland crops of maize, sorghum, soybean and mungbean sown using no-tillage with adequate vegetative mulch on the soil surface have produced yields comparable with, or higher than (especially in drier years), those obtained under conventional tillage (Thiagalingamb, Dalgliesh, Gouldr , McCownB, CogLeD and Chapman, 1996)

Tarkalsona *et al.* (2006) reported that application of NT system in a long term period led to indicative improvement in wheat productivity in comparison with CT system.

Shams-Abadi and Rafiee (2007) resulted that using MT, leads to increase wheat production.

At Pinnarendi in a similar environment under semi- commercial conditions, but where surface mulch was apparently not sufficient to reduce soil temperature and weeds were poorly controlled, yields of peanut, maize and sorghum were lower under no-tillage than under reduced tillage (Cogle *et al.*, 1995)

Higher yields obtained in conservation agriculture through better water use and improved soil quality. (Mrabet, 2000).

Lal (1991) reported from two studies of 8 years or more that larger maize grain yields were maintained with a mulch based no tillage system than with a plough based system.

◆

MATERIALS AND METHODS

A field experiment on "Assessment of Maize based conservation agriculture production system (CAPS) on soil properties in the hilly terrains under North Central Plateau Zone of Odisha" was initiated during 2011-12 under OUAT-University of Hawaii, USA collaborative project SMARTS (Sustainable Management of Agricultural Resources For Tribal Societies) at Regional Research and Technology Transfer Station (RRTTS), OUAT, Kendujhar. The materials used and methods followed in this study are discussed under the following heads.

3.1 MATERIALS

3.1.1 Experimental site

The Experimental site in the Regional Research and Technology Transfer Station, OUAT, Kendujhar which is located at 'B' block (upland) comes under Agro Ecological Sub-region (AESR) 12.3 and North Central Plateau Agro-climatic zone of the state.

3.1.2 Location

It extends between 85^{o} 34' 30.61" E longitude and 20^{o} 50' 55.38" N latitude and situated at an altitude of 499 m above MSL.

3.1.3 Landforms: Piedmont plain.

3.1.4 Geology

The soils of the region are developed from parent material of Colluvial-alluvial deposits (Deposition in different erosional cycles from the hills).

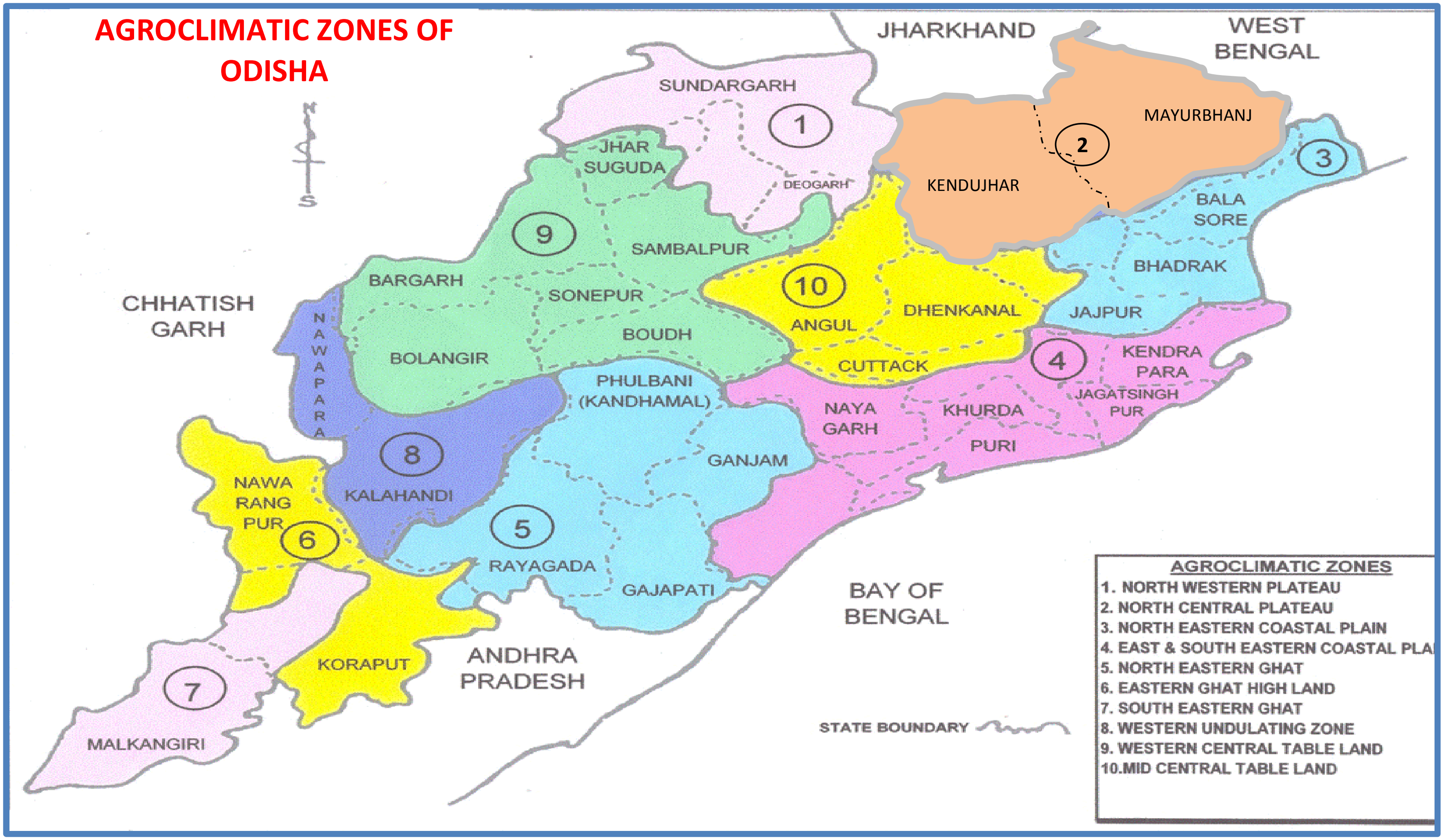


Plate 1. Agroclimatic zones of Odisha

3.1.5 Physiography : Gently sloping upland (1-3 % slope)

3.1.6 Natural vegetation

The natural vegetation of this area is tropical moist deciduous forest. The major tree species of this region are *Ceiba pentandra, Dalbergia sisoo, Casia tora, Syzygium cumini, Azadirachta indica* and *Phoenix species.*

3.1.7 Climate and weather condition

Meteorological data (mean of 10 years) recorded at the RRTTS, Kendujhar from the period 2001-2010 presented in Table 3.1 revealed that the mean annual rainfall at the centre is 1527.26 mm. The rainfall is monsoonic and unimodal. August is the rainiest month and January the driest month with the mean rainfall of 286.96 and 4.36 mm, respectively. April is the hottest (37.50 ^{o}C) and January is the coolest (11.73 ^{o}C) month. The relative humidity varies from the minimum of 34.72% in March to 87.53% in September. The general climate of the region is hot and moist sub humid.

Table 3.1 Mean monthly meteorological data (2001-2010) at Kendujhar

Month	**Mean monthly rainfall (mm)**	**Mean monthly temperature (^{o}C)**		**Mean monthly relative humidity (%)**	
		Max.	**Min.**	**Morning**	**Afternoon**
January	4.36	27.23	11.73	65.91	48.38
February	28.22	29.56	14.87	65.47	39.93
March	27.68	34.33	18.91	59.43	34.72
April	38.02	37.50	22.58	53.38	35.86
May	115.44	36.63	23.91	63.27	48.21
June	276.52	33.57	24.11	75.13	71.06
July	280.42	30.20	23.46	83.98	81.04
August	286.96	30.09	23.25	68.4	84.61
September	275.5	30.00	22.59	87.53	85.23
October	65.14	30.45	19.53	75.83	70.52
November	38.54	28.78	16.41	72.99	64.98
December	5.90	26.70	12.25	70.72	58.83

Table 3.2 Mean monthly meteorological data during the cropping season (April 2012- March 2013)

Month	Rain fall (mm)	No. of rainy days	Temperature(^oC)		
			Max.	Min.	Average
April	45.9	7	37.5	19.7	57.2
May	20.2	4	39.8	25.0	32.4
June	165.8	12	36.1	25.8	30.9
July	172.4	26	30.9	23.9	27.4
August	283.6	22	30.1	23.0	26.5
September	197.8	18	30.4	20.7	25.5
October	98.0	11	29.8	16.3	23.1
November	29.3	6	27.7	12.8	20.2
December	0.8	3	27.4	10.4	18.9
January	9.0	2	26.6	10.6	18.6
February	15.9	4	28.7	13.5	21.1
March	0.3	1	27.7	14.2	20.9
Total	1039.0	116	-	-	-

The prevailing weather during the crop growing season has been presented in monthly mean wise in Table 3.2 and depicted in Fig 3.1 and 3.2. The highest rainfall was in August (283.6mm) and the lowest in March (0.3 mm).The mean monthly maximum temperature was the highest in May (39.8 ^oC) and lowest in December (10.4 ^oC).

3.1.8 Cropping history

The crops grown in the experimental site during different growing season for the preceding four years are represented in Table 3.3

Table 3.3 Cropping history of the experimental plot

Year	Kharif	Rabi	Summer
2008-09	Maize	Onion	Fallow
2009-10	Maize	Tomato	Fallow
2010-11	Black gram	Mustard	Fallow
2011-12	Maize + cowpea (Experimental)	Mustard & horse gram(Experimental)	Fallow
2012-2013	Maize + cowpea (Experimental)	Mustard & horse gram(Experimental)	Fallow

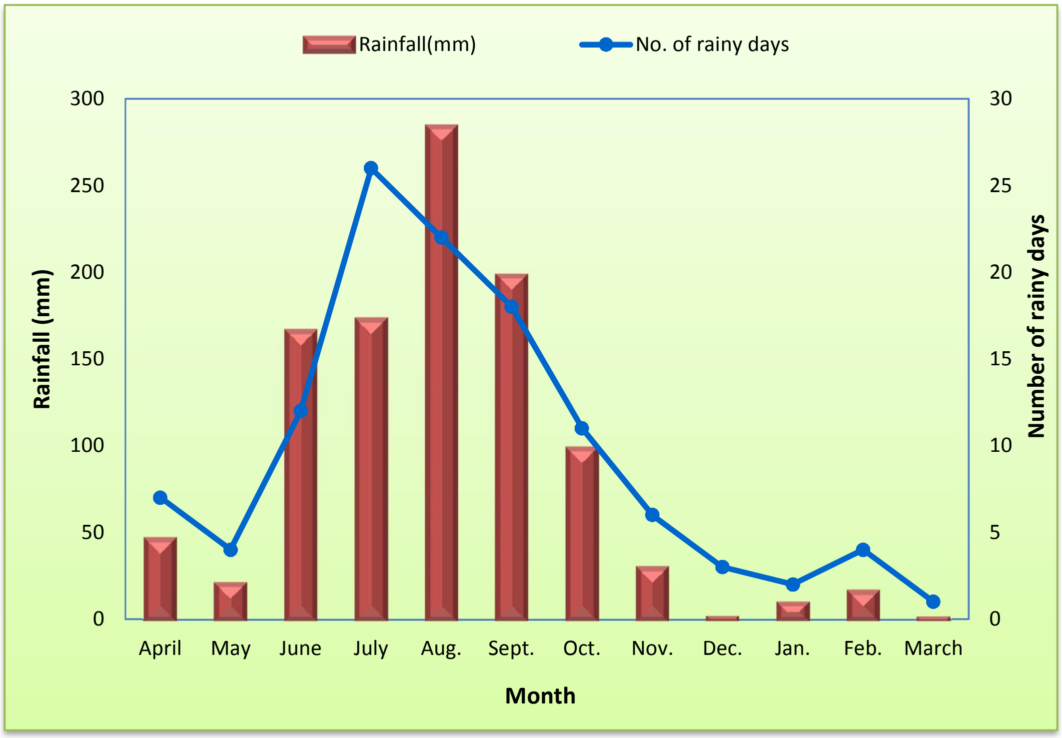


Fig.3.1 Mean monthly rainfall and rainy days during the cropping season (April 2012 – March 2013).

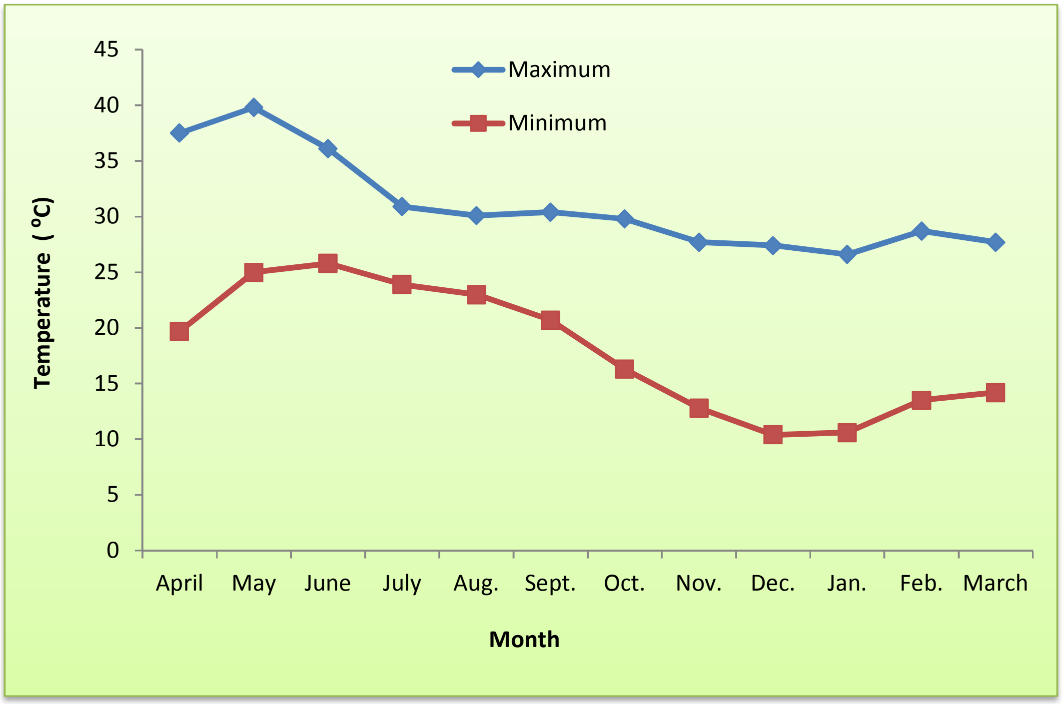


Fig.3.2 Mean monthly temperature data during the cropping season (April 2012 – March 2013)

3.1.9 Study of soil characteristics

Based on soil heterogeneity and variation in land forms, representative soil profiles of dimension 1.2 m x 1.2 m x 1.5 m were exposed. The morphological features of soil pedons were studied and soil samples from different genetic horizons were collected for analysis of various parameters in laboratory.

3.1.9.1 Soil drainage : Moderately well drained**.**

3.1.10 Experimental details

The experiment was designed to study the effect of different components of CAPS (tillage, intercrops and cover-crops) on soil health.

3.1.10.1 Treatment details

The treatment details are given in Table 3.4 and the layout plan is given in Figure 3.3 .The design of the experiment is split-plot with three replications. The four treatments under main- plot (Kharif season) were combination of two tillage practices (Conventional and Minimum tillage) and two intercropping systems (Sole Maize and Maize + Cowpea intercropping. The sub-plot (Rabi season) treatments were three cover crops i.e., Fallow (NCC), Horsegram (H) and Mustard (M).

Table 3.4. Treatment details

Treatment	**Descriptions**
Main plot (kharif season0	
CT-M	Conventional tillage with sole maize
CT-M+C	Conventional tillage with maize+cowpea
MT-M	Minimum tillage with sole maize
MT-M+C	Minimum tillage with maize+cowpea
Sub plot (Rabi season)	
NCC	No cover crop
H	Horse gram as cover crop
M	Mustard as cover crop

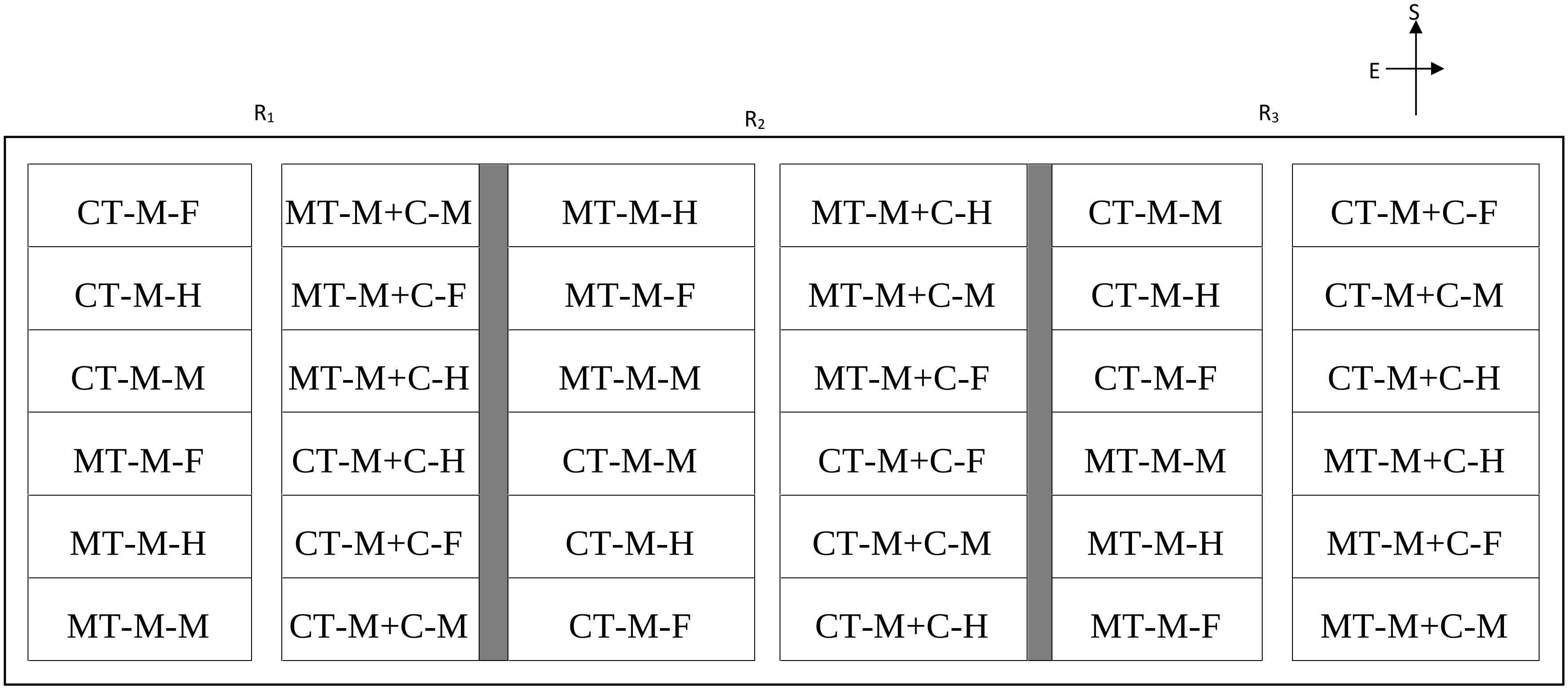
STUDY AREA WITH PROFILE SITE AND EXTERNAL LAND FEATURES

Plate 2 Study area with profile site and external land features

Plate 3. Representative pedon of the experimental site

Plate 4. Other site features around the pedon site

Plate 5 & 6 Many medium to coarse lime nodules and carbonate coats in the B horizon



CT-M-F	MT-M+C-M	MT-M-H	MT-M+C-H	CT-M-M	CT-M+C-F
CT-M-H	MT-M+C-F	MT-M-F	MT-M+C-M	CT-M-H	CT-M+C-M
CT-M-M	MT-M+C-H	MT-M-M	MT-M+C-F	CT-M-F	CT-M+C-H
MT-M-F	CT-M+C-H	CT-M-M	CT-M+C-F	MT-M-M	MT-M+C-H
MT-M-H	CT-M+C-F	CT-M-H	CT-M+C-M	MT-M-H	MT-M+C-F
MT-M-M	CT-M+C-M	CT-M-F	CT-M+C-H	MT-M-F	MT-M+C-M

Fig. 3.3 Layout plan of the experiment

Experimental Design: Split plot
Number of treatments: 12
Number of replication: 03
Individual plot size: 7.2m×3.2m

Main plot (Kharif)

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

Sub plot (Rabi)

F-Fallow
M-Mustard
H-Horse gram

3.1.10.2 Crop details

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

Crops	Variety	Duration	Date of sowing	Date of harvesting
Maize	Pioneer 30R-77	90-100 days	27.6.2012	28.9.2012
Cowpea	Utkal manika	75 days	27.6.2012	5.9.2012
Horsegram	Athagada local	100 days	11.10.2012	18.1.2013
Mustard	Anuradha	75-80 days	11.10.2012	30.12.2012

3.1.10.3 Field preparation

In kharif season, primary tillage was done and field was laid out initially .Then the plots with conventional tillage were given secondary and tertiary tillage.

3.1.10.4 Manure & Fertilizers

The kharif season crops were applied with FYM at an uniform rate of 5t/ha. The recommended chemical fertilizers applied to Maize, Cowpea, Mustard and Horse gram were indicated in the Table 3.5. The fertilizer applied for Maize + Cowpea was based on additive series, taking into consideration 100 per cent plant population of maize and 50 percent plant population of cowpea. The fertilizers were applied in line basally for the crop except maize where nitrogen was applied in three split viz. 25% basal, 50% at first earthing up and rest 25% at second earthing up stage.

Table 3.5 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
Horse gram	20	40	20

3.1.10.5 Sowing, Seed rate and Spacing

During kharif season, for sole maize, spacing of 60 cm x 30 cm was adopted for which a seed rate of 15 kg ha^{-1} was required. But, maize + cowpea as intercrops were sown in 1:1 ratio at a uniform spacing of 30 cm. The spacing adopted for cowpea was 15 cm 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 percent of normal sole cowpea. In Minimum tillage practice, Maize and Cowpea seeds were sown by dibbling in line. In Conventional tillage practice, line sowing of seeds were done and the seeds were covered with soil after sowing. A seed rate of 7.5 kg and 25 kg ha^{-1} was required for mustard and horse gram, respectively.

3.2 METHODS

3.2.1 Collection and processing of soil samples

The morphological features of soil pedons were studied and soil samples from different genetic horizons were collected for analysis of various parameters in laboratory. The soil samples were collected from a depth of 0-10cm from each treatments at the end of second cropping cycle. The samples were dried under shade, crushed, sieved through 2 mm sieve and were preserved in polythene with proper label for analysis.

3.2.2 Methods of soil analysis

The soil samples of the representative pedon and experiment were analysed for different physical, chemical and biological properties following the standard methods.

a) Physical analysis

3.2.2.1 Soil colour

The colour of moist soil samples from horizons of representative pedons was determined in the field by matching the colour with Munsell Soil Colour Chart.

3.2.2.2 Bulk density

The bulk density of the soils from the representative pedon and the experiment was analyzed by core sampler method (Dastane, 1972).

3.2.2.3 Mechanical analysis

The particle size distribution i.e., the percentage of sand, silt, clay was determined by International Pipette Method with the help of Bouyoucos hydrometer following the standard procedure (Piper, 1950). Fifty gram of soil was taken in a beaker and 15 ml of 10% sodium hexametaphosphate was added followed by 200 ml of distilled water and was stirred for 15 minutes with a mechanical stirrer. The content was transferred to a 1000 ml measuring cylinder and the volume was made up to 1 litre. At 5 minutes and 5 hours the temperature and hydrometer readings were taken. Percentage sand, silt, clay were calculated and the textural class was determined using international triangular diagram.

3.2.2.4 Water stable aggregates (WSA)

The WSA in the soils were determined using 250 µm and 53 µm mesh sieve by wet sieving method (Kemper and Rosenau,1986). Total percentage of WSA, percentage of WSA greater than 250µm and percentage of WSA between the size of 53µm and 250µm were found out.

b) Chemical analysis

3.2.2.5 Soil pH

As suggested by Jackson (1973) the pH of soil samples of the representative pedon as well as experiment was determined in 1:2.5 soil:water suspension after equilibration for half an hour with intermittent stirring using the glass electrode digital pH meter, “SYSTRONICS’ (model M.K.VI).

3.2.2.6 Electrical conductivity (EC)

The electrical conductivity of soil samples of the experiment was measured in 1:2.5 soil water suspensions using “SYSTRONICS” conductivity meter (model 306).

3.2.2.7 Organic carbon

The organic carbon of soils of representative pedon and experiment was determined by modified Walkley and Black’s rapid titration method (Jackson, 1973) using Ferroin indicator (Chopra and Kanwar, 1986).

3.2.2.8 Cation exchange capacity(CEC)

The cation exchange capacity of soils of representative pedon and experiment was determined (Chapman, 1965) by leaching with neutral normal NH_4OAc and distilling off the absorbed NH_4^+ into boric acid after washing out excess saturating solution by ethanol. The CEC of the leachate was estimated by titrating with standard acid using bromocresol green-methyl red indicator.

3.2.2.9 Exchangeable cations

Sodium and Potassium : Exchangeable sodium and potassium of the soils of representative pedon and experiment present in NH_4OAc leachate collected during CEC determination were determined by “SYSTRONICS” model 128 flame photometer.

Calcium and Magnesium

Exchangeable calcium and magnesium of the soils of representative pedon and experiment were determined by the method described by Page *et al.*,1982. Exactly 2.5g of soil along with 20 ml of neutral normal ammonium acetate solution was shaken for 30 minutes in a horizontal shaker. Then the sample was filtered and volume was made up to 50 ml. Five millilitre of extract were taken and 3ml of 10% NaOH, 10 drops of each of Hydroxyl amine hydrochloride, TEA (Triethanol amine) and Calcon indicator were added. Then the content was titrated against standard 0.01N EDTA (Ethylene Diamine Tetra Acetic Acid) as described by Jackson(1973). The Ca content was determined from the quantities of EDTA consumed during titration.

First (Ca^{++}+Mg^{++})% was determined by taking 5ml of aliquot. Then little distilled water, 15ml of NH_4Cl-NH_4OH buffer and 10 drops of each of the Hydroxyl amine hydrochloride, TEA, Potassium ferrocyanide were added. The content was gently heated and was made cool. Then 10 drops of EBT (Eriochrome Black-T) was added and titrated against standard 0.01N EDTA to turquoise blue end point as described by Jackson(1973). The Mg content was calculated by deducting Ca % from (Ca+Mg) %.

3.2.2.10 Free calcium carbonate($CaCO_3$)

Free carbonate as $CaCO_3$ equivalent was determined by “acid neutralization method” as per the procedure outlined by Page *et al.* (1982). Five grams of soil was treated with 5ml of 0.5 N HCl, heated and then cooled, added with 50 ml of distilled water. The unreacted acid was determined by titrating with 0.1 N NaOH using phenolphthalein indicator

3.2.2.11 Available nutrients

3.2.2.11.1 Available nitrogen

Available nitrogen of the soils of representative pedon and experiment was determined by alkaline potassium permanganate ($KMnO_4$) method (Subbiah and Asija, 1956).

Five gram of soil sample was taken in a 800 ml Kjeldahl flask and then 25 ml of 0.32% KMnO4 and 25 ml of 2.5% NaOH solution were added with some distilled water. Distillation was done by Kelplus Nitrogen Auto Analyzer and the distillate was collected at receiver tube in the 250 ml conical flask containing 20 ml boric acid (2%) with mixed indicator. The distillate was titrated against 0.02N H_2SO_4 to a pink colour end point. From the amount of H_2SO_4 consumed the amount of available nitrogen was calculated.

3.2.2.11.2 Available phosphorus

Available phosphorus of the soils of representative pedon and experiment was determined spectrophotometrically by Olsen's method (Olsen *et al.*,1954) using 0.5 N $NaHCO_3$ as extracting solution in 1:20 soil-extractant ratio as described by Page *et al.*(1982) .

Exactly 2.5 g of soil was added with 50 ml of Olsen's extractant (0.5N $NaHCO_3$) and was shaken for 30 minutes and filtered through Whatman No.1 filter paper. Five milliliter of aliquot was transferred to 25ml volumetric flask and was acidified to pH 5.0 with 5N H_2SO_4 followed by addition of 4ml of ascorbic acid solution. The volume was made up to 25 ml with distilled water and was shaken. Phosphorus concentration was determined by the help of spectrophotometer (SYSTRONICS-Model 106) at 882nm. Phosphorus concentration was calculated from standard graph prepared by taking known phosphorus concentration.

3.2.2.11.3 Available potassium

Available potassium of the soils of representative pedon and experiment was determined by extracting the soil with neutral normal ammonium acetate solution and estimated by "SYSTRONICS" digital flame photometer, model 128 (Page *et al.*, 1982). Five gram of soil was equilibrated with 25 ml of neutral normal ammonium acetate by shaking for 5 minutes. Then it was filtered by the help of Whatman No.1 filter paper and the potassium concentration in the filtrate was measured in a flame photometer after necessary dilution as described by Page *et al.*(1982).

c) Microbial analysis

3.2.2.12 Enumeration of soil microbial population

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 and spread over Nutrient Agar, Actinomycetes Isolation Agar and Potato Dextrose Agar for enumeration of bacteria, actinomycetes and fungi, respectively. The plates were incubated at 30°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.

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

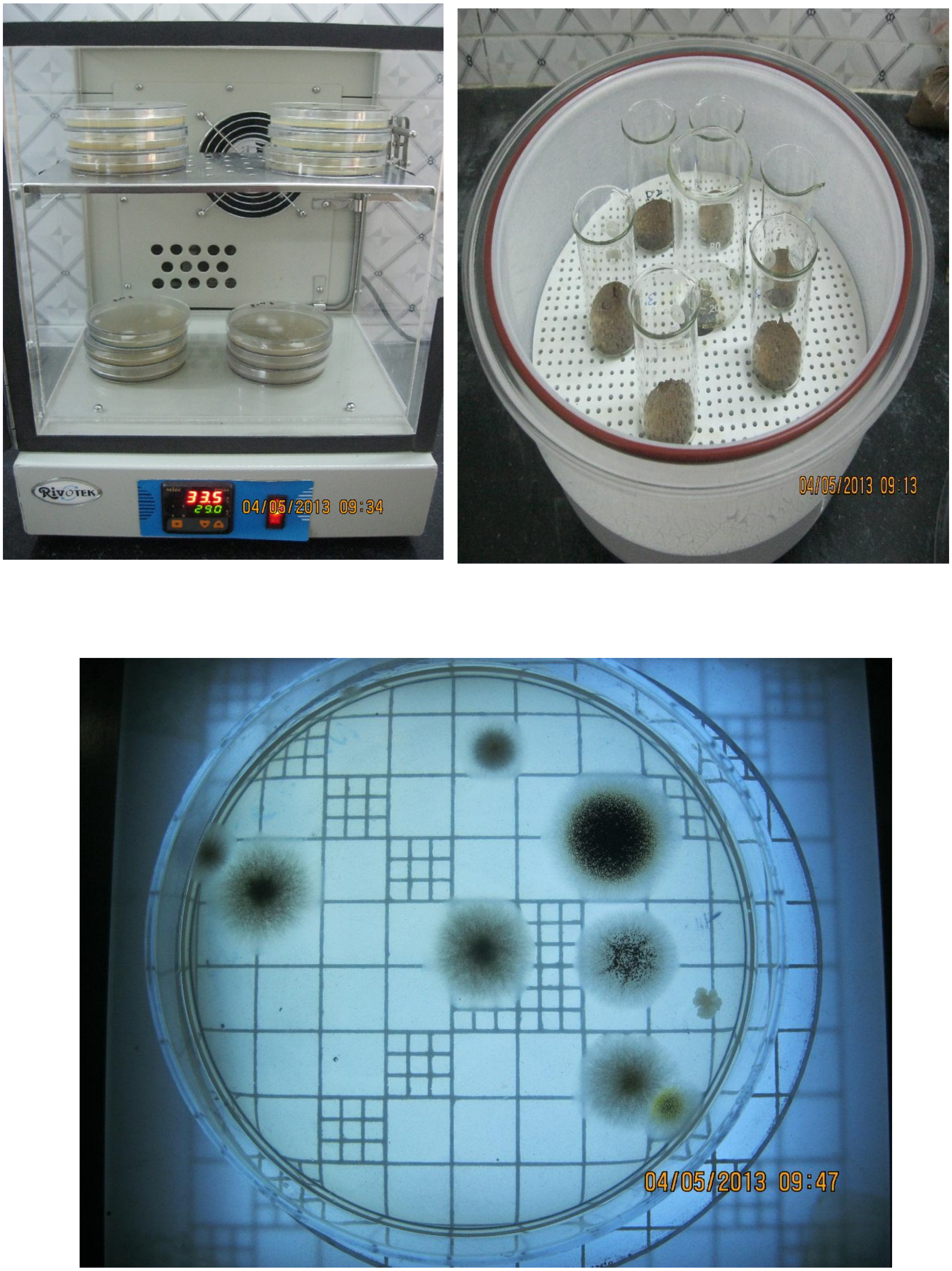


Plate 7. Soil fumigation and plate showing microbes

3.2.2.13 Soil microbial biomass carbon

Microbial biomass carbon was estimated employing fumigation and extraction procedure as described by Vance *et al.*,(1987). The process involved collection of filtrate using Whatman filter paper no.2 by shaking unfumigated soil (20 g) with 0.5 M K_2SO_4 for 30 minutes. 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 analyzed using the method of digestion titration. For digestion of organic carbon 10 ml of filtrate was transferred into a conical flask and 10 ml of $K_2Cr_2O_7$ followed by 20 ml 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, 25 ml distilled water and 5 ml, orthophosphoric acid were added to the digested material and titrated against 0.04 M Ferrous ammonium sulphate with Ferroin as the indicator.

Calculation

$$\text{Microbial biomass carbon} = \frac{\text{EC fumigated soil - EC of unfumigated soil}}{\text{Kc}}$$

where, EC = Extractractable carbon

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

3.2.2.14 Maize-equivalent yield

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 (mustard and horse gram).

3.2.2.15 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).

◆

RESULTS AND DISCUSSION

The impact of Conservation Agricultural Production System (CAPS) involving tillage methods and cropping systems (inter crop, cover crop) on soil health has been assessed after two cropping years in the present study. The characteristics of the soils from a representative pedon and some of the major soil physical, chemical and biological parameters significant for impact assessment of CAPS have been presented in this section.

4.1 CHARACTERISTICS OF THE PEDON SOIL

4.1.1 Morphological characteristics

The morphological soil parameters of the representative pedon are presented in Table 4.1. The soils are very deep (>160 cm) and the colour varies from reddish brown (7.5YR 4/4 M) in the surface to red ((2.5YR 5/6M) in the bottom layer. The soil structure varies from weak to strong, medium sub angular blocky and a textural variation is observed from the surface (scl) to down the depth (sl). Consistency varies from hard, firm, sticky and plastic in the surface to friable, moderately sticky and plastic in the sub surface layers. Many medium to coarse lime nodules and many distinct carbonate coats (strongly effervescent) are observed in the B horizon.

Table 4.1 Morphological soil characteristics of the representative pedon

Horizon	Depth (cm)	Description
Ap	0-13	Reddish brown (7.5YR 4/4 M), sandy clay loam, weak medium subangular blocky structure, hard, firm, sticky and plastic, common fine and medium pores, many fine roots, neutral (pH 7.2), clear smooth boundary.
Bw1	13-50	Brown (5YR 5/3M) sandy loam, moderate medium subangular blocky structure, friable, moderately sticky and slightly plastic, few fine roots, many medium lime nodules and many distinct carbonate coats (strongly effervescent), slightly alkaline (pH 7.7), gradual smooth boundary .
Bw2	50-122	Brown (7.5YR 5/4M) sandy loam, strong medium subangular blocky structure, friable, slightly sticky and slightly plastic, few very fine roots, many coarse lime nodules and many distinct carbonate coats(strongly effervescent), slightly alkaline (pH 7.6), gradual smooth boundary.
Bw3	122-160+	Red (2.5YR 5/6M), sandy loam, moderate medium subangular blocky structure, friable, moderately sticky and slightly plastic, few fine distinct reddish brown (5YR 4/3M) mottles, few fine lime nodules, slightly alkaline (pH 7.8).

4.1.2 Physical and chemical characteristics of the pedon soils

Some of the physical and chemical parameters of the soils from the representative pedon are given in Table 4.2 and 4.3.

The percentage of sand, silt and clay contents of the surface soils were 61.8, 16.6 and 21.6, respectively. A gradual increase in sand contents was observed up to a depth of 122 cm and there afterwards, it increased abruptly. The silt percentage was more or less same except the bottom layer (24.8%). An abrupt decrease in clay was noticed from the depth of 13 cm downwards to the bottom. Stratification was evidenced by wide variation in sand/silt ratio (2.41 to 4.49) between horizons. The BD of the soils ranged from 1.28 to 1.38 Mg m^{-3}.

The pH of the soils ranged from 7.23 in the surface to 7.81 in the depth range of 122-160+ cm. The organic carbon content of the surface horizon is 14.0 g kg^{-1} and it decreased irregularly with depth. The free $CaCO_3$ contents increased abruptly within the depth ranges of 13-50 cm (136.4 g kg^{-1}) and 50-122 cm (114.2 g kg^{-1}). The CEC of the surface layer is 23.88 c mol (p$^+$) kg^{-1} that decreased up to a depth of 122 cm and increased thereafter. The exchange complex of the soils is dominated with Ca^{++} followed by Mg^{++} and the soils are well saturated with bases (78.1-83.1%). The CEC/clay ratio of the soils varies from 1.11 to 1.36.

Table 4.2 Physical characteristics of the pedon soils

Horizon	Depth (cm)	Coarse Fraction (%)	Sand (%)	Silt (%)	Clay (%)	Textural class	Sand/ Silt ratio	BD (Mg m^{-3})
Ap	0-13	9.8	61.8	16.6	21.6	scl	3.72	1.28
Bw1	13-50	14.4	69.8	16.8	13.4	sl	4.15	1.35
Bw2	50-122	15.2	71.8	16.0	12.2	sl	4.49	1.38
Bw3	122-160+	8.8	59.8	24.8	15.4	sl	2.41	1.31

Table 4.3 Chemical characteristics of the pedon soils

Horizon	Depth (cm)	pH (1:2.5)	EC (dS m^{-1})	OC (g kg^{-1})	$CaCO_3$ (%)	CEC	Exchangeable Bases				BS (%)	CEC/ Clay
							Ca^{++}	Mg^{++}	Na$^+$	K$^+$		
						c mol (p$^+$) kg^{-1}						
Ap	0-13	7.23	0.34	14.0	1.8	23.88	12.80	5.64	0.29	1.12	83.1	1.11
Bw1	13-50	7.67	0.38	4.2	12.6	17.72	9.54	3.76	0.26	0.84	81.3	1.32
Bw2	50-122	7.59	0.39	3.9	10.4	16.56	8.72	3.34	0.24	0.64	78.1	1.36
Bw3	122-160+	7.81	0.40	5.3	2.2	20.14	11.20	4.38	0.29	0.72	82.4	1.31

4.2 SOIL PARAMETERS OF THE EXPERIMENT

4.2.1 Soil Physical Parameters

4.2.1.1 Bulk density (BD)

Tillage practices with different cropping system (sole/intercrop) affected the soil BD (Table 4.4, Fig. 4.1) significantly at the end of second cropping cycle. Practice of conventional tillage (CT) increased the BD in the tune of 0.03 units over the initial value of 1.24 Mg m^{-3} whereas it remained unchanged under MT. Imposition of cover crops (H, M) in the systems, however, did not influence the soil BD much as over NCC (1.27 Mg m^{-3}). The lowest BD of 1.22 Mg m^{-3} was recorded in the soils under MT-M+C-H.

Table 4.4 Soil BD (Mg m^{-3}) as influenced by different CAPS

Particulars	**NCC**	**CC (H)**	**CC (M)**	**Mean**
CT-M	1.30	1.31	1.31	1.31
CT-M+C	1.28	1.26	1.27	1.27
MT-M	1.26	1.24	1.25	1.25
MT-M+C	1.25	1.22	1.23	1.23
Mean	1.27	1.26	1.26	
Initial	1.24			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.011	0.007	0.015	0.013
CD (0.05)	0.04	NS	NS	NS

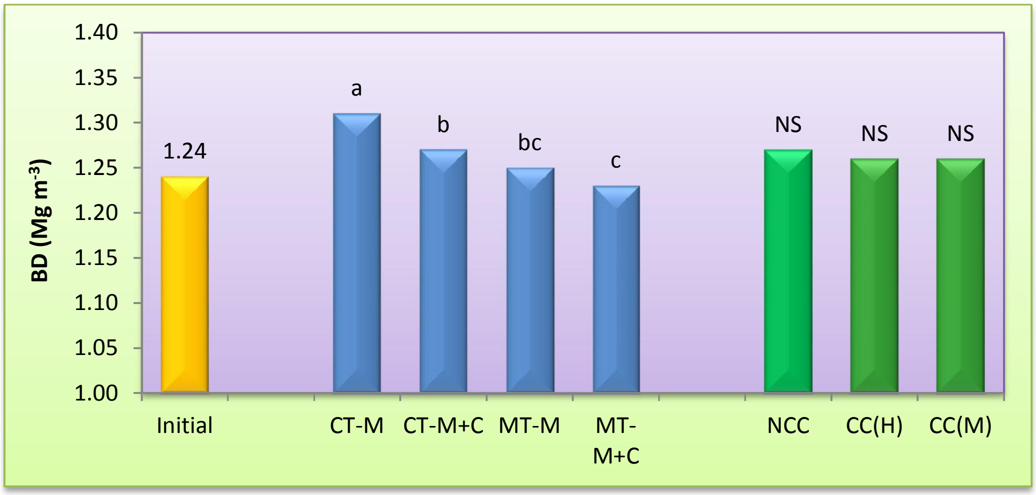


Fig. 4.1 Soil BD (Mg m^{-3}) as influenced by different CAPS. Treatments with same lower case letter within main plots or sub-plots were not significant at P = 0.05

4.2.1.2.1 Macro aggregates (>0.250 mm)

Soil organic matter plays the most vital role in aggregate formation. Significant changes in the percentage of water stable macro-aggregates (>0.250mm) were observed in the soils under different CAPS (Table 4.5a, Fig. 4.2). Continuous practice of CT reduced the macro-aggregates by 2.4% over the initial status (73.7%) as the maximum soil disturbances resulted to rapid decomposition of soil organic matter. Minimum tillage, on the other hand, enhanced the macro-aggregates by 8.7%, which was mostly due to accumulation and preservation of soil organic matter. The M+C inter crop showed significantly higher aggregates (+6.2%) over sole maize (74.2%) .The soils under cover crops did not show any pronounced changes in the contents of water stable macro-aggregates.

Table 4.5a. Effect of various CAPS on water stable macro - aggregates (>0.250 mm) (%)

Particulars	**NCC**	**CC (H)**	**CC (M)**	**Mean**
CT-M	68.6	71.1	70.1	69.9
CT-M+C	72.3	75.2	74.6	74.0
MT-M	76.5	81.6	77.2	78.5
MT-M+C	82.2	85.0	83.9	83.7
Mean	74.9	78.2	76.5	
Initial	73.7			
	M	**S**	**M within S**	**S within M**
SEm (±)	1.15	1.41	2.58	2.83
CD (0.05)	4.0	NS	NS	NS

4.2.1.2.2 Micro-aggregates (0.053-0.250 mm)

The data pertaining to the changes in water stable micro-aggregates under different CAPS are depicted in Table 4.5b and Figure 4.3. The extensive soil disturbances in CT resulted in higher contents of micro-aggregates (+13.3%) over the initial value of 13.12%, which could be due to physical turnover of macro-aggregates. The practice of MT, on the other hand, lowered the contents of micro-aggregates (-13.4%), mostly due to turnover of micro-aggregates into macro-aggregates in presence of higher organic binding agents. This was reflected in the reduced status of micro-aggregates (-23.6%) as against the soils under CT (14.86%). The various cropping systems under MT also significantly reduced the micro-aggregate contents (-11.4%) over the soils under CT (13.9%).

Table 4.5b Effect of different CAPS on water stable micro - aggregates (0.053-0.250mm) (%)

Particulars	NCC	CC (H)	CC (M)	Mean
CT-M	16.60	15.20	15.77	15.86
CT-M+C	14.17	13.57	13.83	13.86
MT-M	12.23	11.63	11.93	11.93
MT-M+C	11.23	10.23	10.87	10.78
Mean	13.56	12.66	13.10	
Initial	13.12			
	M	**S**	**M within S**	**S within M**
SEm (±)	0.289	0.425	0.752	0.850
CD (0.05)	1.00	NS	NS	NS

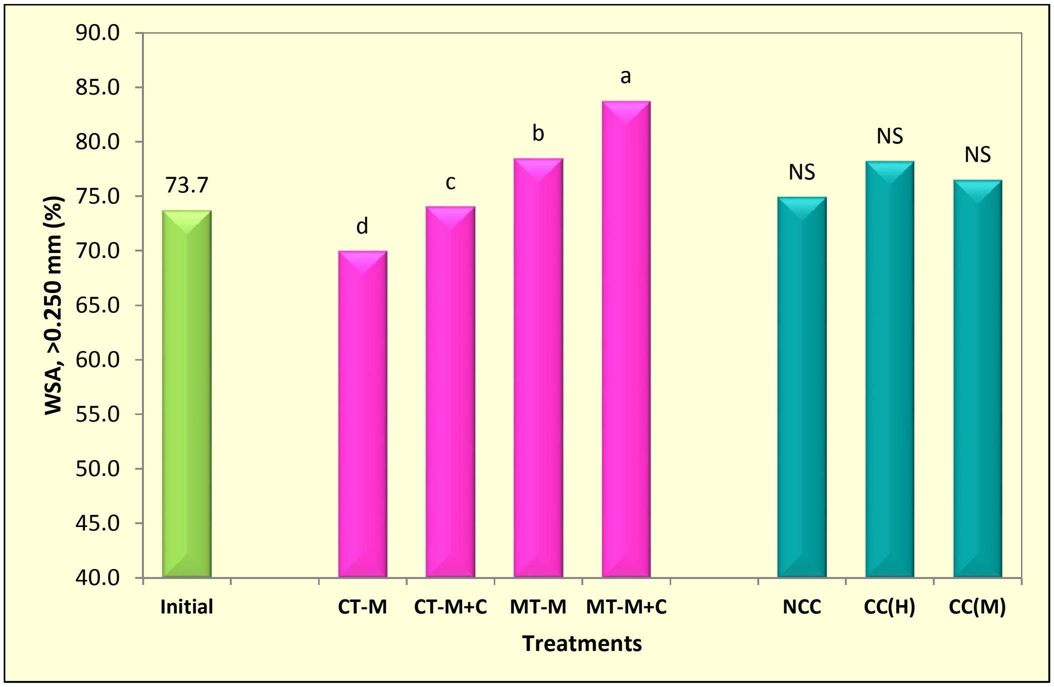


Fig. 4.2 Effect of different CAPS on water stable- macro aggregates (>0.250 mm) (%).

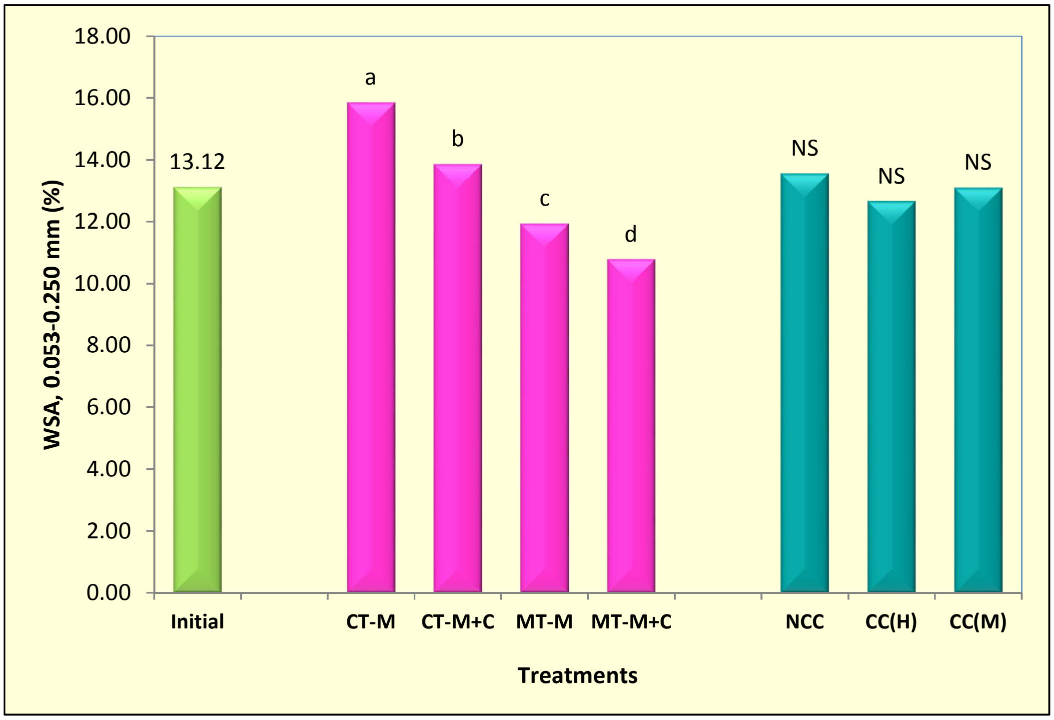


Fig. 4.3 Effect of different CAPS on water stable- micro aggregates (0.053-0.250 mm) (%). Treatments with same lower case letter within main plots or sub-plots were not significant at P = 0.05

4.2.2 Soil Chemical Parameters

4.2.2.1 Soil reaction (pH)

Soil reaction is an important soil quality indicator as it influences nutrient availability and microbial attributes that play a significant role in crop growth and yield.

Practice of different CAPS for two years in succession, lowered the soil pH (Table 4.6 , Fig. 4.4) over the initial status of 7.51 and the maximum decrease was observed in the soils under MT-M+C-H (7.24). Tillage with different cropping systems did not change the soil pH significantly. However, a decreasing trend (-0.05 units) could be observed in soils under MT over CT. Inclusion of follow up cover crops in CAPS decreased the pH in the tune of 0.04 units over NCC (7.33).

Table 4.6 Soil pH (1:2.5) as influenced by different CAPS

Particulars	**NCC**	**CC (H)**	**CC (M)**	**Mean**
CT-M	7.38	7.33	7.32	7.34
CT-M+C	7.35	7.30	7.31	7.32
MT-M	7.30	7.26	7.28	7.28
MT-M+C	7.29	7.24	7.27	7.27
Mean	7.33	7.28	7.29	
Initial	7.51			
	M	**S**	**M within S**	**S within M**
SEm (±)	0.029	0.013	0.035	0.025
CD (0.05)	NS	0.04	NS	NS

4.2.2.2 Soil organic carbon

Significant changes in soil organic carbon (SOC) were observed over the initial status due to the impact of different CAPS at the end of the 2nd cropping cycle (Table 4.7, Fig. 4.5). The minimum soil disturbance in MT elevated the SOC contents to the tune of 17% over the initial status of 6.62 g kg^{-1}. The practice of CT, on the other hand, reduced the OC contents of the soils (-2.4%). Inclusion of cover crops in the cropping system resulted significant increase in SOC contents (+6.8%) over NCC (6.74 g kg^{-1}).The CAPS of MT-M+C-H recorded the maximum SOC of 8.41 g kg^{-1}.

Table 4.7 Impact of different CAPS on soil organic carbon (g kg^{-1})

Particulars	**NCC**	**CC (H)**	**CC (M)**	**Mean**
CT-M	5.46	6.72	6.19	6.12
CT-M+C	6.92	7.07	6.42	6.80
MT-M	7.23	7.96	7.54	7.58
MT-M+C	7.64	8.41	7.75	7.93
Mean	6.81	7.54	6.98	
Initial	6.62			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.173	0.113	0.252	0.225
CD (0.05)	0.60	0.33	NS	NS

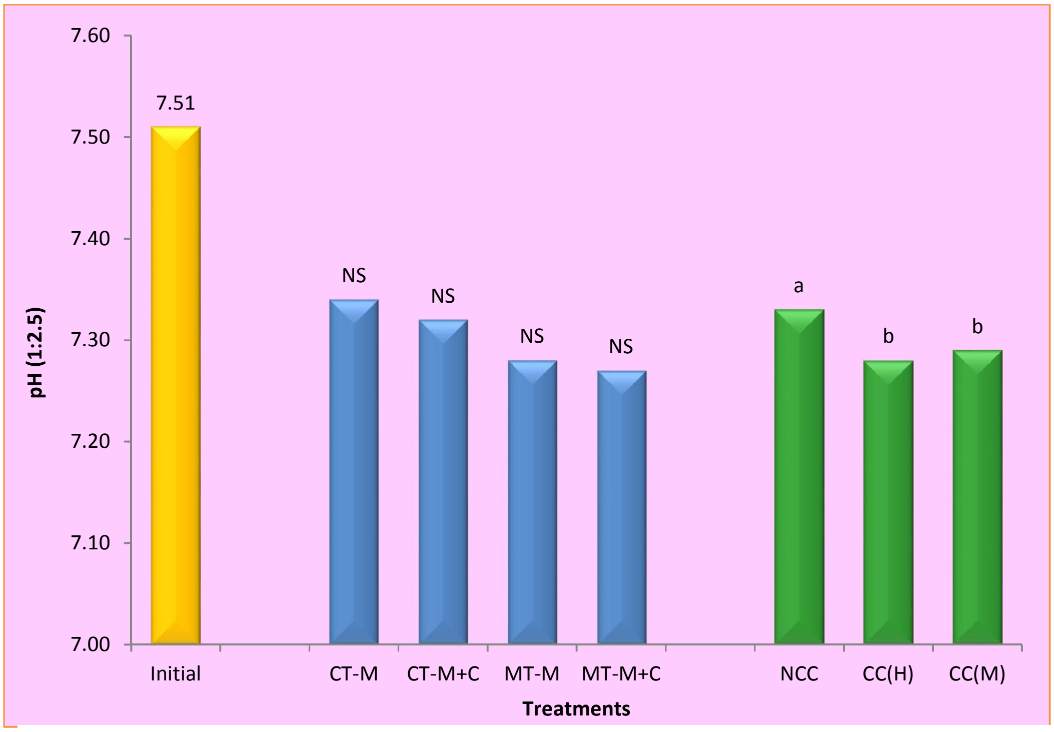


Fig. 4.4 Soil pH (1:2.5) as influenced by different CAPS

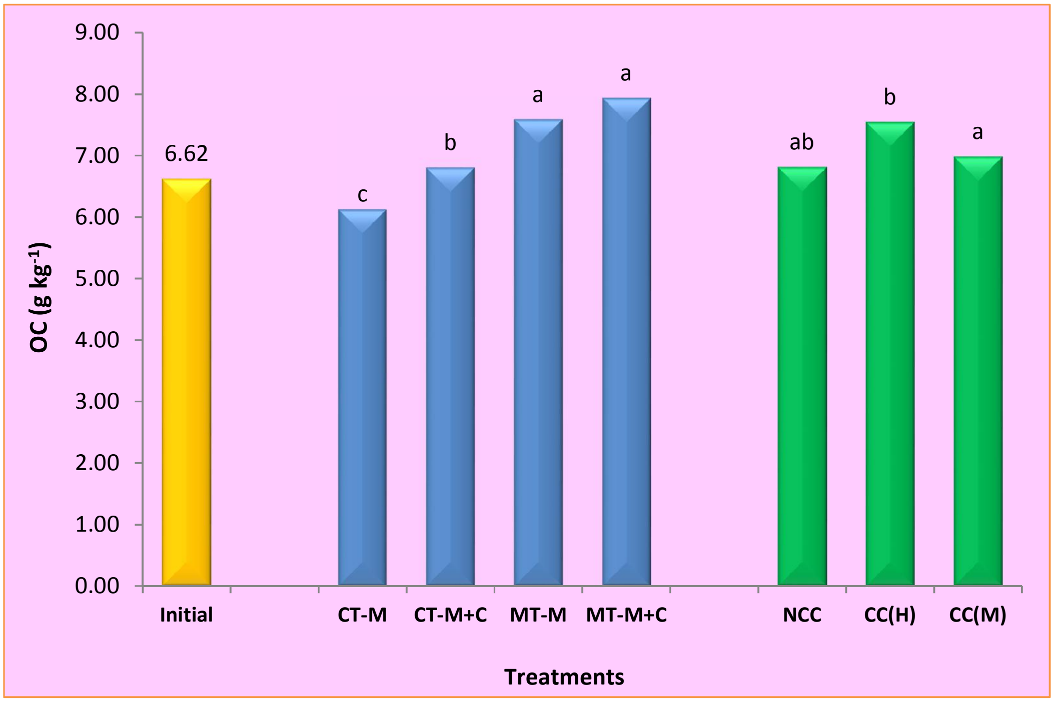


Fig. 4.5 Impact of different CAPS on soil organic carbon (g kg^{-1}) . Treatments with same lower case letter within main plots or sub-plots were not significant at P = 0.05

4.2.2.3 Cation exchange capacity of the soils

Cation Exchange Capacity plays a vital role in nutrient dynamics of both labile and non-labile pool of the soil. Soil organic matter has a significant effect on the CEC of soils.

The CEC of the soils as affected by different CAPS after 2nd cropping cycle is given in Table 4.8 and Figure 4.6. Adoption of MT with different cropping system increased the CEC by 15.3% over the initial value of 25.3 c mol (p+) kg^{-1} and the practice of CT with sole maize {25.34 c mol (p+) kg^{-1}} did alter it over the years. Accumulation of organic matter over the years in MT elevated the CEC of the soils in the tune of 11.2% over CT {26.2 c mol (p+) kg^{-1}}. Cover crops did not have any significant changes in CEC.

Table 4.8 . CEC [c mol (p^+) kg^{-1}] of soils as influenced by different CAPS

Particulars	**NCC**	**CC (H)**	**CC (M)**	**Mean**
CT-M	24.98	25.35	25.69	25.34
CT-M+C	26.21	28.20	27.00	27.14
MT-M	28.03	28.37	28.91	28.44
MT-M+C	29.88	31.18	28.72	29.93
Mean	27.28	28.28	27.58	
Initial	25.32			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.603	0.714	1.312	1.427
CD (0.05)	2.09	NS	NS	NS

4.2.2.4 Exchangeable Bases

4.2.2.4.1 Exchangeable Calcium (Ca^{++})

Exchangeable Ca^{++} occupies the majority of exchange sites in neutral and calcareous soils. Exchangeable and solution Ca^{++} are usually the forms available to the plants. Ca is essential for the cellular activities like cell synthesis, cell elongation and cell division. It also plays important role in enhancing NO_3^- uptake.

The changes in the exchangeable Ca^{++} content of soils due to the impact of different CAPS at the end of the second cropping cycle is presented in Table 4.9 and Figure 4.7. The treatments under MT showed significant increase in exchangeable Ca^{++} due to accumulation of organic matter and the increase was in the tune of 20.4% and 19.9% over the initial value {12.9 c mol (p^+) kg^{-1}} and CT {12.95 c mol (p^+) kg^{-1}}, respectively. Horse gram as cover crop showed significantly higher exchangeable Ca^{++} (8.9%) over NCC {13.65 c mol (p^+) kg^{-1}}.

Table 4.9 Effect of different CAPS on exchangeable Ca^{++} [c mol (p^+) kg^{-1}] of soils

Particulars	**NCC**	**CC (H)**	**CC (M)**	**Mean**
CT-M	11.27	13.01	12.21	12.16
CT-M+C	13.54	14.05	13.63	13.74
MT-M	14.63	15.61	14.95	15.06
MT-M+C	15.15	16.80	16.05	16.00
Mean	13.65	14.87	14.21	
Initial	12.90			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.297	0.303	0.577	0.606
CD (0.05)	1.03	0.88	NS	NS

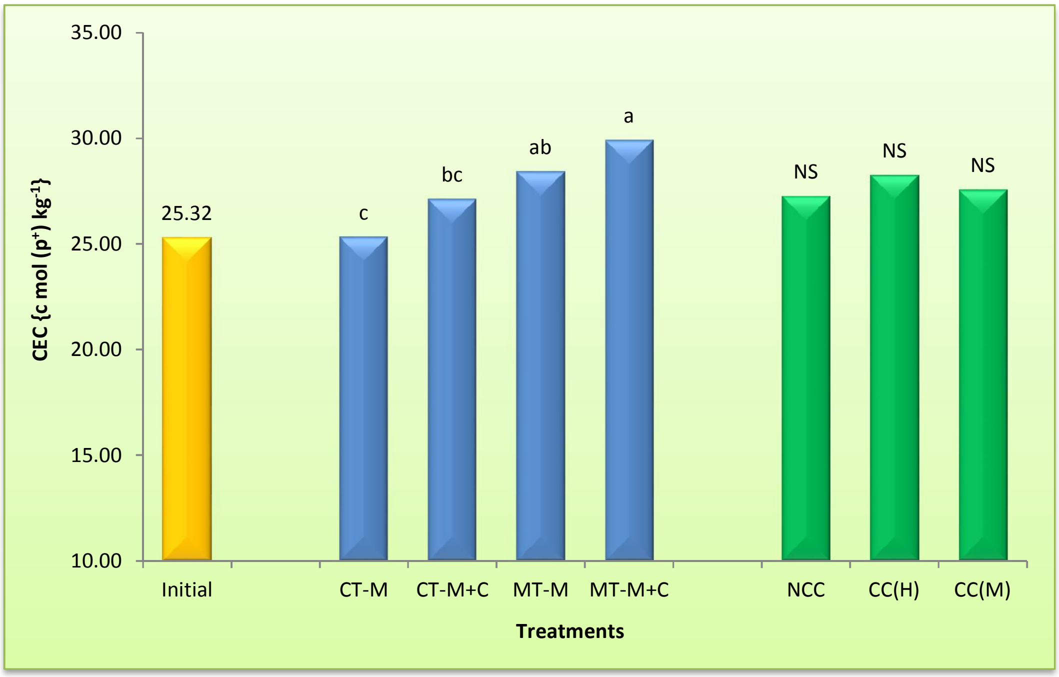


Fig. 4.6 CEC [c mol (p^+) kg^{-1}] of soils as influenced by different CAPS

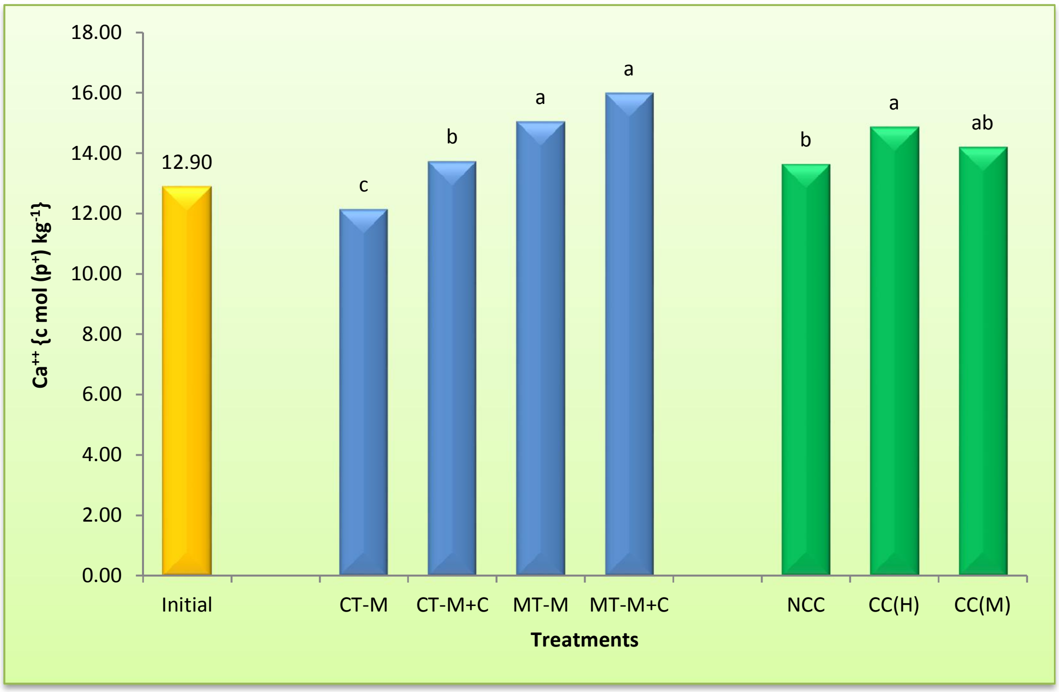


Fig. 4.7 Effect of different CAPS on exchangeable Ca^{++} [c mol (p^+) kg^{-1}] of soils. Treatments with same lower case letter within main plots or sub-plots were not significant at P = 0.05

4.2.2.4.2 Exchangeable Magnesium (Mg^{++})

Soil magnesium originates from weathering of several magnesium bearing minerals. Mg^{++} ions are not strongly adsorbed by clay minerals and organic matter, again they are more prone to leaching as compared to Ca^{++}.In general, the availability of Mg^{++} in soil is found to be less than Ca^{++}. It is an important constituent of chlorophyll and act as enzyme activator.

Results pertaining to the changes in exchangeable Mg^{++} in soils due to the impact of different CAPS is given in Table 4.10 and Figure 4.8. Minimum tillage systems increased the exchangeable Mg^{++} by 20.3% over initial {5.15 c mol (p^+) kg^{-1}} and 18.3% over CT systems {5.24 c mol (p^+) kg^{-1}}. Growing horse gram as cover crop enhanced the exchangeable Mg^{++} contents by 11.7% over NCC {6.09 c mol (p^+) kg^{-1}}.

Table 4.10 Effect of different CAPS on soil exchangeable Mg^{++} [c mol (p^+) kg^{-1}]

Particulars	**NCC**	**CC (H)**	**CC (M)**	**Mean**
CT-M	4.85	5.21	5.01	5.02
CT-M+C	5.31	5.69	5.37	5.46
MT-M	5.77	6.31	6.05	6.05
MT-M+C	6.09	6.80	6.19	6.36
Mean	5.51	6.01	5.66	
Initial	5.15			
	M	**S**	**M within S**	**S within M**
SEm (±)	0.132	0.112	0.226	0.224
CD (0.05)	0.46	0.33	NS	NS

4.2.2.4.3 Exchangeable Potassium (K^+)

Results related to the changes in exchangeable K^+ of the soils due to different CAPS are presented in Table 4.11 and Figure 4.9. Practice of MT with different cropping systems enhanced the exchangeable K^+ contents of the soils by 10.1 % over initial status of 1.68 {c mol (p^+) kg^{-1}}. CT with different systems, however, decreased the exchangeable K^+ by 4.2 % over the initial contents. Different CAPS with cover crops elevated the exchangeable fraction of K^+ by 4.8 % over NCC {1.68 c mol (p^+) kg^{-1}}.

Table 4.11 Impact of various CAPS on soil exchangeable K^+ [c mol (p^+) kg^{-1}]

Particulars	**NCC**	**CC (H)**	**CC (M)**	**Mean**
CT-M	1.47	1.65	1.55	1.56
CT-M+C	1.63	1.69	1.67	1.66
MT-M	1.80	1.87	1.85	1.84
MT-M+C	1.80	1.93	1.88	1.87
Mean	1.68	1.78	1.74	
Initial	1.68			
	M	**S**	**M within S**	**S within M**
SEm (±)	0.016	0.028	0.048	0.055
CD (0.05)	0.06	0.08	NS	NS

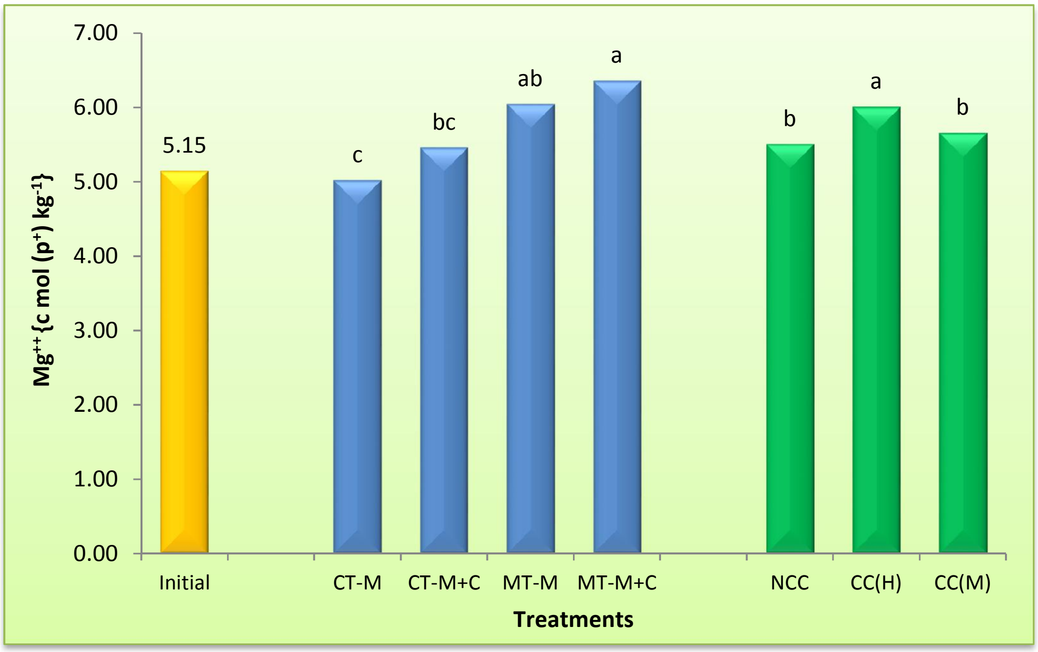


Fig. 4.8 Effect of various CAPS on soil exchangeable Mg^{++} [c mol (p^{+}) kg^{-1}].

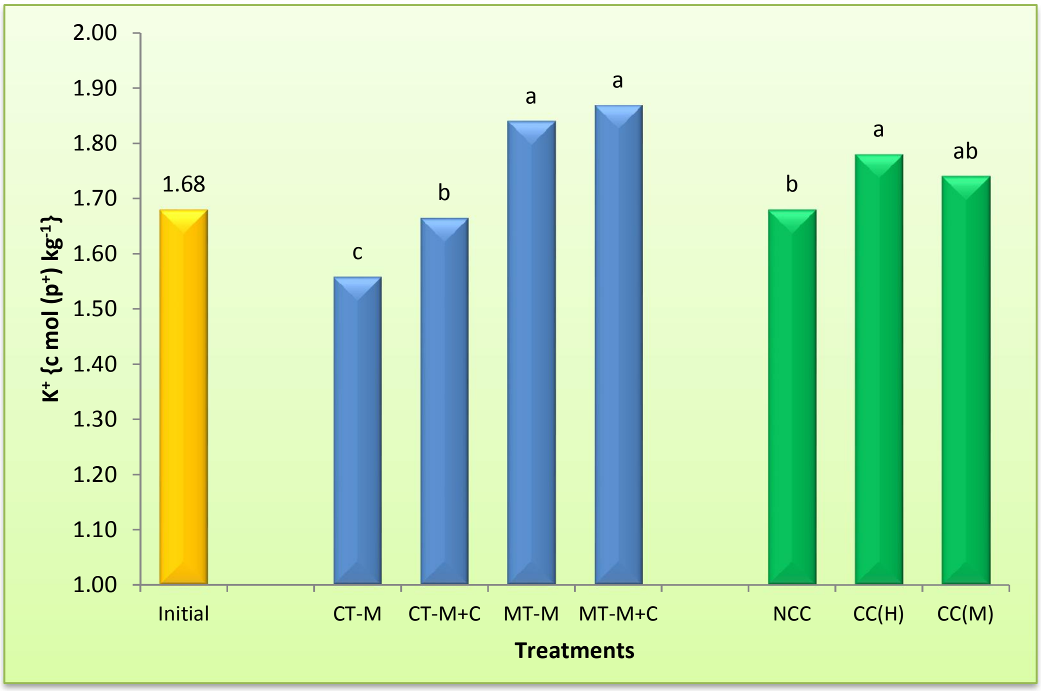


Fig. 4.9 Impact of various CAPS on soil exchangeable K^{+} [c mol (p^{+}) kg^{-1}]. Treatments with same lower case letter within main plots or sub-plots were not significant at P = 0.05

4.2.2.4.4 Exchangeable Sodium (Na^+)

Effect of different CAPS on exchangeable Na^+ of soils are presented in Table 4.12 and Figure 4.10. Tillage with different cropping systems did not affect the exchangeable Na^+ of the soils. However, a marginal decrease (-6.1%) in Na^+ over the initial value of 0.33 c mol (p^+) kg^{-1} was observed in the treatments with CT. Cover crop of horse gram increased the exchangeable Na^+ by 6.1% over NCC {0.33 c mol (p^+) kg^{-1}}.

Table 4.12 Soil exchangeable Na^+[c mol (p^+) kg^{-1}] as influenced by various CAPS

Particulars	NCC	CC (H)	CC (M)	Mean
CT-M	0.30	0.32	0.30	0.30
CT-M+C	0.30	0.33	0.32	0.32
MT-M	0.32	0.33	0.31	0.32
MT-M+C	0.32	0.35	0.32	0.33
Mean	0.31	0.33	0.31	
Initial	0.33			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.006	0.004	0.009	0.009
CD (0.05)	NS	0.01	NS	NS

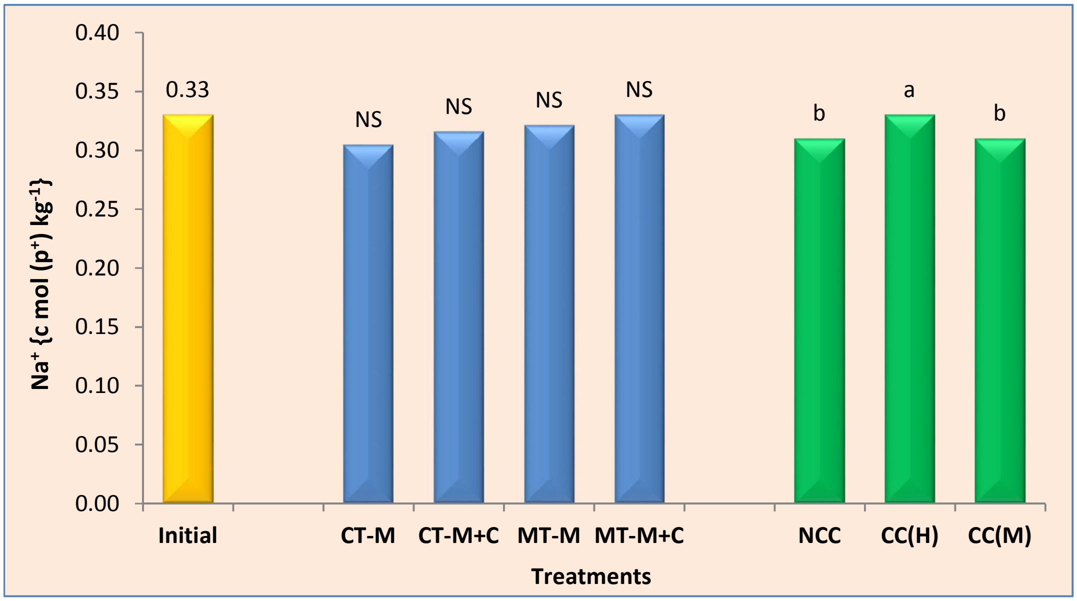


Fig. 4.10 Soil exchangeable Na^+[c mol (p^+) kg^{-1}] as influenced by various CAPS. Treatments with same lower case letter within main plots or sub-plots were not significant at P = 0.05

4.2.2.5 Base saturation (%)

Accumulation and preservation of soil organic matter affected the base saturation significantly in the soils under different CAPS (Table 4.13, Figure 4.11). The practice of MT increased the base saturation of the soils by 3.8% from the initial status of 78.3 % whereas, CT with different systems reduced it by 1.4%. The minimum base saturation per cent was recorded in CT-M (75. 5%). Inclusion of cover crops in the systems did not affect the base saturation of the soils significantly.

Table 4.13 Impact of different CAPS on Base Saturation (%) of soils

Particulars	NCC	CC (H)	CC (M)	Mean
CT-M	72.49	79.71	74.34	75.51
CT-M+C	79.52	77.20	78.15	78.29
MT-M	80.35	85.19	80.20	81.91
MT-M+C	78.31	83.21	85.19	82.24
Mean	77.67	81.33	79.47	
Initial	78.3			
	M	**S**	**M within S**	**S within M**
SEm (±)	1.297	1.510	2.786	3.020
CD (0.05)	4.49	NS	NS	NS

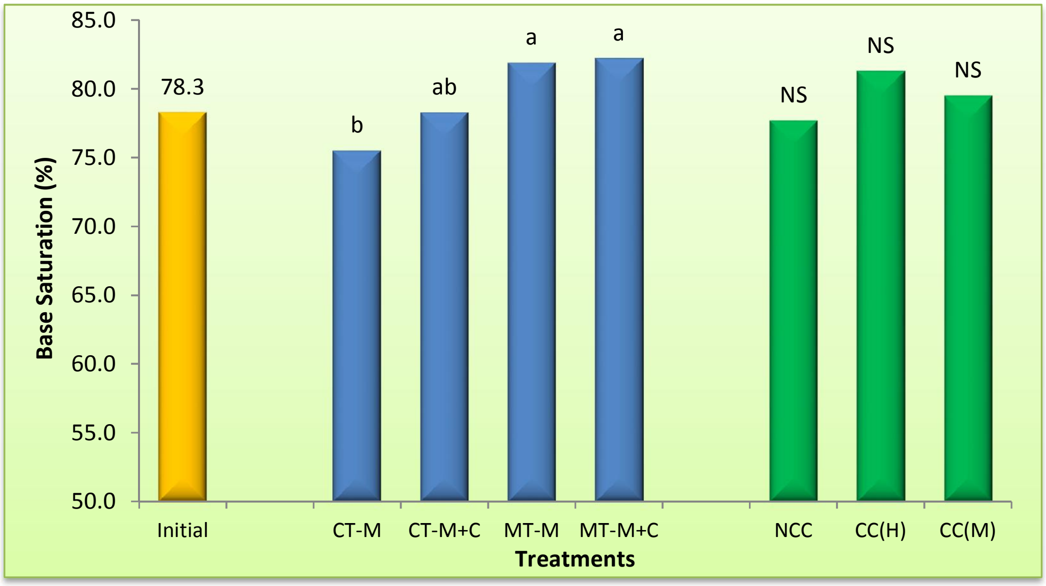


Fig. 4.11 Impact of different CAPS on Base Saturation (%) of soils. Treatments with same lower case letter within main plots or sub-plots were not significant at P = 0.05

4.2.2.6 Available nitrogen

Nitrogen is considered as one of the most important primary nutrients. Plant absorb nitrogen mainly in the form of NO_3^- and NH_4^+. Nitrogen is an integral part of chlorophyll, proteins, amino acids, nucleic acids, enzymes and plays an important role in carbohydrate metabolism in plants.

The data pertaining to available N is presented in (Table 4.14, Fig. 4.12). Continuous accumulation of crop residues and preservation of organic matter have significant effect on available pool of soil nitrogen. Practice of MT, two years in succession, increased available N by 14.3% over the initial status of 266.6 kg ha^{-1}. The soils under MT were also significantly enriched (+13.1%) with available N as compared to CT (269 kg ha^{-1}). Inclusion of horse gram (H) as cover crop significantly increased the available N (+7.5%) over NCC (277.7 kg ha^{-1}), whereas, mustard as cover crop did not influence it much. The maximum (321.8 kg ha^{-1}) and minimum (253.8 kg ha^{-1}) value of available N were recorded in the CAPS of MT-M+C-H and CT-M-NCC, respectively.

Table 4.14 Effect of various CAPS on available N (kg ha^{-1}) of soils

Particulars	NCC	CC (H)	CC (M)	Mean
CT-M	253.8	269.2	254.8	259.3
CT-M+C	272.6	291.2	275.6	279.8
MT-M	288.5	312.0	299.7	300.1
MT-M+C	295.8	321.8	311.2	309.6
Mean	277.7	298.6	285.3	
Initial	266.6			
	M	**S**	**M within S**	**S within M**
SEm (±)	6.70	3.71	9.03	7.42
CD (0.05)	23.2	10.8	NS	NS

4.2.2.7 Available Phosphorus

Phosphorus plays an important role in photosynthesis, root growth and crop maturity. It is absorbed from soil solution as phosphate ions ($HPO_4^{-2}, H_2PO_4^-$).

Changes in available P status of the soils under different CAPS after two cropping years are presented in Table 4.15 and Figure 4.13. MT increased the available P by 8.4% over the initial contents of 15.73 kg ha^{-1}. Similarly, the practice of inter crop M+C resulted higher contents (+11.2%) of available P over sole maize (15.8 kg ha^{-1}). The soils under cover crop of horse gram showed significantly higher contents (+8.6%) of available P over NCC (16.05 kg ha^{-1}). The soils under the CAPS of MT-M+C-H recorded the maximum contents of available P (18.68 kg ha^{-1}) at the end of second cropping cycle.

Table 4.15 Changes in available P (kg ha^{-1}) of soils due to different CAPS

Particulars	**NCC**	**CC (H)**	**CC (M)**	**Mean**
CT-M	14.62	16.21	15.64	15.49
CT-M+C	16.21	18.35	17.40	17.32
MT-M	16.06	16.49	16.03	16.20
MT-M+C	17.29	18.68	17.78	17.91
Mean	16.05	17.43	16.71	
Initial	15.73			
	M	**S**	**M within S**	**S within M**
SEm (±)	0.449	0.357	0.736	0.714
CD (0.05)	1.55	1.04	NS	NS

4.2.2.8 Available Potassium

Potassium is present in the soil solution only as a positively charged cation (K^+) that influences soil cation exchange properties and mineral weathering. It plays important role as an activator of enzymes.

Data pertaining to available K contents as influenced by different CAPS at the end of 2nd cropping cycle, was depicted in Table 4.16 and Figure 4.14. Minimum tillage elevated the available K contents in the tune of 6.7% over the initial status of 340.9 kg ha^{-1} whereas CT reduced it by 3.2%. The treatment of MT-M+C recorded significantly higher available K (371.2 kg ha^{-1}) as compared to CT-M (320.9 kg ha^{-1}). Inclusion of cover crops in the system did not show any significant effect over NCC.

Table 4.16 Effect of various CAPS on available K (kg ha^{-1}) of soils

Particulars	**NCC**	**CC (H)**	**CC (M)**	**Mean**
CT-M	317.4	326.3	318.9	320.9
CT-M+C	335.9	345.4	335.7	339.0
MT-M	338.6	369.2	360.4	356.0
MT-M+C	372.7	373.1	367.8	371.2
Mean	341.1	353.5	345.7	
Initial	340.9			
	M	**S**	**M within S**	**S within M**
SEm (±)	9.49	4.56	12.06	9.12
CD (0.05)	32.8	NS	NS	NS

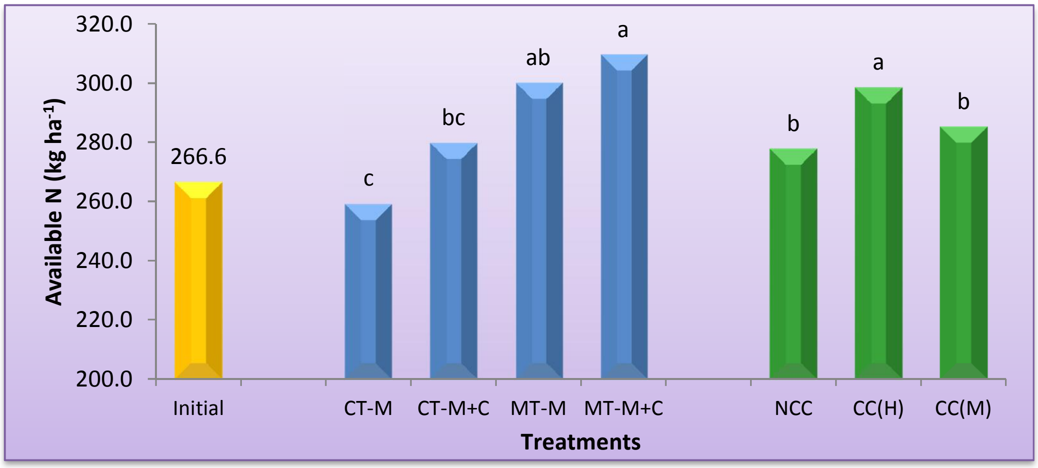


Fig. 4.12 Effect of various CAPS on available N (kg ha^{-1}) of soils.

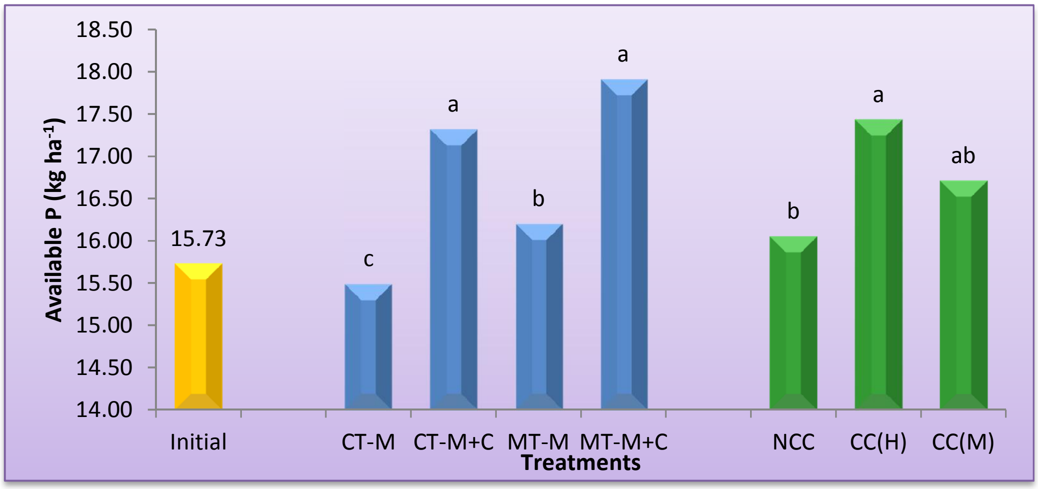


Fig. 4.13 Changes in available P (kg ha^{-1}) of soils due to various

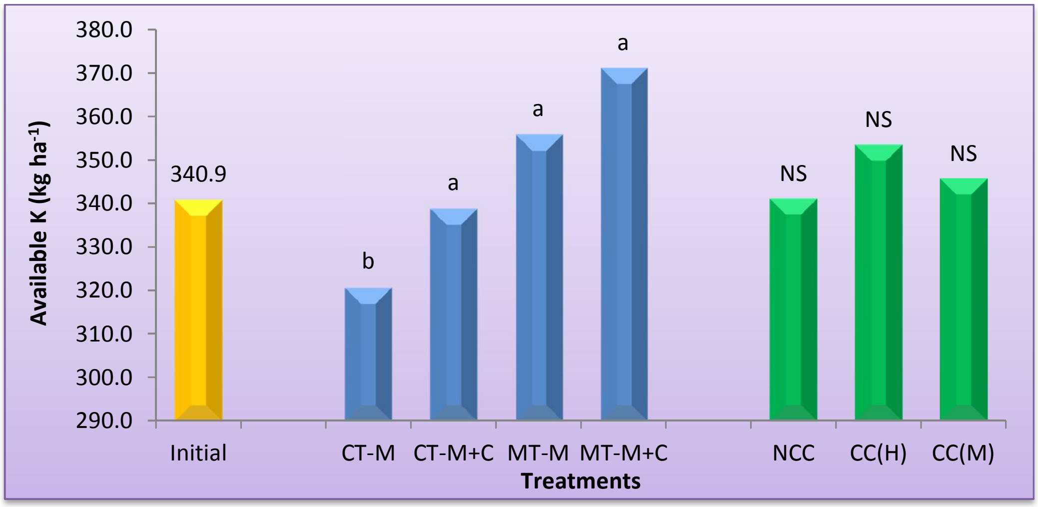


Fig. 4.14 Effect of various CAPS on available K (kg ha^{-1}) of soils. Treatments with same lower case letter within main plots or sub-plots were not significant at P = 0.05

4.2.3 Microbial attributes

4.2.3.1 Bacteria population

Changes in soil organic matter affected the bacteria population significantly in the soils under different tillage with different cropping systems (Table 4.17, Fig.4.15). An increasing trend in bacteria population over the initial status (12.34 x 10^6 cfu g^{-1}) was observed in the soils under different CAPS. MT with different cropping systems significantly increased (+10.8%) the bacteria population over the treatments with CT (13.75 x 10^6 cfu g^{-1}). Cover crops did not change the bacteria status of the soils, significantly, at the end of second cropping cycle.

Table 4.17. Effect of different CAPS on soil bacterial population (x10^6 cfu g^{-1})

Particulars	**NCC**	**CC (H)**	**CC (M)**	**Mean**
CT-M	13.00	13.43	13.13	13.19
CT-M+C	14.03	14.73	14.20	14.32
MT-M	14.90	15.13	15.03	15.02
MT-M+C	15.17	15.80	15.37	15.44
Mean	14.28	14.78	14.43	
Initial	12.34			
	M	**S**	**M within S**	**S within M**
SEm (±)	0.236	0.237	0.453	0.473
CD (0.05)	0.82	NS	NS	NS

4.2.3.2 Actinomycetes population

The soils under different tillage methods with cropping systems showed significant variation in actinomycetes population after the second year of the experiment (Table 4.18, Fig. 4.16). Practice of MT and CT enhanced the actinomycetes status of the soils in the tune of 14.6% and 5.3%, respectively over the initial value (20.85 $\times 10^6$ cfu g^{-1}). Minimum tillage with cropping systems showed significantly higher population of actinomycetes (+8.8%) as compared to CT (21.96 $\times 10^6$ cfu g^{-1}). Growing of horse gram as cover crop after the main crop increased the actinomycetes (+6.4%) over NCC (22.35 $\times 10^6$ cfu g^{-1}).

Table 4.18 Effect of various CAPS on Actinomycetes population (x10^6 cfu g^{-1}) in soil

Particulars	**NCC**	**CC (H)**	**CC (M)**	**Mean**
CT-M	20.63	22.43	21.13	21.40
CT-M+C	21.70	23.67	22.23	22.53
MT-M	22.90	23.63	23.03	23.19
MT-M+C	24.17	25.33	24.33	24.61
Mean	22.35	23.77	22.68	
Initial	20.85			
	M	**S**	**M within S**	**S within M**
SEm(±)	0.337	0.323	0.626	0.646
CD (0.05)	1.17	0.94	NS	NS

4.2.3.3 Microbial biomass carbon (MBC)

Differential accumulation and preservation of soil organic matter in the soils under different CAPS significantly affected the MBC (Table 4.19, Fig.4.17). Imposition of MT enhanced the MBC of the soils by 13.6% over the initial contents (151.8 µg C g^{-1}) and 8.1% over the treatments under CT (159.5 µg C g^{-1}). Similarly, the cropping system of M+C inter crop enhanced the MBC by 10.3% over sole maize (158.0 µg C g^{-1}). Cover cropping with horse gram improved the microbial biomass carbon status significantly (+5.8%) over NCC (161.6 µg C g^{-1}).

Table 4.19 Microbial Biomass Carbon (µg C g^{-1}) as affected by various CAPS

Particulars	NCC	CC (H)	CC (M)	Mean
CT-M	146.6	158.7	153.5	152.9
CT-M+C	163.7	168.7	166.2	166.2
MT-M	155.6	168.9	164.9	163.1
MT-M+C	180.3	187.7	179.5	182.5
Mean	161.6	171.0	166.0	
Initial	151.8			
	M	**S**	**M within S**	**S within M**
SEm(±)	2.358	2.652	4.931	5.304
CD (0.05)	8.16	7.74	NS	NS

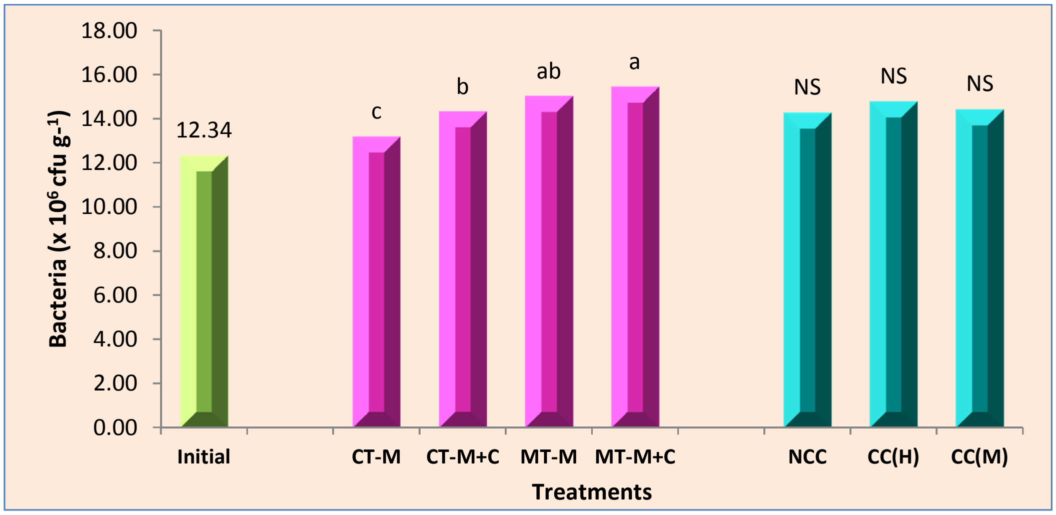


Fig. 4.15 Effect of different CAPS on soil Bacterial population (x10^6 cfu g^{-1}).

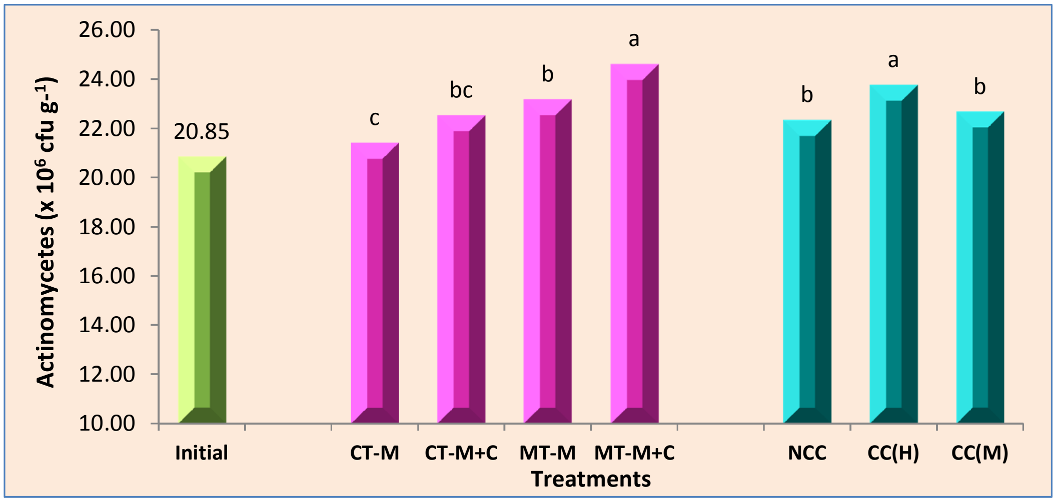


Fig. 4.16 Effect of various CAPS on Actinomycetes population (x10^6 cfu g^{-1}) in soil.

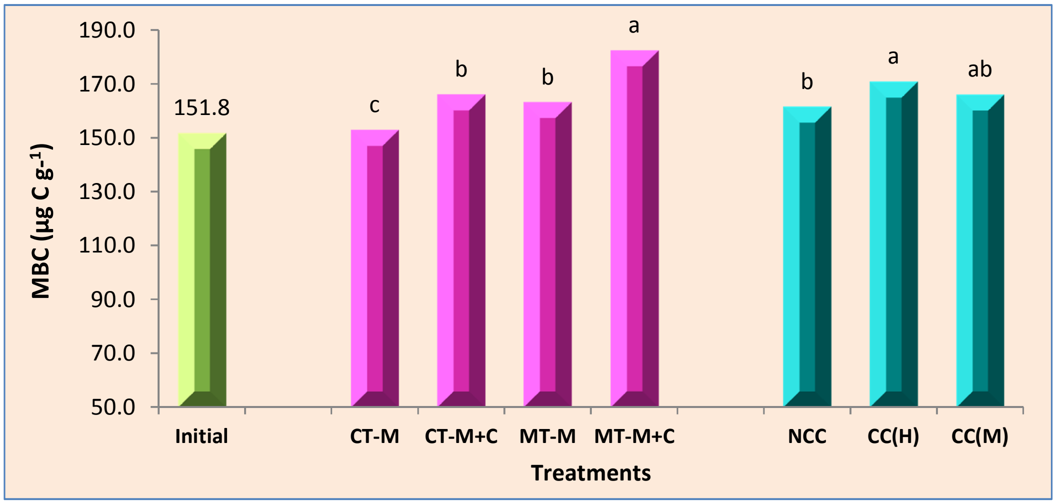


Fig. 4.17 Microbial Biomass Carbon (µg of C g^{-1}) as affected by various various CAPS. Treatments with same lower case letter within main plots or sub-plots were not significant at P = 0.05

4.3 Maize equivalent yield

The maize equivalent yield (MEY) as influenced by different CAPS is presented in Table 4.20 and Fig. 4.18. CT with sole maize, though significantly, has higher MEY (61.95 q ha^{-1}) over MT with sole maize (55.76 q ha^{-1}). MEY from both the tillage systems with maize-cowpea intercrop were at par. Inclusion of mustard and horsegram as cover crop enhanced the MEY significantly over NCC and the increase was in the tune of 20.4 % and 11.4 %, respectively. The maximum MEY of 103.61 q ha^{-1} was obtained from the CAPS of CT-M + C-M, which is at par with the CAPS of MT-M+C –M (102.86 q ha^{-1}).

Table 4.20 Effect of different CAPS Maize Equivalent Yield (q ha^{-1})

Particulars	NCC	CC (H)	CC (M)	Mean
CT-M	46.57	65.37	73.91	61.95
CT-M+C	80.08	97.59	103.61	93.76
MT-M	42.37	59.68	65.25	55.76
MT-M+C	85.42	95.20	102.86	94.49
Mean	63.61	79.46	86.41	
	M	**S**	**M within S**	**S within M**
SEm (±)	1.302	1.241	2.409	2.482
CD (0.05)	4.51	3.62	NS	NS

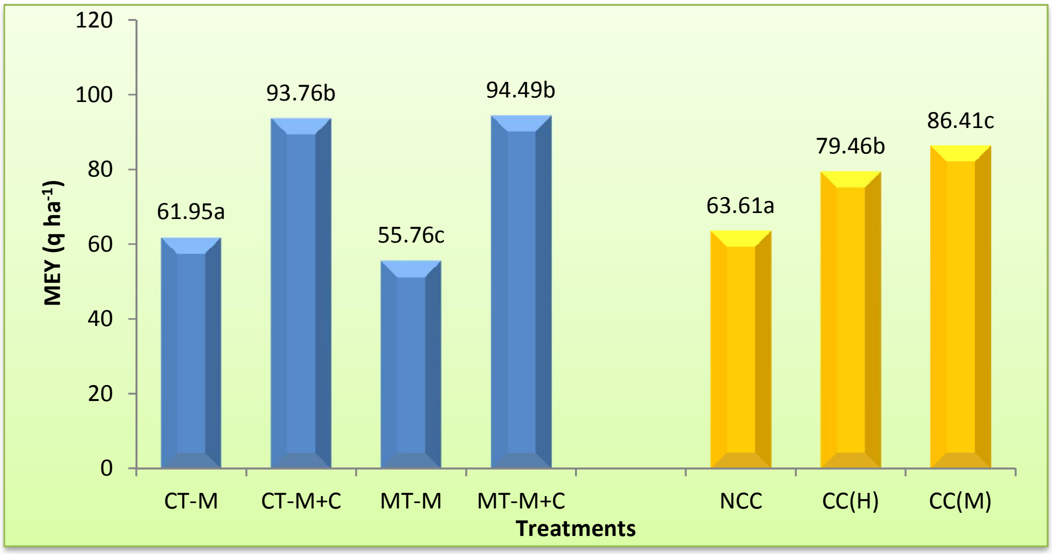


Fig. 4.18 Effect of different CAPS Maize Equivalent Yield (q ha^{-1}). Treatments with same lower case letter within main plots or sub-plots were not significant at P = 0.05

DISCUSSION

Soil health is defined as the continued capacity of soil to function as a vital living system, within the ecosystem and land-use boundaries, to sustain biological productivity, promote the quality of air and water environments, and maintain plant, animal and human health (Doran and Parkin, 1994, Doran and Safely, 1997). The effect of Conservation Agriculture Production System (CAPS) with minimum tillage, cropping system and residue management; as components, on soil health is well established world over. Some promising and interesting results have been obtained from the present study "Assessment of maize based CAPS on soil health in the hilly terrains under North Central Platen Zone of Odisha" and relevant discussion is as follows.

4.4 Characterization and classification of the soils from the representative pedon

4.4.1 Characterization of the soil

The soils of the representative pedon located in the gently sloping upland are very deep, moderately well drained and moderately eroded. Presence of *cambic* sub-surface horizon is evidenced by change of colour (reddish brown to brown), texture (sandy clay loam to sandy loam) and strong structure. The wider sand to silt ratio (≥ 0.2) indicated lithological discontinuity which might be due to the deposition of colluvial-alluvial sediments in different erosional cycle (Gangopadhyay *et al.*, 1998). Presence of medium to coarse lime nodules and carbonate coats in B_w1 and B_w2 horizons might be due to precipitation of Ca^{++}, HCO_3^- in the weathering product from unclassified granites, gneisses , gabbro and to some extent dolomite, under high pH and moderately well drained condition. These particles might have rolled down after formation along with the alluvial sediments down the slope

(Singh *et al.*, 2003). The high base status are related to high pH of the soils. The ratio of CEC:clay (> 1.00) indicates the dominance of smectites in these soils.

4.4.2 Classification of the soils

The soils of the representative pedon are classified as per soil taxonomy (Soil Survey Staff, 1999). The soils of the study area belong to order Inceptisols due to presence of Ustic moisture regime, great group Hapustepts because of presence of free $CaCO_3$ within depth of 125 cm and base saturation more than 60 % within the depth of 25-75 cm. The subgroup of the soils are *Fluventic Haplustepts* because of more than 0.2 % OC contents at a depth of 125 cm and irregular decrease of OC between the depth of 25 to 125 cm. The soil taxonomy up to family level is fine loamy over coarse loamy, mixed, hyperthermic, *Fluventic Haplustepts*.

4.5 Bulk density (BD)

The significant decrease (0.05 Mg m^{-3}) in soil bulk density under MT systems when compared with CT systems may be attributed to more intense plant root operation and increased soil organic matter due to crop residue accumulation in 0-10 cm layer (Fengyun *et al.*,2011). The lower soil BD under MT is also likely due to more aggregation, higher litter content at the soil surface (Lafond *et al.*, 2011). Significant reduction of BD due to considerable improvement in SOM, hence enhanced aggregation and biological activity, has also been observed by Jemai *et al.*, 2013 and Croretto *et al.*, 1998. Minimum tillage also reduce the susceptibility of soils to compaction in loam soils resulting in lower BD (Herencia *et al.*, 2011). Loss of finer soil particles due to water erosion and low SOM contents leading to less aggregation is the reason for higher soil BD in CT system (Lafond *et al.*, 2011). The favorable influence of SOM on BD was justified by the significant negative correlation of SOC with BD (r = - 87**) (Fig. 4.19).

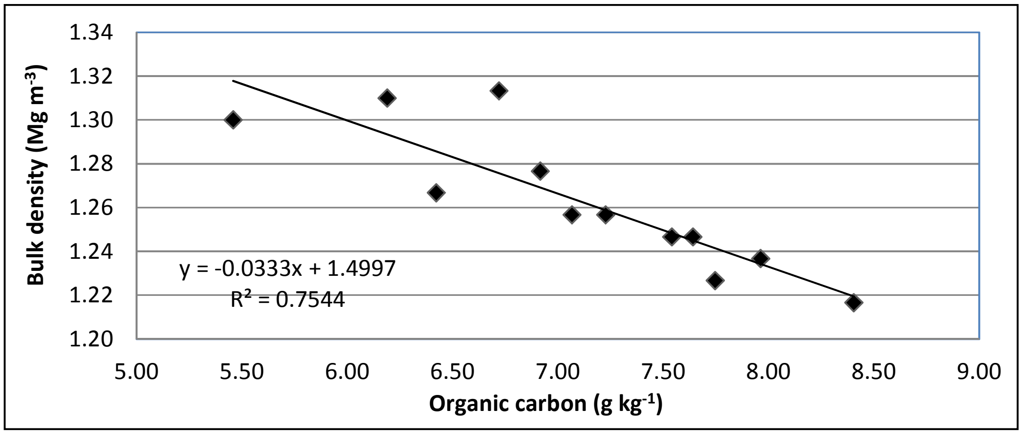


Fig. 4.19. Correlation between bulk density with soil organic carbon of the soils

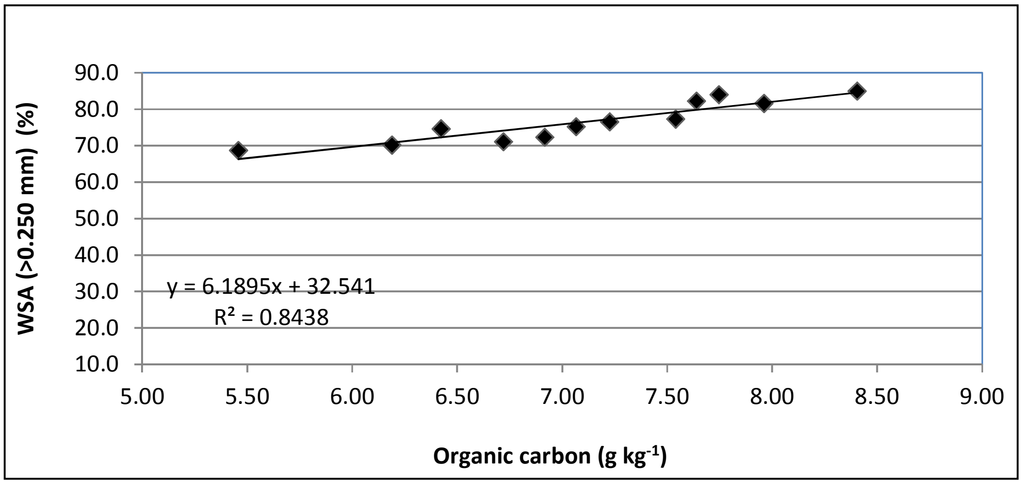


Fig. 4.20. Correlation between water stable macro aggregates with organic carbon of the soils

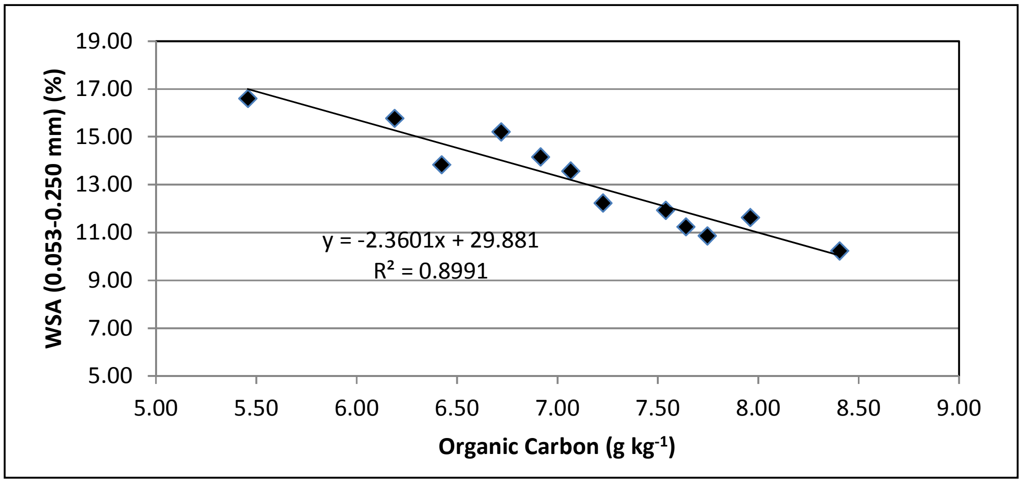


Fig. 4.21. Correlation between water stable micro aggregates with organic carbon of the soils

4.6 Water stable aggregates (WSA)

Higher macro-aggregate contents (81.1%) in MT is related to higher stock of fresh organic matter, hence increased microbial activity and production of microbial binding agents (Mikha *et al*., 2004)

Increased water stable macro-aggregates (> 0.250mm) concomitant with decreased micro-aggregates (0.053-0.250mm) observed in MT might be attributed to lower physical impact leading to lower aggregate turn over (degradation) rates. Conventional tillage (CT), in contrast, disrupts macro-aggregates, thereby enhancing its turnover to micro-aggregates (Six *at al*., 2000a, Balesdent *et al*., 2000, Zotarelli *et al*., 2007). Larger proportion of macro-aggregates in MT was attributed to higher SOC (r = 92**) in these soils (Fig. 4.20 and 4.21). The elevated SOC in MT showed a strong negative correlation with micro-

aggregates (r = -95**) indicating its turnover to macro aggregates.

4.7 Soil reaction (pH)

Marginal decrease (0.05 units) of pH in MT over CT and CC over NCC in the surface soil (0-10cm) might be due to an increase in SOM and associated organic acids (Logan *et al*., 1991, Kern *et al*., 1993). There was a significant, negative correlation between pH and SOC (r = -91**), indicating that higher SOC under MT may partially have an acidifying effect on soils (Thomas *et al*., 2007). (Fig. 4.22).

4.8 Soil organic carbon (SOC)

Soil organic carbon (SOC) is most often chosen as the most important indicator of soil quality because of its impact on major physical, chemical and biological indicators of soil quality (Reeves *et al*., 1997). Significant increase (+ 17%) of SOC in MT with cropping systems was attributed to the greater residue input (5-6 t ha^{-1} of biomass) and reduced biological oxidation associated with less soil disturbance by tillage (Hel *et al*., 2009) or absence of soil redistribution due to reduced tillage (Jemai *et al*., 2013).

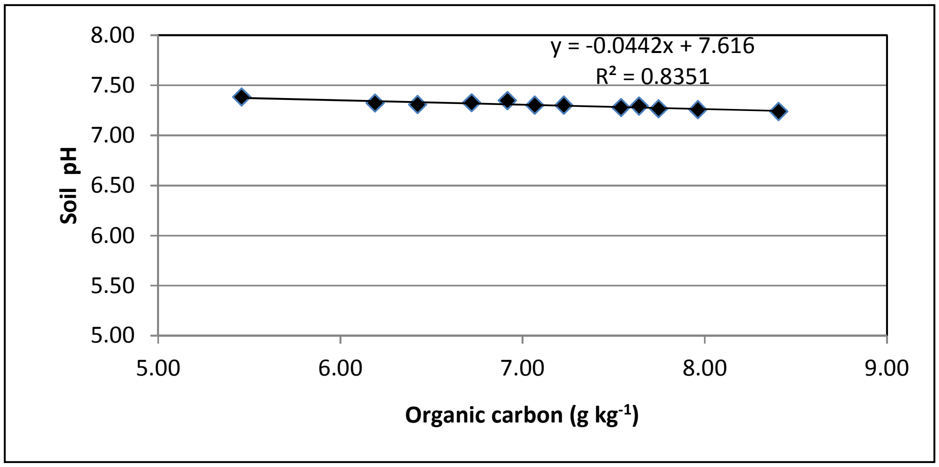


Fig. 4.22. Correlation between soil pH with organic carbon of the soils

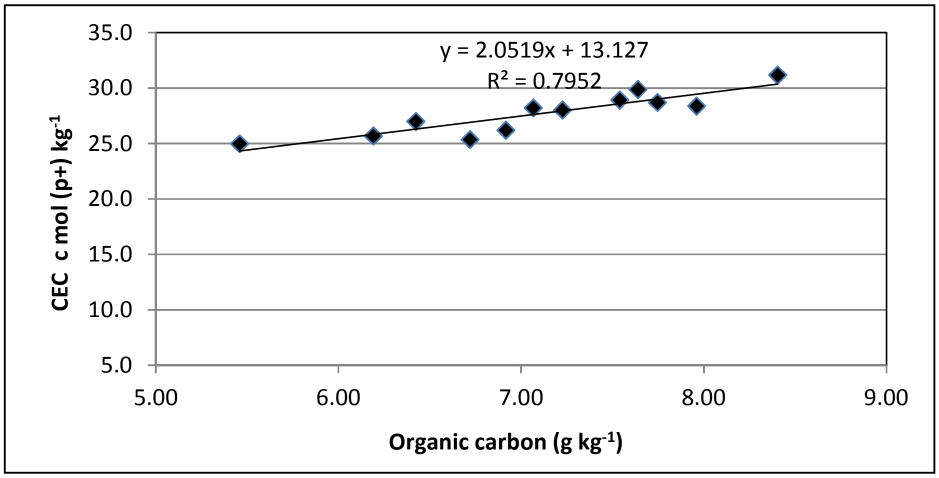


Fig. 4.23. Correlation between CEC with organic carbon of the soils

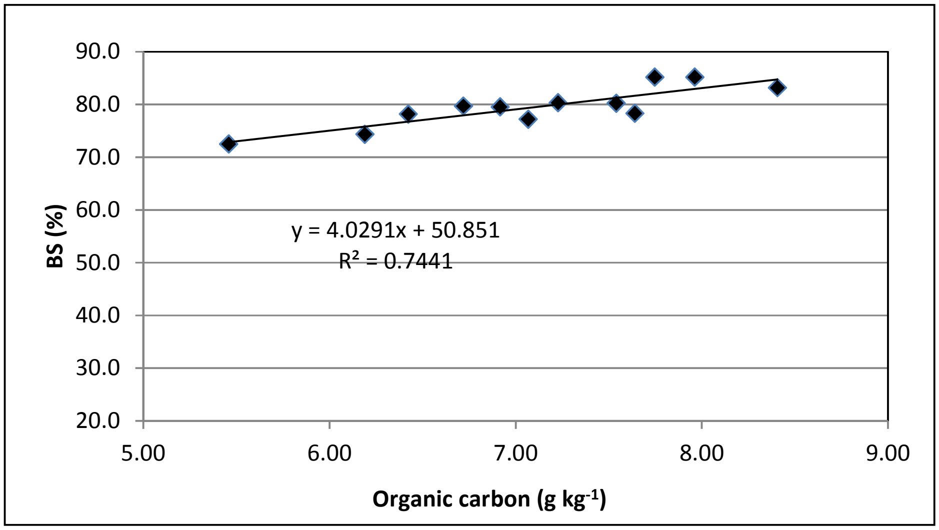


Fig. 4.24. Correlation between base saturation with organic carbon of the soils

The increased aggregate stability due to lower physical impact of MT resulted in lower aggregate turnover rates and therefore improved physical protection of SOC from decompositions and thus higher SOC stocks in these soil. The degradation or higher turnover of macro-aggregates resulted from intense physical disturbance in CT exposed the formerly incorporated SOC to microbial decomposition (Tan *et al*., 2007). The findings of Plaza-Bonilla *et al*., (2013) on protection of SOC because of higher proportion of macro-aggregates and enrichment of C concentration in micro-aggregates under long term maintenance of MT also corroborated the findings of the present study.

4.9 CEC, Exchangeable cations and base saturation

The soil component known to contribute to the soil CEC are clay, organic matter and to a lesser extent, silt (Martel *et al*., 1978, Monrique *et al*., 1991). The soils under MT showed a significant increase (11.2 %) in CEC over CT that could be related to the higher build up and preservation of SOM in MT. The effect of SOM on the point of zero charge (pH_o) of the soil variable change component is considered to be the most important aspect in increasing CEC_v. The greater the difference between soil pH and pH_o, the greater the net surface charges due to variable charge component and SOM has a low pH_o due to presence of carboxyl groups (Oades *et al*., 1989). The significant effect of MT with cover crop on exchangeable Ca^{++} , Mg^{++}, K^+ and Na^+ was evidenced by increase in the tune of 40.7 %, 30.7 %, 28.1 % and 9.2 %, respectively over the soils under CT with NCC. Strong correlation between SOC with CEC (r = 0.89**) (Fig. 4.23) , exchangeable Ca^{++} (r = 0.97**) , Mg^{++}(r = 0.96**) (Fig. 4.25), K^+ (r = 0.96**) and Na^+ (r = 78**) (Fig. 4.26) indicated the contribution of SOM to the CEC and exchangeable cations. The SOM contributed significantly to soil CEC, (Rashid *et al*., 2008) and exchangeable Ca^{++} (Eshetu *et al*., 2004).The elevated stock of SOM in MT also enhanced the base saturation by 3.8 % over SOM depleted CT and a significant positive correlation of SOC with base saturation (r = 0.86**) justified the findings. (Fig. 4.24)

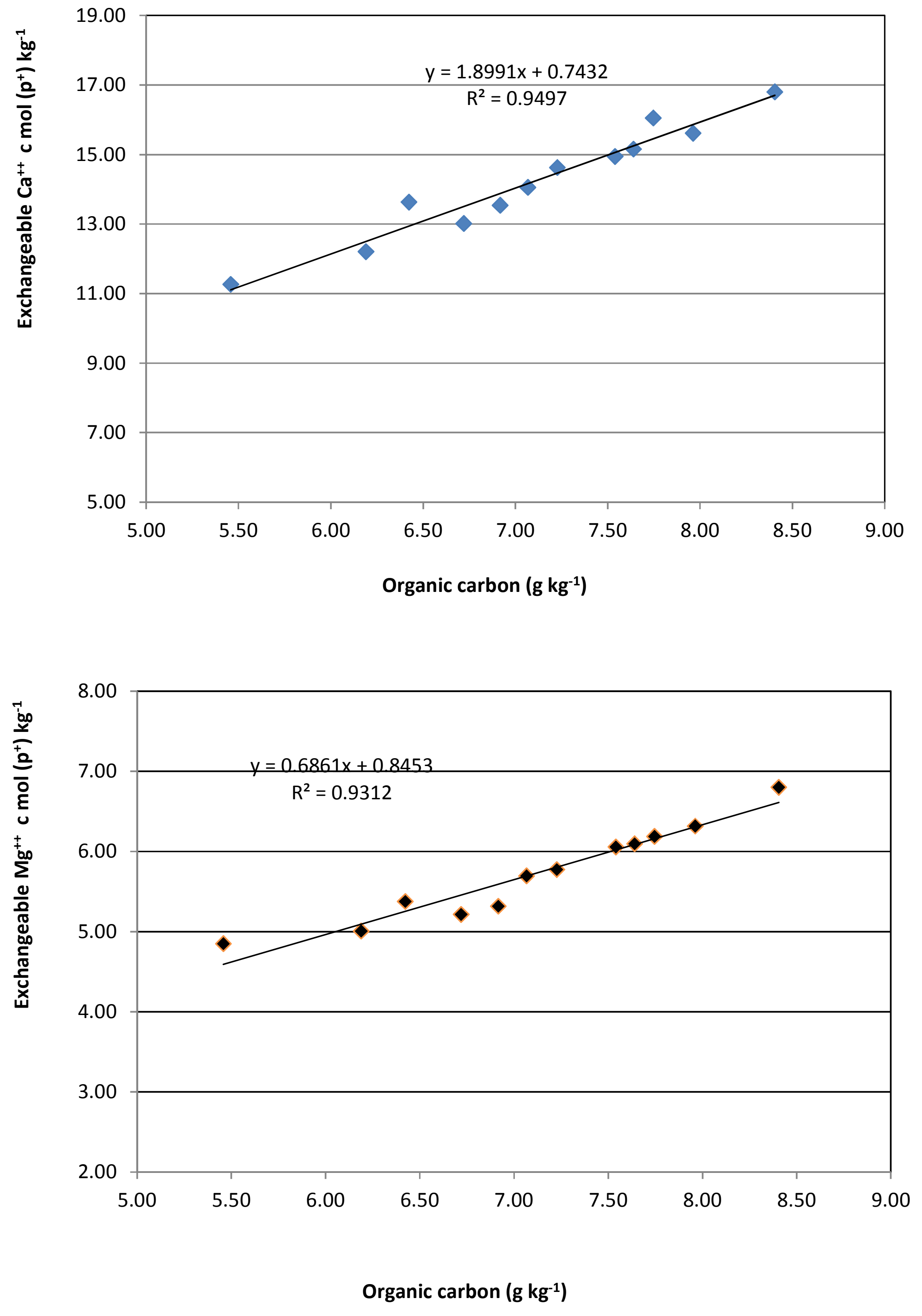
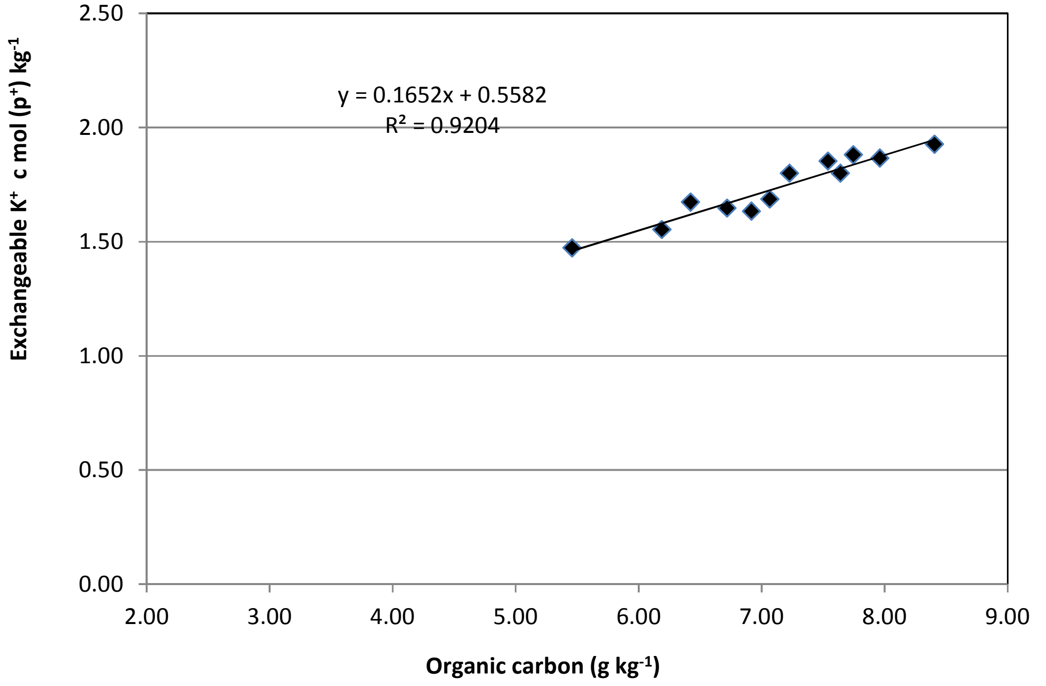


Fig. 4.25. Correlation between exchangeable cations (Ca^{++}, Mg^{++}) with organic carbon of the soils



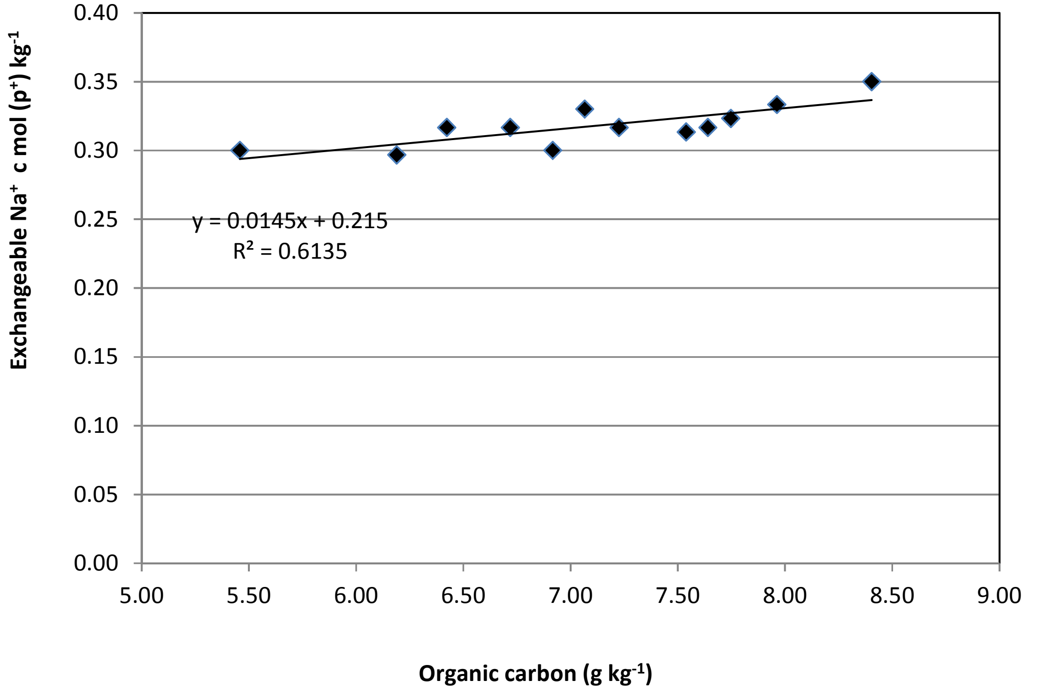


Fig. 4.26. Correlation between exchangeable cations (K^+, Na^+) with organic carbon of the soils

4.10 Available N, P and K

The accumulation and conservation of SOM in MT enhanced the available N, P and K status of the soil as evidenced by strong positive correlation between SOC with available N (r = 0.96**), P (r = 66*) and K (r = 0.93**) (Fig. 4.27). Inclusion of horsegram as cover crop in MT systems enhanced the available N by 7.5 % and P by 8.6 % over NCC. Higher available N with legume cover crop was related to reduced leaching loss of N (Saniju *et al*., 2006). Against the background of improved SOC and nitrogen, P solubilization was greater in the top soils under MT (Zibilske *et al*., 2002) and the increased P availability under MT might be due to decreasing adsorption of P to mineral surfaces (Ohno and Erich, 1997). Contribution of SOM to the available pool of soil K in the top soils under MT has been reported by Thomas *et al*., 2007, Qin *et al*., 2007.

4.11 Microbial attributes

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 soil microbial biomass is a better indicator of how tillage and cropping systems impact soil health and productive capacity (Lupwayi *et al*., 1998, Campbell *et al*., 2001).

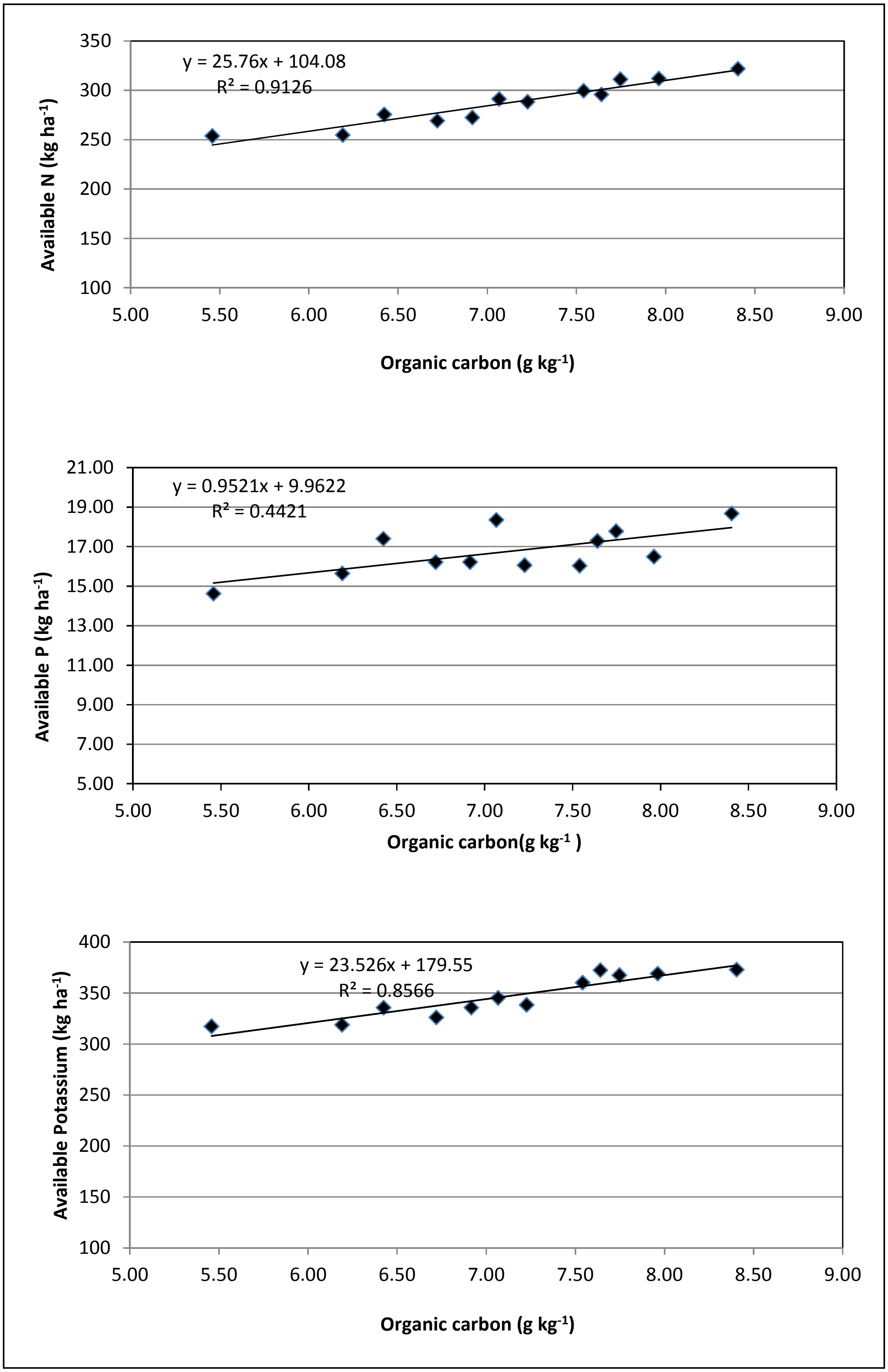


Fig. 4.27. Correlation between available nutrients (N, P and K) with organic carbon of the soils

Deposition of SOM in the soil surface under MT enhanced the bacteria and actinomycetes population by 10.8 % and 8.8 %, respectively over CT. The residue relation and tillage reduction both increased the level of microbial biomass (Kushwaha *et al*., 2001).The microbial biomass carbon in the soils under MT was significantly higher (8.1 %) than that of CT, which might be due to the fact that the fresh SOM at the surface helped to moderate the soil temperature and moisture that is conducive to microbial activity and higher MBC (Balota *et al*., 2004). When flushes of C were supplied to the soil in the form of crop residues, the microbial biomass increased in size until the substrate was depleted. Significant increase in MBC due to addition of organic matter has also been corroborated with the findings of Salin-Gracia *et al.* (1997). The significant positive correlation between SOC with the population of bacteria (r = 93**), actinomycetes (r = 92**) and MBC (r = 84**) (Fig. 4.28) justified the contribution of SOM to these microbial attributes.

4.12 Maize equivalent yield (MEY)

The MEY reduction in MT with sole maize over CT might be related to low active fraction of SOM as a result of slow decomposition due to minimum soil disturbances. The intercrop of maize and cowpea under both MT and CT systems increased the MEY over sole maize because of additional gain from cowpea. The elevated MEY due to inclusion of mustard as cover crop was because of higher selling price of mustard. Though, the MEY under MT systems is marginally lower than CT system at the end of the second cropping cycle, the positive impact of MT on overall soil health will be reflected in yield in the long run.

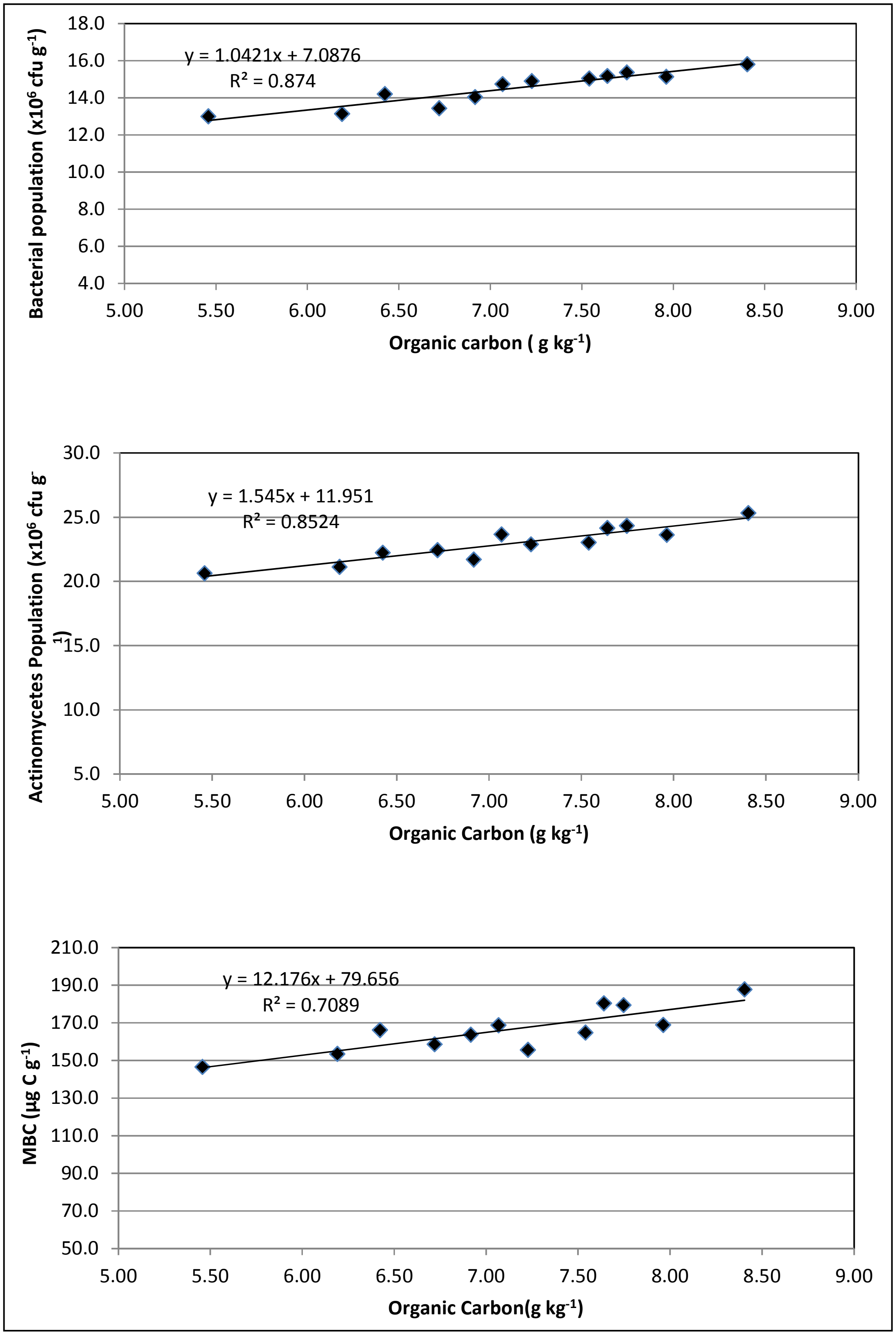


Fig. 4.28. Correlation between microbial population (bacteria and actinomycetes), MBC with organic carbon of the soils

SUMMARY AND CONCLUSION

The soils in the hilly terrains of North Central Plateau agro-climatic zones of Odisha are subjected to various kinds of soil degradation due to less of forest cover, accelerated soil erosion, shifting cultivation and intense mining activities, thus rendering them unproductive. The farmers of this zone are traditionally growing maize as the only rainfed crop under high tillage without any scientific agro-techniques. Conservation agriculture production system (CAPS) involving minimum tillage, legume based intercropping and a follow up cover crop has been thought of as the best possible long term solution for this region that not only maintains the quality of environment but also conserves the natural resources keeping it buffered against risks.

A field experiment entitled "Assessment of maize based conservation agriculture production system (CAPS) on soil health in the hilly terrains under North Central Plateau Zone of Odisha" has been initiated at RRTTS, OUAT, Keonjhar during 2011-12, in split plot design to assess the impacts of CAPS on soil health. The treatment combinations are conventional tillage (CT) and minimum tillage (MT) with sole maize (M) and inter crop maize + cowpea (M + C) in main-plots during wet seasonand Horsegram (H), Mustard (M) and no cover crop (NCC) in sub-plots during dry season.

- The soils of the study area are very deep, moderately well drain and moderately eroded, with reddish brown to brown in colour, sandy clay loam to sandy loam is texture, subangular blacky structure, medium to coarse lime nodules and carbonate coats. The soils are alkaline (pH: 7.2- 7.8), high in OC (14.0 g kg^{-1}) in surface and well saturated with bases (78.1 % to 83.1 %).

- The soils are classified as fine loamy over coarse loamy, mixed, hyperthermic, *Fluventic Haplustepts* because of presence of *cambic* subsurface horizon, ustic soil moisture regime, presence of free $CaCO_3$, high base saturation, OC contents of > 0.2 % (at 125 cm depth), irregular decrease of OC and stratification.
- The CAPS of MT - M+C - H significantly decreased the soil BD to 1.22 Mg m^{-3} over the initial value of 1.24 Mg m^{-3}.
- Continuous practice of CT reduced the macro aggregates by 2.4 % over the initial status of 73.7 % whereas MT enhanced it by 8.7 %. The contents of micro-aggregates under MT was low (11.4 %) as compared to CT (14.9 %).
- Inclusion of cover crops in CAPS decrease the soil pH in the tune of 0.04 units over NCC (7.33).
- The minimum soil disturbance in MT elevated the SOC contents in the tune of 17 % over the initial status of 6.62 g kg^{-1} and the practice of CT, on the other hand, reduced it by 2.4 %. The CAPS of MT- M+C - H resulted in the maximum build up of SOC (8.41 g kg^{-1}).
- The accumulation and preservation of SOM in MT elevated the CEC (+ 15.3 %), Ca^{++} (+20.4 %), Mg^{++} (+20.3 %), K^{+} (+10.1 %) over the initial contents of 25.32, 12.90, 5.15 and 1.68 c mol (p^{+}) kg^{-1}, respectively at the end of 2nd cropping cycle. Similarly, the base saturation of the soils under MT increased to the tune of 3.8 % over the initial status of 78.3 %.
- Physical protection of SOM due to less soil disturbances in MT enhanced the available N , P and K by 14.3 %, 8.4 % and 6.7 % over the initial status 266.6, 15.73 and 340.9 kg ha^{-1}, respectively. Inclusion of horsegram as cover crop significantly increased the available N (+7.5 %), P (+8.6 %) over NCC (277.7, 16.05 kg ha^{-1}).

- The elevated SOM in MT enhanced the population of bacteria (+10.8 %), actinomycetes (+ 14.6 %) and MBC (+13.6 %) over the initial status of 12.34 x10^6 cfu g^{-1}, 20.85 x10^6 cfu g^{-1} and 151.8 µg (g^{-1}, respectively.
- Practice of CT with sole maize recorded significantly higher MEY (61.95 q ha^{-1}) over MT with sole maize (55.76 q ha^{-1}. The maximum MEY of 103.61 q ha^{-1} was obtained from the CAPS of CT-M+C-M, which was at par with the CAPS of MT-M+C-M (102.86 q ha^{-1}).

CONCLUSION

The conservation agriculture production system (CAPS) with components of minimum tillage, maize cowpea intercrop and a follow up cover crop of horsegram elevated the soil organic matter status considerably due to accumulation of litter inputs on the soil surface and less turnover of macro aggregates as a result of minimum physical impacts on the soils. The enhanced SOM contents, in turn, contributed significantly in reduced BD, increased CEC, bases, available nutrients and microbial attributes,. Continuous exposure and redistribution of soils under conventional tillage, on the other hand, depleted the formerly incorporated soil organic matter imparting negative effect on overall soil health. The CAPS of MT- M+C -H appeared to be the best possible choice in the context of improving soil health and yield in the hilly terrains of North Central Plateau Zone of Odisha.

Studies on intra particulate organic matter (iPOM) carbon in different size aggregate fractions, soil moisture characteristics and infiltration rates will substantiate to assess the impact of conservation agriculture production system on soil health, more appropriately.

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