Effect of conservation agricultural practices on selected soil physical properties and carbon pools in black soils of central India

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In partial fulfilment of the requirement for
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MASTER OF SCIENCE

In

AGRICULTURE

(SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)

By

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CERTIFICATE - I

This is to certify that the thesis entitled **“Effect of conservation agricultural practices on selected soil physical properties and carbon pools in black soils of central India”** submitted in partial fulfilment of the requirement for the degree of **MASTER OF SCIENCE** in Agriculture **(Soil Science and Agricultural Chemistry)** of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur is a record of the bonafide research work carried out by **Mr. Salikram Malviya** under our guidance and supervision. The subject of the thesis has been approved by the Student’s Advisory Committee and the Director of Instruction.

No part of the thesis has been submitted for any other degree or diploma (Certificate awarded etc.) or has been published/published part has been fully acknowledged. All the assistance and help received during the course of the investigations has been acknowledged by him.

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Place: Jabalpur **(Salikram Malviya)**
Date:

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LIST OF ABBREVIATIONS

Abbreviation		**Word/Meaning**
%	:	Per cent
T	:	Treatment
ANOVA	:	Analysis of variance
CD	:	Critical difference
m	:	metre
d.f.	:	Degree of freedom
et al.	:	et alii (and other)
g.	:	Gram
ha.	:	Hectare
kg	:	Kilogram
SEm±	:	Standard error of mean
viz.,	:	Vide licet (namely)
i.e	:	that is
Fig.	:	Figure
No.	:	Number
^{o}C	:	Degree centigrade
SMBC	:	Soil Microbial Biomass Carbon
C_{mic}	:	Microbial Carbon
C_{org}	:	Organic Carbon
CT	:	Conventional tillage
RT	:	Reduced/Conservation tillage
MT	:	Minimum tillage
ADS	:	Aggregate distributions
MWD	:	Mean weight diameter
CTS	:	Conventional tillage with residue incorporated
CTB	:	Conventional tillage with residue burn
RTD	:	Reduced tillage with heavy tandem disc harrow
RTR	:	Reduced tillage with rotary tiller
RNT	:	Reduced tillage with heavy tandem disc harrow for the first crop + no-tillage for the second crop
RCW	:	Rice-wheat consortium
WCCA	:	World congress on conservation Agriculture
EC	:	Electrical conductivity
SMC	:	Soil moisture content
PACA	:	Professional Alliance for conservation Agriculture
PPM	:	Parts per million
NT	:	No till
CH	:	Chisel
TP	:	Till plant
CASA	:	Centre for Advancement of Sustainable agriculture
POC	:	Particulate organic carbon
ST	:	Shallow tillage
DOC	:	Dissolved organic carbon
HWC	:	Hot water extractable carbon
MTR	:	Minimum tillage with rototiller
MTD	:	Minimum tillage with disc

CHAPTER- I

INTRODUCTION

Though the country had attained self sufficiency in food grain production (50 mt in 1950-51 to 259 mt in 2012-13 (source: www.pib.nic.in) surpassing all previous years' records but the productivity of the country is still low and stagnating. Notwithstanding to this jubilant mood, world is facing a crisis like situation for staple food grains especially rice and wheat due to a paradigm shift from food crops to energy and/or bio-fuel plants. There is a very little room for expanding area under cultivation but the productivity can be improved through vertical intensification of agriculture keeping in view the sustainability of the production system with sound strategies to sustain or improve environmental as well as human health.

Soil and water management form the basis for sustainable system of productive Agriculture. These natural resources like soil and water are deteriorating/declining at faster rate, which necessitates the need of conservation agriculture to restore the soil quality, enrich soil organic carbon (SOC) and also to feed the population of India projected to be about 1.48 billion by 2030. Conservation agriculture is a way to achieve goals of enhanced productivity and profitability while protecting natural resources and environment. It can also act as a suitable mitigation policy under the future climate change scenario which is going to be a reality in near future.

Now a day, people have come to understand that agriculture should not only be high yielding, but also sustainable (Reynolds and Borlaug 2006). Farmers concerned about the environmental sustainability of their crop production systems combined with ever-increasing production costs have begun to adopt and adapt improved system management practices which lead to the ultimate vision of sustainable agriculture. Conservation agriculture has been proposed as a widely adapted set of management principles that can assure more sustainable agricultural production. The name 'conservation agriculture' has been used to distinguish this more sustainable agriculture from the narrowly-defined ’conservation tillage’ (Wall *et al.,* 2007). Conservation tillage is a widely-used terminology to denote soil management systems that result in at least 30 percent of the soil surface being covered with crop residues after seeding of the subsequent crop (Jarecki and Lal, 2003).

Intensive tillage accelerates the oxidation of organic matter and converts crop residues into CO_2, which is liberated to the atmosphere contributing to the green house gases and global warming of the planet (Baker *et al.,* 2007; Reicosky, 2003; Lal, 1995 and Lal *et al.,* 1998). In addition to this the prevalent practices of residue burning is another major cause of CO_2 release to atmosphere. On the contrary, no-till/conservation tillage would contribute to increase carbon (C) deposits into the soil. Therefore, conservation agriculture (CA) in and semi-arid regions of India has to be understood in a broader perspective (Tomar, 2008; Venkateshwaralu *et al*., 2009)

CA aims at system of raising of crops in a rotation without tilling the soil while retaining the crop residues on the soil surface (Abrol and Sunita, 2005 & 2006, WCCA, 2009) with three key principles i) minimum (mechanical) soil disturbance, ii) maximum (permanent) soil cover/residues and iii) appropriate (diversified) crop sequences/rotations.

Climate change models predict decreased precipitation in many of the world’s cropping regions and, as a result, the substantial land area devoted to rainfed agriculture is likely to become less productive, unless there are major changes in the geographical locations where major crops are grown. Such reductions in productivity may be minimized by novel crop management techniques and the introduction of improved genotypes with enhanced resilience to a biotic stresses. Accelerated atmospheric CO_2 concentration of 387 ppm which is increasing @ 2 ppm/ year (Lal, 2008; Agrawal and Pathak, 2009) is resulting in an unprecedented global warming. Further, this results in drastic change in rainfall pattern with erratic and high intensity downpours, change in mean annual temperature; prolonged-midseason dry spells are disastrous characters of the current monsoon trend (William, 2009). Because of such situation arising, farmers are facing difficulties to have at least one good harvest either in *kharif* or *rabi.*

Farming in the arid and semi-arid region is mainly dependent on the south-east monsoon rain. Mean annual rainfall of the region is varied from 700 mm to 1300 mm which necessitates varied cropping patterns across the rainfed region. Development of cropping systems that are resilient to these climatic extremes as well as sustain soil quality and productivity has been, and continues to be, a major challenge to farmers /scientists /researchers in the rainfed region. Worldwide, CA practices are spread over to about 125 mha, whereas in India it spreads only <2 to 3 mha.

In recent past, CA is gaining momentum in terms of some experimental results and also by some initiatives made by Professional Alliance for Conservation Agriculture (PACA) and Centre for Advancement of Sustainable Agriculture (CASA). However, adoption of CA in these areas/regions is very low due to the mindset/attitudinal change, non-availability of farm equipment to small and marginal farmers as well as difficulty in management of crop residues. The benefit of conservation agriculture has been realized after certain minimum resident period of time. However, the information on impact of conservation agriculture on soil organic carbon, soil microbial biomass carbon and other selected soil physical properties are scanty in the black soils of central India. Thus, an attempt has been made to study the selected soil properties under conservation agriculture experiment with following objectives

Objectives:

1. To study the effect of conservation agriculture on the selected soil physical properties.
2. To study the effect of conservation agriculture on soil carbon pools and microbial biomass carbon under different cropping systems in black soils of central India.

CHAPTER - II

REVIEW OF LITERATURE

Indian agriculture is largely characterized by rainfed farming, with more than 60 percent of the cropped area being dependent on rainfall.

Madhya Pradesh (MP) state is known for its numerous river basins and is spread over about 30.7 m ha, out of which nearly 50 per cent area is cultivable / arable. In spite of numerous rivers and river basins in the state only 20 percent of the agricultural area is under some form of irrigation. Farming in the state is mainly dependent on the south-west monsoon rain. Mean annual rainfall shows wide variation, it varies from 700 mm in the west to 1300 mm in the east necessitating varied cropping patterns across the state. Development of cropping systems that is resilient to these climatic extremes has been, and continues to be, a major challenge to farmers /scientists /researchers in the rainfed region.

Conservation agriculture (CA) adopted in comprehensive way, over a period of time will bring multitude benefits like minimizing soil loss, conserving water, controlling weeds enriching SOC and increasing productivity in the face of challenges facing agriculture sector (Abrol and Sunita, 2005; Venkateswarlu *et al.* 2009) The various benefits are, reduced cost of cultivation, enhanced efficiency of applied nutrients and water- resulting from physical, chemical and biological improvement in soil, enhanced carbon (C) sequestration, builds-up of soil organic matter (SOM) and reduced green house gases (GHGs) emissions.

Conservation agriculture (CA) in arid and semi-arid regions (India) should be understood in a broader perspective. The term CA refers to the system of raising of crops in a rotation without tilling the soil while retaining the crop residues on the soil surface (Abrol and Sunita, 2006) with three key principles.

1. Minimum (mechanical) soil disturbance
2. Maximum (permanent) soil cover/residues
3. Appropriate (diversified) crop sequences/rotations

Conservation tillage is more appropriate under rainfed agriculture than zero tillage. The CA practice has to be adopted holistically so that it minimizes soil loss, conserves water and control weeds for success of crop production under rainfed conditions. (Venkateswarlu *et al.* 2009). It CA adapted and adopted in a comprehensive way over a period of time, it may bring multitude benefits in the face of challenges facing agriculture sector (Abrol and Sunita, 2005).

The various benefits are listed below.

- Short-term: Reduced cost of cultivation
- Medium term: (3-5yrs) Enhanced efficiency of applied nutrients and water-resulting from physical, chemical and biological conditions.
- Long-term: Enhanced carbon sequestration build up of SOM and Mitigating GHGs emissions.

In India, efforts to adopt and promote resource conservation technologies (RCTs) have been underway for nearly a decade. Only in the recent past, these technologies are finding acceptance by the farmers. The Rice-Wheat Consortium (RWC) for indogangetic plains (IGP) (by CGIAR and NARS) has brought national attention for adopting conservation agriculture. This system has pronounced effects on mitigation of GHG emission and adaptation to climate change. Adoption of conservation agriculture has expanded to cover about 2-3 m ha (RWC, 2005; WCCA Report, 2009) and there is a scope for intensifying it based good results obtained in the North western and Central India. Another estimate reported, just about 2 million hectares under this agriculture practice in India, which rests on conserving precious resources such as water, diesel, labour and protect land from degradation. If the total land under conservation agriculture reaches 3.5 million hectares, the saving in diesel alone would be 120 million litres (Joshi, 2008).

Crop residues in general serve a number of beneficial functions, including soil surface protection from erosion, water conservation and maintenance of soil organic matter (OM) Large amounts of residue in the soil surface have traditionally been viewed as a nuisance, and have been associated with mechanical planting difficulties, poor crop-stand establishment, decreased efficacy of herbicides, release of growth-inhibiting allelopathic compounds, and ultimately, yield reductions. Therefore, crop residues, particularly wheat residue, are commonly burned or plowed under followed by discing to prepare a seedbed for double cropped soybean (Prasad,1999).

The quantity of residues remaining during the cropping season is also influenced by the rate of residue decomposition. Nitrogen-rich legume residues, such as those from beans and soybean, decompose much more rapidly than nitrogen-poor cereal straw and other residues with high C/N ratios. On the other hand, legumes used as a cover crop can provide a weed smothering cover, protection from raindrop impact, and important additions to organic matter. Harvesting procedures can drastically affect the quantity of residues remaining in the field.

Status of Conservation agriculture

International status

According to recent estimates, the extent of Conservation Agriculture worldwide is more than 105 Mha (Derpsch and Friedrich, 2009) on the global scale; no-tillage is almost exclusively a large or medium-sized fanner domain of cropped area, no-till has been practiced on 46.8 percent (49.5 Mha) in South America in which Brazil is the leader with 22 Mha or 45 percent of its total cultivated land, (Bhale and Wanjari, 2009; Anonymous, 2008; Derpsch and Friedrich, 2009) About 38 percent (40 Mha) of no-till is practiced in USA and Cananda, and 11. 5 percent in (12 Mha) in Australia and New Zealand: with less than 4 percent of no-tillage in the rest of the world including South Asia, East and SE Asia, Africa, and Europe(Dennis Garnity,2008).

Research conducted at USDA with specialized equipment shows that soil carbon was lost very rapidly in the form of CO_2, within minutes after soil preparation and that the amount lost was directly related to the intensity of tillage. After 19 days, the total C loss, from the plot of ploughed under wheat residues, was up to 5 fold higher than from plots not ploughed.

Reicosky (1997) reported that average short-term carbon loss from 4 conservation tillage tools was 31percent of the CO_2 from the mould board (MB) plough. The MB plough lost 13.8 times more CO_2 loss as compared to the soil not tilled while conservation tillage tools averaged about 4.3 fold more CO_2 loss. It is estimated that wide dissemination of conservation tillage could offset as much as 16 percent of worldwide fossil fuel emissions. In Brazil, grain production doubled from 57.8 mt in 1991 to 125 mt in 2004 due to increased area under no-tillage. (Anonymous, 2008).

In an another study, conducted at Brazil to evaluate the effect of different tillage systems (Zero-till and Conventional tillage) on the change in soil carbon stocks over a 20-year period, approximately 10 Mg ha^{-1} of soil carbon in the 0-100 cm depth interval was lost under continuous zero till. However, under conventional tillage system losses were greater (up to 30 Mg ha^{-1}) when mould board (MB) was used and/or tillage was performed twice a year (Jantalia *et al.*2007) Conservation tillage reduces soil erosion and increasing organic matter, aggregation, water infiltration and water holding capacity compared with conventional tillage under low (OM) organic matter (highly weathered), erodible soils of Southeastern USA (Lal, 1997 and Sainju *et al.* 2006).

A separate study was conducted on clayey soils of Central Greece under conventional cultivation and conservation tillage of winter cereals (Wheat) adopting conservation tillage that fuel saving of 40 percent compared to conventional cultivation, increased cumulative infiltration due to improved soil structure and macropore formation (such as worm holes and root channels) and it recorded yield reduction of 5 percent under no-tillage which indicates the negligible yield reduction (Papayiannopoulou *et al.*2008). Results of long-term (25 years) study conducted in Morocco under rainfed situation showed that the No-tillage system also offer ways to enhance resource productivity; water productivity and water use efficiency, soil quality and better-cost effectiveness.Results reveal that in all cases higher yields under drought conditions and higher or equal under normal conditions (Gharras *et al.* 2009).

National status

Vertisols and associated soils occupy 73 million hectares (22.5 % of total geographical area) in sub-humid and semi-arid tropics of India, out of which more than 60 mha spread in MH, MP, Gujarat, and Northern part of Karnataka.

In India, efforts to adopt and promote resource conservation technologies have been underway for nearly a decade. Only in the recent past, these technologies are finding acceptance by the farmers. The Rice-Wheat Consortium for IGP (by CGIAR and NARS) has brought national attention for adopting CA. This conservation agriculture (CA) has pronounced effects on mitigation of GHG emission and adaptation to climate change. Adoption of CA has expanded to cover about 2-3 mha (RWC, 2005, WCCA Report 2009) Residue burning is a prevalent practices in many parts especially in Bhopal, Harda, Khanwa, Guna and Chhindwara districts of MP state. CA is yet to go from experimental plots / Research Stations to farmers' fields. Off late, CA is gaining momentum in terms of some experimental results and also by some initiatives made by PACA and CASA. However, adoption of CA in these areas/regions is very low.

A series of long term experiments (1991-2000) were conducted in rice-wheat under Vertisols (Jabalpur). Studies indicated that in (rice-wheat) both the crops, adoption of no-tillage had a slight advantage in terms of yields as compared to conventionally tilled plots. Deep tillage did not benefit either of the crop yields compared to conventional tillage. Similarly, straw mulch application @ 5 tha^{-1} was found highly effective in further improving yield. With the adoption of CA, the beneficial effects are likely to increase over time due to improvement in soil quality (Tomar, 2008).

Need for Crop Sequences/Rotations

Long-term strategy of annual crop sequencing that optimizes crop and soil use options to attain production, economic, and resource conservation goals by using sound ecological management principles (Karlen 2004; Tanaka *et al.* 2002; Liebig *et al.* 2007) Understanding of short-term (2-4 yr) crop effects on relevant agronomic and environmental parameters is critical to successful implementation of this system for sustainable production. Crop rotation has been practiced as a beneficial management practices for centuries.

- Crops rotation offers a diverse “diet” to soil microorganisms.
- Performs a function of biological pumps.
- Nutrients leached down to deeper layers are recycled by the deep rooted crop grown in rotations.
- It performs phytosanitory function as it prevents the carryover of crop-specific pests and diseases.

Legumes are grown as intercrops or in rotation with cereals and other crops and have been important components of sustainable farming systems since ancient times. It improves soil fertility because of their nitrogen (N) fixing ability, thus sparing indigenous N (Giller and Wilson, 1991; Wani *et al.* 1995 and 2003) In many long-term field experiments the beneficial effects of rotations on CS have been proved (Hulugalle, 2000; FAO report 2001 and 2002; Blair and Crocker, 2000; Ryan *et al.* 2006; Ryan *et al.* 2008 and Danga *et al.* 2009). Inclusion of legumes, favour improvement of soil quality and build up soil carbon (C). This leads to increased crop yields and consequently the amount of residue available to be returned to the soil (Wani *et al.*1994 and Paustian *et al.* 1997).

Katsvairo and Cox (2000) reported that corn yield was 17 percent greater in the soybean-wheat/red clover-corn rotation under (MB plough) with low chemical input compared to continuous corn under high chemical management. Similarly, corn yielded was 7 percent greater in soybean-corn rotation under low chemical management compared with continuous corn under high chemical management**.**

Effect of Conservation agriculture on soil properties

Three conservation tillage systems, chisel (CH), till-plant (TP), and no-till (NT), were compared to conventional (mould/board) tillage (CN) for differences in depth zone (5 cm) and upper profile (5–15 cm) soil temperatures and related soil thermal properties. In-row spring soil temperatures were highest in CN, slightly lower in TP and CH, and lowest in NT. The maximum difference in daily average temperature observed between tillage treatments occurred on 2 May 1982 when the NT, CH, and TP treatments were 5.9, 2.3, and 1.8°C cooler than CN, respectively. Soil thermal diffusivity (K') in the 5- to 15-cm zone was 20 to 25 percent higher in the NT treatment than in the CN and CH treatments, which were not significantly different. In 1 of 2 yr, K' was significantly higher in the TP treatment than in the CN and CH treatments. The reduction in soil temperatures observed with conservation tillage was attributed to differences in thermal admittance (μ), heat flux to deeper depth, and total heat inputs to the soil profile. The higher thermal admittance and heat flux in the NT treatment produced lower upper profile soil temperature.

Long-term impact of conservation tillage practices on soil properties of Vertisols were studied under soybean–wheat system in Bhopal. Conservation tillage practices that is, no-tillage (with crop residues retained on the surface and direct drilling of seed) and reduced tillage (residue retained + one sweep tillage) were as effective as conventional tillage (residue removed + one summer tillage by sweep cultivator + two tillage by sweep cultivator) in terms of crop productivity under soybean and wheat (Hati *et al.* 2009). Wheat residue incorporation or retention coupled with application of 28 kg N ha^{-1} through fertilizer or organic manures (~4 t FYM ha^{-1}) was more beneficial than burning in terms of enhanced crop productivity and soil fertility. Wheat residue incorporation resulted in 20–22 percent higher yields in soybean and 15–25 percent in wheat as compared to residue burning (Subba Rao *et al.* 2009). Temporal changes on soil water storage were studied under conservation tillage in soybean at IISS, Bhopal. In the early stage of the crop, moisture content in the profile was more in MB and conventional tillage followed by reduced tillage and no-till treatments due to more infiltration rate. In later stage profile moisture storage was higher in RT and NT compared to CT and MB due to the presence of residues and bio-pores and less disturbance of surface soil in conservation tillage.

Sharma *et al.* (2009) reported significant effects (8 years) of tillage as well as conjunctive nutrient–use treatments on sorghum and mung bean grain yields at Hyderabad. Conventional tillage up to the eighth year of the study maintained 12.8 and 11.2 percent higher sorghum and mung bean grain yields, respectively, compared to reduced tillage. After eight years, reduced tillage tended to be equal or better than conventional tillage in improving crop yields. Energy saving data showed that conservation tillage could save about 20 litres of diesel and 187,331kcal of energy ha^{-1} over the conventional system. This raised the hope of success of reduced tillage in at SAT Alfisols, if practised over a long–term.

Jin *et al.* (2010) reported that Conservation tillage (CT) was recognized as an advanced agricultural technology that might reduce drought and improve the physical condition of soils worldwide. An increase in water infiltration and a reduction in water and wind erosion could be achieved through the use of no-tillage, minimum tillage, and residue cover.

Paula and Teodor, (2012) revealed that soil moisture was higher in no-tillage (NT) and minimum tillage (MT) at the time of sowing and in the early stages of vegetation and differences diminished over time. Moisture determinations showed statistically significant differences. The MT and NT applications reduced the thermal amplitude in the first 15 cm of soil depth and increased the soil temperature by 0.5-2.2°C. Water dynamics and soil temperature showed no differences on the effect of crop yields. However, wheat production at MT and NT applications had no significant differences; soybean production was significantly affected by MT and NT applications. The differences in crop yields were recorded at maize and could be a direct consequence of loosening, mineralization and intensive mobilization of soil fertility.

Aggregate and mean weight diametre (MWD)

Soil structural stability is the ability of aggregates to remain intact when exposed to different stresses (Kay *et al.* 1988) and measures of aggregate stability are useful as a means of assessing soil structural stability. Shaking of aggregates on a wire mesh both in air (dry sieving) and in water (wet sieving) are commonly used to measure aggregate stability (Kemper and Rosenau, 1986) With dry sieving the only stress applied is the one from the sieving, while with wet sieving the samples are additionally exposed to slaking. Therefore, the mean weight diameter (MWD) of aggregates after dry sieving is generally larger than MWD after wet sieving.

Zero tillage with residue retention improves dry aggregate size distribution compared to conventional tillage (Govaerts *et al.* 2009 and 2007a) The effect on water stability of aggregates is even more pronounced, with an increase in MWD of wet sieving reported for a wide variety of soils and agroecological conditions (Govaerts *et al.* 2009, 2007b, Lichter *et al.* 2008, Li *et al.* 2007, Pinheiro *et al.* 2004, Chan *et al*. 2002, Filho *et al.* 2002, Hernanz *et al.* 2002 and Carter 1992). Even when conventional tillage results in a good structural distribution, the structural components are weaker to resist water slaking than in zero tillage situations with crop residue retention, where the soil becomes more stable and less susceptible to structural deterioration. The reduced aggregation in conventional tillage is a result of direct and indirect effects of tillage on aggregation (Bear *et al.* 1994 and Six *et al.* 1998). Physical disturbance of soil structure through tillage results in a direct breakdown of soil aggregates and an increased turnover of aggregates (Six *et al.* 2000) and fragments of roots and mycorrhizal hyphae, which are major binding agents for macro aggregates.

Bordovsky *et al.* (1999) revealed that bulk density under the reduced tillage system was higher than with the conventional tillage system. However, saturated hydraulic conductivity (Ks) of the surface soil was increased by reduced tillage practices compared with conventional tillage. This was possibly due to higher amounts of micro-aggregates and larger macro pores under the reduced tillage system. Residue removal decreased the Ks of surface soil, especially in reduced-tillage grain sorghum and wheat plots. Micro aggregation values were higher with residue retained than with residue removed (27.1 vs. 23.5 g kg^{-1} in dry land and 32.3 vs. 27.1 g kg^{-1} in irrigation) Results indicate that residue removal from Rolling Plains soils should be discouraged. Because of higher bulk density, use of a reduced tillage system may result in the need for occasional deep chiseling to reduce the effects of compaction.

Hajabbasi and Hemmat (2000) reported that a wet sieving method was used to determine aggregate size distribution (ASD), and mean weight diametre (MWD) as indices of soil aggregate stability. Soil organic carbon was also determined. For the first three years of the experiment, ASD and MWD at 0±15 cm were similar in different tillage treatments, except for direct drilling which had a significantly higher amount of aggregate greater than 2 mm and 2±1 mm diametre compared to the conventional method. At the second and third sampling depths all treatments had similar influence on ASD and MWD. Tillage treatments showed a significant effect on ASD and MWD in the fourth year of the experiment in all three depths. Almost 70 percent of the aggregates in the MD system were less than 0.25 mm, while only 55 percent of the aggregates in the direct drilling methods were less than 0.25 mm diametre. The four-year yield average for conventional and non-inversion tillage systems was 7264 and 6815 kg ha yr^{-1}, respectively. Although, direct drilling improved soil structural stability, its lower yield (5608 and 4731 kg ha yr^{-1} for TP and NT, respectively) potential would indicate that reduced tillage systems (i.e. CD) appear to be the accepted alternative management compared to conventional practice (MD)

Knapen *et al.* (2008) Indicated that only a small fraction (10% on average) of the difference in soil detachment rate between conventional and conservation tillage could be attributed to the dissipation of shear forces on the residues. The remaining decrease in soil detachment during concentrated runoff after a two-year application of conservation tillage could be explained by the increased dry bulk density and root and crop residue content in the topsoil that reduced soil erodibility.

İsmail (2011) revealed that the tillage effects on HC, BD and PR were significant at soil depth of 0-30 cm. The hydraulic conductivity was higher in CTS, and followed by conventional tillage with residue burned (CTB), reduced tillage with heavy tandem disc harrow (RTR), reduced tillage with rotary tiller (RTD), reduced tillage with heavy tandem disc harrow for the first crop + no-tillage for the second crop (RNT) and and no tillage (NT) (expand) practices, respectively. The hydraulic conductivity values under NT in 2007 and 2008 were 20 and 30 percent lower at 0-30 cm depth compared with CTS, respectively. The conventional tillage treatments in the semi-arid conditions improved the HC with decreasing BD and PR of the clayey soil. The BD and PR values were higher under NT treatments than the tilled plots and increased with depth. The values of soil compaction indicators were significantly greater under no-tillage and reduced tillage as compared to those under conventional tillage in all soil depths studied.

Effect of conservation agriculture on soil organic carbon

Soil organic matter (SOM) and related soil properties are the probably the most widely acknowledged indicators of the soil quality. Small changes in soil organic carbon (SOC) resulting from changes in soil management are often difficult to measure but have pronounced effects on soil behavior and microbial processes. It may take many years for controlling soil management properties to cause measurable differences in soil organic carbon (Silcora *et al*. 1996). Changes in a small but relatively labile fraction of soil organic carbon (SOC) may provide an early indication or improvement that is response to management practices. The labile fractions of soil C important to study in their own right as then fractions fuel the soil food web and therefore greatly influence nutrient cycles and many biologically related soil properties. The labile fractions of soil C are often termed the soil C, which belongs to a highly recalcitrant or passive pool that is only very slowly altered by microbial activities (Islam and wail, 2000).

Potter *et al.* (1997) revealed that the no-till treatments resulted in significant differences in SOC distribution in the soil profile compared with stubble mulch tillage in all four crop rotations, although differences were largest in the continuous cropping systems. Continuous wheat averaged 1.71 percent SOC in the surface 2 cm of soil compared with 1.02 percent SOC with stubble mulch tillage. Continuous sorghum averaged 1.54 percent SOC in the surface 2 cm of soil in no-till compared with 0.97 percent SOC with stubble mulch tillage. Total SOC content in the surface 20 cm was increased 5.6 t C ha^{-1} in the CW no-till treatment and 2.8 t C ha^{-1} in the CS no-till treatment compared with the stubble mulch treatment. Differences were not significantly different between tillage treatments in the WF and WSF systems. No-till management with continuous crops sequestered carbon in comparison to stubble mulch management on the southern Great Plains, whereas fallow limits carbon accumulation.

Gregorich *et al.* (2001) made a comparison of continuous maize cultivation with a legume-based rotation. Rotation system had a greater effect on soil C than did fertilizer. The difference between mono-cultured maize and the rotation was 20 C ha^{-1} while the effect of fertilization was 6 C ha^{-1} after 35 years. In addition, the SOM present below the ploughed layer in the legume-based rotation appeared to be more biologically resistant. A positive effect on SOC (an increase of 2- 4 t ha^{-1}) was also found with legumes and alternate cattle grazing in semi-arid Argentina (Miglierina *et al.* 2000).

Oliver *et al.* (2003) evaluated that soil functions of contemporary agricultural management practices, the adjustment of microbial biomass and C and N mineralization capacities was monitored during 9 years following the implementation of conventional and reduced tillage, and mineral N and pig slurry fertilization systems. Soil microbial biomass content and microbial activities decreased continuously from initial values. The decrease was slowed by slurry application, compared to either no or mineral N fertilization, and both slurry and mineral N application stimulated soil microbial activities in the long-term. There were no significant differences in microbiological characteristics between conventional and reduced tillage for the 0 to 30 cm soil depth but microbial biomass and activity were highest from 0 to 15 cm depth under reduced tillage. Changes in several microbial properties became evident when analyzing the whole experiment of 9 years and the soil unit is also of importance as shown by higher microbial activity level in Anthrosols in comparison to Luvisols.

Anderson (2004) showed that cropping systems in rotations could be designed to reduced weed community density several fold; tillage lessens this rotational effect by burying weed seeds and prolonging their survival in soil. Crop residues on the soil surface reduce weed seedling establishment in no-till systems, but tillage eliminates this effect. Crops also yielded less after tillage compared with no-till in this semiarid climate. Tillage might help in managing herbicide resistance, but it also may increase.

Sakine and Anyl (2005) reported that the highest organic carbon was obtained from minimum tillage with rototiller (MTR), followed by minimum tillage with disc (MTD) and conventional tillage (CT) Penetration resistance was measured pre-fall tillage, and during the growing period and gave the following values ($P < 0.05$) for CT, MTR and MTD: 1.65, 1.18 and 1.57 MPa, and 1.33, 1.35 and 1.76 MPa at 18-30 cm. Although there were no statistically significant differences between the tillage systems, grain yield was higher in MTR than in CT and MTD. Consequently, we expect MTR to be more sustainable because of increased grain yield and improving soil physical properties over the long term compared with CT and MTD.

Haene *et al.* (2009) reported that reduced tillage (RT) agriculture resulted in a higher stratification of SOC in the soil profile than conventional tillage (CT) agriculture. However, the total SOC stock in the 0-60 cm layer was not changed, even after 20 of years RT agriculture. The microbial biomass carbon (MBC) was significantly higher in the 0-10 cm layer under RT agriculture, even after only 5 years, compared to CT agriculture. The higher SOC and microbial biomass carbon (MBC) content in the upper 0-5 cm layer of RT fields resulted in a higher C mineralization rate in undisturbed soil in the laboratory. Simulating ploughing by disturbing the soil resulted in inconsistent changes (both lower and higher) of C mineralization rates. More over a crop rotation with root crops, with heavy soil disturbance every 2 or 3 years at harvest, possibly limited the anticipated positive effect of RT agriculture.

Chen *et al.* (2009) reported that conventional tillage with residue removal (CT), shallow tillage with residue cover (ST), and no-tillage with residue cover (NT) were investigated. Carbon and N in various aggregate-size classes and various labile organic C fractions in the 0–15- and 15–30-cm soil layers were evaluated. The ST and NT treatments had 14.2 and 13.7 percent higher SOC stocks and 14.1 and 3.7 percent higher total N (NT) stocks than CT in the upper

15 cm, respectively. Labile C fractions: particulate organic C (POC), permanganate oxidizable C ($KMnO_4$-C), hot-water extractable C (HWC), microbial biomass C (MBC) and dissolved organic C (DOC) were all significantly higher in NT and ST than in CT in the upper 15 cm. $KMnO_4$-C, POC and HWC were the most sensitive fractions to tillage changes. The portion of 0.25– 2 mm aggregates, mean weight diametre (MWD) and geometric mean diameter (GMD) of aggregates from ST and NT treatments were larger than from CT at both 0–15- and 15–30-cm soil depths. The ST and NT treatments had significantly higher SOC and NT in the 0.25–2 mm fraction at both depths and significantly higher NT content in the upper 15 cm. Positive significant correlations were observed between SOC, labile organic C fractions, MWD, GMD, and macro aggregate (0.25–2 mm) C within the upper 15 cm. They have concluded that both variants of conservation tillage (NT and ST) increase SOC stock in the rainfed farming areas of northern China and are therefore more sustainable practices than those currently being used.

Gwenzi *et al.* (2009) showed that seasonal yields significant ($P < 0.05$) tillage effects, but 6-year mean yields (t ha-1) were similar (CT: 4.49, MT: 4.33, NT: 4.32 for wheat; CT: 3.30, MT: 2.82, NT: 2.83 for cotton) Overall, MT and NT improved soil structural stability and carbon sequestration, while impacts on crop productivity were limited. Therefore, MT and NT are more sustainable tillage systems for the semi-arid regions than conventional tillage.

Karoline *et al.* (2009) opined that RT agriculture in a higher stratification of SOC in the soil profile was better than CT agriculture. However, the total soil organic carbon (SOC) stock in the 0-60 cm layer was not changed, even after 20 of years RT agriculture. The MB-C was significantly higher in the 0-10 cm layer under RT agriculture, even after only 5 years, compared to CT agriculture. The higher SOC and MB-C content in the upper 0-5 cm layer of RT fields resulted in a higher C mineralization rate in undisturbed soil in the laboratory. Simulating ploughing by disturbing the soil resulted in inconsistent changes (both lower and higher) of C mineralization rates. A crop rotation with root crops, with heavy soil disturbance every 2 or 3 years at harvest, possibly limited the anticipated positive effect of RT agriculture in our research.

Effect of Conservation agriculture on soil microbial biomass carbon (SMBC)

Soil organic matter is an important component of soil quality and productivity; however, its measurement alone does not adequately reflect changes in soil quality and nutrient status. Instead, measurements of biologically active fractions of organic matter, such as microbial biomass carbon and nitrogen, and potential C and N mineralization, could better reflect changes in soil quality and productivity that alter nutrient dynamics. Therefore, measuring microbial biomass is a valuable tool for understanding and predicting long-term effects on changes in land use and associated soil conditions.

The microbial biomass of soil is defined as the part of the organic matter in the soil that constitutes living microorganisms excluding plant roots and soil animals. The microbial biomass consists mostly of bacteria and fungi, which decompose crop residues and organic matter in soil resulting in release of nutrients, such as nitrogen (N), phosphorus (P) and sulphur (S) into the soil that are available for plant uptake. It is generally expressed in the milligrams of carbon per kilogram of soil or micrograms of carbon per gram of dry weight of soil. Typical biomass carbon ranges from 1 to 5 percent of soil organic matter. About half the microbial biomass is located in the surface 10 cm of a soil profile. Soil microbial biomass, carbon on the average, constitutes only about 1 percent of the soil organic carbon (Moore *et al.* 2000), yet it may comprise up to 44 percent of the active pool of soil nitrogen (Liang *et al.* 1999) Therefore, the size of soil Cmic pool and its turnover have significant bearing on the overall productivity of soils. Several studies indeed show a close relationship between soil microbial biomass and nutrient availability to plants (Jenkinson and Ladd, 1981; Houot and Chaussod, 1995).

Soil microorganisms play a crucial role in carbon flow and nutrients cycling in ecosystems. Soil microbial biomass, a living part of soil organic matter constitute a transformation matrix for added and native organic matter and act as a labile reservoir for plant available N, P and S (Jenkinson and Ladd, 1981;

Singh *et al.*1989) The size of the microbial biomass can be considered as an index of soil fertility and indicator of soil quality (Bending *et al.* 2004), which depends primarily on rate of nutrient fluxes (Singh *et al.* 2007) and quality and quantity of organic inputs determining the community structure (Peacock *et al.* 2001) Immobilization and mineralization of nutrients by and from the soil microbial biomass makes a considerable contribution to plant nutrition (Singh *et al.* 1989; Raghubanshi *et al.* 1990).

When discussing the microbial biomass in soil, two different situations may be explored. In the first, the biomass size is considered to remain relatively constant over time and C plus other nutrients simply flow through the biomass. Carbon and other nutrients enter the biomass as complex organic forms and leave as carbon dioxide or mineralized forms of the elements. The second case involves the addition of a substrate to soil which stimulates the growth of the microbial biomass and the fate of the nutrients in the organic material may result in their release to the mineral form or they may become incorporated in the expanding microbial biomass pool.

Organic C, N, P, S <------> microbial <-------> CO_2, mineral N, biomass mineral P, mineral S

Soil microbial biomass carbon (MB-C) comprises 1-5 percent of total organic carbon (Zhang and Zhang, 2003; Nsabimana *et al.* 2004; Gil-Sotres *et al.* 2005) Because of its high turnover rate, MB-C could respond more rapidly to changes of soil environment than soil organic matter (Powlson *et al.* 1987) Microbial biomass constitutes a significant part of the potentially mineralizable N and serves both as the transformation agent and source-sink of nitrogen (Bonde *et al.* 1998) Consequently, the microbial biomass nitrogen (MB-N) may have significant impacts on nitrogen availability and overall soil nitrogen cycling (Singh *et al.* 2009) The microbial biomass phosphorous (MB-P) accounts for 2–10 percent of total soil phosphorous (Chen *et al.* 2003 and Agbenin and Adeniyi, 2005) The rapid turnover of phosphorous in microbial pool may contribute a major source to available phosphorous pool, as phosphorous is released from microbial biomass is highly available to plant uptake, and also the microbial immobilization of inorganic P protects the phosphorous from physico-chemical fixation (Chauhan *et al.*1981; Oberson *et al.* 2001).

Soil physico-chemical properties influence the level of biomass and the activity of soil microorganisms. Soil with relatively higher organic matter input usually develops a larger microbial biomass. Because, the microbial biomass affects soil fertility and hence ecosystem functioning, the measurement of microbial biomass, activity and nutrient levels have attracted considerable attention to study soil nutrient cycling (Singh *et al.*1989; Srivastava and Singh, 1991) Contribution of soil microbial biomass towards nutrients flow, organic matter turnover (Garcia *et al.*1996) and soil structural stability (Beyer *et al.*1992) have led to soil microbiologists to use it as a tool for soil management and perturbation studies (Smith and Papendick, 1993; Duxbury and Nkambule, 1994) Thus, microbial biomass can be considered as an important parameter for assessment of soil functional status.

The microbial biomass is affected by factors that change the water or carbon content of soil, and include climate, soil type and management practices. The microbial biomass grows best in warm and moist conditions. Consequently areas with warm moist climates will have a greater microbial biomass than cold or dry areas. Soil type can also influence the size of the microbial biomass. Soils with higher clay contents generally have a higher microbial biomass as they retain more water and often contain more organic C. Soil pH is also important as microbial growth declines under conditions that are too acid or too alkaline. A soil pH near 7.0 is most suitable for microbial growth.

Management has a major impact on microbial biomass in agricultural soils, due largely to its ability to impact the amount of organic carbon entering the soil. The amount of labile carbon present in soil is of particular importance for the microbial biomass. Labile carbon is carbon that is easily broken down by microorganisms, and is largely made up of crop residues and particulate organic matter. This carbon provides a readily available energy source for microbial decomposition, and soils with more labile C tend to have a higher microbial biomass. In many agricultural soils where concentrations of labile carbon are low, the microbial biomass is often ‘starved’ because it doesn’t have enough organic C. Studies have shown that biological activity in cropping soils is generally low compared to other land uses, such as pasture or native vegetation, due to the low amount of labile carbon present. Management practices that can increase soil carbon and thus soil microbial biomass includes: i) reducing the length of fallow periods to recharge soil moisture reserves significantly reduces soil biological activity because of the lack of substrate available to soil organisms during this period, ii) retaining crop residues can increase the substrate available for microbial growth and iii) practices that minimize soil break-up, such as zero tillage, can also help to maintain soil organic matter and microbial biomass. Tillage practices that are less disruptive to soil can increase the microbial biomass. Less disruptive tillage increases the microbial biomass by increasing labile carbon in soil. These management practices also protect soil aggregates and do not break fungal networks, which are an important habitat for the microbial biomass in soil.

From the foregoing review, the information on impact of conservation agriculture on soil organic carbon, soil microbial biomass carbon and other selected soil physical properties are scanty in the black soils of central India. Thus, an attempt has been made to study the selected soil properties under conservation agriculture experiment.

CHAPTER-III

MATERIALS AND METHODS

A field experiment was initiated during 2010-11 at the research farm of the Indian Institute of Soil Science, Bhopal. The present investigation was carried out during 2012-13 to evaluate the "Effect of conservation agricultural practices on selected soil physical properties and carbon pools in black soils of central India."

Location of experimental site

Experimental site is situated at $23^0$18'N and 77024' E, with 485 M above mean sea level and has sub-humid tropical climate with a mean annual air temperature of 25^oC and annual rainfall of 1208 mm. Total Rainfall received during 2012 was 966.8 mm in which 886 mm was received during the crop growth period (Fig 3.1).

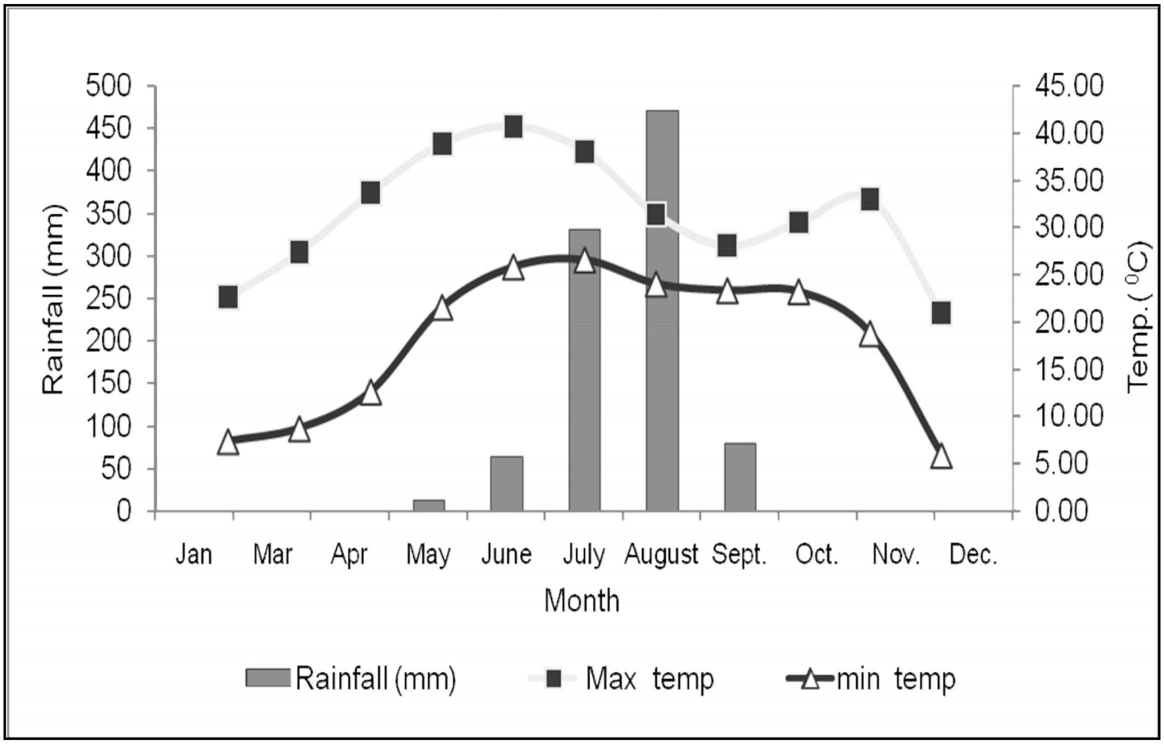


Fig. 3.1 Meteorological data for the year 2012

Experimental Soil

A Vertisol (fine clay, montmorillonite, Typic Haplustert) with pH 8.1, CEC 42 c mol (P^+) kg^{-1} and OC 0. 59 percent (0-15 cm) .The soil from the experiment site was sampled before the initiation of the experiment and its fertility status assessed. The available N, P and K status of initial soil in 0-15 cm was 309, 13.89 and 381 kg ha^{-1}, respectively. There was decreasing trend of available nutrients with increasing depth.

Table 3.1. Initial soil properties of experimental site

Soil parameters	**0-15 cm**	**15-30 cm**
pH	8.31	8.55
EC(dSm^{-1})	0.20	0.19
OC (%)	0.59	0.49
N (kg ha^{-1})	309.5	215.4
P (kg ha^{-1})	13.9	12.4
K (kg ha^{-1})	381.2	294.9
Micronutrients (mg kg^{-1})		
Cu	1.64	1.44
Mn	7.14	9.47
Fe	5.59	6.72
Zn	0.57	0.44
Carbon pools (%)		
Very labile	0.32	0.26
Labile	0.18	0.20
Less Labile	0.09	0.04
Non-labile	0.70	0.58
TOC (%)	1.28	1.07
MWD (mm)	0.43	0.44
Bulk Density (Mg m^{-3})	1.35	1.55

Table 3.2. Experimental details

Treatment details	**Sub-plot (Crop sequences/Rotations)**	
Main plot	**First year**	**Second year**
1. Conventional Tillage	1. Soybean- Fallow*****	Soybean – Fallow*****
2. Conservational Tillage (RT)	2. Maize- Gram	Soybean - Fallow
	3. Soybean- Fallow******	Maize- Gram
	4. Soybean+Pigeon pea	Soybean+Pigeon pea
	5. Soybean+ Cotton	Soybean+ Cotton
	6. Soybean– Wheat	Soybean– Wheat

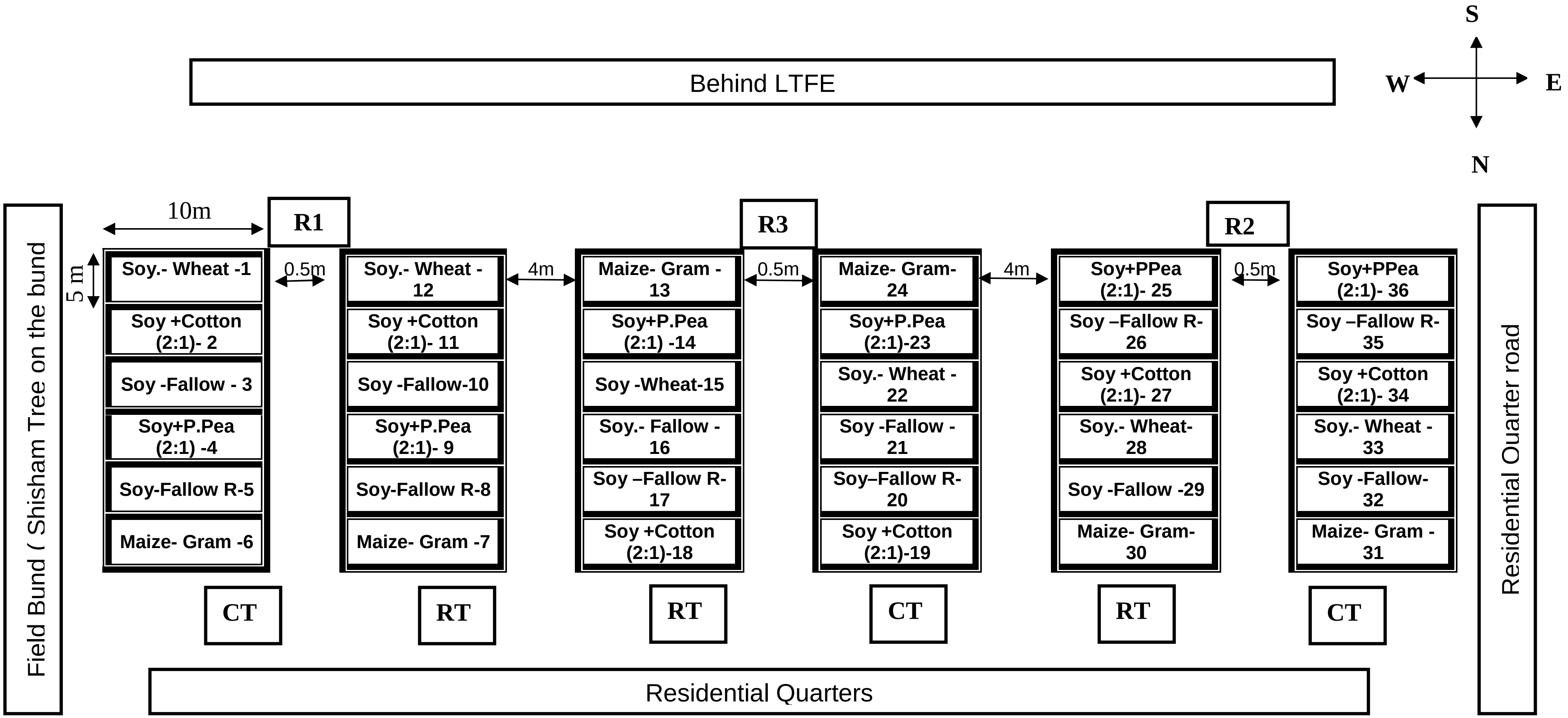
Design: Split plot, Single rotation ***** Double rotation*

Main plot: Two tillage systems

- **i) Conventional tillage**: 3-4 tillage operations using duck foot cultivator or sweep tillage/planting, residue removal during *Kharif* and one sweep tillage followed by planting during *Rabi* season.
- **ii) Reduced tillage** (Conservation Tillage with 30 percent residue retained on the field): Reducing tillage operation by half during *Kharif* cultivation i.e one sweep tillage followed by sowing/planting, residue retained on the field, direct sowing during *Rabi*.

- **Sub-plot : 6** Cropping rotations/sequences
- **Plot size:** 5×10 = 50 m^2
- **Replication: Three**
- **Rotations: Two year rotation (6 years)**

Present investigation was carried out during 2012-13 i.e third crop cycle.



CT-Conventional Tillage, RT- Reduced Tillage, Design: Split plot, Replication: Three, Plot Size: 5 x10m

Fig. 3.2 The layout and plan of experiment

Varieties

The crop varieties were used for the present investigation is given below in (table 3.3).

Table 3.3 Experimental crops and varieties

S. No.	Name of crops	Varieties
1	Wheat	Malwa Shakti
2	Soybean	JS 335
3	Cotton	Bt Cotton
4	Pigeon pea	*Aasha* (Local)
5	Maize	Kanchan 101
6	Gram	JG 130

Table 3.4. Fertilizers dose

Crops	Fertilizer Dose (N:P:K in Kg/ha)
Soybean	30:60:30
Cotton	90:45:45
Pigeon pea	30:60:60
Wheat	120:60:40
Maize	120:60:40
Gram	40:60:30

Once in two-years Farm yard manure (FYM) was applied @ 5 tha^{-1}

Table 3.5 Procedure adopted for soil analysis

Soil indicator	Method	Reference
pH	1 : 2.5 Soil water suspension	Jackson (1973)
EC	1 : 2.5 Soil water suspension	Jackson (1973)
Organic carbon (%)	Chromic acid oxidation	Walkley and Black (1934)
Carbon pools	Differential quantity of H_2SO_4Chromic acid oxidation	Chan *et al.* (2001)
Soil microbial biomass carbon	Chloroform fumigation method	Vance *et al*.(1987)
Total Organic Carbon	Dry combustion method	CHN Analyzer model SSM-5000 A
Bulk density	Core method	Blake and Hartge (1986)
Aggregate size distribution	Yoder's wet sieving apparatus	Yoder (1936)
Infiltration	Double ring Infiltrometer	Bouwer, (1986)
Soil temperature	Wood thermometer	--

Determination of Soil Parameters

1. Soil Organic Carbon (Oxidizable Carbon)

Organic carbon content of the soil sample was determined following the wet digestion method (Walkley and Black, 1934; Walkley, 1947). One gram soil was digested with 10 ml potassium dichromate ($K_2Cr_2O_7$) and 20 ml conc. H_2SO_4 in dark condition for 30 min. then excess dichromate was determined by titration with ferrous ammonium sulphate [$Fe(NH_4)(SO_4)_2.6H_2O$] after adding 10 ml conc. H_3PO_4 using diphenyl amine indicator. Similarly, blank experiment was carried out to determine the amount of dichromate used for digestion of carbon which indirectly tells the amount of carbon in soil. Organic carbon percentage was calculated from the following formula:

$$\% \text{ OC} \quad = 10 \times \frac{\text{Blank - Sample reading}}{\text{Blank reading} \times \text{wt. of sample}} \times 0.003 \times 100$$

2. Carbon pools (Chan *et al*. 2001)

The determination of oxidizable carbon was repeated using 5 and 10 ml of concentrated sulphuric acid instead of the 20 ml specified by Walkley and Black (1934). The resulting three acid-aqueous solution ratios of 0.5:1, 1:1 and 2:1 (which corresponded respectively to 12 N, 18 N, and 24 N of H_2SO_4) allowed comparison of oxidizable organic carbon extracted under increasing oxidizing conditions (Walkley, 1947). The amount of oxidizible organic carbon determined using 5, 10, and 20 ml of concentrated sulphuric acid when compared with total carbon concentration allowed separation of total organic carbon into four fractions of decreasing oxidizability:

i) **Very lablile carbon (Fraction 1)** (12 N H_2SO_4)-organic carbon oxidizible under 12 N H_2SO_4,

ii) **Labile carbon (Fraction 2)** (18 N-12 N H_2SO_4)-the difference in oxidizible organic carbon extracted between 18 N and 12 N H_2SO_4;

iii) **Less labile carbon (Fraction 3)** (24 N-18 N H_2SO_4)-the difference in oxidizible organic carbon extracted between 24 N and 18 N H_2SO_4. The 24 N H_2SO_4 is equivalent to the standard Walkley-Black method; and

iv) **Non-Labile carbon (Fraction 4)** (TOC-24 N H_2SO_4)-residual organic carbon after reaction with 24 N H_2SO_4 when compared with the total carbon determined by the TOC analyzer.

3. Microbial biomass carbon (Voroney *et al.* 1993)

20 ml of chloroform was taken for each 10 g of sample in a separatory funnel, washed chloroform two times with conc. H_2SO_4 with half volume of chloroform and discarded the acid bottom phase carefully after phase separation. Taken precautions to open the stop cock after shaking to release the pressure. Wash twice with the same volume of distilled water similarly to made the chloroform free from ethanol and collected the bottom whitish phase. After that kept not more than 40 ml ethanol free chloroform in 100 ml beaker, placed some glass bead in the beaker to reduce bumping. Then all the beakers containing

sample and chloroform placed in vacuum desiccators. Lined the inner surface of the desiccators with moistened filter paper. To ensure proper sealing of lid joint use a rubber tube to direct the exhaust through water. Then switch on the vacuum pump and kept it on until the chloroform boils for about five minutes. Close the outlet and put the beaker containing chloroform and the inner paper lining, performed back suction five to six time to ensure removal of any excess of chloroform vapors released vacuum slowly.

Unfumigated or fumigated samples taken from BOD incubator, were transferred in 250 ml conical flasks, and 25 ml of 0.5 M potassium sulfate was added to these flasks and shaken for ½ hour. After shaking the suspension was filtered through Whatman No. 1 filter paper. Then 10 ml of filtrate was transferred in 500 ml conical flash. 10 ml of potassium dichromate (0.2N) and 10 ml H_2SO_4 and 5 ml ortho-phosphoric acid were added to each flask. Two blanks with 10 ml of K_2SO_4 along with the acid were also prepared as mentioned above. The flasks were kept on plate at 100°C for ½ hour under refluxing condition. Flasks were taken and about 250 ml of distilled water was added immediately. The contents were allowed to cool down to room temperature and 2 or 3 drops of Ferroin indicator were added and titrated the contents against 0.05N ferrous ammonium sulphate to get a brick red end point.

4. Soil reaction (pH) and EC

Soil pH and EC were determined in 1:2.5 soil-water suspension using combined glass electrode for pH, and Conductivity Bridge for EC as per the procedure given by Jackson (1973).

5. Aggregate Stability and Mean Weight Diameter

Aggregate stability of soil samples was determined by using a wet sieving method (Yoder, 1936). The Yoder apparatus have a vertical stroke of 45 mm, and was operated for 10 min at a speed of 29 - 35 strokes / min. A set of sieves each consisting of six sieves of different diameters ranging from 0.125 - 4.00 mm (as for dry sieving) arranged in a descending order was fixed in the assembly. The soil sample was kept on the top of each set. It was immersed in water at room temperature. The sieves were then oscillated vertically and rhythmically, so that water was made to flow up and down throughout the screens and the assemblage of aggregates. At the end of 10 minutes period, the nest of sieves was removed carefully from the water and the oven dry weight of the material retained on each sieve was determined. The results were corrected for the coarse primary particles retained on each sieve to avoid designating them falsely as aggregates. A known amount of the soil sample collected from the field was immersed in water for short period of time for wetting. The wetted sample was sieved through a nest of sieve in Yodder's apparatus (Yoder R.E. 1936), which raises and lowers the nest of sieves. This was done to simulate the disruptive forces of water and facilitate the sieving of water stable aggregates through sieves. After about 30 minutes, sieves along aggregate were removed and dried in an oven at 105^{o}C. The dry aggregates were collected and weighed. The weight of these aggregate also includes weight of primary particles of respective sieve sizes. Therefore, soils of these aggregates from sieves were dispersed sand passed through the respective sieves. The mass retained on the respective sieves represents primary particles or sand fraction and hence was deducted from the mass of aggregates to get correct estimate of aggregate. To represent the aggregation status of soil by a single value, MWD was calculated.

$$\mathrm{MWD} = \sum_{k=1}^{n} \mathbf{d}_{\mathrm{i}}\ \mathrm{w}_{\mathrm{i}}$$

Where,

n = number of size fraction, di = mean diametre of each size range

wi = fraction weight of aggregate in that size range of total dry weight of the sample analysed.

6. Gravimetric method of soil moisture content (SMC)

Soil water content was determined by drying a known mass of moist soil sample in an oven at 105^{o}C. This method involves three independent measurements, viz. the mass of the wet soil, the mass of dry soil and mass of the container. The dry mass of the soil was taken after drying the soil in an oven at a temperature of 105°C for 24 hours or till mass becomes constant. At this temperature, all water except that chemically bound was driven out of soil. Take the soil samples, water contents of which were to be determined, with the help of auger or sampling tube. Place the moist soil samples in moisture boxes. Weight the samples after taking them to laboratory. Place the boxes with lids off in an oven at a temperature of 105°C to dry the soil to a constant weight. Remove samples from the oven. Replace the lids and place the boxes in the desiccators. Upon cooling, determine the mass of dry soil and the moisture boxes.

$$\text{Percent water} = \frac{\text{Mbsm - Mbsd}}{\text{Mdsd - Mb}} \times 100$$

Where

M_{bsm} = Mass of moisture box + moist, g

M_{bsd} = Mass of moisture box + dry soil, g

M_b = Mass of empty moisture box, g

$M_{bsm} - M_{bsd}$ = Mass of water in the soil, g

$M_{bsd} - M_b$ = Mass of dry soil, g

7. Bulk density (BD)

Dry bulk densities of the samples were determined by core method (Blake and Hartge, 1986). Cores with field soil were dried to 105°C in the oven and weighed. Bulk density of soil was calculated from the formula:

$$\text{BD (Mg m}^{-3}\text{)} = \frac{(X - Y)}{V}$$

Where, X= Weight of core with oven dry soil, Y= Weight of core, V= Volume of core.

8. Soil Temperature

Soil temperature has measure on experimental field at weekly interval 0 to 5 cm depth by wood thermometer during 7.45 AM and 2.00 PM at periodic intervals.

9. Penetration resistance/Soil strength

Penetration resistance was measured using a penetrometer, an instrument that measures the soil resistance to penetration in kilo pascal. In other words soil strength is ‘resistance to penetration’ was measured from 0 - 45 cm depths under the experimental plots. Measurements were done after harvest of kharif crop by using a cone penetrometer (make; CP 40 II from Rimik).

10. Infiltration rate measurements

When water was pounded on the soil surface in a field, its level gradually falls down. The rate of recession (fall) of the water level given the infiltration rate of the soil. During infiltration, appreciable lateral movement of water might also occurred. To avoid error due to this lateral movement, two concentric iron rings (infiltrometers) were used. Water level in the both the rings should be kept nearly equal. The infiltration was the measured in the inner ring only. The rate of water intake per unit area varies markedly with the size of the rings. Infiltration rate studies were preceded by a careful description of texture, structure, surface conditions, layering sequence in the profile, initial soil moisture and any other specific problems of the region in which the soil was located.

Install infiltrometer rings in a uniform and nearly level plot. Pond 15 –20 cm of water in outer as well as inner ring. Recoded the fall of water level in inner ring at 1, 3, 5, 10, 20, 30, 40, 60, 80, 100, 120 minutes and thereafter on hourly basis till the intake was constant. However, the time intervals of observation could be varied according to objectives of study and soil permeability. More water should be added into the rings when water level falls by 4 to 5 cm in order to check drastic water level fluctuations which might affect constant intake rate otherwise. Using scale and Hook's gauge. Record the water level and time just before and after responding. Keep the intervals between these two observations as short as possible to avoid error caused by intake during the refilling period and infiltration rate of the soil was calculated.

11. Statistical Analysis

The data collected on various characters were analysed separately according to procedure given by Panse and Sukhatme (1961). Critical difference (C.D.) value was calculated only for those characters, which were found significant at 5 percent level of significance. The skeleton on analysis of variance of the design was presented in the Table 3.6.

Table 3.6. Skeleton of ANOVA for the design of experiment

Sources of variation	**d.f.**	**SS**	**MSS**	**$F_{cal.}$**	**$F_{tab.}$**
Replication	2	SSR	MSR		
Tillage System	1	SSTS	MSTS	$\frac{MSTS}{MSEa}$	$F_{5\%}$ (1,2)
Error (a)	2	SSEa	MSEa		
Cropping System	5	SSCS	MSCS	$\frac{MSCS}{MSEb}$	$F_{5\%}$ (5,20)
TS×CS	5	SS (TS×CS)	MS (TS×CS)	$\frac{MS(TS\times CS)}{MSEb}$	$F_{5\%}$ (5,20)
Error (b)	20	SSEb	MSEb		
Total	35				

Where,

SSR = Sum of square due to replication

SSTS = Sum of square due to Factor TS

SSEa = Sum of square due to error (a)

SSCS = Sum of square due to Factor CS

SS (TS×CS) = Sum of square due to TS x CS

SSEb = Sum of square due to error (b)

$$\text{MSR} = \frac{\text{SSR}}{\text{r - 1}}$$

$$\text{MSTS} = \frac{\text{SSTS}}{\text{t - 1}}$$

$$\text{MSEa} = \frac{\text{SSEa}}{\text{(r - 1) (ts - 1)}}$$

$$\text{MSV} = \frac{\text{SSCS}}{\text{ts - 1}}$$

$$\text{MS (TS}\times\text{Cs)} = \frac{SS(TS \times CS)}{\text{(ts - 1) (cs - 1)}}$$

$$\text{MSEb} = \frac{\text{SSEb}}{\text{ts(r - 1) (cs - 1)}}$$

The F test was applied for judging the significance of Tillage system and Cropping systems and their interaction effect. Comparison of means corresponding to different significant effect was made by using critical difference at 5% level of significance which was worked out by using the following formula.

Standard errors for the difference between any two treatments mean S.E (m):

(i) S.E. for the difference between any two tillage system means:

$$\text{S.E. (tsi-csj)} = \sqrt{\frac{2MSEa}{rcs}}$$

C.D. (at 5%) = S.E. (tsi - csj) × t 5% (error a d.f.)

(ii) S.E. for the difference between any two cropping system means:

$$\text{S. E. (csi-csj)} = \sqrt{\frac{2MSEb}{rts}}$$

C.D. (at 5%) = S.E. (csi - csj) × t 5% (error b d.f.)

(iii) S.E. for the difference between any two cropping system means at the same level of tillage system:

$$\text{S.E. (tsicsi-tsicsj)} = \sqrt{\frac{2MSEb}{r}}$$

C.D. (at 5%) = S.E. (tsicsi-tsicsj) x t 5 %(error b d.f.)

(iv) S.E. for the difference between any two tillage system means at the same or different levels of cropping system:

$$\text{S.E. (tsicsi-tsjcsj)} = \sqrt{\frac{2\left[(CS-1)MSEb + MSEa\right]}{rcs}}$$

C.D. (at 5%) = S.E. (tsicsi-tsjcsj) x t tab.

Where,

$$\text{t tab.} = \frac{(CS-1)MSEb \times tb + MSEa \times ta}{(CS-1)MSEa + MSEb}$$

Where, t (a) and t (b) are tabulated' values at error (a) and error (b) d.f., respectively.

CHAPTER-IV

RESULTS

Results obtained during the present investigation on “Effect of conservation agricultural practices on selected soil physical properties and carbon pools in black soils of central India" has been presented in this chapter. The results of the observations recorded and analysis carried out to determine the soil properties namely soil moisture content (SMC), soil temperature, bulk density (BD), mean weight diametre (MWD), infiltration rate, soil strength, soil reaction (pH), electrical conductivity (EC), soil organic carbon (OC), microbial biomass carbon (MBC) and carbon pools under different tillageand cropping systems are presented below.

The effects of experimental variables described in the order in which they occupy the position in the analysis of variance tables, i.e., Tillage system, cropping systems and their interaction (TS x CS). In mean values, only such treatments, data has beenfound statistically significant are discussed in order to provide a quick grasp of trends in responses exhibited by certain parameters, reported.

4.1. Soil pH

Mean data of pH value for CT and RT varied from 8.32 to 8.34; 8.47 to 8.50; 8.45 to 8.45; 8.46 to 8.49 for 0-5, 5-15, 15-30 and 30-45 cm depth, respectively. It is inferred that pH value increased with increasing depth. Among the cropping systems compared, soybean-fallow recorded the lowest pH (8.27) and maize gram recorded the highest soil pH (8.40) in 0-5cm depth. Whereas in 5-15cm depth, soybean+ cotton (2:1) and soybean + pigeon pea recorded the lowest soil pH (8.47) and the highest pH (8.50) was observed under maize-gram and soybean-fallow. Both tillagesystem and cropping systems did not have significant difference on soil pH value. (Table 4.1)

4.2. Soil EC

Mean data of EC value for CT and RT varied from 0.19 to 0.18; 0.14 to 0.17; 0.14 to 0.13; 0.14 to 0.13 dS m^{-1} for 0-5, 5-15, 15-30 and 30-45 cm depth, respectively. In general surface layer (0-5cm) recorded higher EC compared to lower soil depth. Barring 0-5 cm depth, EC value is higher under reduced tillage (RT) compared to conventional tillage (CT). It is inferred that EC value decreased with increasing depth. Among the cropping systems compared, soybean+ cotton (2:1) recorded the lowest EC (0.16 dS m^{-1}) and both maize gram and soybean+ pigeon pea (2:1) recorded the highest EC (0.20 dS m^{-1}) in 0-5cm depth. Where as in 5-15cm depth, soybean- fallow (R) recorded the lowest soil EC (0.13 dS m^{-1}) and the highest EC was observed under maize-gram and soybean-wheat (0.18 dS m^{-1}). Almost negligible changes of EC occurred under lower depths between tillage treatments. Both tillagesystem and cropping systems did not have significant difference on soil EC value. (Table 4.2)

4.3. Soil moisture content

The data on soil moisture content (SMC) was influenced by tillage system and cropping system recorded at harvest stage of *kharif* crop is presented in (table 4.3a).

Among the tillage system, reduced tillage (RT) recorded significantly higher SMC value (19.65%).The lowestSMC value (19.06%) was observed in conventional tillage (CT) in 0-15cm depth and same trend was found in 15-30 cm depth. However, in deeper layer there was no significant difference in soil moisture content.

At surface layer (0-15 cm), soil moisture content was also significantly influenced by cropping systems soybean-fallow (R) recoded significantly higher SMC (20.70%). The lowest SMC was observed in soybean-wheat (18.09%).same trend was found in 15-30, 30-45cm in depth.

The interaction effects between tillage system and cropping systems was significant for SMC in sub surface layer (15-30 cm). Under RT soybean-fallow (R) (21.90%) cropping systems superior over other cropping system, however at par with CT in soybean-fallow(R) (21.74%). The lowest SMC was observed in soybean + cotton (2:1) (17.93%) CT in treatment combination. Cropping systems soybean-fallow (R) was found significant higher SMC over soybean-wheat, soybean + cotton (2:1), soybean-fallow, soybean + pigeon pea and maize-gram for RT and CT. Theinteraction tillage system and cropping system on SMCwere notsignificanteffect at surface layer(0-15 cm) and deeper layer (30-45 cm).

The effect of different tillage system and cropping system on soil moisture, recoded at flowering stage of *rabi* crops is illustrated in (table 4.3b). The SMC varies significantly among the tillage practices.

At surface layer (0-15 cm), reduced tillage (RT) recorded significantly higher SMC of (15.56%). The lowest SMC was noticed in CT (14.72%). At sub-surface and deeper layer (i.e.15-30 and 30-45 cm) was not significant for tillage practices. At surface layer (0-15 cm), among the cropping system, soybean-wheat recorded (16.32%) significantly higher SMC compared to other cropping system in surface layer (0-15 cm). The lowest SMC (14.78%) was observed in maize-gram.

At sub-surface layer (15-30 cm), among the cropping systems soybean + cotton (2:1) (17.52%) significantly higher SMC was observed at par with soybean-wheat (17.49%), soybean-fallow (17.44%) andsoybean-fallow (R) (17.26%) and over soybean + pigeon pea (2:1) (17.12%). The lowest SMC (16.69%).was recorded in maize-gram.

The interaction effects between tillage system and cropping systems on SMC were not significant in 0-15, 15-30 and 30-45 cm depth.

The effect of different tillagesystemand cropping system on soil moisture, recorded at maturity stage of *rabi* crops is depicted in (table 4.3c).

At surface layer (0-15 cm), the tillage system and cropping systems influenced significantly higher the soil moisture content was observed in RT (10.60%). The lowest value of SMC was recorded in CT (9.24%). At sub-surface layer (15-30 cm), the tillage system were not significant for SMC. At deeper layer (30-45 cm) tillage practices influenced the SMC higher was recorded in RT (15.65%). The lowest value of SMC was measured in CT (14.82%).

At surface layer (0-15 cm), among the cropping systems soybean-wheat (11.52%) significantly higher SMC was recorded at par with maize-gram (10.29%), soybean-fallow (R) (10.20%) and soybean + cotton (10.05%) and over soybean-fallow (9.37). The lowest SMC (8.10%) was observed in soybean + pigeon pea.

At deeper layer (30-45 cm), among the cropping systems soybean + pigeon pea (2:1) (16.41%) significantly higher SMC was recorded at par with maize-gram (16.39%), soybean-fallow (15.87%) and soybean-fallow (R) (15.16%) and over soybean + cotton (2:1) (13.80%). The lowest SMC (13.79%) was observed in soybean-wheat.

The interaction effects between tillagesystem and cropping systems on SMC were not significant in 0-15, 15-30 and 30-45 cm depth.

4.4. Soil bulk density

The data on bulk density (BD) were influenced by tillage system and cropping systems observed at different soil depth is presented in (table 4.4). In this study, we have observed that BD under both the tillagesystem and cropping system which were increased with depth. Bulk density observed at various depths was significantly affected by the tillage system.

At surface layer (0-7.5 cm), the tillage system had significant effect on BD was recorded in CT (1.37 Mg m^{-3}). The lowest BD was observed in RT (1.34 Mg m^{-}3). Same trend was found in other different depth (i.e. 0-7.5, 7.5-15, 15-22.5, 22.5-30 cm).

Irrespective of soil depth the interaction effects between tillage systemand cropping systems on BD were not significant in 0-7.5, 7.5-15, 15-22.5, 22.5-30 cm depth on bulk density.

4.5. Mean Weight diameter

In this study, aggregate stability was measured at surface (0-15 cm) and sub-surface layers (15-30 cm). The effect of different tillagesystem and cropping system on aggregate stability is presented in (table 4.5). In surface layer, aggregate stability represented by MWD was significantly affected by tillage and cropping systems; whereas in sub-surface layer only tillage showed significant effect on MWD. At both depths, RT recorded higher MWD compared to CT under all the cropping systems. On an average, higher MWD was observed at lower depth compared to surface layer under all the cropping systems.

At surface layer (0-15 cm), the tillage system significantly higher mean weight diameter (MWD) was reported in RT (.53 mm). The lowest MWD was observed in CT (.50 mm). Same trend was found in sub-surface layer.

At surface layer (0-15 cm), among the cropping systems soybean-wheat (0.59 mm) significantly higher MWD was observed at par with soybean + cotton (2:1), maize-gram (0.54 mm) and over soybean-fallow (0.49 mm), soybean-fallow (R) (0.47 mm) and soybean + pigeon pea (2:1) (0.45 mm). The same trend was found in case of tillage practices in subsurface layer (15-30 cm). But cropping systems on MWD was not significant.

The interaction effects between tillage system and cropping systems on MWD were not significant in 0-15 and 15-30 cm depth.

4.6. Penetration resistance (PR)

Effect of conservation tillage on penetration resistance data is presented in (table 4.6). Mean data of PR values shows highest value was observed under RT (1.60 Mpa) than CT (1.55 Mpa). The tillage system did not have significant effect in 0-5 cm depth, however, the PR value increased with increasing depth.

Among the tillage system compared, RT recorded higher value from 5-15cm compared to CT. Below 15cm both the tillage systems converge at one point.

4.7. Soil thermal regime

Mean of soil temperature recorded during *rabi* season under both tillage and cropping systems didn't show any significant difference. Data were averaged over cropping system and presented in (Table 4.7).Minimum soil temperature (0 – 5 cm depth) at 7.00AM and maximum at 2.00PM varied between 9 and 20^{o}C and 23-32^{0}C, respectively. At 7.00AM soil temperature was higher in RT than CT throughout the growth period; whereas at 2.00PM, the trend was reversed between the two treatments.

4.8. Infiltration rate

Result indicated that infiltration rate was increased under reduced tillage (2.32 cm.hr^{-1}) (RT) as compared to conventional tillage (1.56 cm hr^{-1}) (CT) irrespective of times.Similar trend was observed under steady state infiltration between tillage treatments. Among the cropping system, the highest value (2.69 cm.hr^{-1}) was observed under soybean-fallow system and the lowest value (1.30 cm.hr^{-1}) was observed under maize-gram system (Table 4.8).

4.9. Soil organic carbon (SOC)

Mean data of SOC value for CT and RT varied from 0.55 to 0.58 percent, 0.46 to 0.49percent,0.42 to 0.45percent for 0-15, 15-30 and 30-45 cm depth, respectively. In general, surface layer (0-15cm) recorded higher SOC compared to lower soil depths. Irrespective of soil depths, higher SOC was recorded under reduced tillage (RT) compared to conventional tillage (CT) practices. The reduced tillage was significantly higher SOC value than conventional tillage (CT) in 0-15cm depth, whereas in the lower depths (i.e. 15-30 and 30-45cm) tillage systems did not have any significant effect.It is also inferred that SOC value decreased with increasing soil depth. It is further inferred from the data that cropping systems had significant effect on SOC content. Among the cropping systems compared, soybean-fallow (R) recorded significantly higher OC (0.59%)

than soybean-wheat (0.54%) in 0-15cm depth. Almost similar trend was observed under in 15-30cm depth. SOC data of 30-45 cm indicated that maize-gram (0.48%) and soybean-fallow (0.46%) cropping system recorded significantly higher value compared to other systems. It is clear from the data that the SOC content under RT is significantly higher than CT after three years of crop-cycle. (Table 4.9)

4.10. Soil microbial biomass carbon (SMBC)

Mean data of SMBC value for CT and RT varied from 326.2 to 359.3 µg c g^{-1} of soil; 217 to 274.6 µg c g^{-1} of soil for 0-15 and 15-30 cm depth, respectively. In general, surface layer (0-15cm) recorded significantly higher SMBC compared to lower soil depth. Irrespective soil depths, significantly higher SMBC was recorded under reduced tillage (RT) compared to conventional tillage (CT) practices. The reduced tillage was significantly higher SMBC value than conventional tillage (CT) under both depths. It is also inferred that SMBC value decreased with increasing soil depth. It is further inferred from data that cropping systems had significant effect on SMBC content. Among the cropping systems compared, soybean +pigeon pea (2:1) followed by soybean-wheat and maize-gram recorded significantly higher SMBC value than other cropping system in 0-15cm depth. Almost similar trend was observed under in 15-30cm depth. It is clear from the data that the SMBC content under RT is significantly higher than CT after three years of crop-cycle(Table 4.10). The interaction effects between tillage system and cropping systems was significant for SMBC 0-15 and 15-30cm soil depth. At surface layer (0-15 cm), under RT soybean +pigeon pea (2:1) cropping systems was superior over all treatment combination at par with CT in soybean +pigeon pea (2:1). Cropping systems soybean + pigeon pea (2:1) was found significant higher SMBC over other cropping system soybean-wheat, soybean + cotton (2:1), soybean-fallow, soybean-fallow (R) , and maize-gram for RT and CT. At sub surface layer (15-30 cm), under CT soybean +pigeon pea (2:1) cropping systems was superior over all treatment combination. Cropping systems soybean + pigeon pea (2:1) was observed significant higher SMBC over other cropping system soybean-wheat, soybean + cotton (2:1), soybean-fallow, soybean-fallow (R) and maize-gram for CT and RT.

4.11. Soil organic carbon pool

The data on soil carbon pools were presented in table (4.11a). At surface layer (0-15cm), soil carbon pool was significantly affected by the tillage systems. Whereas cropping system and their interaction effect did not show any significant effect on carbon pools. However, in surface layer only cropping system showed significant effect on less labile carbon.

At surface layer (0-15 cm), under very labile carbon significantly higher carbon pool was recorded in RT. The lowest carbon pool was observed in CT, and same trend was found in less labile carbon and non labile carbon. Under labile carbon significantly higher was noticed in CT (0.19%). The lowest carbon pool was recorded in RT (0.18%).

At surface layer under less labile carbon significantly higher was observed in cropping systems soybean-fallow (R) (0.16%) at par with maize-gram (0.14%) and over soybean-fallow (0.12%). The lowest carbon pool was recorded in soybean-wheat (0.10%).

The data relating to soil carbon pool have been illustrated in (table 4.11b). At sub-surface layer (15-30 cm), soil carbon pool was significantly affected by tillage practices. At sub-surface layer (15-30 cm), under very labile carbon statistically significantly higher carbon pool was recorded in RT. The lowest carbon pool was observed in CT, and same trend was found in less labile carbon and non labile. Under labile carbon significantly higher carbon was pool in CT (0.19%). The lowest carbon pool was recorded in RT (0.18%). At sub-surface layer (15-30 cm), among the cropping systems was not significant in very labial and labile carbon.

Under less labile carbon significant higher carbon pool was recorded in soybean-fallow(R) (0.15%) at par with maize-gram (0.15%) cropping and over soybean-fallow (0.12), soybean + pigeon pea (2:1) and soybean +cotton (2:1) (0.11%). the lowest carbon was observed in soybean-wheat (0.10%).

Under non labile carbon significantly higher carbon pool was measured in soybean-wheat (0.61%) copping systems at par with soybean + cotton (2:1) (0.57%) and over soybean-fallow(R) (0.48 %) soybean + pigeon pea (2:1) (0.47%). The lowest carbon pool was recorded in maize-gram (0.41%). and soybean-fallow (0.43%).

The interaction effects between tillage system and cropping systems was significant for less labile carbon surface layer (0-15cm). Under CT maize-gram cropping systems treatment combination superior over all treatment combination at par with RT in soybean-fallow(R), CT in soybean- fallow, RT in maize-gram and in soybean- fallow. Cropping systems maize-gram was observed significant higher less labile carbon over other cropping system soybean-wheat, soybean + cotton (2:1), soybean-fallow, soybean + pigeon pea (2:1) and soybean-fallow (R) for CT and RT.

4.12. Crop yields

Yield parameters were recorded during third crop cycle and yield data were converted into soybean equivalent yield (q ha^{-1}) (Table 4.12). It was inferred that tillage had no effect on soybean grain equivalent (SGE) after three years of crop cycle. Among the cropping systems studied, maize-gram recorded significantly higher yield (45.70 q ha^{-1})followed by soybean+ pigeon pea (2:1) (31.62 q ha^{-1}) andsoybean-wheat (29.74 q ha^{-1})cropping system. Barring soybean-wheat system (31.52 q ha^{-1}) under CT, all other crop yields were recorded higher yield under RT after third crop cycle.

CHAPTER-V

DISCUSSION

The results of present investigation entitled “Effect of conservation agricultural practices on selected soil physical properties and carbon pools in black soils of central India " presented in the previous chapter are discussed in the light of the findings obtained by other workers. Wherever possible efforts have been made to explain the reasons for the results obtained.

5.1. Soil pH and EC

Irrespective of all the depth, soil pH and EC data showed no significant value under different tillage and cropping systems (Fig. 5.1). Moderation/ changes in soil pH and EC may be possible if continuous additions residue along with minimum soil disturbances. The results of the present study corroborates with findings of Smith and Doran, (1996) who have reported that across all depths there was no significant change in EC and pH values and it was very well below the thresholds limits.

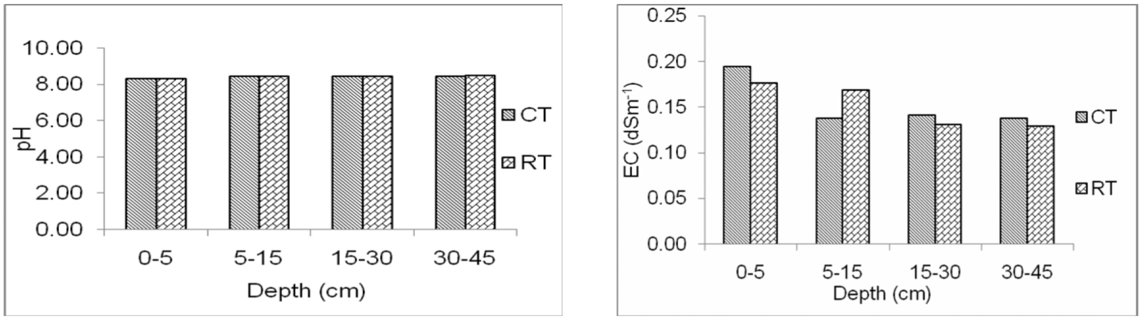


Fig.5.1.Effect of soil pH and EC(dSm^{-1}) under different tillage systems

5.2. Soil moisture

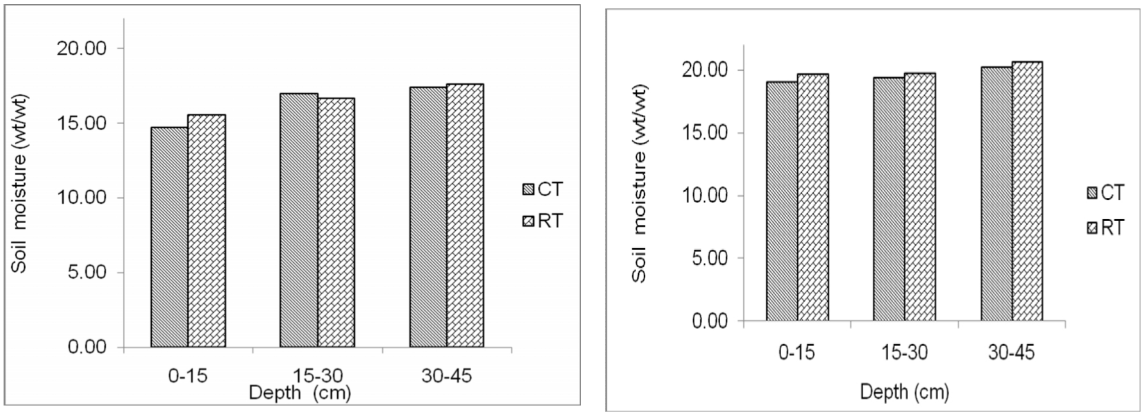
Soil moisture defined as the water held in soil pores in liquid and vapours phases. It is the source of water for plant use in particular, in the rainfed area like central India. Water serves four general conditions in plants: the major constituent of the physiologically active tissue; as a reagent in photosynthetic and hydrolytic processes; as a solvent for salts, sugars and other solutes and water is also essential for the maintenance of turgidity necessary for cell enlargement and growth. Therefore, it is vital to check critical crop growth stage, so as to take mitigation measures like timely planting and soil and water conservation practices (Kamoni, 1985).

In present investigation, soil moisture content under different tillage and cropping systems were recorded on three date/growth stages. Soil moisture content at surface layer (0-15 cm) was significantly affected by the tillage treatments in all three sampling date. The reduced tillage (RT) practices had higher moisture content than conventional tillage CT (Fig.5.2. a,b and c). An increase of 3 percent, 5 percent and 13 percent moisture was observed on harvest stage of *kharif*, flowering stage of *rabi* and maturity stage of *rabi*, respectively. Similarly, reported no-tillage recorded slightly higher average soil moisture content compared to conventional tillage. At surface layer, cropping systems also affected significantly at all the sampling date but couldn't get any trend of moisture variation among the cropping systems. With advances in crop growth stage, soil is depleted with moisture due to water extracted through crop root. Here, moisture content was depleted from first sampling date to second sampling date, but increase in soil moisture was observed at third date due to coincidence of rainfall event. At this layer of soil, there was no significant interaction effect between tillage and cropping system was observed.

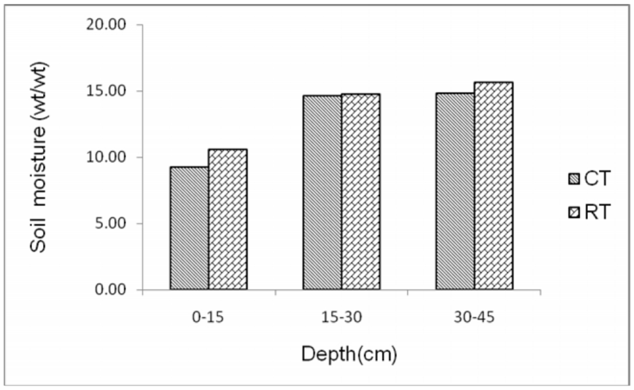
At sub surface soil layer (15-30 cm), soil moisture was significantly affected only at first date of sampling, on remaining two date of sampling, no significant difference in soil moisture was observed between tillage systems. Although, higher moisture content was observed in RT compared to CT except on third date of sampling, where, CT plot had higher moisture content. An increase of 1.7 percent and 1.1 percent moisture was observed on harvest stage of *kharif*, maturity stage of *rabi* in RT plot, whereas, CT plot has 2 percent higher moisture content compared to RT on flowering stage of *rabi*. Barring second date of sampling, cropping systems significantly affect the moisture content, however, no trend was observed among the cropping system. Like surface layer, subsurface layer did not show any interaction effect between the tillage system and cropping system. At deeper soil layer (30-45 cm), tillage systems did not show any significant effect on soil moisture content on first and last sampling date, but on second date tillage significantly affect the soil moisture. The plot with RT was having higher moisture content compared to CT. An increase of 1.9 percent 5.3 percent and 1.3 percent moisture was observed on harvest stage of *kharif*, maturity stage of *rabi* and flowering stage of *rabi*, respectively. Observation recorded at first and second date of sampling showed that, soil moisture content was significantly affected by the cropping system, whereas, moisture content of soil on last date of sampling did not show any significant difference among the cropping system. Like surface layer and subsurface layer, this layer also did not show any interaction effect between the tillage system and cropping system.

Tillage influences crop growth by changing moisture removal patterns over the growing season. Moisture removal patterns are of most importance to semi-arid regions since moisture is usually the limiting crop yield factor (Lindwall, 1984). Tillage Incorporate crop residue into the soil and changes the moisture removal pattern. Tillage can cause a significant loss of soil moisture. Every tillage pass can cause the loss of approximately 0.25 inch of plant available water. Further, crop residue moderates soil temperature leading to a reduction in soil moisture evaporation, especially at the top 1-2 inches. Residue also reduces the amount of wind at the soil surface and, subsequently, reduces soil moisture evaporation. Reduced tillage leave more plant material on the soil surface resulting in increased infiltration of water, less surface crusting and less evaporation loss (Sprague and Triplett 1986; Unger *et al.* 1991).

These are some of the possible reason of higher moisture content in RT compared to CT. Tillage also changes soil properties and the way the environment effects those properties. Soil properties and environment determine the rate of water movement in liquid and gaseous form into and out of soil. To understand how tillage changes soil moisture, soil properties affecting moisture need to be understood. Unfortunately, the relationship between soil moisture and tillage has not been completely defined (Friedrich, *et* *al*. 2012). Kanwar (1989) reported tillage systems affected soil-water tensions in the surface layer of soil. However, differences were not statistically significant at the 5% level. These results are in agreement with finding of the present study. Similarly, (Allen *et al.* 1980) found conservation tillage increased fallow season soil water storage and resulted in larger crop yields in dry land wheat and sorghum crops. Johnson *et al.* (1984) compared three conservation tillage systems, chisel plowing, till plant and no till, to conventional moldboard plowing. Soil moisture advantages with conservation tillage varied because of profile water content, delayed plant growth and soil characteristics.



a. Harvest stage of Kharif **b. Flowering stage of Rabi**



c. Maturity stage of Rabi crops

Fig.5.2. Effect of Soil moiture content (%)under tillage systems

Tessier *et al.* (1990) reported, that in general, conservation tillage significantly improved water available to crops. Chang and Lindwall (1989) found, in an experiment running for 28 years that the water holding capacity in the upper 150 mm layer of soil was higher in NT compared to conventional tillage. Less intensively tilled soils usually have larger pores compared to intensively tilled soils, resulting in higher infiltration rates throughout the growing season. Contrary to the advantages of reduced tillage, conventional till resulted in soils with higher initial water infiltration rate, but this rate decreased rapidly due to surface sealing from rainfall (Triplett *et al.* 1968).

5.3. Bulk density

Tillage generally improves soil conditions for plant growth, especially under the circumstances where the soil presents zones of high strength and compaction. However, tillage may also exert adverse effect on soil conditions when it is performed in less than adequate soil moisture, or when inadequate tillage implements are used. Bulk density (BD) is an indicator of soil compaction and reflects the soil's ability to function for structural support, water and solute movement, and soil aeration. Generally, loose, porous soils and those rich in organic matter have lower bulk density. Sandy soils have relatively high bulk density since total pore space in sands is less than that of silt or clay soils. Fine-textured soils, such as silt and clay loams, that have good structure have higher pore space and lower bulk density compared to sandy soils.

In present investigation, effect of different tillage systems on BD was significant and CT plot had higher BD than RT under all four depths (0-7.5cm, 7.5-15 cm, 15-22.5 cm and 22.5-30 cm) and cropping systems (Fig.5.3). In past, several researchers worked to quantify dynamics of BD under different tillage systems and found mixed results. Studies conducted by Blevins and Frye, (1993) at Kentucky found, no significant effect on bulk density even after 20 years of corn production compared to no-tillage and moldboard-plow tillage. The surface 0-5 cm of the no-tillage and RT soil had slightly lower bulk density than the surface of the CT system. Similar results were reported by (Teklu *et al.* 2011) that by bulk density and porosity were not affected by the treatments, and all were within an acceptable. In contrast (Gantzer and Blake, 1978) in Minnesota found significantly higher bulk densities (1.24 to 1.32 g cm^{-3}) of a clay loam soil in no-tillage than in plow tillage (1.05 to 1.12 g cm^{-3}). Hill and Cruse (1985) reported no significant effect of tillage methods (no-tillage, conventional tillage, and minimum tillage) on bulk density of a loess-derived Iowa soil. Contrary to this, most of literature showed higher BD in RT and No-tillage compared to CT in long term tillage treatment (Czyz and Dexter, 2009; Pranagal *et al.* 2005).

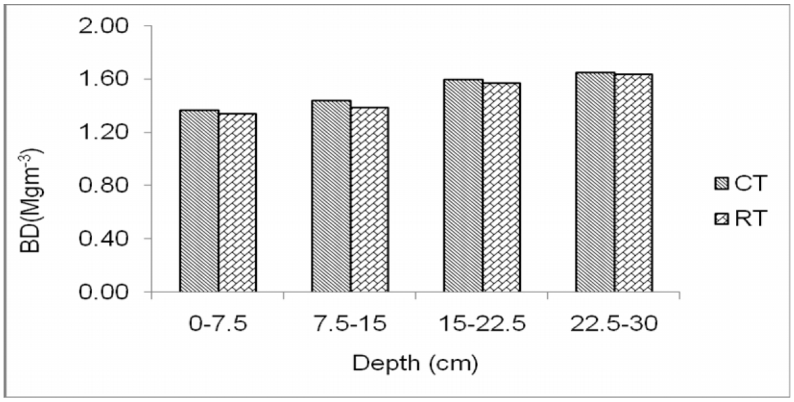


Fig.5.3. Effect of Bulk density (Mg m^{-3}) under different tillage systems

With depth, BD showed increasing trend under both the tillage systems and all cropping systems. Bulk density typically increases with soil depth since subsurface layers have reduced organic matter, aggregation, and root penetration compared to surface layers and therefore, contain less pore space. Subsurface layers are also subject to the compacting weight of the soil above them.

5.4. Soil aggregation

Favorable soil aggregation is important to improve soil fertility and quality with particular emphasis on SOC sequestration, increasing agronomic productivity, enhancing porosity and decreasing erodibility. Stability of aggregate is used as an indicator of soil structure (Six *et al.* 2000). Aggregation results from the rearrangement of the soil constituent particles, flocculation and cementation and it is arbitrated by SOC, biota, ionic bridging, clay and carbonates and oxide content but not all compounds in soils are responsible for aggregation. Different kinds of organic matter stabilize aggregates of different sizes. Organic matter promotes aggregation through the linkage clay-polycations-organic matterpolycations-clay (Tisdall and Oades, 1982). Various indices have been proposed for expressing the distribution of aggregate sizes such as mean weight diametre (MWD), geometric mean diameter, coefficient of aggregation and many more. MWD is widely used index to integrate aggregate size distributions obtained by mechanical sieving. In most studies, MWD measurements showed an important variation under different cropping and tillage practices.

The MWD was significantly affected by tillage system at surface and sub-surface layers. In RT, MWD was 6 percent and 3.5 percent greater than CT in surface and sub-surface layers, respectively. (Fig.5.4.) At 0-15 cm layers, MWD was significantly affected by cropping systems, whereas, in 15-30 cm, MWD did not showed any significant differences among the cropping. Along the depth, larger MWD was observed in sub-surface layer under both the tillage systems and all the cropping system studied. At both the surface layer of soil, MWD did not show any interaction effect between tillage system and cropping system.

Changes in aggregate stability may serve as early indicators of recovery or degradation of soils. Aggregate stability is an indicator of organic matter content, biological activity, and nutrient cycling in soil. Generally, the particles in small aggregates (< 0.25 mm) are bound by older and more stable forms of organic matter. Microbial decomposition of fresh organic matter releases products (that are less stable) that bind small aggregates into large aggregates (> 2-5 mm). These large aggregates are more sensitive to management effects such as tillage system and cropping system.

Larger MWD in RT is attributed to higher organic content in this treatment. It is well established fact that soil organic carbon is a basic factor affecting aggregation. It has been reported that aggregates ranging from 2 to 0.25 mm in size is protected by organic carbon binding agents otherwise, under heavy and intensive cultivation; the aggregates would be disrupted (Elliott, 1986, Bear *et al.* 1994). Larger diameter in RT, indicates that less tillage maintains the crop residues on the surface and favors stability at surface layers of the soil with respect to similar situations under CT with removal of soil (Carpenedo and Mielniczck 1990; Campos *et al.* 1995). Comparing cropping systems, higher MWD was observed under soybean-wheat cropping system in both the tillage systems and depths except RT ad 15-30 cm. Higher MWD in Soy-wheat system is attributed to crop residue left by the wheat crop during previous years. Others crops like soybean, pigeon pea and chick pea are leguminous crops and does not have much residue to add into soil. Similar results were shown by Hajabbasi and Hemmat (2000).

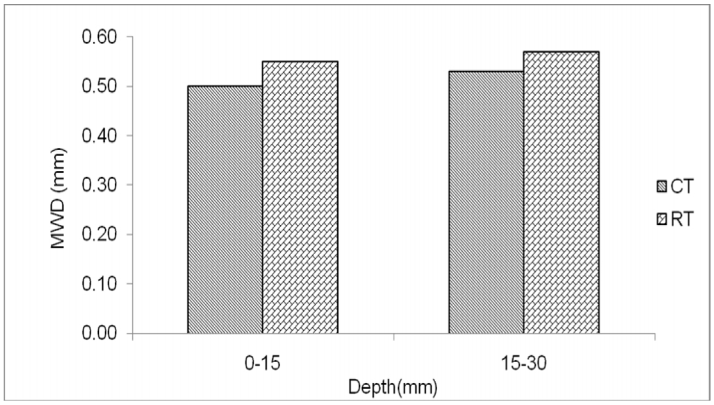


Fig.5.4. Effect of Mean weight diametre (mm) under different tillage systems

5.5. Soil thermal regime

After soil water, soil temperature is perhaps the most important transient physical property of soil to affect crop growth. Research shows that soil temperature affects both the rate and thoroughness with which a plant root system permeates soil (Kaspar and Bland, 1992). Several chemical, physical and biological processes into the soil are affected by its thermal conditions, which may affect the plant growth and crop production. Increases in the soil temperature reduce the period of germination emergence of seedlings and increase processes such as microbiological activities, growth and activity of plant roots, also affecting the permeability of root cells to water. Several factors such as tillage, moisture content and BD influence the variability of soil temperature in the field (Shumway *et al.* 1989; Davidoff *et al*.1986).

The time trends of soil temperature measured during *rabi* season in both the tillage and all cropping systems didn't show any significant difference. For simplicity, the data were averaged over cropping system and presented in (Fig. 5.5) Minimum soil temperature (0-5 cm depth) at 7.00AM and maximum at 2.00PM varied between 9 and 20^{o}C and 23-32^{0}C, respectively. At 7.00AM, soil temperature was higher in RT than CT throughout the growth period; whereas at 2.00PM h, the trend was reversed between the two treatments.

Relatively higher soil temperature at 7.00 AM and lower temperature at 2.00 PM, RT is attributed to presence of crop residue at surface in this treatment. Crop residues regulate the soil temperature depending upon its amount and type. Crop residues usually have reflective and conductive properties that differ from mineral soil, with concurrent changes in the surface net-radiation and soil heat-flux density. Several researchers have shown that crop residue and other surface mulches modify mineral-soil temperature (Burrows and Larson, 1962; Cruse *et al.* 1982; Radke, 1982) by changing the soil thermal properties (volumetric heat capacity, thermal conductivity, and thermal diffusivity). These properties ultimately affect the magnitude of heat flux into the soil profile (Hillel, 1980).

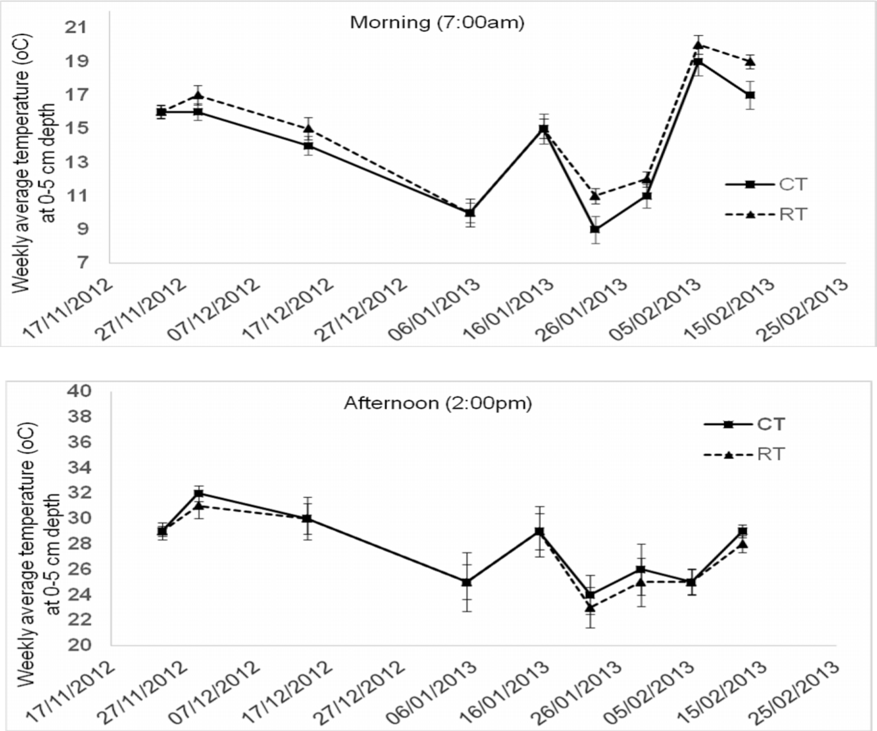


Fig. 5.5 Soil temperature at weekly interval under conservation agriculture

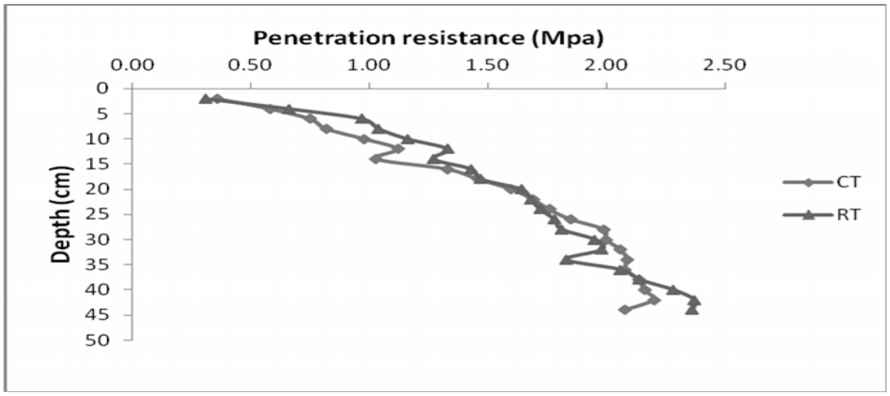
5.6. Infiltration rate

Observation recorded the fall of water level in inner ring at 1, 3, 5, 10, 20, 30, 40, 60, 80, 100, 120 and 270 minutes and thereafter on hourly basis till the intake is constant. Result indicated that infiltration rate was increased under reduced tillage (RT) as compared to conventional tillage (CT) irrespective of times. Similar trend was observed under steady state infiltration between tillage treatments. Tillage reduces water infiltration by breaking large pores, and the small pores are clogged by the dislocation of soil particles. When there is no surface residue, raindrops break the soil aggregates, which clog soil pores leading to slow water Infiltration and increase in surface runoff. Additionally, subsequent rains result in more runoff because of potential soil crusting. Research has shown a significant decrease in water infiltration rate as the intensity of tillage increased. Similarly, Nyamadzawo *et al*. (2012) reported that infiltration rates were greater under conservation agriculture practices (>35 $mm \cdot h^{-1}$) when compared to CT (<27- 29 $mm \cdot h^{-1}$). On fallows infiltration rates ranged from 24-35 $mm \cdot h^{-1}$ when compared to < 15 $mm \cdot h^{-1}$ in maize under CT. The results showed that CT resulted in reduced infiltration rates, increased soil and water loss when compared to fallowing and conservation agriculture across different range of soils. Conservation agriculture practices and fallowing are potential sustainable cropping practices that reduce soil and water loss and increase water use efficiency. In contrast, Dixit *et al*. (2003) reported higher infiltration rate in conventional tillage than no-tillage. This might be due to high porosity causing saturated flow down to the profile.

5.7. Penetration resistance (PR)

PR is relatively easy and useful indicator for rapid evaluation of soil strength and structural changes (Lowery and Morrison, 2002). Soil strength is ‘resistance to penetration’ was measured kilo pascal from 0-45 cm depth under the experimental plots. Measurements were done after harvest of *kharif* crop by using a cone penetrometer (Fig.5.6). In order to get a trend in penetration resistance data, reading taken were averaged over cropping systems. In contrast

(Teklu, 2011) reported that reduced tillage (RT) has resulted in the lowest PR, despite its increased crusting. This is because PR was measured up to the depth of 15 cm while the effects surface crust was limited to the upper few millimeters. Thus, reducing the frequency of tillage may reduce soil compaction, improve aeration, and enhance root growth and access to nutrients and water (Thompson *et al.* 1987). Dixit *et al*. (2003) reported that higher shear strength value obtained under no-tillage compared to the conventional tillage. Therefore, no-tillage probably offered more resistance to root growth than conventional tillage.



*each value is average of 12 plots (averaged over cropping system)

Fig.5.6. Penetration Resistance (PR) under different tillage systems

5.8. Soil organic carbon (SOC)

Crop residues are precursors of the SOC pool, and returning more crop residues to the soil is associated with an increase in SOC concentration (Dolan *et al.* 2006). The effects of conservation tillage on SOC accumulation may vary with the amount and characteristics of residues returned to soil. Annual increases in residue production within a cropping system and/ or decreased tillage frequencies maintain SOC levels or even increase them with time, depending on the quantity and quality of residue input to the soil (Havlin *et al.* 1990; Peterson *et al.* 1998). Moreover, during tillage a redistribution of the soil organic matter takes place. Small changes in soil organic carbon can influence the stability of macro-aggregates. Carter (1992) found a close linear relationship between organic carbon and MWD.

In the present investigation, SOC data revealed that tillage practices were significantly different. The reduced tillage was significantly different from conventional tillage (CT) in 0-15cm depth, whereas in the lower depths (*i.e* 15-30 and 30-45cm) tillage practices did not have significant effect. However, cropping system did have effect on SOC content. The possible reason might be the reduction in tillage operations coupled with residue addition in the surface layer (0-15cm) compared to sub-surface layers. Among the cropping system studied, soybean fallow (rotated with maize-gram in preceding year) recorded significantly higher carbon in surface and subsurface layers. It is clear from the data that the SOC content under RT is significantly higher than CT after three years of crop-cycle (Fig 5.7). However, conventional tillage system resulted in reduction in SOC over initial value, whereas the SOC content under reduced tillage after third year crop cycle is maintained / buffered to its initial value. It is evident from the perusal of data that to bring significant changes in SOC under tillage system it requires a long term continuous residue addition coupled with minimum disturbances in soil. Similarly, no-tillage farming systems usually help to maintain soil organic matter (SOM) and aggregate stability (Rhoton, 2000). In a another study, (Bhattacharya *et al.* 2012) reported results of the study conducted in the Indian Himalayas, a reduction in tillage intensity led to a significantly larger SOC accumulation in the surface soil layer (0–5 cm), but not in the 5- to 15-cm soil layer after 6 yr of cropping. The year-round NT management practice was very effective for SOC sequestration in a rainfed lentil–finger millet rotation system (net gain in SOC storage was about 0.37 Mg ha^{-1} yr^{-1} in the 0 to 15 cm soil layer.

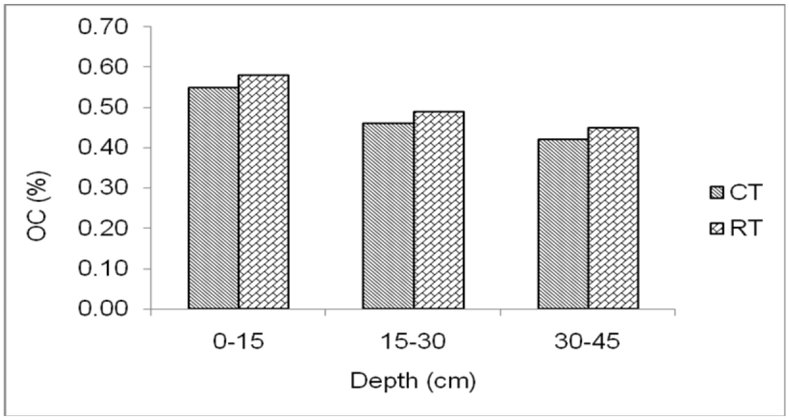


Fig.5.7. Effect of Soil organic carbon (%) under different tillage systems

5.9. Soil microbial biomass carbon

The microbial biomass is affected by factors that change the water or carbon content of soil, and include climate, soil type and management practices. The microbial biomass grows best in warm and moist conditions. Consequently areas with warm moist climates will have a greater microbial biomass than cold or dry areas.

From the soil microbial biomass carbon (SMBC) data, it was inferred that significant difference were observed among soybean+ pigeon pea, soybean – wheat and soybean + cotton (2:1) cropping system compared to soybean fallow system. Whereas, SMBC value were at par in soybean-fallow R and maize gram cropping system, among surface and subsurface soil.

Further, the result indicated that irrespective of soil depth the SMBC contents were significantly higher under RT over CT. This was attributed to residue addition increases microbial biomass due to increase in carbon substrate under RT. The highest SMBC value was observed higher soybean + pigeon pea (2:1) system and the lowest value was under soybean- fallow system (Fig 5.8). Similarly, (Govaerts *et al*. 2007b) reported that in the subtropical highlands of Mexico, residue retention resulted in significantly higher amounts of SMB-C and N in the 0-15 cm layer compared to residue removal.

Spedding *et al*. (2004) found that residue management had more influence than tillage system on microbial characteristics, and higher SMB-C and N levels were found in plots with residue retention than with residue removal, although the differences were significant only in the 0-10 cm layer. The influence of tillage practice on SMB-C and N seems to be mainly confined to the surface layers, with a stronger stratification when tillage is reduced (Alvear *et al.* 2001, Salinas-Garcia *et al.* 2002). Alvear *et al*. (2005) found higher SMB-C and N in the 0-20 cm layer under zero tillage than under conventional tillage (disk-harrowing to 20 cm) in an Ultisol from southern Chile and attributed this to the higher levels of C substrates available for microorganism growth, better soil physical conditions and higher water retention under zero tillage. Pankhurst *et al.* (2000)

found that zero tillage with direct seeding into crop residue increased the build-up of organic C and SMB in the surface soil. Similarly, Teklu *et al.* (2007) reported that increase in the total organic carbon content and the soil microbial biomass carbon (MBC) under conservation tillage practices (RT and GM) for five years (1998 to 2002).

Salinas-Garcia *et al.* (2002) reported that SMB-C and N were significantly affected by tillage, but primarily at the soil surface (0–5 cm) where they were 25–50% greater with zero tillage and minimum tillage than with disk ploughing to 30 cm. At lower depths (5-10 and 10-15 cm), SMB-C and N were generally not significantly different.

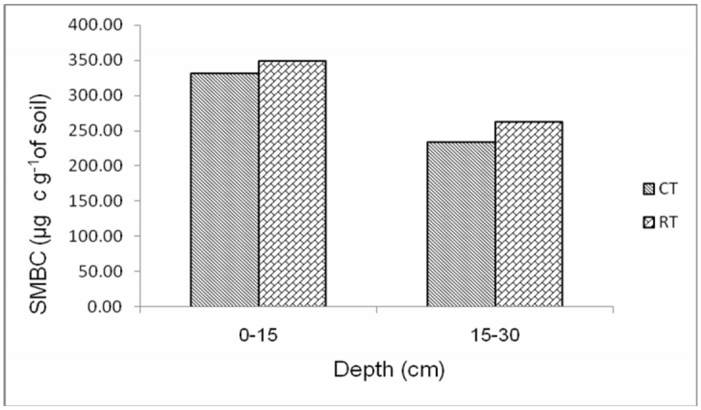


Fig.5.8 Effect of soil microbial biomass carbon (µg c g^{-1} of soil) under different tillage systems

5.11. Carbon pools

Hermle *et al.* (2008) distinguished the following soil C fractions: (i) the easily decomposable fraction (labile), representing an early stage in the humification process, (ii) material stabilised by physical– chemical mechanisms (intermediary) and (iii) the biochemically recalcitrant fraction (stable). Similarly, Chan *et al.* (2001) has also outlined four different fractions of soil carbon namely very labile, labile, less labile and non-labile. The first two fractions have been categorised into active pool (readily available form), whereas, the rest of fractions were categorized into stable pools. The different carbon fractions of the soil have different availability and turnover times in the soil. The SOC of the labile pool, which consists mainly of particulate organic matter (POM) and some dissolved organic carbon, is readily available and consequently rapidly decomposed while the resistant SOC fraction is old, in close contact with mineral surfaces, and provides limited access to micro-organisms (Hermle *et al.* 2008).

The labile fraction plays a crucial role in the formation of aggregates (Six *et al.* 2001), and responds rapidly to changes in soil management because of its rapid turnover time (Franzluebbers, 2002). Research generally shows an enrichment of the organic matter in labile forms as tillage intensity reduces (Chan *et al.* 2002).

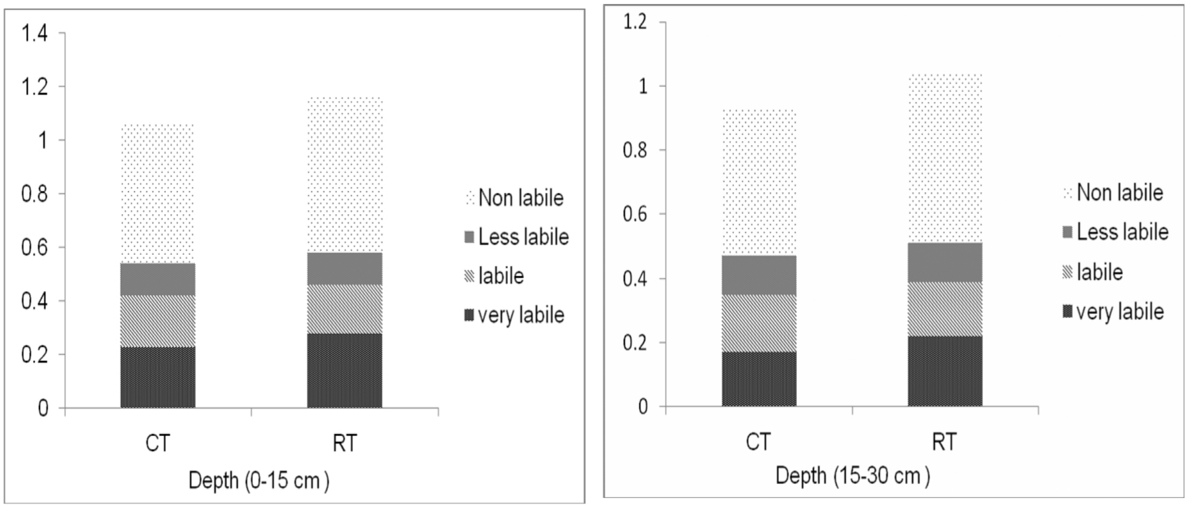


Fig.5.9. Effect of Soil carbon pool (%) under different tillage systems

Irrespective of tillage practices, very labile, labile and non-labile carbon pools were found to be statistically significant and higher in surface layer than subsurface layer. Whereas, less labile carbon pools showed no significant difference between surface and sub-surface layer. Among the tillage practices, reduced tillage showed higher value (0.28% and 0.60%) than conventional tillage (0.23% and 0.53%) and found to be significant with respect to very labile and non-labile carbon pools at 0-15cm. This was ascribed to reduction in tillage and crop residue addition under reduced tillage. Similarly, higher values were observed only in very labile (0.22%) and non-labile carbon pools (0.53%) under reduced tillage and found to be significant over conventional tillage practice

(0.17% and 0.46%). It is evident that more tillage operations enhance oxidation organic carbon and reduction in tillage practices helps in reverting this process. However, among tillage practices and soil depth, significant differences were observed with respect to labile and less labile carbon pools. Among cropping system, carbon pools were found to be statistically significant at both surface and sub-surface layer. It is also clear that interaction effect between tillage and cropping system were found to be non-significant with respect to carbon pools.

In the present investigation, results on carbon pools revealed that among the four fractions non-labile fraction/pools registered highest value followed by very labile pools under 0-15 cm depth. It is very well corroborated with initial soil sample carbon pools in the following order: non-labile>very labile>labile> less labile. It is evident from the study that the reduced tillage recorded significantly different in terms of carbon pools after three years of crop cycle. It is also perceived from the data that there may be likely shift from in one pool to another carbon pools with residue addition and reduction in tillage operations in the long term (Fig. 5.9).

5.12. Effect of conservation tillage on crop yields

Yield parameters were recorded during third crop cycle and yield data were converted into soybean equivalent yield (q ha^{-1}). It was inferred that tillage had no effect on soybean grain equivalent after three years of crop cycle. Among the cropping systems studied, maize-gram recorded higher yield followed by soybean+ pigeon pea (2:1) and soybean-wheat cropping system. Barring soybean-wheat system under CT, all other crop yields were under RT after third crop cycle. This was possibly attributed to improvement in soil structure three years of continuous reduced tillage. Similarly, (Hati *et al.*2009) reported that conservation tillage practices that is, no-tillage (with crop residues retained on the surface and direct drilling of seed) and reduced tillage (residue retained + one sweep tillage) were as effective as conventional tillage (residue removed +

one summer tillage by sweep cultivator + two tillage by sweep cultivator) in terms of crop productivity under soybean and wheat. In a another study, wheat residue incorporation or retention coupled with application of 28 kg N ha^{-1} through fertilizer or organic manures (~4 t FYM ha^{-1}) is more beneficial than burning in terms of enhanced crop productivity and soil fertility. Wheat residue incorporation resulted in 20–22 percent higher yields in soybean and 15–25 percent in wheat as compared to residue burning (Subba Rao *et al.* 2009). A series of long term experiments (1991-2000) were conducted in rice-wheat under Vertisols (Jabalpur) indicated that in (rice-wheat) both the crops, adoption of no-tillage had a slight advantage in terms of yields as compared to conventionally tilled plots. Deep tillage did not benefit either of the crop yields compared to conventional tillage. Similarly, straw mulch application @ 5 tha^{-1} was found highly effective in further improving yield. With the adoption of CA, the beneficial effects are likely to increase over time due to improvement in soil quality (Tomar, 2008).

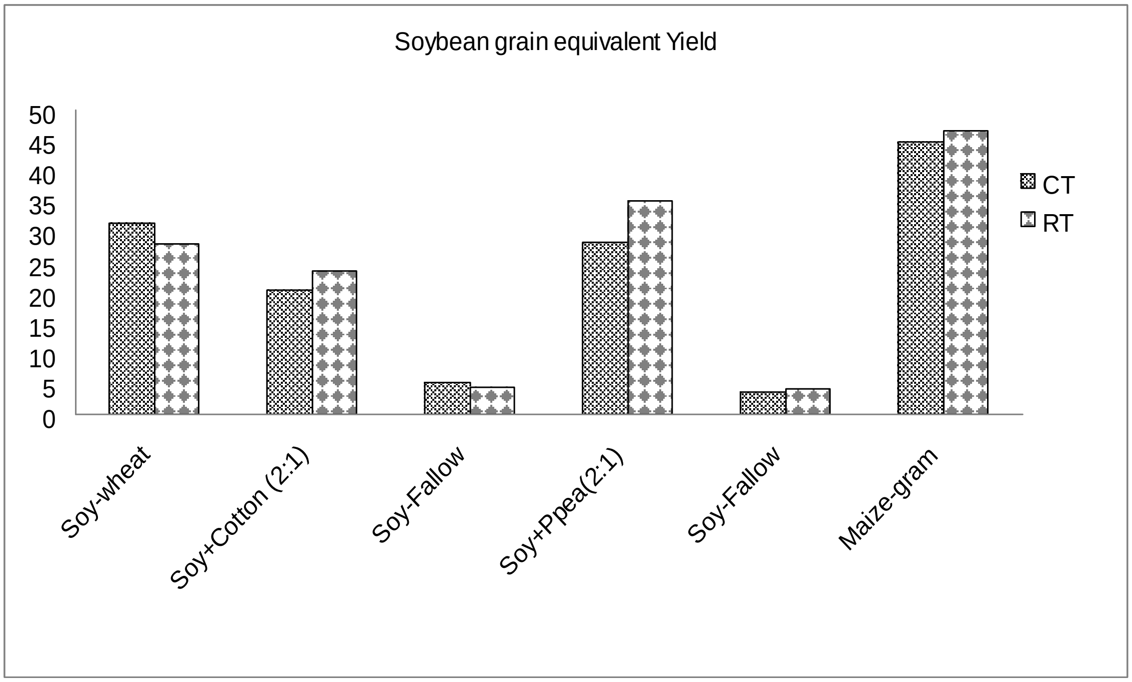


Fig. 5.10: Effect of soybean grain equivalent yield (q ha^{-1}) under different tillage systems

Similarly, Govaerts *et al*. (2006a and 2006b) showed that the highest crop yields as well as the highest soil quality status under zero tillage with crop residue retention. Tillage often delays timely planting of crops, with subsequent reductions in yield potential. By reducing turnaround time to a minimum, zero-tillage can get crops planted on time and thus increase yields without greater input cost (Hobbs and Gupta, 2003). Similarly, Dixit *et al.* (2003) reported that the grain and straw yield of wheat under no-tillage system were higher than conventional system. There was an increase of 17.09 percent grain yield of wheat under no-tillage system. This might be due to greater availability of moisture at maturity stage, release of nitrogen by the decomposing stubbles, better germination and lower weed intensity under this system. Similarly, Hobbs *et al*. (2002) reported that growing direct-seeded rice without puddling soils and wheat yields after non-puddled rice are higher than after puddled rice (Fig. 5.10).

CHAPTER VI

SUMMARY, CONCLUSION AND SUGGESTION FOR FURTHER WORK

The present investigation was carried out at The Indian Institute of Soil Science, Bhopal during 2012-13 to assess the effect of conservation agricultural practices on selected soil physical properties and carbon pools in black soils of central India. The result from the present investigation has been discussed and the major findings have been summarized and concluded as below.

- Maize-gram cropping system recorded the highest soybean grain equivalent yield (SGEY) followed by soybean + pigeon pea (2:1) and soybean-wheat.
- It was inferred that both tillage and cropping systems did not have any significant effect on soil pH and EC.
- Physical properties like soil moisture, soil temperature, penetration resistance and bulk density have been favourably influenced by tillage and cropping system.
- Infiltration rate and mean weight diametre (MWD) is higher in RT compared to CT after third crop cycle.
- Soil organic carbon (SOC) was also higher in RT compared to CT, Similarly
- SMBC was significantly higher in RT compared to CT under both the soil depths
- From the study, it was inferred that though slight improvement was observed under some soil properties after three years of implementation of different tillage systems. However, it requires minimum of 4-6 years of continuous residue addition coupled with minimal soil disturbance for getting conspicuous impact on these properties.

- CA is definitely a sustainable production system which not only conserves natural resources but also enhances productivity and soil quality. Location specific CA technology generation–dissemination–adoption of CA technologies has to be looked into for broader perspective and it has to go hand in hand, that is, close partnership with farmers. The main advantage of CA practices can be availed in rainfed agro eco-regions, if practices appropriately over long-term basis.

Some of the future researchable issues emanated from the study are

- Inter-disciplinary research efforts are required to develop appropriate implements for seeding in zero-tillage, residue incorporation and intercultural operations under conservation agriculture.
- Detailed study on carbon sequestration, green house gas (GHG) emissions, fate of fertilizer nutrient under high residue conditions, carbon credits, soil aggregate size carbon, energy saving, weed dynamics and pest incidence should be studied in detail under conservation agriculture experiment.

Table 4.1. Effect of conservation agriculture practices on pH of soil at different depths

Treatments	0-5 cm			5-15 cm			15-30 cm			30-45 cm		
	CT	RT	Mean	CT	RT	Mean	CT	RT	Mean	CT	RT	Mean
Soy-wheat	8.26	8.34	**8.30**	8.43	8.58	**8.51**	8.37	8.37	**8.37**	8.41	8.44	**8.42**
Soy+ Cotton(2:1)	8.33	8.23	**8.28**	8.44	8.49	**8.47**	8.44	8.42	**8.43**	8.44	8.50	**8.47**
Soy-Fallow*	8.30	8.40	**8.35**	8.46	8.54	**8.50**	8.53	8.46	**8.49**	8.48	8.51	**8.49**
Soy+ Pigeon pea (2:1)	8.30	8.47	**8.39**	8.48	8.45	**8.47**	8.45	8.54	**8.49**	8.42	8.50	**8.46**
Soy-Fallow (R)**	8.28	8.25	**8.27**	8.48	8.47	**8.48**	8.43	8.39	**8.41**	8.48	8.43	**8.46**
Maize-Gram	8.45	8.34	**8.40**	8.53	8.47	**8.50**	8.50	8.50	**8.50**	8.54	8.54	**8.54**
Mean	**8.32**	**8.34**		**8.47**	**8.50**		**8.45**	**8.45**		**8.46**	**8.49**	
		SEm ±	**CD (5%)**		**SEm ±**	**CD (5%)**		**SEm±**	**CD (5%)**		**SEm±**	**CD (5%)**
Tillage system		0.023	NS		0.010	NS		0.027	NS		0.039	NS
Cropping system		0.045	NS		0.036	NS		0.038	NS		0.033	NS
CS within TS		0.064	NS		0.051	NS		0.054	NS		0.047	NS
TS within CS		0.063	NS		0.047	NS		0.056	NS		0.058	NS

Note: Soy-Fallow*= single rotation, Soy-Fallow (R) **= Double rotation (Maize- Gram), CT=Conventional tillage, RT= Reduced/Conservation tillage, CS= Cropping system, TS = Tillagesystem

Table4.2. Effect of conservation agriculture practices on EC (dSm^{-1}) of soil at different depths

Treatments	**0-5 cm**			**5-15 cm**			**15-30 cm**			**30-45 cm**		
	CT	**RT**	**Mean**	**CT**	**RT**	**Mean**	**CT**	**RT**	**Mean**	**CT**	**RT**	**Mean**
Soy-wheat	0.23	0.16	**0.19**	0.14	0.21	**0.18**	0.16	0.12	**0.14**	0.15	0.12	**0.13**
Soy+ Cotton(2:1)	0.15	0.16	**0.16**	0.13	0.18	**0.15**	0.15	0.14	**0.14**	0.13	0.12	**0.13**
Soy-Fallow*	0.21	0.16	**0.19**	0.15	0.13	**0.14**	0.13	0.14	**0.14**	0.13	0.12	**0.13**
Soy+ Pigeon pea (2:1)	0.21	0.20	**0.20**	0.13	0.14	**0.14**	0.13	0.13	**0.13**	0.13	0.15	**0.14**
Soy-Fallow (R)**	0.18	0.16	**0.17**	0.14	0.12	**0.13**	0.15	0.13	**0.14**	0.13	0.13	**0.13**
Maize-Gram	0.19	0.22	**0.20**	0.13	0.23	**0.18**	0.13	0.13	**0.13**	0.15	0.13	**0.14**
Mean	**0.19**	**0.18**		**0.14**	**0.17**		**0.14**	**0.13**		**0.14**	**0.13**	
		SEm ±	**CD (5%)**		**SEm ±**	**CD (5%)**		**SEm±**	**CD (5%)**		**SEm±**	**CD (5%)**
Tillage system		0.003	NS		0.008	NS		0.006	NS		0.003	NS
Cropping system		0.016	NS		0.010	NS		0.010	NS		0.007	NS
CS within TS		0.023	0.069		0.014	NS		0.015	NS		0.010	NS
TS within CS		0.021	0.065		0.015	NS		0.015	NS		0.009	NS

Note: Soy-Fallow*= single rotation, Soy-Fallow (R) **= Double rotation (Maize- Gram), CT=Conventional tillage, RT= Reduced/Conservation tillage, CS= Cropping system, TS = Tillagesystem

Table4.3a. Effect of conservation agriculture practices on soil moisture content (%) at harvest stage of *kharif* crop in different soil depths

Treatments	**0-15 cm**			**15-30 cm**			**30-45cm**		
	CT	**RT**	**Mean**	**CT**	**RT**	**Mean**	**CT**	**RT**	**Mean**
Soy-wheat	17.92	18.27	**18.09**	17.95	18.39	**18.17**	19.21	19.39	**19.30**
Soy+ Cotton (2:1)	17.92	18.78	**18.35**	17.93	18.83	**18.38**	19.57	19.83	**19.70**
Soy-Fallow*	19.05	19.22	**19.14**	19.13	19.36	**19.24**	20.27	21.05	**20.66**
Soy+ Pigeon pea (2:1)	19.60	20.29	**19.94**	19.84	20.13	**19.98**	20.14	21.05	**20.59**
Soy-Fallow (R)**	20.32	21.08	**20.70**	21.74	21.90	**21.82**	22.10	22.43	**22.27**
Maize-Gram	19.54	20.23	**19.88**	19.81	19.86	**19.83**	19.96	19.94	**19.95**
Mean	**19.06**	**19.65**		**19.40**	**19.75**		**20.21**	**20.61**	
		SEm ±	**CD (5%)**		**SEm ±**	**CD (5%)**		**SEm ±**	**CD (5%)**
Tillage system		0.024	0.149		0.066	0.402		0.091	NS
Cropping system		0.225	0.664		0.195	0.576		0.239	0.706
CS within TS		0.318	NS		0.276	0.814		0.339	NS
TS within CS		0.292	NS		0.260	0.821		0.322	NS

Note: Soy-Fallow*= single rotation, Soy-Fallow (R) **= Double rotation (Maize- Gram), CT=Conventional tillage, RT= Reduced/Conservation tillage, CS= Cropping system, TS = Tillage system

Table 4.3b. Effect of conservation agriculture practices on soil moisture content (%) at flowering stage of *rabi* crops in different soil depths

Treatments	0-15 cm			15-30 cm			30-45 cm		
	CT	**RT**	**Mean**	**CT**	**RT**	**Mean**	**CT**	**RT**	**Mean**
Soy-wheat	15.99	16.64	**16.32**	17.03	17.94	**17.49**	18.26	18.57	**18.42**
Soy+ Cotton(2:1)	14.58	15.05	**14.82**	17.26	17.78	**17.52**	17.59	17.41	**17.50**
Soy-Fallow*	14.10	15.64	**14.87**	17.65	17.22	**17.44**	17.84	19.07	**18.46**
Soy+ Pigeon pea (2:1)	14.68	15.21	**14.94**	16.69	17.54	**17.12**	18.92	18.45	**18.69**
Soy-Fallow (R)**	14.61	16.02	**15.31**	17.08	17.44	**17.26**	12.59	12.88	**12.73**
Maize-Gram	14.35	14.78	**14.57**	16.35	17.03	**16.69**	19.19	19.21	**19.20**
Mean	**14.72**	**15.56**		**17.01**	**17.49**		**17.40**	**17.60**	
		SEm ±	**CD (5%)**		**SEm ±**	**CD (5%)**		**SEm ±**	**CD (5%)**
Tillage system		0.067	0.408		0.126	NS		0.161	NS
Cropping system		0.230	0.680		0.239	0.704		0.441	NS
CS within TS		0.326	NS		0.337	NS		0.623	NS
TS within CS		0.305	NS		0.333	NS		0.591	NS

Note: Soy-Fallow*= single rotation, Soy-Fallow (R) **= Double rotation (Maize- Gram), CT=Conventional tillage, RT= Reduced/Conservation tillage, CS= Cropping system, TS = Tillagesystem

Table4.3c. Effect of conservation agriculture practices on soil moisture content (%) at maturity stage of *rabi* crops in different soil depths

Treatments	**0-15 cm**			**15-30 cm**			**30-45 cm**		
	CT	**RT**	**Mean**	**CT**	**RT**	**Mean**	**CT**	**RT**	**Mean**
Soy-wheat	10.90	12.13	**11.52**	14.44	12.74	**13.59**	13.65	13.93	**13.79**
Soy+ Cotton(2:1)	8.91	11.19	**10.05**	13.15	14.52	**13.84**	13.13	14.46	**13.80**
Soy-Fallow*	8.58	10.17	**9.37**	14.61	14.95	**14.78**	15.25	16.50	**15.87**
Soy+ Pigeon pea (2:1)	7.46	8.74	**8.10**	15.79	14.70	**15.25**	15.22	17.61	**16.41**
Soy-Fallow (R)**	9.95	10.45	**10.20**	15.65	16.25	**15.95**	15.54	14.77	**15.16**
Maize-Gram	9.64	10.95	**10.29**	14.03	15.49	**14.76**	16.13	16.65	**16.39**
Mean	**9.24**	**10.60**		**14.61**	**14.78**		**14.82**	**15.65**	
		SEm ±	**CD (5%)**		**SEm ±**	**CD (5%)**		**SEm ±**	**CD (5%)**
Tillage system		0.003	0.017		0.036	NS		0.014	0.086
Cropping system		0.508	1.499		0.748	NS		0.776	2.290
CS within TS		0.719	NS		1.058	NS		1.098	NS
TS within CS		0.656	NS		0.966	NS		1.002	NS

Note: Soy-Fallow*= single rotation, Soy-Fallow (R) **= Double rotation (Maize- Gram), CT=Conventional tillage, RT= Reduced/Conservation tillage, CS= Cropping system, TS = Tillage system

Table 4.4. Effect of conservation agriculture practices on bulk density (Mg m^{-3}) of soil at different depths

Treatments	**0-7.5 cm**			**7.5-15 cm**			**15-22.5 cm**			**22.5-30 cm**		
	CT	**RT**	**Mean**	**CT**	**RT**	**Mean**	**CT**	**RT**	**Mean**	**CT**	**RT**	**Mean**
Soy-wheat	1.39	1.35	**1.37**	1.42	1.38	**1.38**	1.60	1.57	**1.60**	1.66	1.65	**1.66**
Soy+ Cotton(2:1)	1.34	1.34	**1.34**	1.45	1.40	**1.40**	1.59	1.55	**1.59**	1.65	1.65	**1.65**
Soy-Fallow*	1.35	1.31	**1.33**	1.42	1.36	**1.36**	1.59	1.56	**1.59**	1.65	1.64	**1.65**
Soy+ Pigeon pea (2:1)	1.35	1.31	**1.33**	1.45	1.39	**1.39**	1.60	1.58	**1.60**	1.66	1.65	**1.66**
Soy-Fallow (R)**	1.38	1.36	**1.37**	1.46	1.41	**1.41**	1.61	1.57	**1.61**	1.64	1.63	**1.64**
Maize-Gram	1.39	1.35	**1.37**	1.45	1.42	**1.42**	1.60	1.58	**1.60**	1.65	1.64	**1.65**
Mean	**1.37**	**1.34**		**1.44**	**1.39**		**1.60**	**1.57**		**1.65**	**1.64**	
		SEm ±	**CD (5%)**		**SEm ±**	**CD (5%)**		**SEm ±**	**CD(5%)**		**SEm ±**	**CD(5%)**
Tillage system		0.0004	0.0025		0.0001	0.0005		0.0003	0.0018		0.0001	0.0005
Cropping system		0.0686	NS		0.0720	NS		0.0804	NS		0.0837	NS
CS within TS		0.0970	NS		0.1018	NS		0.1138	NS		0.1183	NS
TS within CS		0.0886	NS		0.0930	NS		0.1039	NS		0.1080	NS

Note: Soy-Fallow*= single rotation, Soy-Fallow (R) **= Double rotation (Maize- Gram), CT=Conventional tillage, RT= Reduced/Conservation tillage, CS= Cropping system, TS = Tillagesystem

Table4.5. Effect of conservation agriculture practices on mean weight diametre (mm) of soil at different depths

Treatments	0-15 cm			15-30 cm		
	CT	RT	Mean	CT	RT	Mean
Soy-wheat	0.58	0.60	**0.59**	0.58	0.57	**0.58**
Soy+ Cotton(2:1)	0.53	0.55	**0.54**	0.56	0.58	**0.57**
Soy-Fallow*	0.47	0.50	**0.49**	0.56	0.58	**0.57**
Soy+ Pigeon pea (2:1)	0.44	0.46	**0.45**	0.55	0.57	**0.56**
Soy-Fallow (R)**	0.45	0.49	**0.47**	0.53	0.56	**0.55**
Maize-Gram	0.53	0.55	**0.54**	0.54	0.56	**0.55**
Mean	**0.50**	**0.53**		**0.55**	**0.57**	
		SEm ±	**CD (5%)**		**SEm ±**	**CD (5%)**
Tillage system		0.001	0.009		0.001	0.064
Cropping system		0.015	0.045		0.022	NS
CS within TS		0.021	NS		0.031	NS
TS within CS		0.020	NS		0.028	NS

Note: Soy-Fallow*= single rotation, Soy-Fallow (R) **= Double rotation (Maize- Gram), CT=Conventional tillage, RT= Reduced/Conservation tillage, CS= Cropping system, TS = Tillagesystem

Table4.7. Average soil temperature (0-5 cm) under different tillage systems

Times(minutes)	**Morning(7.00am)**		**Afternoon(2.00pm)**	
Date	**CT**	**RT**	**CT**	**RT**
24/11/2012	16	16	29	29
29/11/2012	16	17	32	31
14/12/2012	14	15	30	30
5/1/2013	10	10	25	25
15/1/2013	15	15	29	29
22/1/2013	9	11	24	23
29/1/2013	11	12	26	25
5/2/2013	19	20	25	25
12/2/2013	17	19	29	28

Table4.8. Effect of conservation tillage on steady state infiltration rate (cmhr^{-1})

Treatments	**CT**	**RT**	**Mean**
Soy-wheat	1.15	2.44	**1.79**
Soy+ Cotton(2:1)	1.42	1.98	**1.70**
Soy-Fallow*	2.58	2.80	**2.69**
Soy+ Pigeon pea (2:1)	2.40	1.92	**2.16**
Soy-Fallow (R)**	0.99	2.97	**1.98**
Maize-Gram	0.81	1.80	**1.30**
Mean	**1.56**	**2.32**	

Note: Soy-Fallow*= single rotation, Soy-Fallow (R) **= Double rotation (Maize- Gram), CT=Conventional tillage, RT= Reduced/Conservation tillage, CS= Cropping system, TS = Tillagesystem

Table4.6. Effect of conservation agriculture practices on penetration resistance (in Mpa)

Depth (cm)	CT	RT
2	0.31	0.36
4	0.58	0.66
6	0.75	0.97
8	0.82	1.04
10	0.98	1.16
12	1.12	1.33
14	1.03	1.27
16	1.33	1.43
18	1.49	1.47
20	1.60	1.64
22	1.69	1.68
24	1.76	1.72
26	1.85	1.78
28	1.99	1.81
30	2.00	1.95
32	2.06	1.98
34	2.09	1.83
36	2.08	2.06
38	2.14	2.14
40	2.16	2.28
42	2.20	2.37
44	2.08	2.36

Table 4.9. Effect of conservation agriculture practices on soil organic carbon (%) of soil at different depths

Treatments	0-15 cm			15-30 cm			30-45 cm		
	CT	**RT**	**Mean**	**CT**	**RT**	**Mean**	**CT**	**RT**	**Mean**
Soy-wheat	0.53	0.55	**0.54**	0.43	0.44	**0.43**	0.39	0.40	**0.40**
Soy+ Cotton(2:1)	0.55	0.56	**0.55**	0.41	0.44	**0.43**	0.36	0.40	**0.38**
Soy-Fallow*	0.55	0.57	**0.56**	0.48	0.53	**0.51**	0.44	0.48	**0.46**
Soy+ Pigeon pea (2:1)	0.55	0.59	**0.57**	0.44	0.50	**0.47**	0.40	0.48	**0.44**
Soy-Fallow (R)**	0.58	0.59	**0.59**	0.51	0.53	**0.52**	0.43	0.46	**0.44**
Maize-Gram	0.56	0.59	**0.58**	0.51	0.52	**0.51**	0.48	0.49	**0.48**
Mean	**0.55**	**0.58**		**0.46**	**0.49**		**0.42**	**0.45**	
		SEm ±	**CD (5%)**		**SEm ±**	**CD (5%)**		**SEm ±**	**CD (5%)**
Tillage system		0.002	0.011		0.008	NS		0.010	NS
Cropping system		0.009	0.028		0.020	0.058		0.011	0.032
CS within TS		0.013	NS		0.028	NS		0.015	NS
TS within CS		0.012	NS		0.027	NS		0.017	NS

Note: Soy-Fallow*= single rotation, Soy-Fallow (R) **= Double rotation (Maize- Gram), CT=Conventional tillage, RT= Reduced /Conservation tillage, CS= Cropping system, TS = Tillagesystem

Table4.10. Effect of conservation agriculture practices on soil microbial biomass carbon (SMBC) (µg c g^{-1} of soil) of soil at different depths

Treatments	**0-15 cm**			**15-30 cm**		
	CT	**RT**	**Mean**	**CT**	**RT**	**Mean**
Soy-wheat	335.7	385.1	**360.4**	233.7	275.4	**254.6**
Soy+ Cotton(2:1)	299.1	338.4	**318.8**	222.8	277.1	**250.0**
Soy-Fallow*	284.9	296.8	**290.9**	180.8	267.7	**224.3**
Soy+ Pigeon pea (2:1)	419.6	431.2	**425.4**	285.6	345.4	**315.5**
Soy-Fallow (R)**	296.2	320.6	**308.4**	180.8	261.9	**221.4**
Maize-Gram	321.5	407.9	**364.7**	198.2	220.0	**209.1**
Mean	**326.2**	**359.3**		**217.0**	**274.6**	
		SEm ±	**CD (5%)**		**SEm ±**	**CD (5%)**
Tillage system		1.668	10.153		1.232	7.435
Cropping system		4.379	12.919		0.891	8.540
CS within TS		6.193	18.270		1.218	3.592
TS within CS		5.895	18.870		1.659	7.761

Note: Soy-Fallow*= single rotation, Soy-Fallow (R) **= Double rotation (Maize- Gram), CT=Conventional tillage, RT= Reduced/Conservation tillage, CS= Cropping system, TS = Tillagesystems

Table 4.11a. Effect of conservation agriculture practices on carbon pool (%) at 0-15 cm depth

Treatments	**0-15 cm**											
	Very labile			**Labile**			**Less labile**			**Non labile**		
	CT	**RT**	**Mean**	**CT**	**RT**	**Mean**	**CT**	**RT**	**Mean**	**CT**	**RT**	**Mean**
Soy-wheat	0.22	0.28	**0.25**	0.20	0.18	**0.19**	0.11	0.09	**0.10**	0.57	0.62	**0.59**
Soy+ Cotton(2:1)	0.23	0.28	**0.26**	0.20	0.20	**0.20**	0.12	0.10	**0.11**	0.53	0.62	**0.57**
Soy-Fallow*	0.23	0.26	**0.24**	0.21	0.19	**0.20**	0.11	0.12	**0.12**	0.54	0.58	**0.56**
Soy+ Pigeon pea (2:1)	0.26	0.32	**0.29**	0.17	0.17	**0.17**	0.12	0.10	**0.11**	0.53	0.62	**0.57**
Soy-Fallow (R)**	0.23	0.26	**0.24**	0.19	0.18	**0.18**	0.16	0.16	**0.16**	0.51	0.59	**0.55**
Maize-Gram	0.24	0.27	**0.25**	0.20	0.18	**0.19**	0.13	0.14	**0.14**	0.49	0.59	**0.54**
Mean	**0.23**	**0.28**		**0.19**	**0.18**		**0.12**	**0.12**		**0.53**	**0.60**	
		SEm ±	**CD (5%)**		**SEm ±**	**CD (5%)**		**SEm ±**	**CD (5%)**		**SEm ±**	**CD (5%)**
Tillage system		0.0004	0.0022		0.0003	0.0015		0.0003	0.0018		0.0004	0.0021
Cropping system		0.0130	NS		0.0096	NS		0.0063	0.0185		0.0288	NS
CS within TS		0.0184	NS		0.0135	NS		0.0089	NS		0.0407	NS
TS within CS		0.0168	NS		0.0123	NS		0.0081	NS		0.0371	NS

Note: Soy-Fallow*= single rotation, Soy-Fallow (R) **= Double rotation (Maize- Gram), CT=Conventional tillage, RT= Reduced/Conservation tillage, CS= Cropping system, TS= Tillagesystem

Table4.11b. Effect of conservation agriculture practices on carbon pool (%) at 15- 30 cm depth

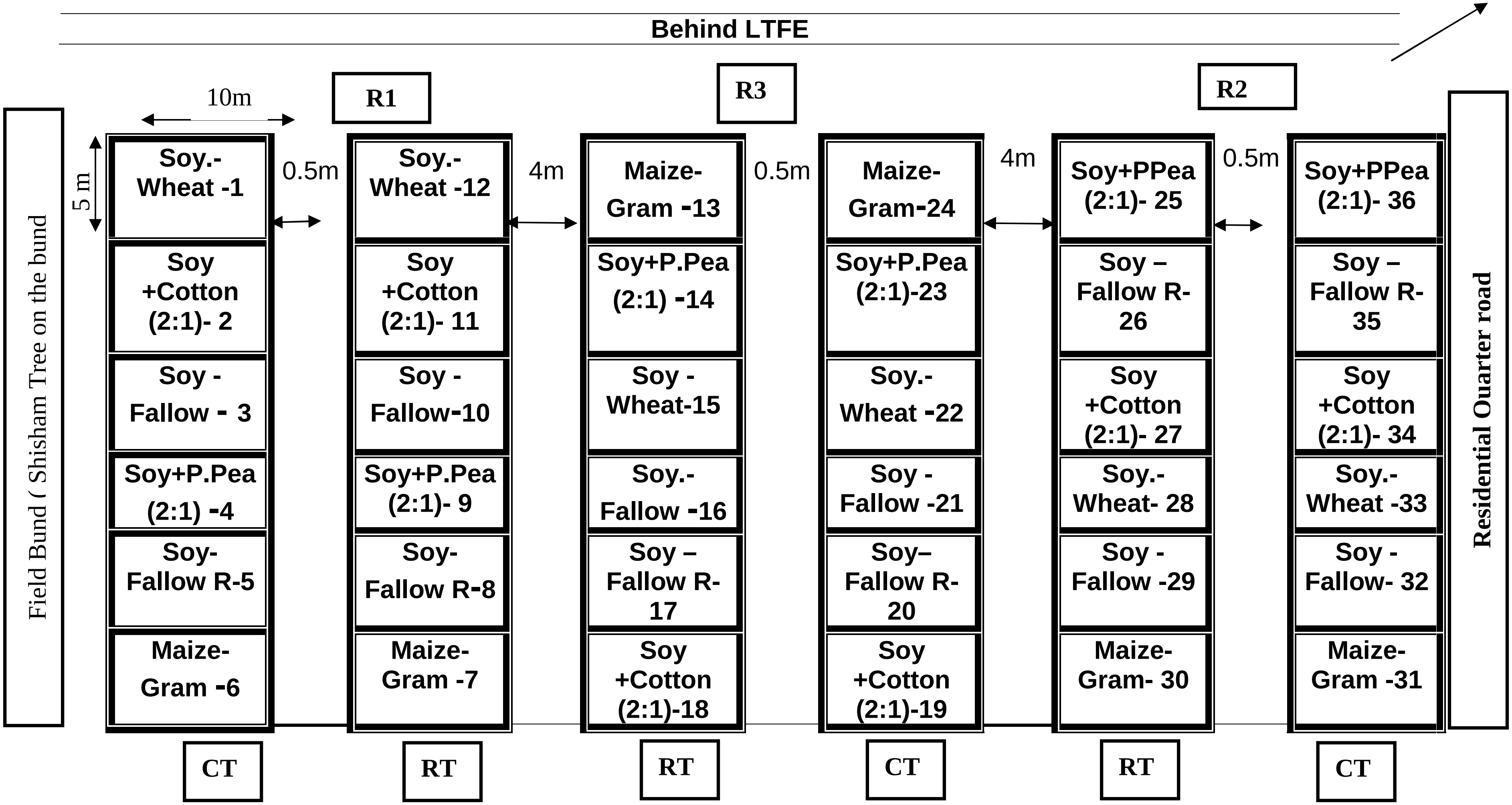
Treatments	15-30 cm											
	Very labile			Labile			Less labile			Non labile		
	CT	RT	Mean	CT	RT	Mean	CT	RT	Mean	CT	RT	Mean
Soy-wheat	0.17	0.23	**0.20**	0.20	0.16	**0.18**	0.06	0.10	**0.08**	0.55	0.67	**0.61**
Soy+ Cotton(2:1)	0.17	0.21	**0.19**	0.17	0.17	**0.17**	0.11	0.11	**0.11**	0.51	0.63	**0.57**
Soy-Fallow*	0.20	0.21	**0.20**	0.18	0.17	**0.17**	0.11	0.13	**0.12**	0.42	0.44	**0.43**
Soy+ Pigeon pea (2:1)	0.17	0.22	**0.19**	0.18	0.17	**0.17**	0.09	0.12	**0.11**	0.46	0.47	**0.47**
Soy-Fallow (R)**	0.19	0.21	**0.20**	0.18	0.17	**0.18**	0.15	0.16	**0.15**	0.43	0.52	**0.48**
Maize-Gram	0.16	0.22	**0.19**	0.16	0.18	**0.17**	0.17	0.13	**0.15**	0.40	0.42	**0.41**
Mean	**0.17**	**0.22**		**0.18**	**0.17**		**0.12**	**0.12**		**0.46**	**0.53**	
		SEm ±	**CD (5%)**		**SEm ±**	**CD (5%)**		**SEm ±**	**CD (5%)**		**SEm ±**	**CD (5%)**
Tillage system		0.0003	0.0018		0.0004	0.0022		0.0006	0.0034		0.0011	0.0066
Cropping system		0.0100	NS		0.0088	NS		0.0062	0.0183		0.0253	0.0746
CS within TS		0.0141	NS		0.0125	NS		0.0088	0.0258		0.0357	NS
TS within CS		0.0129	NS		0.0114	NS		0.0080	0.0238		0.0326	NS

Note: Soy-Fallow*= single rotation, Soy-Fallow (R) **= Double rotation (Maize- Gram), CT=Conventional tillage, RT= Reduced/Conservation tillage, CS= Cropping system, TS= Tillagesystem

Table 4.12.Effect of conservation agricultural practices on soybean grain equivalent yield (qha^{-1})

Treatments	**CT**	**RT**	**Mean**
Soy-wheat	31.52	27.96	**29.74**
Soy+ Cotton(2:1)	20.36	23.57	**21.96**
Soy-Fallow*	5.31	4.58	**4.94**
Soy+ Pigeon pea (2:1)	28.25	34.99	**31.62**
Soy-Fallow (R)**	3.56	4.31	**3.94**
Maize-Gram	44.89	46.51	**45.70**
Mean	**22.31**	**23.65**	
		SEm ±	**CD (5%)**
Tillage system		0.672	NS
Cropping system		0.817	2.410
CS within TS		1.156	3.409
TS within CS		1.250	4.820

Note: Soy-Fallow*= single rotation, Soy-Fallow (R) **= Double rotation (Maize- Gram), CT=Conventional tillage, RT= Reduced/Conservation tillage, CS= Cropping system, TS= Tillagesystem



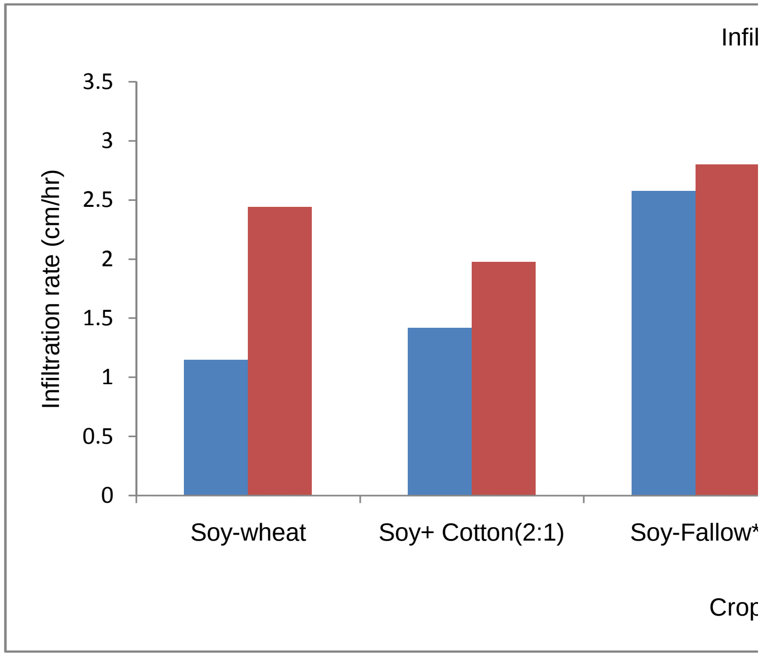
CT-Conventional Tillage, RT- Reduced Tillage

Layout of 1st, 3rd and 5th Year

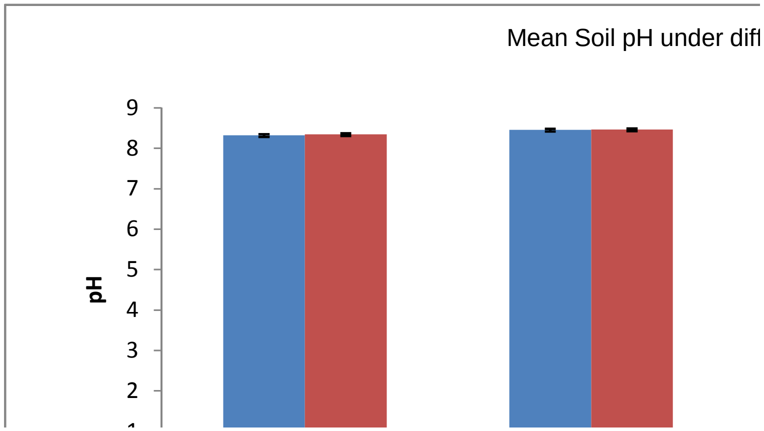
Design: Split plot, Replication: Three, Plot Size : 5 x 10m

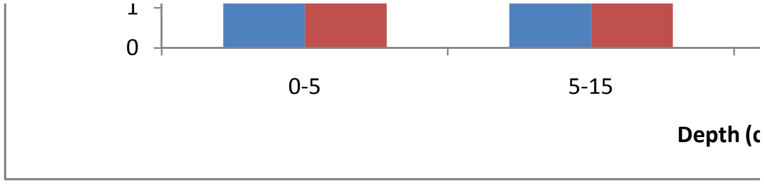
Residential Quarters

Treatments	CT	RT
Soy-wheat	1.15	2.44
Soy+ Cotton(2:1)	1.42	1.98
Soy-Fallow*	2.58	2.8
Soy+ Pigeon pea (2:1)	2.4	1.92
Soy-Fallow (R)**	0.99	2.97
Maize-Gram	0.81	1.8



Teatment	CT	RT
0-5	8.32	8.34
5-15	8.45	8.46
15-30	8.45	8.45
30-45	8.46	8.49
SE	0.033416563	0.032787193





treatment	Soy-wheat	Soy-Cotton	Soy-Fallow	Soy-P. pea	Soy-Fallow R	Maize-Gram
0-5	8.30	8.28	8.35	8.39	8.27	8.40
5-15	8.45	8.39	8.50	8.47	8.43	8.50
15-30	8.37	8.43	8.49	8.49	8.41	8.50
30-45	8.42	8.47	8.49	8.46	8.46	8.54

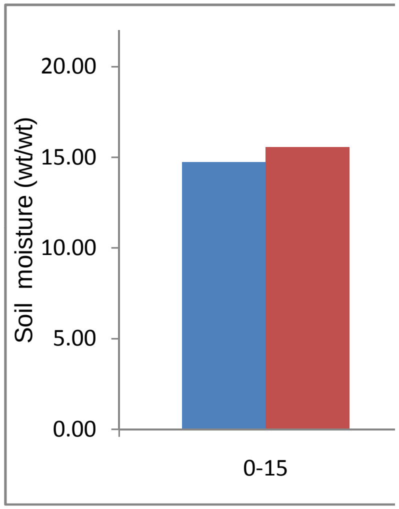
Teatment	CT	RT
0-5	0.19	0.18
5-15	0.14	0.17
15-30	0.14	0.13
30-45	0.14	0.13
SE	0.014	0.012

treatment	Soy-wheat	Soy-Cotton	Soy-Fallow	Soy-P. pea	Soy-Fallow R	Maize-Gram
0-5	0.14	0.14	0.14	0.13	0.14	0.13
5-15	0.19	0.16	0.19	0.20	0.17	0.20
15-30	0.18	0.15	0.14	0.14	0.13	0.18
30-45	0.13	0.13	0.13	0.14	0.13	0.14

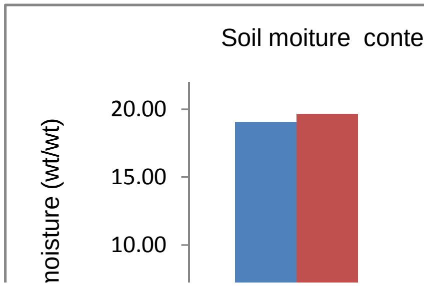
flowering stage of rabi

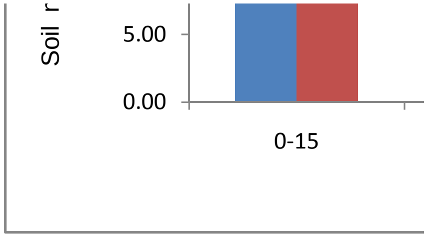
	Soy-wheat	Soy-Cotton	Soy-Fallow	Soy-P. pea	Soy-Fallow R	Maize-Gram
0-15	16.32	14.82	14.87	14.94	15.31	14.57
15-30	17.49	17.52	17.44	17.12	14.76	16.69
30-45	18.42	17.50	18.46	18.69	12.73	19.2

	CT	RT
0-15	14.72	15.56
15-30	17.01	16.66
30-45	17.40	17.60
SE	0.723953267	0.510522608



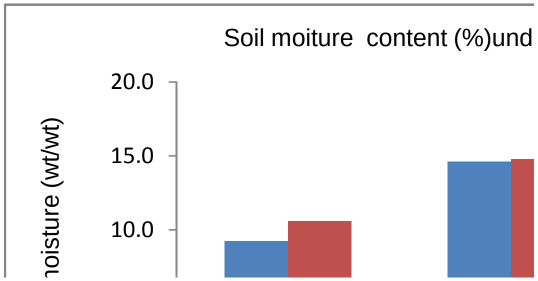
	CT	RT
0-15	19.06	19.65
15-30	19.40	19.75
30-45	20.21	20.61
SE	0.295395215	0.263881286

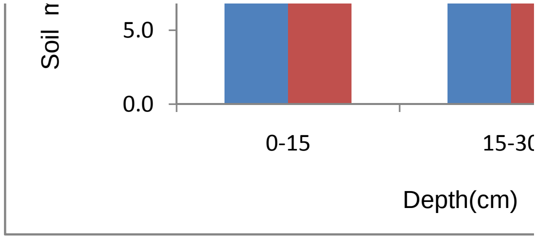




	Soy-wheat	Soy-Cotton	Soy-Fallow	Soy-P. pea	Soy-Fallow R	Maize-Gram
0-15	18.09	18.35	19.14	19.94	20.7	19.88
15-30	18.17	18.38	19.24	19.98	21.82	19.83
30-45	19.3	19.7	20.66	20.59	22.27	19.95

	CT	RT
0-15	9.2	10.6
15-30	14.6	14.8
30-45	14.8	15.7



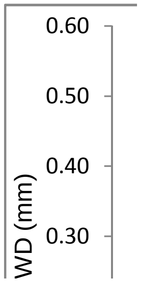


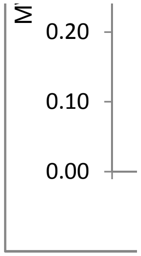
	Soy-wheat	Soy-Cotton	Soy-Fallow	Soy-P. pea	Soy-Fallow R	Maize-Gram
0-15	11.52	10.05	9.37	8.10	10.20	10.29
15-30	13.59	13.84	14.78	15.25	15.95	14.76
30-45	13.79	13.80	15.87	16.41	15.16	16.39

	0-7.5	7.5-15	15-22.5	22.5-30
CT	1.37	1.44	1.6	1.65
RT	1.34	1.39	1.57	1.64

	Soy-wheat	Soy-Cotton	Soy-Fallow	Soy-P. pea	Soy-Fallow R	Maize-Gram
0-7.5	1.37	1.34	1.33	1.33	1.37	1.37
7.5-15	1.38	1.4	1.36	1.39	1.41	1.42
15-22.5	1.6	1.59	1.59	1.6	1.61	1.6
22.5-30	1.66	1.65	1.65	1.66	1.64	1.65

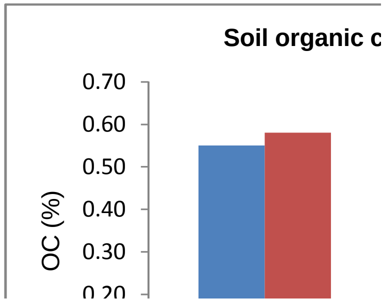
	0-15	15-30
CT	0.50	0.53
RT	0.55	0.57

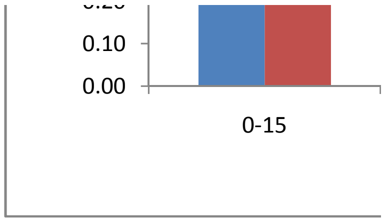




	Soy-wheat	Soy-Cotton	Soy-Fallow	Soy-P. pea
0-15	0.59	0.54	0.49	0.45
15-30	0.58	0.57	0.57	0.56

	CT	RT
0-15	0.55	0.58
15-30	0.46	0.49
30-45	0.42	0.45

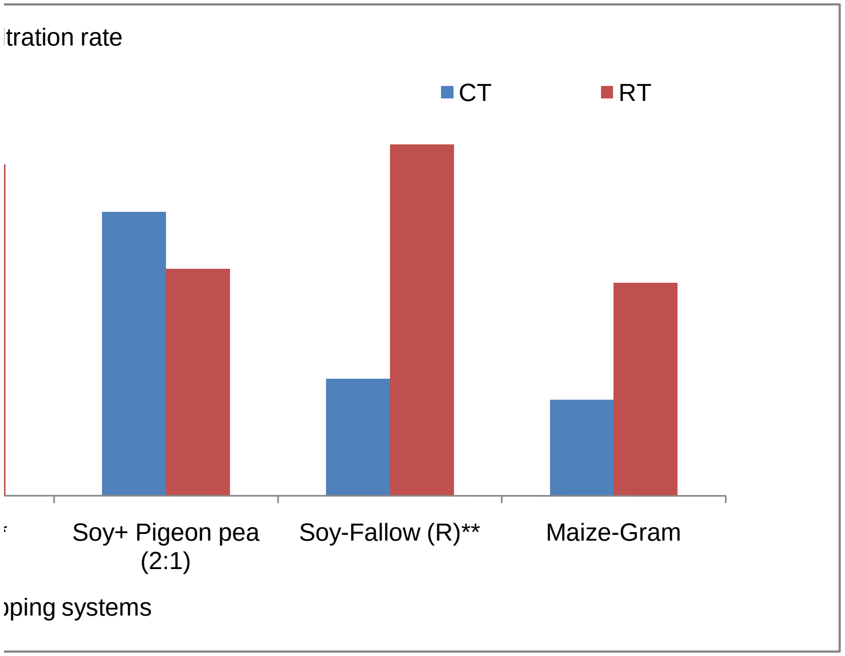


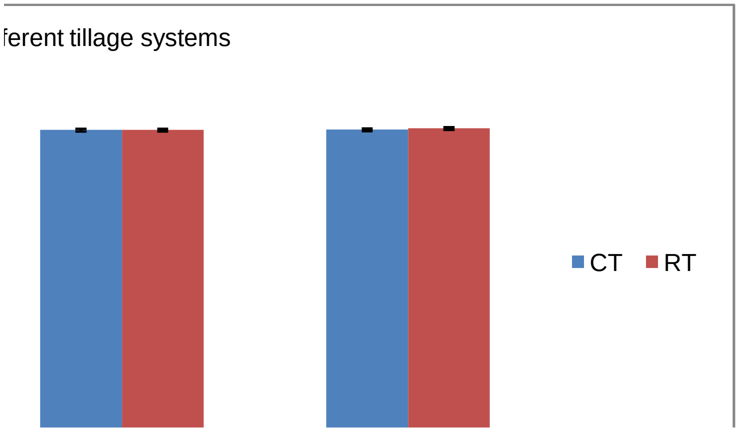


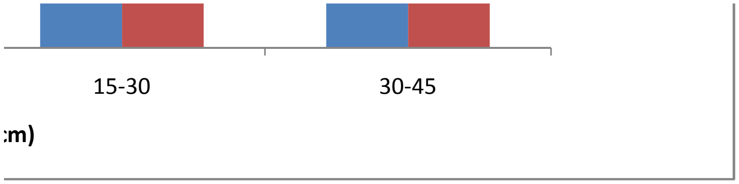
	Soy-wheat	Soy-Cotton	Soy-Fallow	Soy-P. pea	Soy-Fallow R
0-15	0.54	0.55	0.56	0.57	0.59
15-30	0.43	0.43	0.51	0.47	0.52
30-45	0.40	0.38	0.46	0.44	0.44

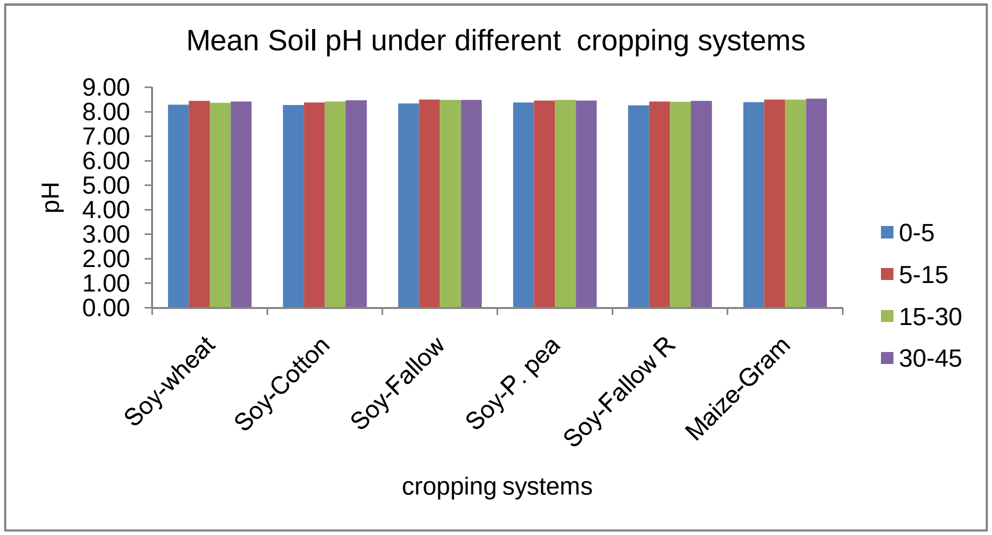
	0-15	15-30
CT	331.0	233.7
RT	349.0	262.2

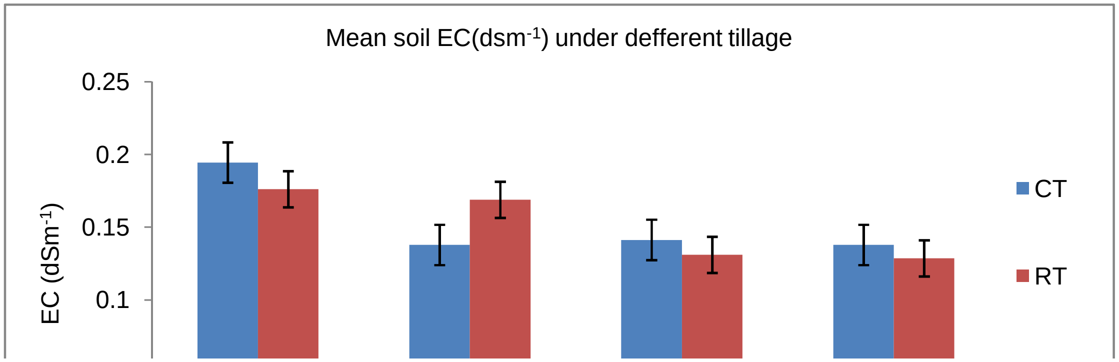
	Soy-wheat	Soy-Cotton	Soy-Fallow	Soy-P. pea	Soy-Fallow R
0-15	360.0	318.0	290.0	425.0	308.0
15-30	247.9	243.3	217.6	308.9	214.7

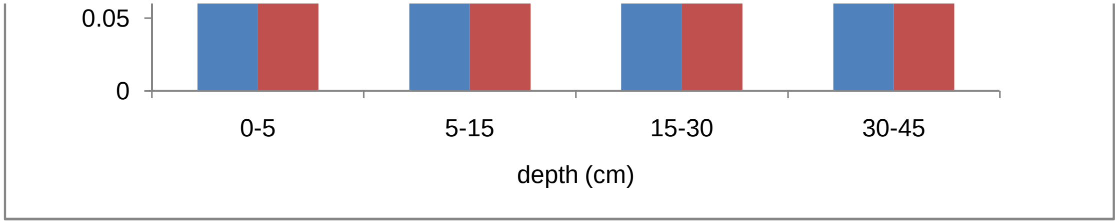

tration rate
CT
RT
Soy+ Pigeon pea (2:1)
Soy-Fallow (R)**
Maize-Gram
ping systems

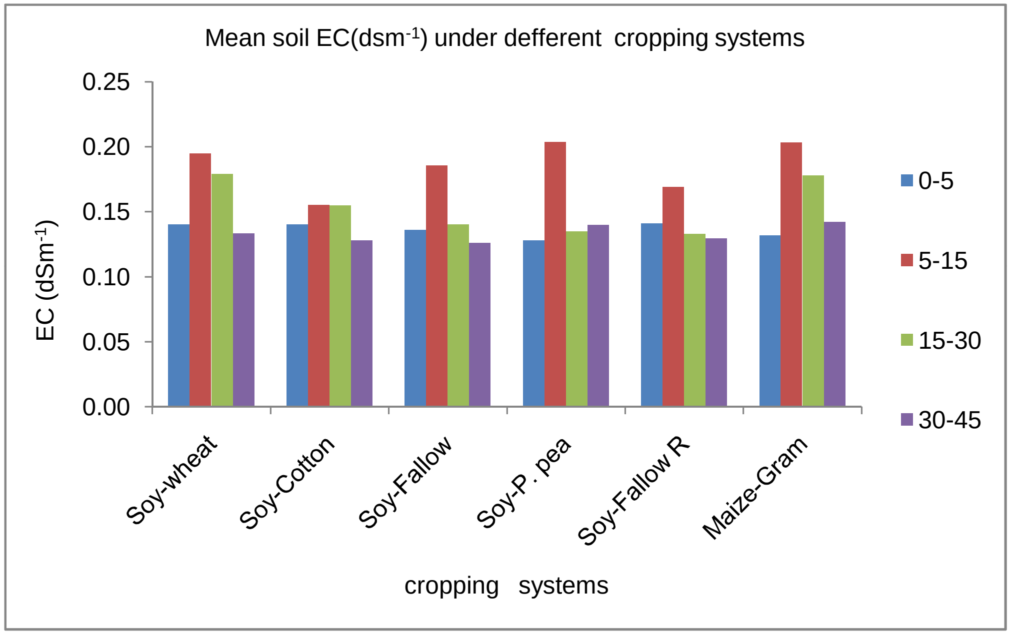

ferent tillage systems
CT
RT

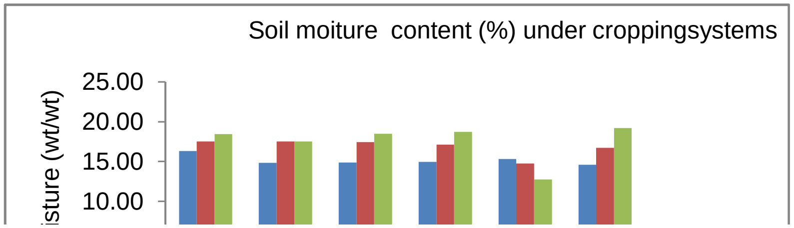


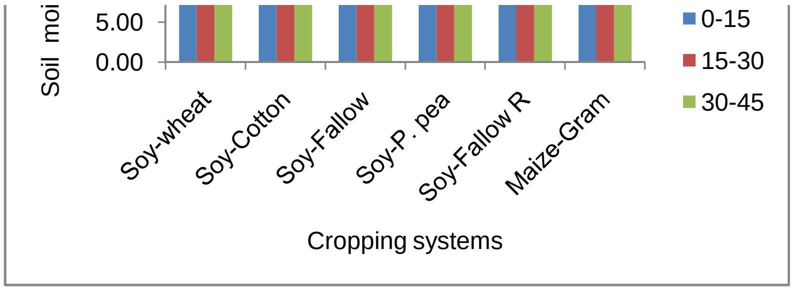

Mean Soil pH under different cropping systems

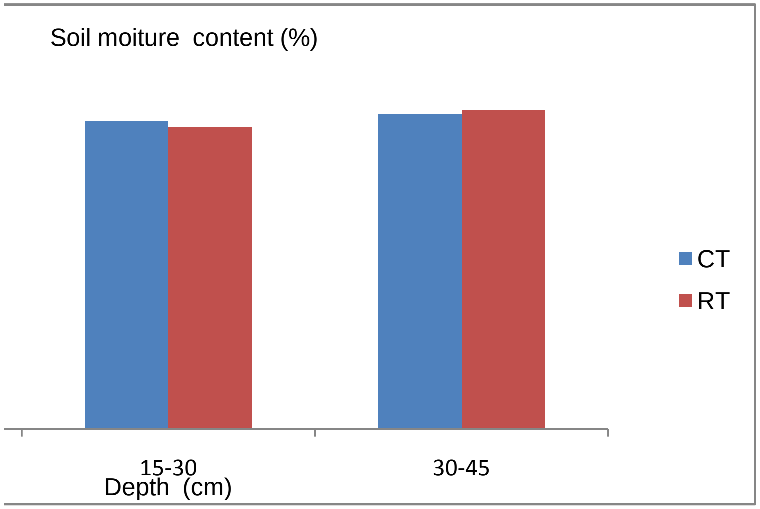

Mean soil EC(dsm^{-1}) under defferent tillage

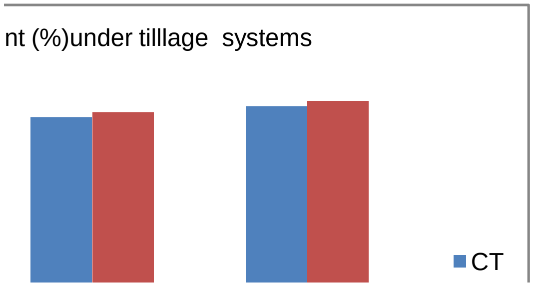

0.05
0
0-5
5-15
15-30
30-45
depth (cm)

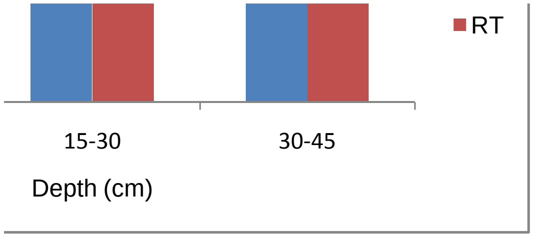

Mean soil EC(dsm-1) under defferent cropping systems
0.25
0.20
0.15
0.10
0.05
0.00
EC (dSm-1)
Soy-wheat
Soy-Cotton
Soy-Fallow
Soy-P . pea
Soy-Fallow R
Maize-Gram
cropping systems
0-5
5-15
15-30
30-45

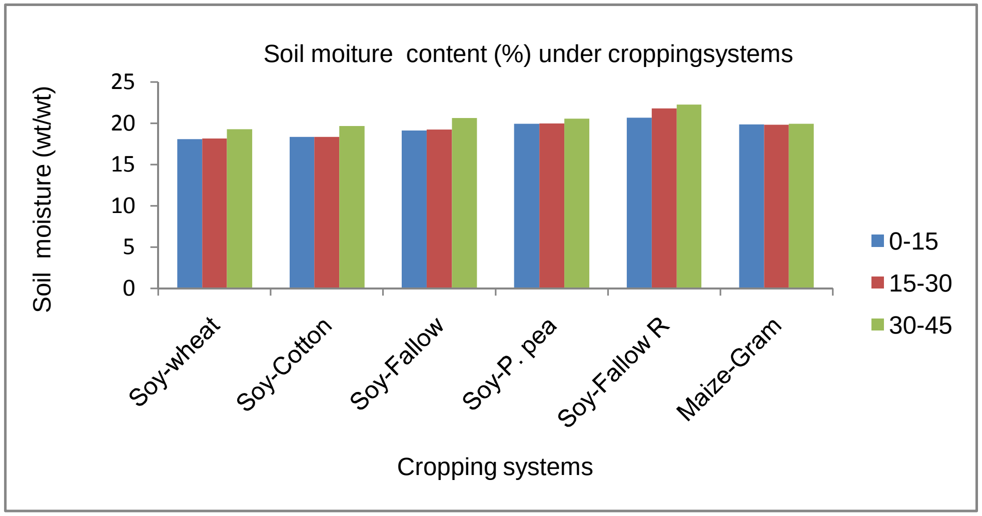

Soil moiture content (%) under croppingsystems
25.00
20.00
15.00
10.00
isture (wt/wt)

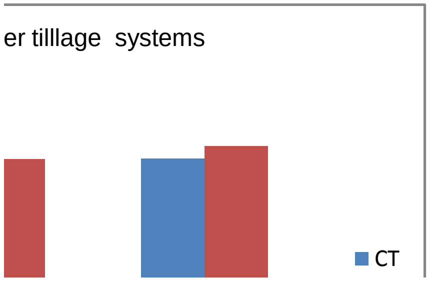

Soil moi
5.00
0.00
Soy-wheat
Soy-Cotton
Soy-Fallow
Soy-P . pea
Soy-Fallow R
Maize-Gram
Cropping systems
0-15
15-30
30-45

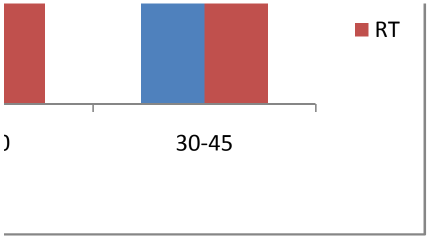

Soil moiture content (%)
15-30
30-45
Depth (cm)
CT
RT

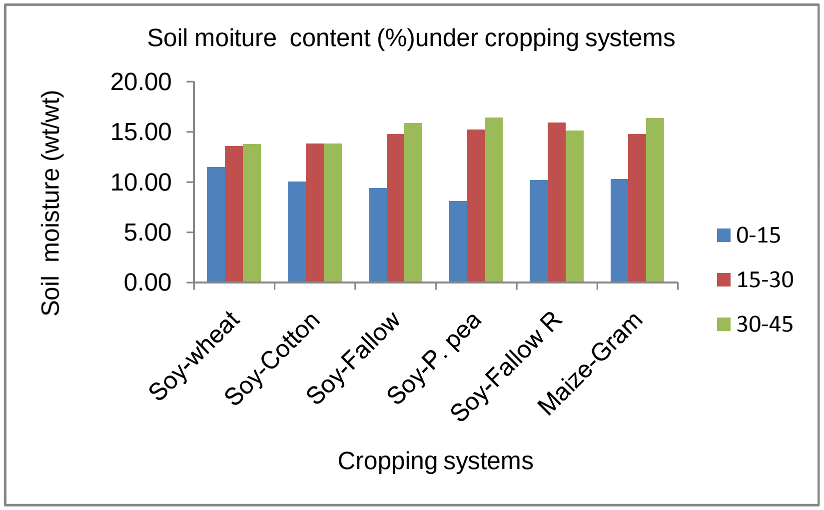

nt (%)under tilllage systems
CT

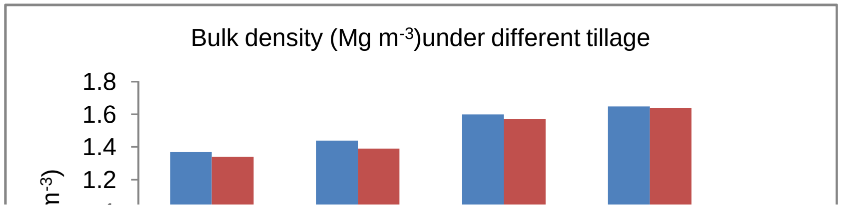

RT
15-30
30-45
Depth (cm)

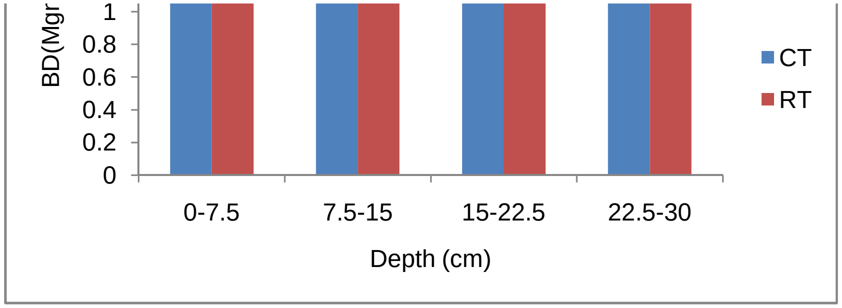

Soil moiture content (%) under croppingsystems
Soil moisture (wt/wt)
25
20
15
10
5
0
Soy-wheat
Soy-Cotton
Soy-Fallow
Soy-P . pea
Soy-Fallow R
Maize-Gram
Cropping systems
0-15
15-30
30-45

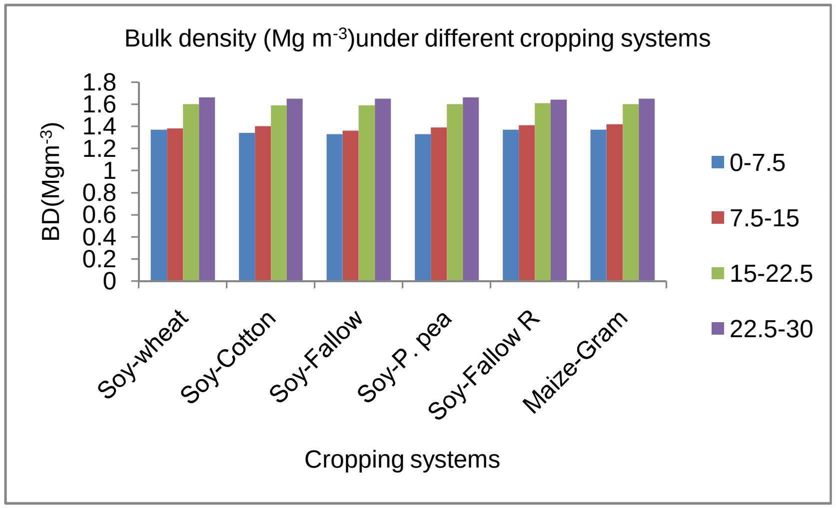

er tilllage systems
CT

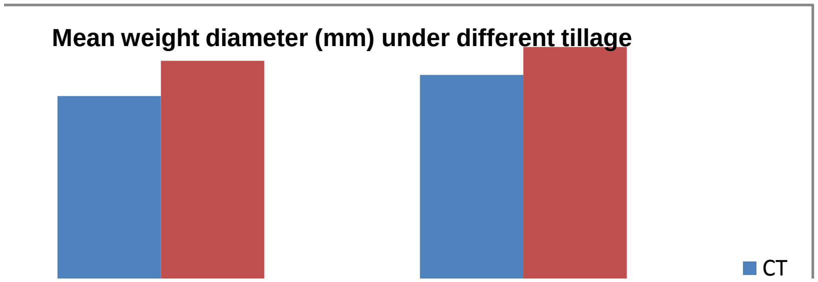

30-45
🟥 RT

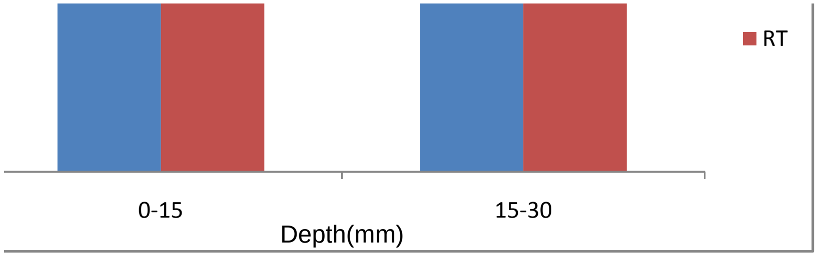

Soil moiture content (%)under cropping systems
Soil moisture (wt/wt)
20.00
15.00
10.00
5.00
0.00
Soy-wheat
Soy-Cotton
Soy-Fallow
Soy-P . pea
Soy-Fallow R
Maize-Gram
Cropping systems
🟦 0-15
🟥 15-30
🟩 30-45


Bulk density (Mg m-3)under different tillage
1.8
1.6
1.4
1.2

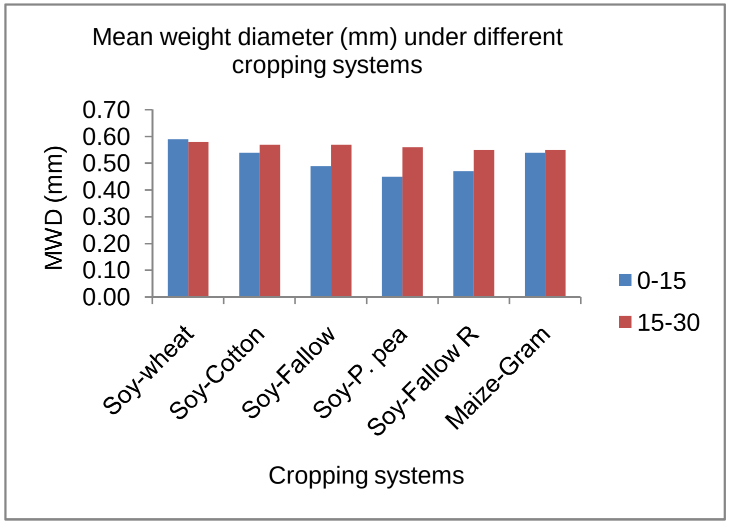

BD(Mgr
1
0.8
0.6
0.4
0.2
0
0-7.5
7.5-15
15-22.5
22.5-30
Depth (cm)
CT
RT

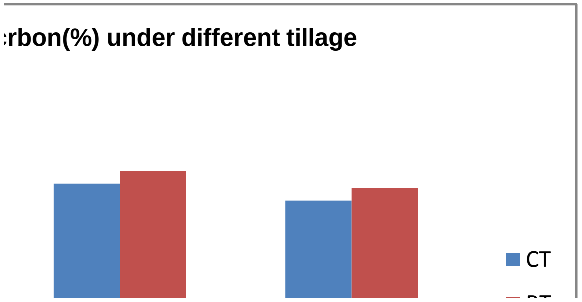

Bulk density (Mg m^{-3})under different cropping systems
BD(Mgm^{-3})
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Soy-wheat
Soy-Cotton
Soy-Fallow
Soy-P . pea
Soy-Fallow R
Maize-Gram
Cropping systems
0-7.5
7.5-15
15-22.5
22.5-30

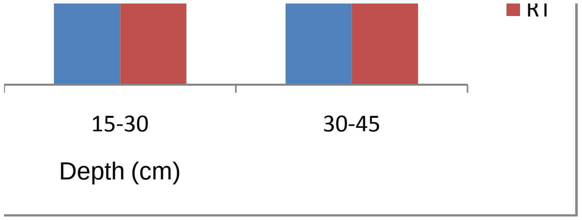

Mean weight diameter (mm) under different tillage
CT



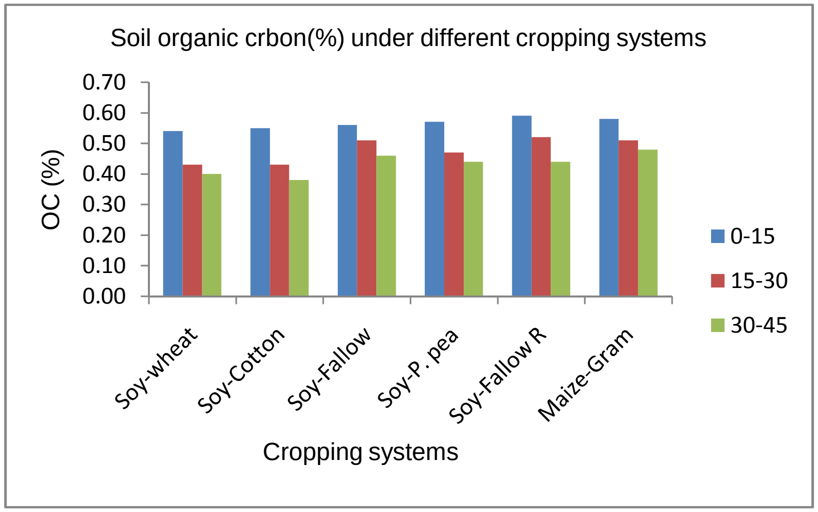
Soy-Fallow R	Maize-Gram
0.47	0.54
0.55	0.55

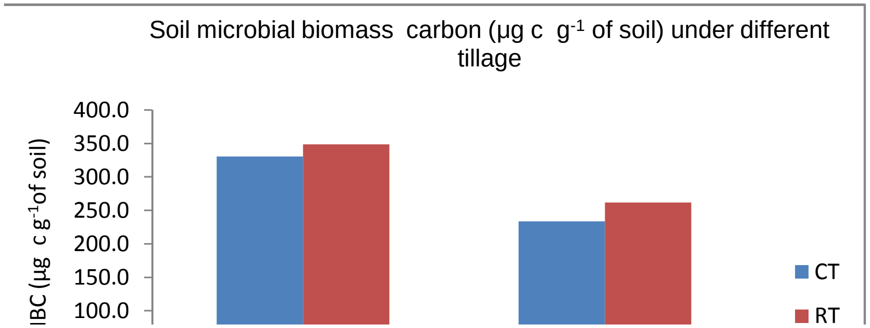


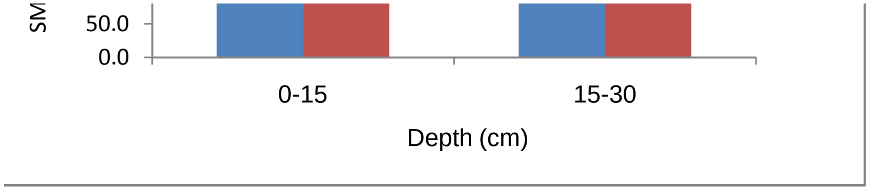




Maize-Gram
0.58
0.51
0.48


Soil organic crbon(%) under different cropping systems

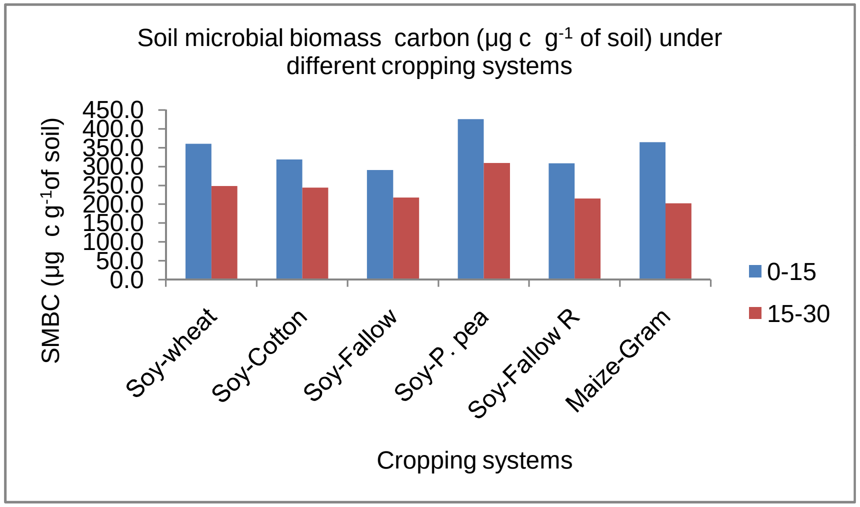

Soil microbial biomass carbon (µg c g^{-1} of soil) under different tillage



Maize-Gram

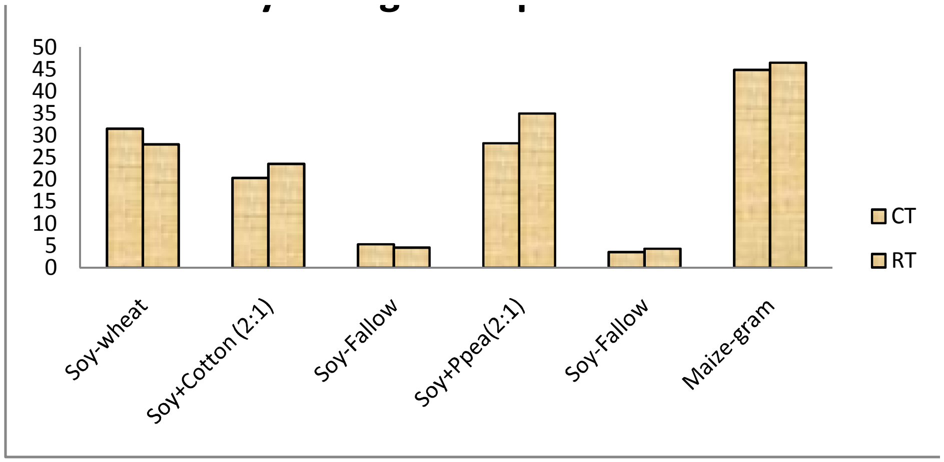
364.0

202.5



CT RT

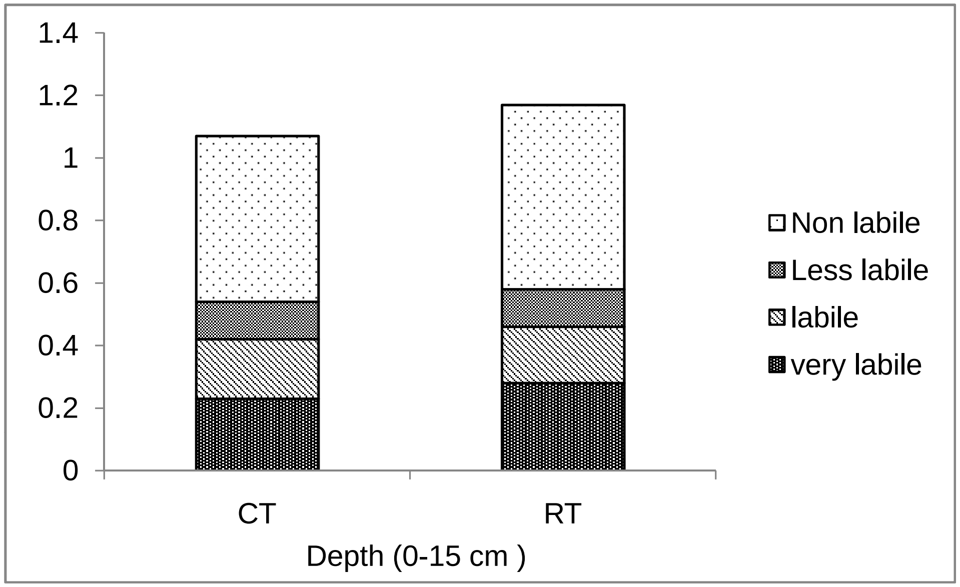
Soy-wheat	31.52	27.96
Soy+Cotton (2	20.36	23.57
Soy-Fallow	5.31	4.58
Soy+Ppea(2:1)	28.25	34.99
Soy-Fallow	3.56	4.31
Maize-gram	44.89	46.51



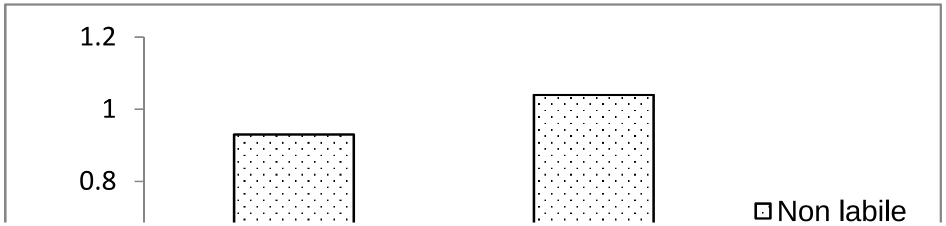
very labile		labile		Less labile		Non labile	
CT	RT	CT	RT	CT	RT	CT	RT
0.23	**0.28**	**0.19**	**0.18**	**0.12**	**0.12**	**0.53**	**0.59**

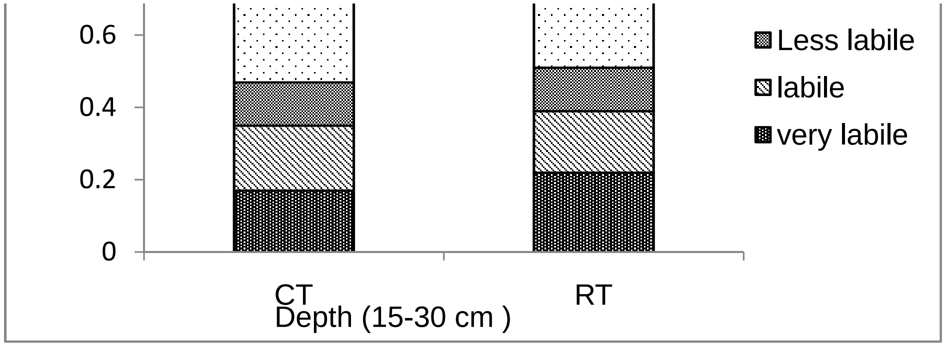
15-30 cm

	CT	RT
very labile	**0.23**	**0.28**
labile	**0.19**	**0.18**
Less labile	**0.12**	**0.12**
Non labile	**0.53**	**0.59**



	CT	RT
very labile	**0.17**	**0.22**
labile	**0.18**	**0.17**
Less labile	**0.12**	**0.12**
Non labile	**0.46**	**0.53**




0.6
0.4
0.2
0
CT
RT
Depth (15-30 cm)
Less labile
labile
very labile

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ABSTRACT

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ABSTRACT

Conservation agriculture is a way to achieve goals of enhanced productivity and profitability while protecting natural resources and enhancing soil quality. The information on impact of conservation agriculture on soil organic carbon pools, soil microbial biomass carbon and soil physical properties are scanty in the black soils of central India. Keeping this in view, an attempt has been made to study the effect of conservation agriculture under different cropping systems on soil organic carbon, microbial biomass carbon and selected soil physical properties in black soils of central India.

Soil samples (surface and subsurface) were collected from experimental field under conservation agriculture experiment for soil analysis after three crop cycle. Results revealed that irrespective of all the depth, soil pH and EC data showed no significant difference under different tillage and cropping systems. The soil moisture content and mean weight diameter (MWD) at surface layer (0-15 cm) was significantly affected by the tillage treatments. Under reduced tillage (RT) practices, soil moisture content and MWD was higher than conventional tillage (CT) with an increase of 3-13 %. However, bulk density (BD) was significantly higher in CT than RT and statistically significant among tillage and cropping system at surface and sub-surface layer.

Soil organic carbon (SOC) data revealed that tillage practices were significantly different. The reduced tillage was significantly different from conventional tillage (CT) in 0-15 cm depth, whereas in the lower depths (i.e 15-30 and 30-45 cm) tillage practices did not have significant effect on SOC. However, cropping system did have effect on SOC content. The SMBC values were significantly different under tillage treatments. Among the cropping system studied, soybean+ pigeon pea (2:1), soybean – wheat and soybean + cotton (2:1) cropping systems were significantly different over soybean-fallow system. Whereas, SMBC value were at par in soybean fallow (rotated with maize-gram) and maize-gram cropping systems.

Impact of tillage system on SOC was found to significant only at surface layer (0-15 cm) and higher SOC value was observed under reduced tillage system as compared

to CT. Among carbon pools studied, very labile, labile and non-labile were found to be significant among tillage system. Reduced tillage practices resulted in increased carbon pools particularly very labile and non-labile pools over CT. However, cropping system does not have any significant effect on SOC and carbon pools at different soil depth at the end of 3rd crop cycle.

Yield data indicated that that tillage had no effect on soybean grain equivalent (SGE) after three years of crop cycle. Among the cropping systems studied, maize-gram recorded significantly higher yield (45.70 q ha^{-1}) followed by soybean+ pigeon pea (2:1) (31.62 q ha^{-1}) and soybean-wheat (29.74 q ha^{-1}) cropping system.

From the study, it was inferred that though there was a relative improvement of some soil properties like moisture content, organic carbon and pools, and microbial biomass carbon under reduced tillage after three years of crop cycle, however conspicuous/ significant results will be visible in the long term.

VITA

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