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**Performance of maize (*Zea mays* L.) under long  
term tillage practices and diversified cropping  
systems**

मालू राम यादव  
**Malu Ram Yadav**



सस्य विज्ञान संभाग  
भा.कृ.अनु.प.—भारतीय कृषि अनुसंधान संस्थान  
नई दिल्ली 110 012

**DIVISION OF AGRONOMY  
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# **Performance of maize (*Zea mays* L.) under long term tillage practices and diversified cropping systems**

By

**Malu Ram Yadav**

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submitted to the Post-Graduate School,  
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**Approved by the Advisory committee:**

Chairperson	:	_____
		(Dr. C.M. Parihar)
Co-Chairperson	:	_____
		(Dr. Dinesh Kumar)
Member	:	_____
		(Dr. S.L. Jat)
Member	:	_____
		(Dr. Vijay Pooniya)
Member	:	_____
		(Dr. Eldho Varghese)

ICAR-Indian Institute of Maize Research  
Pusa Campus, New Delhi-110 012

---

**Dr. C.M. Parihar**  
Scientist

**CERTIFICATE**

This is to certify that the thesis entitled “**Performance of maize (*Zea mays* L.) under long term tillage practices and diversified cropping systems**” submitted to the Post-Graduate School, ICAR-Indian Agricultural Research Institute, New Delhi, in partial fulfilment of the requirements for the degree of Master of Science in Agronomy, embodies the results of *bona fide* research work carried out by **Mr. Malu Ram Yadav** under my guidance and supervision. No part of the thesis has been submitted for any other degree or diploma.

All the assistance and help received during the course of the investigation have been duly acknowledged by him.

New Delhi-110 012  
Date: 26<sup>th</sup> June, 2015

**(C.M. Parihar)**  
Chairman  
Advisory Committee

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## ABBREVIATIONS

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CA	: Conservation agriculture
CGR	: Crop growth rate
CT	: Conventional tillage
DAS	: Days after sowing
GMD	: Geometric mean diameter
LAI	: Leaf area index
kPa	: Kilo pascal
MJ	: Mega joule
mg	: Mili gram
INR (₹)	: Indian national rupees
MWD	: Mean weight diameter
NUE	: Nitrogen-use efficiency
PB	: Permanent bed
RGR	: Relative growth rate
RUE	: Resource use efficiency
TSC	: Total soil carbon
SOC	: Soil organic carbon
ZT	: Zero tillage

## CHAPTER-I

### INTRODUCTION

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Maize (*Zea mays* L.), assume worldwide significance due to its utilization as a human food and livestock feed, as well as a source for several hindered industrial products. Its share in the total production of cereals system increased from 26.2 per cent in 1991 to 29.2 per cent in 2001 and further to 36.7 percent in 2014. The suitability of maize to diverse agro-ecologies is unmatched by any other crop due to its ability to grow in diverse climatic conditions. Together with rice and wheat, being an economically important crop worldwide, maize provides food and nutritional security to more than 4.5 billion people of 94 developing countries through contributing about 30% in food calories and protein (Shiferaw *et al.*, 2011). In Asia, area under maize cultivated is about 57.59 million hectares, yielding about 288.85 million metric tons and about 67 per cent of the total maize production in the world comes from low and lower-middle income countries and play an important role in the livelihoods of millions of poor farmers (FAO, 2015). By 2050, the expected demand of maize will be doubled (Rosegrant *et al.*, 2008).

India is the second most important maize growing country in Asia, and presently ranked sixth-largest producer and fifth-largest consumer of maize in the world. Indian maize production increased from 11.5 million tons in 2002-03 to 24.5 million tons in 2013-14. Maize being a third important grain cereal crop in the country and contributes to nearly 9 per cent of the national food basket, at the same time it contributes to more than half of the coarse cereal production of the country. The growing poultry industry is the biggest driver in the country, consuming nearly 13-14 million tons of maize or over half of the country's maize production. Consequently, with the current and projected challenges for natural resources such as water scarcity, temperature stresses, etc. maize is coming up as a potential component crop in major cereal based systems of India (Dass *et al.*, 2012).

Soil tillage is one of the fundamental agro-technical operations in agriculture because of its influence on soil properties, environment and crop growth. Since, continuous soil tillage strongly influences the soil properties, hence it is important to follow appropriate tillage practices that avoid the degradation of soil structure, maintain crop yield as well as ecosystem stability. Traditionally, maize and wheat

are grown either in row geometry or by random broadcasting, mostly after thoroughly tilling the field till proper tilth is obtained for good field emergence.

To obtain a good seed bed in conventional tillage, the repeated ploughings not only involve high expenditure but also consume time which many a times delay the sowing of the crops resulting in low yields in intensive cropping system where gap between the harvest of one crop and sowing of the next crop is very short. Reduced or conservation tillage systems are gaining more attention in recent years with the rising concern to natural resource degradation. The efficiency of input-use *viz.*, water, fertilizers, herbicides and others depend on tillage and crop establishment practices. Experimental finding reveals that conservation agriculture (CA) practices with minimum mechanical soil disturbance, permanent soil cover by diversified crops residues, is an efficient and economical option for input saving and climate change adaptation. Some of the agronomic practices like zero tillage (ZT), raised bed planting and residue management have been found to be the potential resource conservation technologies (RCT's) which can play a vital role to save the scarce natural resources like land and water.

On the other hand the escalating prices of the agricultural inputs going to affect the crop production cost due to use of diesel in agriculture on hand and higher fertilizer and agrochemical prices on other hand. Recently conservation agriculture (CA) based crop management practices involving lesser soil disturbance, soil cover and cost-effective cropping sequences found to be useful in reduction in production cost besides providing environmental services in terms of lower carbon emission and soil health improvement. The area under CA is increasing due to shortage of labour and escalating input prices in South Asian region and CA is already practices on 157 m ha area worldwide (FAO, 2015). So, there is need for adoption of the conservation agriculture (CA) in India for harnessing crop production profitability and making soil more productive with more environmental and social benefits.

Across the globe distinguish scientists have also reported that the CA involving various resource conservation technologies (RCTs) encompasses practices that enhance resource or input-use efficiency and provide immediate, identifiable, and demonstrable economic benefits such as reduction in production costs, saving in water, fuel and labour requirements, and timely establishment of crops resulting in improved yields. It offers an opportunity for reducing and reversing the downward

spiral of resource degradation, lowering cultivation costs and making agriculture resource–use-efficient, economical and sustainable.

In post green revolution era to achieve the production targets and food security use of high yielding varieties/hybrids, fertilizers, irrigation, agro-chemicals, mechanization, shift in land use pattern and farmers friendly government policies were helpful. But, these conventional modes of agriculture under intensive cereal based production systems leads to the increased scarcity of resources (labour, water, energy and biodiversity, etc.) and production cost along with decline in environmental quality (Jat *et al.*, 2005). These are the major challenges for present agricultural sustainability of the country and can be solved by adopting recently developed new technologies focused on efficient resource-use and their conservation. Under such situation conservation agriculture based crop management practices *viz.*, Zero-tillage, permanent beds should have to receive high priority to ensure the past gains of agriculture productivity with low cost.

The deteriorating soil health, declining soil organic matter content, increased micronutrient deficiencies and reduced partial factor productivity has put a big question mark on the sustainability of rice-wheat cropping system as high intensity puddling in rice results in poor tilth, increased soil strength in surface and sub-surface layers due to illuviation of clay and iron and manganese compounds, decreased hydraulic conductivity and infiltration, which lead to water stagnation, poor root development and hence water stress in wheat crop, and lower recharging of aquifers, all these factors reduce yield of wheat following rice (Bhushan and Sharma, 1999). Under the upcoming limitations of natural resource base, lowering productivity of different crops and ecological imbalances with the existing cropping systems, maize (*Zea mays* L.) based cropping sequences are emerging as an better alternative option for diversification of rice-wheat, rice-rice and other cropping systems. With the development of high yielding varieties and hybrids in maize which are competitive to rice with respect to farm profitability and the resource-use efficiency under diverse soils and climatic conditions, maize-wheat cropping system is gaining importance. Maize, a crop with high yield and market potential due to its C<sub>4</sub>-photosynthesis mechanism, fits well into rice-wheat system by replacing rice. Maize production leads to considerable savings in water, particularly when it replaces irrigated rice in the rice-wheat system. Maize-wheat cropping system has emerged as a potential system, covering an area of 1.13 million hectare and

contributes about 2.25% to national the food grain production (Yadav and Subba Rao, 2001).

In future there is every possibility that area under maize-wheat, maize-maize and maize-chickpea cropping systems is going to increase under resource conservation technologies to address the aberrant climatic conditions like heat stress and depleting water table. So far, there is no systematic research quantify on performance of *khariif* maize and soil health long term tillage practices in maize-based cropping systems. At the same time scanty information is available on profitable diversified maize-based cropping systems under long term tillage practices in different production ecologies of the country. Hence, the research work entitled “*Performance of maize (Zea mays L.) under long term tillage practices and diversified cropping systems*” was undertaken to study the long term effect of different tillage practices and cropping systems on maize productivity, profitability, input use efficiency and soil health. The specific objectives of the field study were:

1. To study the effect of different tillage practices and diversified cropping systems on growth, productivity and quality of maize, and
2. To assess the impact of different tillage practices and cropping systems on profitability, input use efficiency and soil health.

## CHAPTER-II

### REVIEW OF LIETERATURE

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The cultivation land predominantly been achieved by inverting profile of soil using plough and this soil inversion in some situations can lead to degradation of soil structure leading to a compacted soil composed of fine particles with low levels of soil organic matter (SOM). Such soils are more prone to soil loss through water and wind erosion eventually resulting in desertification, as experienced in USA during 1930s (Biswas, 1984). The mono-cropping also leads to build of biotic (pest, disease, weed, etc) and abiotic (nutrient, salt, water, etc.) stresses in crop production which makes many a times farming unsustainable. Inefficient input use and management practices leads to resource degradation, widespread contamination of surface and groundwater with associated health hazards to humans and animals. The suitable tillage operations can alleviate the soil problems while indiscriminate tillage practices may leads to soil structure deterioration, accelerated erosion, depletion of organic matter, decrease in essential nutrients and disruption in water cycles (Lal, 1993). The production and productivity of any system can be sustained by improving soils physico-chemical and biological properties.

Conventional tillage operations alter these properties in every cropping cycle and thereby affect the soil system. In this context, resource conservation systems had drawn the attention of agronomists to devise innovative tillage and residue management techniques for efficient resource management and sustained productivity. To combat soil erosion loss and to preserve soil moisture conservation tillage technologies were developed in USA (Aggarwal *et al.*, 2000). CA was introduced as a concept for resource-efficient agricultural crop production based on an integrated management of soil, water and biological resources combined with external inputs to achieve sustainable and profitable agriculture and subsequently aim to improved livelihoods of farmers. To achieve this, CA is based on three principles that are believed to enhance biological processes above and below the ground. These are: (1) minimum or no mechanical soil disturbance; (2) permanent organic soil cover (consisting of a growing crop or a dead mulch of crop residues) and (3) diversified crop rotations (Giller *et al.*, 2009). We collected research findings of experiments conducted world over and especially in India

on tillage practices influence on maize crop performance and soil properties. In this chapter, we summarized published result pertaining to our investigation entitled “*Performance of maize (Zea mays L.) under long term tillage practices and diversified cropping systems*”.

### **2.1. Growth and yield**

The growth and yield attributes of any crop influenced by many above and below ground factors and a combination of good condition results in better yield. Results of various on-farm participatory trials suggested little or no difference in yield and yield attributes of zero-till (ZT) maize compared to best managed conventional crop (Gupta *et al.*, 2002). Bed planting helped in increased aeration of root zone and assured plant stand by increasing emergence particularly in crusting type soils which resulted in higher maize grain yield (Morrison *et al.*, 1990; Potter *et al.*, 1996). In a field experiment conducted at PAU, Ludhiana, Ram *et al.* (2010) revealed that all the growth parameter (plant height, dry matter and LAI), yield attributes (cobs/plant, grains/cob and 1000-grains weight) and yield performance of maize under different CT and ZT practices were observed statistically at par. It was also observed that the yield of maize obtained under ZT was comparable to CT provided if the best agronomic practices were followed (Mishra and Singh, 2005). Dhillon *et al.* (1987) after a 12 year long term experiment on maize and wheat sequence concluded that the response of different tillage (ZT and one/four discing) practices had non-significant effect on grain yield of both the crops. Famba *et al.* (2011) also observed that there were no yield differences between traditional tillage and different seeding technologies under CA, without crop residues, led to the conclusion that CA practices under the study conditions will not favour short term benefits.

Pedersen and Lauer (2004) also reported that the yields of wheat, maize and soybean obtained under ZT were comparable to CT under proper managed field. In a long term field trial 16% yield reduction was found in crop yield from NT planted maize crop against deep CT (Kaskarbayev *et al.*, 2002). Similarly, lower plant height, LAI, weight/cob, grain and stover yield of maize under minimum tillage (MT) then CT practices were reported by Singh *et al.* (2007) at New Delhi. Jat *et al.* (2006) also reported marginally lower yields of maize under ZT than CT practices. The yield

reduction in NT/ZT had been explained by more weed infestation under ZT maize environment. However, soil moisture in profile was reported higher in minimum or NT treatments than CT plots. Singh *et al.* (2011) reported that under MT mean decrease in grain and stover yield was 6.8-12.1% and 5.9-17.1% compared to CT. In another study Wang *et al.* (2015) also reported that CT had 13-20% and 40-55% higher grain yield of maize than MT and ZT respectively.

Memon *et al.* (2014) observed that plant height, test weight, grain yield and dry matter were higher under MT as compared to CT and ZT maize. In another study with four different tillage system, viz., CT, ZT, raised bed (RB) and ridge and furrow (RF) were tried in maize with two mulch viz. no mulch (NM) and paddy straw mulch (PSM at 4.0 t/ha). RF recorded 18.0% higher seed yield followed by RB (14.5%) and CT (7.5%) over ZT. However, stover yield was 10.1, 8.6 and 5.1% higher for RF, RB and CT over ZT, respectively (Choudhary *et al.*, 2013). Afzalnia and Zabihi (2013) reported that ZT method decreased thousand kernels weight, silage yield, and grain yield of maize compared to the CT method for 11.1, 2.4, and 18.2%, respectively. Ghosh *et al.* (2015) reported that mean maize yield was 1.6 t/ha with conventional agriculture compared to 2 t/ha in CA plots, an increase in yield of about 27%.

Beside these negative or no effect of ZT on the maize performance several studies also reported positive impact on crop. Conservation tillage practices with mulching of legume residue had 23-33% and 14-19% higher grain yield of maize under maize-wheat cropping system than no mulch and planting basin, respectively (Sime *et al.*, 2015). Ram (2006) reported higher values of plant height, dry matter accumulation, LAI, CGR and RGR under permanent bed with legume residue than no-residue. The similar results were also reported by Tolk *et al.* (1999). Bachmann and Friedrich (2002) from Bolivia reported that NT with direct seeding of crop significantly increased the crop yield and there was 17% yield increase across of soybean, maize and wheat crops compared to CT. The results of an experiment conducted on maize shows that among the tillage practices, highest plant height (173.1 cm), grain (9.32 t/ha) and straw yield (11.73 t/ha) were recorded in ZT practices (Patil *et al.*, 2014). Jat *et al.* (2005) at Modipuram, Uttar Pradesh reported that maize productivity was marginally higher with NT then CT practices. A study conducted at IARI, New Delhi revealed that bed planting

significantly improved the yield of maize crop over flat planting (Singh *et al.*, 2009). Jat *et al.* (2005) reported that maize productivity was highest (5.66 t/ha) under FIRB system followed by NT and lowest (4.39 t/ha) in CT with an average productivity of 4.93 t/ha.

Srivastava *et al.* (2005) reported under FIRB and NT planting QPM hybrids better performed over to CT in sandy loam soil in terms of yield, water productivity and profitability. Aquino (1998) reported that farmers of Yaqui Valley obtained 8% higher yields of wheat, maize and soybean at 15% less operational costs from raised bed planting as compared to conventionally flat systems of crop growing. Aggarwal *et al.* (2000) reported significantly higher yield and water use efficiency of maize under raised bed planting than flat planting. Torbent *et al.* (2001) suggested that the corn yield in Texas responded positively to planting a corn row either on beds or a conservational tillage system (zero tillage). Similarly, from a field experiment conducted at Ludhiana (India), Kaur and Mahay (2005a) obtained about 25% higher grain yield with raised bed planting of maize than flat sowing. The higher yield in bed planting with bed was due to increased number of cobs per plant and more grains per cob than flat sowing. Planting of two rows per bed proved inferior to row per bed but gave 9.5% higher yield compared with flat sowing. Jat *et al.* (2006) reported that yields of maize were recorded an average 4 and 16% higher with permanent beds compared with CT and ZT, respectively. Similarly, Singh *et al.* (2007) also reported relatively higher maize grain yield (6.9-14.6%) as compared to CT.

In another long-term study on maize-based conservation agriculture (CA) systems in Malawi (Thierfelder *et al.*, 2015) noticed that grain yields of various maize based cropping sequences increase significantly (24–40%) over time under NT + legume residues retention on the surface compared with the traditional ridge and furrow system over CT. Incorporation of legume stover (cowpea, groundnut, dry bean and soybean) compared to stover removal increased the total dry matter yield of maize under maize-mustard cropping system (Svubure *et al.*, 2010). The maize grain (5.18 and 4.29 t/ha) and stover yield (5.73 and 4.72 t/ha) with and without incorporation of grain legume stover was consistently higher than those from the maize after maize or after fallow plots. Soil incorporation of food legumes (groundnut, bambaranut, cowpea,

pigeon pea and soybean) produced significant effects on 100-grains weight of maize on sandy soil ecologies of Nigeria (Egbe and Ali, 2010).

Sharma and Behera (2009) conducted an experiment to study to evaluate and quantify the effect of different grain legumes inclusion productivity, profitability, N economy and soil fertility in maize based cropping system at New Delhi. They found that through inclusion of various pulses resulted in significantly higher maize-equivalent yield range from 11 to 26% than without inclusion of pulses. Zamir *et al.* (2013) also reported that ZT + legume residue gave maximum test weight (341.67 g) and grain yield (6.33 t/ha) of maize in different cropping sequences and it was followed by CT + saw dust mulch (4.92 t/ ha). Raimbault and Vyn (1991) reported that maize yields were not significantly affected by different cropping system but were greater with maize in rotations where legumes incorporated than in continuously grown maize due better physico-chemical condition of the soil under maize- legume cropping system. Ojiem *et al.* (2014) reported that inclusion of legumes increased maize yields in the subsequent long run compared with continuous maize, while the increase in yield of maize after green manure legumes was stronger than that after grain legumes. Maize yield responded strongly due to improved N availability in legume- maize based cropping systems.

The above reviewed literature suggests that the tillage practices have either no or positive and negative effect on maize yield, growth parameters and yield attributes in different agro-climatic situations. Thus tillage requirement of maize in various agro-climatic situations needs to be worked out separately as no system works universally for achieving higher crop performance and yields. At the same time information is also meager on tillage and cropping systems interactions effect on maize growth parameters, yield attributes and yields.

## **2.2. Soil physical parameters**

### *Bulk Density (BD) and Penetration resistance (PR)*

After tillage, soil rapidly settles, recovers its former BD which shows that tillage had temporary effect on this property of soil (Lampurlanes and Cantero-Martinez 2003). Gwenzi *et al.*, (2009) stated that the conversion from CT to MT and NT had no noticeable effects on BD even after six years of long term study in maize crop.

However, several research workers have reported the higher BD under ZT than CT practices (Kumar *et al.*, 2002; Meena and Behera, 2008; Bhattachaya *et al.*, 2008). Afzalnia and Zabihi, (2013) reported that soil cone index was significantly affected by tillage methods and under this study ZT method in 0.20-0.30 m soil depth range had the maximum cone index which is indicator of PR which means the BD was higher in this treatment. Dhiman *et al.* (2001) reported the increased in the bulk density of the soil from 1.50 g/cc in CT to 1.58 g/cc in NT.

The comparison of tillage practices revealed that soil BD increased with increasing depth in all tillage systems and soil PR was higher under RT and NT than CT (Hill and Cruse, 1985). Wilkens *et al.* (2002) found that higher BD and PR in NT system than CT systems on a silt loam soil. He also noted that soil strength had been significantly increased after conversion of field from a tilled to NT system. Mean yearly soil BD at a depth of 0-200 mm was greater under NT (1.52 g/cm<sup>3</sup>) than under CT (1.42 g/cm<sup>3</sup>) when averaged across all crops (Franzluebbbers *et al.*, 1995). Across soil textures (sandy loam to clay loam), BD was greater under ZT than deep tillage in upper 20 cm soil profile (Kay and VandenBygaart, 2002). Gal *et al.* (2007) observed higher BD in the 0-30 cm layer under ZT than under CT on a silty clay loam after 28 years of long term study, but no difference in the 30-100 cm layer. In another study, Bell and Raczkowski (2008) reported that NT increased BD of a sandy loam soil from 1.3-1.5 g/cm<sup>3</sup> within a year due to natural setting and consolidation. Fabrizzi *et al.* (2005) also found higher BD and PR in NT experiments in Argentina, but the values were below thresholds which could affect wheat yields. The authors also concluded that the experiment had a short time frame and more time was needed to assess the effect on BD. Ozpinar and Cay (2005) found that MT systems resulted in lower BD at 0-20 cm due to loosening the surface soil by rotary tiller and disc, while CT had lower BD at 20-30 cm soil depth due to mould board plough.

Jat *et al.* (2005) also reported lower BD values under raised beds than flat system due to looseness and lower soil compaction. Bautista *et al.* (1996) working in a semi-arid ecosystem found that ZT plus mulch reduced BD and the similar results also reported by Obalum and Obi (2010). Hu *et al.* (2007) in their four years study at Luancheng, reported that NT significantly increased the topsoil (0-5cm) BD, while RT

maintained a lower BD compared to CT. Camara and Klein (2005) reported that soil chiseling under NT decrease the BD. In a long-term experiment at a fixed site in Heilongjiang province, five different tillage systems were compared for their effects on the BD. The treatment of RT had a lower BD than other treatments (Yu and Zhang, 2007). Salem *et al.* (2015) reported significant differences between soil BD and cone index of ZT and those of RT, MT, and CT, during the growing season but it was non-significant at the time of harvesting in few soil layers. Overall, in most soil layers, tillage practices affected BD and cone index in the order of ZT > RT > MT > CT. Blanco-Canqui *et al.* (2006) reported that maize residue retention in ZT for a period of one year in silty loam soil @ 5 and 10 t/ha reduced BD in 0-5 cm layer from 1.42 to 1.26 g/cm<sup>3</sup>. Utomo *et al.* (2013) from a long-term experiment on tillage reported that BD and soil strength in upper layer after 24 years of cropping were similar among treatments, but the soil strength under CT at 50-60 cm depth was 28.2% higher than NT.

The benefits of CA especially when rotated with leguminous crops, increase over time which indicates improvements in soil structure and fertility (Thierfelder *et al.*, 2012) Verhulst *et al.* (2011) reported that most of the physical soil parameters measured in different maize based sequences were significantly affected while only BD was not affected by tillage-legume residue system. Ram *et al.* (2010) from Punjab also reported higher BD values under continuous ZT-maize than CT-maize, but lower values of soil BD under legume residue applied treatments than without residue ZT and CT practices in maize-wheat system. Under CA based long-term study, reported that maize rotated with cowpea (*Vigna unguiculata* L.) and sunnhemp (*Crotalaria ochroleuca* L.) resulted in 6% lower bulk density compare to continuous maize-maize cropping system.

#### *Hydraulic conductivity (K)*

Saturated hydraulic conductivity ( $K_{sat}$ ) was found to be positively and significantly related with the total soil macro-pores (Rasse *et al.*, 2000). A short period (2-3 years) is not enough for tillage to affect  $K$  of sandy loam and other soils (Buschiazzo *et al.*, 1998). The  $K$  was lower with ZT than CT due to higher BD and compaction in surface as well as sub surface layers (Singh *et al.*, 2002). Ferreras *et al.* (2000) found that infiltration and/or hydraulic conductivity were lower under NT than inversion tillage.

In contrast to above discussion several studies also reported positive effect of CA practices to improve soil  $K$  and this can be improved and evaporation can be decreased by NT and crop residue cover (Li *et al.*, 2011). Disruption of macro-pores continuity by tillage can reduce  $K$  (Logsdon *et al.*, 1990). Azooz and Arshad (1996) also reported that the  $K_{\text{stat}}$  values were significantly greater in NT (0.36 to 3.0 cm/hr) than in CT (0.26 to 1.06 cm/hr). McGarry *et al.* (2000) observed higher values of  $K$  under NT relative to tilled treatments due to a greater number of macropores through higher fauna activity and the litter of residues formed by accumulated organic matter. Chen *et al.* (2014) reported that among the different tillage practices RT significantly lowered soil BD in the furrow, at least  $0.15 \text{ g/cm}^3$  lower than that in NT and CT, thus increasing the initial soil infiltration rate by 30% which is an indicator of higher  $K_{\text{sat}}$ .

Under a long-term study on different tillage practices author found that both infiltration as well as  $K_{\text{sat}}$  of the soil was positively influenced by tillage practices and the numerical values were ranged from 1.2 cm/h (RT) to 4.6 cm/h (NT) for infiltration and  $K_{\text{sat}}$  at 0–10 cm depth increased from 1.78 to 3.37, 1.57 to 2.95 and 1.37 to 2.28 (10.2 cm/h) under NT, RT and CT, respectively (Kahlon *et al.*, 2013). Williams and Weil (2004) reported that hydraulic conductivity was higher on beds than flat system of planting. Soil  $K_{\text{sat}}$  at 8 weeks after tillage decreased with increased intensity of soil manipulation by tillage but the highest  $K$  was recorded under NT and the least under plough (Osunbitan *et al.*, 2005). Bhattacharya *et al.* (2006) reported that unsaturated  $K$  increased more with increasing matric potential in NT than CT.  $K_{\text{stat}}$  values in all the studied soil depths were significantly greater under ZT than those under CT (300 to 344 mm/day) and the unsaturated conductivity values at 0-75 mm soil depth under ZT were significantly higher than those computed under CT at all the suction levels, except at -10, -100, and -400 KPa suction.

Legume residue as mulch on soil surface increases the  $K$  as it adds organic matter in soil which improves the soil macro-aggregates that might facilitate easy movement of water in the soil in cereal-legume based cropping system in compared with continuous cereal-cereal system (Das *et al.*, 2001 and Rasool *et al.*, 2007). At the same time (Rahi *et al.*, 2014) reported that  $K$  and BD parameters were little influenced by various rates of residue application in maize-wheat cropping sequence but these

parameters were positively correlated with legume incorporation instead of continuous maize growing. Thierfelder *et al.* (2012) under CA based long-term study, reported that maize rotated with cowpea (*Vigna unguiculata* L.) and sunnhemp (*Crotalaria ochroleuca* L.) resulted in an increase of up to 331% in water infiltration compare to continuous maize-maize cropping system.

#### *Soil Aggregation*

Aggregated soil structure has a beneficial influence on soil moisture status, nutrient dynamics, and soil tilth (Hillel, 2004) and these are desirable characteristics of soil for higher crop productivity. The legume residues retention at soil surface not only increases the aggregate formation, but it also decreases the breakdown of aggregates by reducing erosion and protecting the aggregates against raindrop impact. This effect is lost when the residues are burned in maize based cropping system. Soil structure stability is the ability of aggregates to remain intact when exposed to different biotic and abiotic stresses and soil aggregation is a dynamic process that depends on various agents such as soil fauna, roots, inorganic binding agents and environmental variable (Six *et al.*, 2004). Agricultural practices influence the quantity and persistence of binding agents, which may lead to aggregate formation or breakdown. Thus soil aggregation can be used to evaluate agricultural management practices and select those that optimize crop growth and minimize soil nutrient loss. Tillage disrupts soil aggregates mechanically and fragments root and mycorrhizal hyphae, which are major binding agents for micro-aggregates (Wang *et al.*, 2015). Soon and Lupwayi (2012) showed that soil water-stable aggregates (>0.25) mm were decreased with straw incorporated by disking in the high rainfall region of China. Thus the effect of straw incorporation on soil aggregation is not clear

In Brazil, Marcolan *et al.* (2007) reported that by tilling the soil and lime incorporation after four years of NT, BD and porosity improved, but the aggregate stability decreased. They further reported that four years under NT were necessary to recover the original aggregate stability condition. Soil physical attributes were more uniform in CT, but the aggregate stability in the surface layer was lower and was related to organic carbon content. Reports in published literature on the effect of residue on water stable aggregates (WSA) are also mixed. Unger (1997) found no difference in

mean weight diameter (MWD) of WSA between NT and CT at Texas. However, he observed that in some cases the percentage of small aggregates was larger in the NT than CT treatment. The use of NT significantly improved soil aggregation and SOC and SON sequestration in surface but not in sub-surface soils (Wright and Hons, 2005). Moreover, the C:N ratio and bio-chemical properties of crop residues affects its decomposition and SOM dynamics which influences soil aggregation (Martens, 2000). In contrast, an increase in the proportion of macro-aggregates coupled with an enrichment of OC concentration within micro-aggregates under NT, compared to CT, has been reported in long-term experiment (Plaza-Bonilla *et al.*, 2013), reinforcing the idea that the accumulation of SOC under NT is a slow and gradual process (Denef *et al.*, 2007).

Among the three soil depths, MWD of WSA at 0–10 cm soil depth was increased the most by the straw incorporation treatments. At the same time the aggregate stability in various soil depth (0–10, 10–20, 20–30 cm), straw incorporation significantly increased soil aggregate stability by ranges of 5.0–23.2%, 10.3–32.1%, 10.6–47.9% over control, respectively where straw was not incorporated in the two years (Thomas *et al.*, 2007). Frey *et al.* (1999) reported that the length of fungal hyphae was 1.9 to 2.5 times higher in NT than CT surface soil (0-5 cm). Tillage also hastens soil organic matter (SOM) decomposition and reduces the soil carbon content by increasing the access of micro-organisms to SOM upon aggregate destruction (Six *et al.*, 1999; Balasdent *et al.*, 2001). Beare *et al.*, (1994) reported that soil (0 to 5 cm layer) from CT plots had fewer WSA (> 2mm) and lower total C and N concentration than soil from adjacent plot under NT for the same length of time of 13 years. Greater soil macro-aggregation in NT due to reduced disturbance normally caused by ploughing has been reported by several authors (Filho *et al.*, 2002; Pinheiro *et al.*, 2004). Madari *et al.* (2005) showed that NT with residue cover had higher aggregate stability, higher aggregate size values and total organic carbon (TOC) in soil than CT in Brazil. Research on CA showed that NT with stubble retained treatment had more WSA (Zhang *et al.*, 2009). Retaining crop residues on the soil surface lead to a increase of SOC, which improved soil aggregate stability (Limon-Ortega *et al.*, 2002) and the return of biological diversity to the soil, particularly earthworms (Chan, 2001).

Govaerts *et al.* (2007) reported that soil from permanent raised beds (PB) with full residue retention had significantly higher MWD for wet and dry sieving compared to conventionally till raised beds (CTB) in Mexico. PB with full residue retention had significantly higher aggregate stability compared to those with residue removal. Studies from Australia have also suggested that structural stability is influenced by tillage and bed systems (Hulugalle and Finlay, 2003). Legume crops can influence aggregation because the roots, especially fine roots, and organic substances released from roots may contribute to aggregate formation, shrinkage and formation of numerous small cracks (Hillel, 2004). Numerous studies showed that NT practices, with legume incorporation or legume residue left on the soil surface increase SOC, improve soil aggregation, and preserve the nutrients for plant and soil micro-organisms (Jacobs *et al.*, 2009). Raimbault and Vyn (1991) reported that continuous maize had a lower proportion of fine aggregates compared with maize grown in rotations with legumes and soil aggregate stability was highest with maize + inclusion of a legume in the rotation improved aggregate stability compared with that under continuous maize. Cropping systems that include crop rotations are often beneficial for soil aggregation. Barley-Maize-Mungbean rotation increased MWD by 6.7% in mould-board ploughing system and 33.3% in chisel ploughing system, compared to the maize monoculture (Bissonette *et al.*, 2001).

Karlen *et al.* (1994) showed that normal rates of legume residue combined with ZT resulted in better soil aggregation, and this could be increased by adding more residues (Roldan *et al.*, (2003). In an another tillage experiment positive effect of the incorporation of legume residues by tillage rather than leaving them on the soil surface, which could result in better contact between soil particles and soil microbes in maize-wheat cropping system and they found a strong, positive correlation between the percentage of small macro aggregates and the C concentration of the free light fraction (an indicator of plant material inputs) in treatment RT + legume residue and a marginal correlation in RT, while no correlations were found in NT. (Christopher *et al.*, 2009; Zhao *et al.*, 2012). Wang *et al.* (2015) at semi-arid region of China, reported that residue incorporation in maize-wheat cropping system significantly increased MWD in range of 16.1–40.3%, 10.1–36.0%, 11.0–36.3% compared with control where straw was not

incorporated at 0–10, 10–20, 20–30 cm soil depth, respectively. Fresh residue forms the nucleation center for the formation of new aggregates by creating hot spots of microbial activity where new soil aggregates developed (De Gryze *et al.*, 2005).

Better soil structure and soil physical properties, namely macro-porosity, aggregate stability and higher infiltration have been reported under conservation tillage, and residue management when compared with CT and residue removal. However, little information on long-term changes of these properties under conservation agriculture is available. The above reviewed literature suggests that the tillage practices have either no or positive and negative effect on soil bulk density, hydraulic conductivity and soil aggregation in different agro-climatic situations. Thus tillage requirement of soil in various agro-climatic situations needs to be worked out separately as no system works universally for better soil physical properties. At the same time information is meager on cropping system and cropping systems x tillage practices interactions effect on these properties under various agro-climatic situations in maize systems.

### **2.3. Soil chemical properties**

#### *Soil pH*

Another important soil quality indicator affected by cultivation systems is soil pH. Beri *et al.* (1992) concluded from 10 years of experiment that pH of soil was not influenced due to soil management practices even with the residue application. The similar results were also reported by Kumar *et al.* (2004). This may be due to buffering capacity of soil which offered resistant against change in pH. Similarly, Duiker and Beegle (2006) did not observe significant tillage effects on the pH of 0–15 cm soil layer. Tillage and straw management usually had little or no effect on soil pH in any soil layer (Malhi *et al.*, 2011a).

Tolessa *et al.* (2014) from Ethiopia under a long term experiment on tillage and fertilization observed that MTRR (minimum tillage with residue retention) resulted in lower soil pH with N fertilization of tillage system. The enhanced soil acidification that coincides with MTRR may impact negatively on maize production in the long run without a proper liming. Utomo *et al.* (2013) in a long-term experiment on tillage and N fertilization reported that high N rate reduces the soil pH as much as 10% at (0-40 cm) depth of the soil throughout the all tillage practices. Kettler *et al.* (2000) reported that

the main effect of ploughing on soil pH was more significant for 0–7.5 cm soil depth and both NT and sub-till treatments, which leave plant residues at or near soil surface, were of lower pH than mould board ploughing treatments at all depths. Hulugalle and Entwistle (1997) reported that pH was lower under minimal tillage as compared with CT, whereas Thomas *et al.* (2007) observed no effect of tillage on pH in the 5–20 cm layer. Soil pH was 0.1 to 0.3 units lower under NT in all soil increments except in the 22.5 to 30 cm increment of the Wooster soil where no significant differences in pH were observed among the tillage intensities (Dick, 1983). From another study Grant and Bailey (1994) reported that the soil pH reduced in the 10 to 12.5 cm soil depth, corresponding to the zone of fertilizer application under sandy loam as well as silty clay loam. Li *et al.* (2015) in a long term conservation tillage based study found that soil pH decreased about 0.5 units after 22 years of RNT (under combination ridge with no-tillage), and this difference may be responsible for the decrease of N mineralization and nitrification rates observed under RNT.

On the silty clay soil, pH was higher under ZT than CT in the 10 to 15 cm depth and tended to be higher under ZT than CT at all depths below 15 cm. From a rainfed experiment in the highlands of Mexico Govaerts *et al.* (2007) reported that pH was significantly higher in the topsoil (0–5 cm) of the permanent raised beds (PB) with full residue retention compared to conventional raised beds with residue retention.

#### *Soil Carbon*

Carbon sequestration is a strategy to achieve food security through improvement of soil quality (Lal, 2004). Conventional tillage increases oxidation of SOM, while ZT reduces its oxidation because of less mixing with the soil. Therefore, one would expect a substantial increase of TOC in soil under ZT compared to CT (Halvorson *et al.*, 2002) especially in soils with relatively low initial organic matter content (Thomson *et al.*, 2006). NT is one of the CA based measures that have been applied in the last three decades all over the world in order to maintain or increase the stock of organic carbon in soil and mitigate CO<sub>2</sub> emissions (Dimassi *et al.*, 2014). Long-term tillage can cause a loss of 20 to 50% of original SOC levels, where by most of this loss occurs at the beginning of tillage practices i.e. first years to decades. Eventually, a new equilibrium is reached, at a level which will depend on tillage frequency and intensity (Conant *et al.*,

2007). However, its beneficial effects on SOC stocks have not been always proved, and contrasting results have been reported due to different methodological approaches, soil depth considered, years of NT implementation, etc. (Powlson *et al.*, 2014). Green manure incorporation has also been demonstrated to improve the soil structure and increase SOC accumulation (Higashi *et al.*, 2014).

Under long-term study on maize-based conservation agriculture (CA) systems in Malawi noticed that the amount of soil carbon in the soil did not significantly affect the yield benefits between CT and ZT practices (Thierfelder *et al.*, 2015). Thomas *et al.* (2007) did not find a significant difference with SOC between ZT and CT. Tillage treatments did not affect SOC significantly although OC values with conservation tillage were numerically higher than with CT but it may become significant when tillage is practiced over a longer period of time (Sharma and Acharya, 2000). Intensive tillage management has caused a significant loss of SOM and serious soil degradation (Liu *et al.*, 2010). Kaiser *et al.* (2014) under a conservation tillage based study found that in surface soil larger stocks of the labile C and N pool under NT and RT (C, 1.7 and 1.3 t/ha; N, 180 and 160 kg/ha) than with CT (C, 0.5 t/ha; N, 60 kg/ha). The stocks of the stable C and N pools were not affected by the tillage intensity but were positively correlated with the stocks of the clay-size fraction and oxalate soluble aluminum, indicating a strong influence of site-specific mineral characteristics on the size of these pools. In contrast, they also found significantly larger stocks of the labile C pool under CT (2.7 t/ha) than with NT and RT (2.0 t/ha) for the sub-surface soils. Aziz *et al.* (2015) observed that NT treatment showed significant increase in total C (30%), active C (10%), and passive salt extractable (18%) and microwave extractable C (8%) and total nitrogen (15%) compared to CT practices and maximum effect of NT was observed under corn-soybean-wheat-cowpea crop rotation.

Most comprehensive field studies have shown that ZT results in greater accumulation of SOM in surface layers (0-20 cm) than CT (Kern and Johnson, 1993; Govaerts *et al.*, 2007). Zero-tillage, on the other hand, combined with permanent soil cover, resulted in a build-up of OC in the surface layers (Lal, 2005). Wright and Hons (2004) reported that NT management increased soil aggregation, produced higher concentrations SOC and SON in macro-aggregates and stored more soil SOC and SON

in the 0-15 cm depth than CT. NT minimizes SOM losses and is a promising strategy to maintain or even increase soil C and N stocks (Bayer *et al.*, 2000). As SOC changes directly related to the quantity of crop residues returned to the land, agronomic practices that influence yield and affect the residues returned to soil are likely to influence SOC (Campbell *et al.*, 2000). Returning more crop residues associated with an increase in SOC concentration (Wilhelm *et al.*, 2004; Dolan *et al.*, 2006). It can be hypothesized that CT with all plant residues incorporated by disking is actually a system that rapidly breaks down the organic carbon inputs, while carbon coming from roots in permanent raised beds with all residues removed maintains some C in the soil. Similar findings were also reported by Sarkar and Kar (2011).

Decomposition rates of SOM are lower with MT and residue retention, consequently organic carbon content increases with time (Gwenzi *et al.*, 2009). West and post (2002) concluded that a move from CT system to ZT with residue retention can sequester an additional carbon while reducing the emission of carbon from the soil in a long term. Alvarez (2005) found that the accumulation of SOC under reduced and ZT was an S-shape time-dependent process, which reached a steady state after 25-30 years. Blanco-Canqui and Lal (2008) also found with some crops and some crop rotations decreased SOC in ZT compared to CT. The mechanisms that govern the balance between increased or no sequestration after conversion to ZT are not clear. Although more research is needed some factors that play a role can be distinguished. NT farming also reduces the unnecessarily repaid oxidation of soil organic matter to CO<sub>2</sub> which is induced by tillage (Nelson *et al.*, 2009). The reduced use of tractors and other powered equipment results in lower emissions and up to 70% in fuel saving with CA have been reported (FAO, 2008). Organic carbon levels were significantly higher with direct drilling, compared to CT (Chan *et al.*, 2002).

Thierfelder *et al.* (2012) under CA based long-term study, reported that maize rotated with cowpea (*Vigna unguiculata* L.) and sunnhemp (*Crotalaria ochroleuca* L.) resulted in 31% greater soil carbon, and 32.5–36 t ha<sup>-1</sup> less cumulative soil erosion in maize-legume rotational field after seven cropping seasons compared to continuous maize-maize cropping system. Saha and Ghosh (2013) reported that legume residue management practices significantly increased SOC density and SOC stock (40 to 165%)

relative to the control through incorporation of crop biomass and vegetation over the time period in maize-mustard cropping system under hill agro-ecosystem. Tillage can also influence the distribution of SOC in the profile with higher SOM content in surface layer with ZT than with CT, but a higher content of SOC in the deeper layers where legume residue is incorporated through tillage in various maize-based cropping systems (Dolan *et al.*, 2006 and Jantalia *et al.*, 2007). Govaerts *et al.* (2007) reported that permanent raised beds with full residue retention increased SOM content 1.4 times in the 0-5 cm layer compared to CT raised beds with straw incorporated in maize-wheat cropping system. Baker *et al.* (2007) found that cereal based crop rotation systems which include legumes in conservation agriculture (CA) accumulated about 11 t/ha of carbon after 9 years. West and Post (2002) found that moving to ZT in wheat- maize & wheat-fallow rotations showed significant increase in SOC in former and therefore, ZT may be a recommended practice for sequestering C.

#### *Available major nutrients (NPK)*

The increase in soil N suggests that the N-supplying power of soil can be improved by returning straw to the soil and eliminating tillage (Malhi *et al.*, 2011). Astier *et al.* (2006) observed significantly higher total N under ZT compared to CT in the highlands of Central Mexico. Almost similar results were obtained by Borie *et al.* (2006) and Atreya *et al.* (2006). Govaerts *et al.* (2007) reported that increasing the amount of straw retention under permanent raised beds increased total soil N as compare to without residue retention. Tillage induced disturbance in soil structure increases mineral N release from active and physically protected pools (Kristensen *et al.*, 2000). Deep tillage causes excessive N mineralization for cereals, which cause lodging as a result, and RT helps in avoiding such situations (Riley, 1998). As RT is thought to increase net immobilization and lower net mineralization, it results in lower nitrate concentrations in the soil solution. Govaerts *et al.* (2007) reported that concentration of NO<sub>3</sub>-N in the CT system was larger as compared to the permanent system, total N was significantly higher under both ZT on the flat and permanent raised beds compared to CT in the highlands of Central Mexico. Gosai *et al.* (2009) reported that the total N varied significantly across the tillage types and study sites. Adoption of RT, fertilization and crop diversity can increase organic N and mineralizable N stored in the soil (Nyborg *et al.*, 1995; Soon and

Arshad, 1996; Janzen *et al.*, 1998; Patra *et al.*, 1999; Campbell *et al.*, 2001; Malhi *et al.*, 2009), thus improving soil fertility and nutrient supplying capacity of soil. These findings illustrated that NT practice could be useful for improving soil chemical properties.

Neugschwandtner *et al.* (2014) reported that SOC, total nitrogen, PMN (potentially mineralizable nitrogen), P and K increased in the uppermost soil layer with reduced tillage intensity. The SOC, total nitrogen, P and K were more evenly distributed in DP (deep ploughing) whereas a generally higher decline downwards the soil profile was observed with lower tillage intensity resulted in a decrease of P and K in 30-40 cm. Gholami *et al.* (2014) reported that NT has 0.12, 12.04 and 360.29 mg/kg of higher nitrogen, phosphorus and potassium respectively compare to CT.

A stratification of phosphorus under different tillage practices was observed where Mehlich-3 P and orthophosphate concentration had accumulated in the deep layer of NT possibly due to preferential movement (Abdi *et al.* 2014). Piegholdt *et al.* (2013) from Germany also reported that total P content in the top soil (0-5 cm) of NT which was 15% higher compared to CT, while with increasing depth the total P content decreased more under NT than under CT. The higher P contents in the topsoil of NT presumably resulted from the shallower incorporation of harvest residues and fertilizer P compared to CT, whereas estimated P losses due to water erosion were only small for both treatments. Utomo *et al.* (2013) from a long-term experiment on tillage and N fertilization reported increased total soil N at 0-5 cm depth as much as 19% but at 0-10 cm depth, MT with no N had highest exchangeable K, while CT with medium N rate had the lowest.

Verhulst *et al.* (2009) reported that macronutrients (P, Ca, Mg, K) were not affected by tillage-straw management, probably because the soil was rich in those nutrients (Ca, Mg, K) or adequate fertilization (P). No-till treatments have higher P, K and SOC in the 0-2.5 cm soil layer than CT (Betrol *et al.*, 2007). It is well known that large K amount taken up by wheat, but the major part of it remains in the residues after harvesting (Du Preez and Bennie, 1991). Govaerts *et al.* (2007) reported that on the average, permanent raised beds had higher concentration of K by 1.65 and 1.43 times in the 0-5 cm and 5-20 cm layer, respectively, compared to conventional tilled raised beds.

They further, revealed that in both the tillage systems, K accumulation was more in the top 0-5 cm layer than lower layers. Standley *et al.* (1990) observed a higher exchangeable K in the top soil (0-2 cm) when sorghum stubble retained in comparison with stubble removed.

Zero tillage conserved and increased availability of nutrients, such as K, near the soil surface where crop roots proliferate (Franzenluebbers and Hons, 1996). Increased stratification of nutrients in ZT compared CT is generally observed. Franzluebbers (2002) even proposed the use of a stratification ration for chemical properties as a possible parameter for soil quality. Du Preez *et al.* (2001) observed increased level of K in ZT compared to CT, but this effect declined with depth. However, Duiker and Beegle (2006) found no effect of tillage on available K concentrations.

Rotations with leguminous crops have the potential to increase level of nitrogen in soil through biological nitrogen fixation (Giller *et al.*, 2011). Although the use of mineral fertiliser alone will not solve the challenges of soil degradation and declining fertility (Ngwira *et al.*, 2012), there are strong advocates for such quick solutions (Gilbert, 2012). The rapid depletion of soil organic carbon (SOC) coincides with the adoption of sole crop agro-ecosystem management practices in temperate biomes (Stavi and Lal, 2012). This has resulted in a 30 to 50% loss of SOC in the top soil (Berhongeray *et al.*, 2013). Legume based cereal cropping system use their resources more efficiently since the mixed arrangement of crops captures resources from different parts of the soil, and/or uses resources at different times, and/or in different forms of N (Echarte *et al.*, 2011). Additionally, the mixing of residues from cereal and legume crops causes complex interactions that influence the magnitude of N cycled through the intercrops compared to sole crops (Flavel and Murphy, 2006). Contribution of legumes towards N economy in cereal-based cropping systems is well-known. Sharma and Behera (2009) conducted an experiment to study to evaluate and quantify the effect of different grain legumes inclusion on N economy and soil fertility in maize based cropping system at New Delhi. They found that through inclusion of various pulses resulted in addition of N varied from 11.5-38.5 kg/ha which improved productivity of following wheat to a variable extent. Residual soil fertility in terms of organic C and N showed an improvement under maize-based intercropping systems followed by wheat,

and the beneficial effect was more pronounced with sole cropping of legumes due to greater addition of residues.

Previous research under long-term NT management has shown higher amounts of available P in the surface thin layer (0-5 cm) under NT than CT due to P application and from decomposition of crop residues retained on the soil surface under various ZT-maize based cropping system (Ismail *et al.*, 1994 and Malhi *et al.*, 2011a). Gosai *et al.* (2009) reported that available P of the soil varied remarkably along the crops growing duration, its depth and upon the tillage tool employed. Positive effect of returning legumes residue in improving P fertility of soil and thus increasing potential for long-term sustainability of soil productivity IN various maize based crop rotations was reported by Malhi *et al.* (2011a). Tolessa *et al.* (2014) from Ethiopia under a long-term experiment on tillage and fertilization observed that MTRR (minimum tillage with residue retention) resulted in higher contents of extractable P and exchangeable K than MTRV (minimum tillage with residue removal) and CT in various cereals based cropping sequences. Shafi *et al.* (2007) and Bakat *et al.* (2009) were also reported significant increase in soil N content due to legumes residue incorporation. Aziz *et al.* (2015) also observed that total nitrogen increased significantly by 23% in NT over CT treatment and maximum effect of NT was observed under corn-soybean-wheat-cowpea crop rotation its happen because of inclusion of two legumes in this cropping system which in turn improving soil fertility status.

#### *Nutrient uptake (NPK)*

The nutrient accumulation in any crop plant affected not only by genotypes but management practices also makes significant differences. Sime *et al.* (2015) showed that the nutrient concentration of maize under ZT and MT were significantly lower than CT. Lavado *et al.* (2001) found that there was no significant difference of macronutrient concentration in cereal based (wheat-maize) cropping system across different tillage management practices however, concentration of these nutrient were found slightly higher in ZT compared to CT . Hargrove (1985) reported that NT treatments resulted in a redistribution and concentration of soil nutrients at the soil surface, compared with CT which resulted in higher uptake of the nutrient from ZT compared to CT plots. Naresh *et al.* (2014) found that N and P uptake was significantly higher in PB than CT but there

was no significant difference for K uptake across the tillage practices. Alam *et al.* (2014) in a four study observed that tillage practices had significant impact on the uptake of macronutrients. The total N (%) content ranged from 0.063 to 0.082% and maximum total N content (0.082%) was found in ZT however, the minimum total N content (0.063 %) was noted in CT. After four years, the total N content was 73.68, and 13.79% higher in ZT than the CT, and MT, respectively. It was observed that the total N (%) content gradually increased in ZT and MT with progressing time. At the same time P and also follow the same trend and found maximum under ZT compared to CT and MT plots in all the four year as well as after harvest of last crop at the fixed experimental site.

Astier *et al.* (2006) observed that N concentration of maize stover and grain was not affected by residue and tillage but these had a significant effect on P concentration in stover due to low stover production. Phosphorous concentration in grain was not affected by treatments Maize N uptake was significantly affected by residue management and tillage. Higher N uptake was observed with ZT + residue management. Residue management might increase the content of soil mineral N in the long runs in comparison to mono-cropping without residue management systems (Wani *et al.*, 1995). Tiscareno *et al.* (1999) also reported that legume inclusion in maize based cropping systems significantly influenced P.

Glubiak and Korzeniowskation (2014) found that ZT did not cause changes in the concentration of macro elements in maize grain in relation to CT which proved that ZT performed better under resource limited condition. Similar results of no difference between ZT and CT in terms of the concentration of N in the grain of corn (Mehdi *et al.*, 1999; Iqbal *et al.*, 2005; Campbell *et al.*, 1998).

In contrast in an another study De Vita *et al.* (2007) reported differences in the concentration of N in wheat grain between ZT and CT where higher content was found in former practice in maize-wheat cropping systems. Chalka and Nepalia (2006) reported during both the years of investigation maize-soybean recorded maximum nitrogen uptake which was statistically superior over rest of the systems. Although all cropping systems were statistically superior over sole maize but they were at par with each other. On mean basis maize -soybean, maize-cowpea, maize-greengram and maize-blackgram registered 37.5, 22.1, 18.5 and 17.1% increase in nitrogen uptake,

respectively over sole maize. P and K uptake were also follow the same trend and their higher uptake were observed under various maize-legume cropping system compared to maize-maize cropping system. In recent efforts on soil fertility replenishment in Africa the introduction of legumes as intercrop and/or in rotation promoted to minimize external inputs (Mucheru-Muna *et al.*, 2010). However, Matusso *et al.* (2014) reported that legume inclusion may also accelerate soil nutrient depletion in cereal system particularly for P, due to more efficient soil nutrients use and higher removal through the harvested crops.

#### **2.4. Input-use efficiency**

##### *Energy relation*

Agriculture productivity closely linked and positively correlated with the energy inputs. For sustainable energy management the efforts have to be double pronged, firstly efficient use of commercial energies, and secondly harnessing renewable energy sources as supplementary and substituting commercial energy sources. The direct energy inputs to crop production systems comes from power sources required for performing various operations (human, draft animals, engines, farm machineries and water pumps, *etc.*) as well as indirect energy inputs (seeds, organic manures, fertilizers, pesticides, growth regulators, *etc.*). The energy consumption increasing at a steady rate to improve productivity in Indian agriculture but the energy-use efficiency is declining consistently (Sharma and Thakur, 1989).

Parihar *et al.* (2012) and Jat *et al.* (2014) reported that system productivity in term of maize equivalent yield was influenced significantly due to different tillage practices and the PB panting resulted into maximum system productivity during both of year of investigation compare to ZT and CT. Parihar *et al.* (2011) also found that establishment of maize through ZT resulted in maximum energy output, energy productivity and net energy over CT in diversified maize based cropping systems. The ZT practices reduce the energy requirement due to saving of energy in tillage practices as well as in weeding operations than CT practices (Jain *et al.*, 2007). Gupta *et al.* (2007) also reported significantly more energy-use efficiency and energy productivity under ZT than CT. However, Chaudhary *et al.* (2006) reported that input energy consumption was higher with residue application than no-residue application under ZT

practices. Ram *et al.* (2010) found minimum input energy and energy output/input ratio (13.82) in PB treatment while energy output (3, 92,035 MJ/ha/year) was highest in NT + straw in maize–wheat cropping system.

Srivastava (2003) reported that tillage before planting which required about one-third (936 MJ/ha) of the total operational energy (2795 MJ/ha) could be saved without adversely affecting the yield with ZT (4.85 t/ha) compared to CT (4.94 t/ha) experiments. The largest contribution of CA to reducing the CO<sub>2</sub> emissions associated with farming activities made by the reduction of tillage operations (Govaerts *et al.*, 2009). Erenstein and Laxmi (2008) compared studies in rice–wheat systems in the Indo-Gangetic Plains and found seasonal savings in diesel for land preparation with ZT to be in the range of 15–60 l/ha, with an average of 36 l/ha or 81 % saving across the studies, equivalent to a reduction in CO<sub>2</sub> emission of 93 kg/ha/year. West and Marland (2002) reported estimates for C emissions from agricultural machinery, averaged over corn, soybean, and wheat crops in the United States of 69.0, 42.2, and 23.3 kg C/ha/yr for CT, RT, and ZT, respectively. The reduced use of tillage for soybean and cotton crops has reduced energy consumption and has led to reduced soil erosion and the associated benefits for water quality (Jerry Nelson, 2007).

The adoption of high yielding varieties, expansion of irrigation facilities, mechanization and fertilizer, diesel electricity combination have pushed the demand for commercial energy to a new height. Among the field crops, legumes involve much less energy expenditure than cereals. In Germany, energy output: input ratios of rapeseed (*Brassica campestris* L.) were generally the highest at intermediate N rates. Kadleek and Cervinka (2000) reported that indirect energy demands of wheat production systems made up 92–94 % of total consumption with most energy use associated with the use of fertilizers and agro-chemicals. More energy has been consumed in fertilizer treatments for soybean–chickpea crop sequence compared to control and increasing the levels of nutrients decreased the energy-use efficiency and productivity (Joshi *et al.*, 1998).

Parihar *et al.* (2012) and Jat *et al.* (2014) reported that among the various maize based cropping system maize-wheat-mungbean result into maximum system productivity over maize-mustard-mungbean and maize-maize-sesbania because this system include legume which not only contributed in yield but also provide better soil

health which in turn improve system productivity. At the same time the carbon based sustainability index (CSI) and carbon efficiency (CE) was observed maximum in maize-maize-sesbania cropping system compared to maize-wheat-mungbean and maize-mustard-mungbean system. This happen due to inclusion of two maize crops in a year resulted into higher CSI and CE which reflect the ability of maize crop to more carbon sequestration than any other crop. Parihar *et al.* (2011a) reported that maize-chickpea-sesbania cropping sequence resulted in maximum energy output, energy productivity and net energy in various maize based cropping system.

#### *Water productivity*

The efficiency of conservation tillage to improve water storage is universally recognized. This is very important not only in arid and semi-arid zones (Lampurlanes and Cantero-Martinez, 2006) but also in heavy rainfall areas of north eastern hill region in India (Das *et al.*, 2014), where management of crop residues is of prime importance to obtain sustainable crop productions and for conserving natural resources and enhancing water productivity. Adoption of CA enhanced water-use efficiency (WUE) by 12% with maize-rapeseed sequence to as high as 228% under rice-pea sequence (Das *et al.*, 2014). Sharma *et al.* (2013) found that under rainfed condition in maize-wheat sequence, maize field should be ploughed immediately after maize harvesting and covered with maize straw mulch @ 5 t/ha up to wheat sowing to reduce the evaporation losses and soil water storage for the succeeding wheat crop. This practice leads to increase soil moisture conservation efficiency about 3 times higher than control treatments (maize harvesting at 30 cm height and tillage at the time of wheat showing). It has been estimated that an additional 23 kg/ha wheat grain yield can be achieved per mm of conserved moisture. Wang *et al.* (2015) in semi-arid region of China reported that straw incorporation significantly increased water productivity of maize.

Parihar *et al.* (2011) found that establishment of maize through ZT resulted in maximum water productivity over CT in diversified maize based cropping systems in Indo-Gangetic plain (IGP). In rice-wheat systems in the Indo-Gangetic Plains, ZT is reported to save irrigation water in the range of 20-35% in the wheat crop compared CT, reducing water usage by approximately one million liter/ha (Gupta *et al.*, 2002a; Hobbs and Gupta, 2003). The savings arise because ZT wheat can be sown just after the

rice harvest, making use of the residual moisture for wheat germination, potentially saving a pre-sowing irrigation, and because irrigation water advances faster in untilled soil than in tilled soil (Erenstein and Laxmi, 2008). Similarly, higher WUE was also reported in NT (Chauhan *et al.*, 2000) and with bed planting (Kaur and Mahey, 2005; Ram *et al.*, 2010). Mrabet *et al.* (2002) reported that the pre-planting tillage was unnecessary in addition; high residue rates under NT were not converted into higher water use by wheat. The ZT combined with crop residue retention on the soil surface greatly reduces erosion and enhances water-use efficiency compared to CT (Johnston *et al.*, 2002).

Jat *et al.*, (2005) reported that the water productivity either crop of maize and wheat was remarkably higher in FIRB planting (2.79 and 1.98) followed by NT (1.74 and 1.89) and the lowest (1.36 and 1.38) in CT system. But, the magnitude of increase in water productivity due to FIRB/NT systems compared to CT planting was higher in maize than wheat. Khan (2002) and Yadav *et al.* (2002) reported that raised bed planting saved 30-40% irrigation water, increased grain yield by 20% and reduced tillage cost in wheat. Tolk *et al.* (1999) reported that mulch increased the maize grain yield, above ground biomass and WUE by 17, 19 and 14%, respectively as compared with bare soil treatment. Ram *et al.* (2011) in a CA based study at PAU Ludhiana, reported that maize and wheat planted on raised beds recorded about 7.8% and 22.7% higher water-use efficiency than under flat layout, respectively whereas straw mulch showed no effect on water use and water-use efficiency in maize. Parihar *et al.* (2011) reported that maize-chick pea-sesbania cropping sequence resulted in maximum water productivity in various maize based cropping systems.

## **2.5. Economics**

Tillage practices contribute greatly to the labour cost in any crop production system resulting to lower economic returns (Labios *et al.*, 1997). Economic outcomes of CA are likely to be specific to particular people, places and situations (Gowing and Palmer, 2008). This is due to heterogeneity between regions (Erenstein *et al.*, 2012) and between farms in a region (Tittonell *et al.*, 2005) and heterogeneity in institutional factors (Stonehouse, 1996), farm sizes, risk attitudes, interest rates, access to markets (for inputs and outputs), farming systems, resource endowments and farm management skills,

driving differences in benefits and costs of CA. Low labour, animal or equipment requirements are major advantage of conservation tillage because it allows elimination of several operations. Maximum reduction in operations occurs with no-tillage system, but this system generally involves the use of herbicides to control weeds. Stubble mulch tillage was more economical than one way disk tillage for wheat production in Bushlands, Texas, even though fuel use was similar. The use of ZT significantly reduces energy costs, mainly by reducing tractor operational costs associated with conventional methods (Erenstein and Farooq, 2009).

Parihar *et al.* (2011) reported that highest maize yield were noticed in PB planting compare to ZT and CT similar trend were also observed in wheat when it is sown followed by maize in maize-wheat mungbean cropping system which in turn resulted into highest net return as well as B:C ratio. Khatri *et al.* (2014) from Nepal reported that tillage and residue had no significant effect on B: C ratio (Table 10). However, higher B:C ratio was obtained from ZT (2.42) as compared to CT (2.20) which indicates that ZT is more profitable . The higher B C ratio from ZT was due to the lower cost of production and higher gross return. Paudel *et al.* (2015) reported that higher net returns obtained in ZT than CT and at the same time intercropping of maize and soybean in 2:2 ratio recorded maximum benefit and maize grain yield equivalent as well as land equivalent ratio than sole and intercropping treatments. Erenstein and Laxmi (2008) reviewed a several studies of the economics of zero tillage in the Indo-Gangetic Plains. They found that due to site specificity and methodological differences the profitability of the various studies is sometimes complicated. Nevertheless, the results consistently showed benefits-both cost savings and increased yields. On average, slightly more than half of the benefits were due to cost savings and slightly less than half were due to yield increases

Gathala *et al.* (2015) observed that maize net returns and benefit cost ratio ranged from \$945/ha and 1.9 under CT to \$1350/ha and 2.4 under PB respectively. The CA-based tillage and establishment options have significant advantages in terms of reduced production cost and labour use, and increased net returns for maize in rice-maize cropping system. Sharma *et al.* (2011) reported that maximum benefits could be obtained from minimum tillage (€ 202.4/ ha) followed by raised bed (€ 164.2/ha) and no

tillage (€ 158.3/ha) and lowest in conventional tillage (€ 149.5/ha). Benefit-cost ratio was highest in minimum tillage (0.71) and lowest in conventional tillage (0.44). Mazvimavi *et al.* (2012) found that gross return was positively related to labour and seed in CA but negatively in conventional farming.

Dhillon *et al.* (2002) reported that wheat could be grown successfully under ZT on beds and flats, and thus allowing considerable saving in the cost of cultivation through ZT as compared to CT. Jat *et al.* (2005) reported that cost of cultivation was lowest (US\$ 241/ha) under NT and highest (US\$ 393/ha) under CT maize crop mainly through saving in cost for tillage practices. For wheat crop, cost of production was minimum (US\$ 279/ha) under FIRB followed by NT and maximum (US\$ 375/ha) under CT mainly because of difference in cost of tillage and irrigation water. Pulatov (2002) from Uzbekistan reported 3.96, 3.57 and 3.44 t/ha of wheat yield under PB, CT and NT treatments, respectively and also showed usefulness and input saving ZT and indicated higher output for bed planting technologies. Sayre and Limon-Ortega (2002) reported that PB planting of wheat gave 48% higher returns over CT beds. In addition to providing grain yield, ZT reduced the production costs (15-20%) by eliminating 4-8 tillage operations practiced under CT system (Landers *et al.*, 2001). Jat *et al.* (2006) reported that yields of the highest yielding varieties were similar on NT permanent beds and CT. There was an average 4% increase in grain yield and 20% increase in profitability with NT permanent beds compared with CT, and 16 and 24% increase in yield and profitability on NT permanent beds compared with NT on the flat.

The ZT technology proved to be a wise choice as it was reported to be economical as well as ecologically viable as compared with CT due to saving in labour, fuel, repair and machinery overhead charges and less emission of green house gases ( Singh *et al.*, 2001a; Zentner *et al.*, 2002 ). Malik *et al.* (2004) reported that ZT led to reduction in tillage cost from ₹2000 to ₹6500/ha, early sowing by 7-10 days in moist soil, less *Phalaris minor* problem and proper placement of seed. Mishra and Singh (2009) reported that continuous ZT (ZT-ZT) generated higher net return (₹ 28,085 and ₹ 14,225) and B:C ratio (2.50 and 1.89) in soybean-wheat and soybean-linseed cropping systems due to lower cost of cultivation and higher yield. Jat *et al.* (2005) also reported that net return from maize and wheat crops and system as a whole was more under NT

compared to FIRB and CT. The extent of net return from maize-wheat cropping system under NT was 30 and 322 US\$/ha more over FIRB and CT, respectively. This indicates that maize-wheat cultivation under NT has been more economical.

The net benefit values in maize were higher for most of the food legume incorporation plots compared to N, P and K 45 kg/ha, indicating higher profitability of food legume incorporate than the inorganic fertilizer option (Egbe and Ali, 2010). Ram *et al.* (2011) in a CA based study at PAU Ludhiana reported that net returns from the maize -wheat system were more in NT and PB than with CT.

Ojiem *et al.* (2014) reported that inclusion of grain legumes generally provided better returns than those with green manures. Intercropping bean with maize provided an additional bean yield that did not come at the expense of maize yield and improved returns to land and labour, but more so in the high potential zones. The results demonstrate the strong impact of biophysical diversity on the productivity of the legumes and suggest the need for careful targeting of legume technologies to the different biophysical conditions.

## **2.6. Grain quality**

### *Protein content*

Chemical composition and grain quality of crops is affects with various tillage system and management practices and mineral elements in grain also depend on the type and composition of soil as well as on crop location (Cubadda *et al.*, 1969). Chopra and Angiras (2007) observed that various tillage practices did not significantly influence the protein and starch content in maize grains, but higher protein content was observed in CT and PB compared to ZT. Similarly Lopez *et al.* (1998) also reported higher grain protein content in maize for CT than NT. Hassan *et al.* (2014) also reported that grain protein contents in maize were significantly affected by tillage practices. Moreover, maximum protein contents were (8.86%) observed in CT which was statistically at par to PB while minimum protein contents were found in ZT. Vita *et al.* (2007) and Andrija *et al.* (2009) reported that under CT, highest protein content was obtained than ZT-Maize. Cociu and Alionte 2011 reported that protein content in maize and wheat decreased almost parallel with the grain yield increase and significantly influenced by tillage practices, in maizethe value ranged between 7.6% for the ZT and 9.7% for CT.

Starch content of maize grains also showed a tendency similar to protein content, namely diminishing together with the grain yield increase. As concerns the winter wheat crop, protein content was comprised between 13.2%, registered when planted in ZT system, and 15.7% CT in maize-wheat-soybean sequence. Debaeke *et al.* (1996) demonstrated that reduced tillage of wheat had a negative impact on protein content and quality of grain.

In contrast Sessiz *et al.* (2010) reported that under a long term tillage experiment in maize significantly higher protein content in ZT compared to CT. Wozniak *et al.* (2014) conducted an experiment to assess the impact of legume residue management and tillage on grain quality of wheat. They found that the interaction of residue management practices and different tillage practices were significant in terms of protein content in grain. Grain of high quality (higher contents of protein and gluten, and higher density) originated from CT with residue incorporation, compared to RT and ZT with residue retention. Similarly, López-Bellido *et al.* (2001) also reported higher grain quality (protein content) under CT compared to ZT planted maize in maize –wheat cropping system.

Najafinezhad *et al.* (2007) reported that the protein content in maize grain was significantly higher under ZT compared to CT due to decomposition of the residue in the later stage of maize growth period (when the soil N content is low) is the reason of more grain protein in minimum tillage with residue retention. Zamir *et al.* (2013) conducted an experiment to assess the impact of different tillage practices on quality of maize. Among tillage practices mean maximum value of grain protein (10.26%) was observed in subsoil tillage with residue retention which is statistically at par with those with zero tillage with residue retention (9.54%) but the mean minimum content (8.12%) was observed in CT with residue incorporation. This combined effect of tillage and residue management showed better results as compare to sole application of tillage. Rafiq *et al.* (2010) stated that increase in nitrogen content in the grain significantly increases the grain protein content of maize when it was planted in ZT over CT. These results are in line with Boomsma *et al.* (2009) who stated that CA based maize absorb more nitrogen and water which increased chlorophyll contents and thus causing more protein contents. Temperly and Borges (2005) observed that protein content was

significantly lowered in CT as compared with ZT planted maize in maize based cropping sequences.

#### *Zn and Fe content*

Glubiak and Korzeniowska (2011) reported that tillage system did not significantly affect the micronutrient content of cereal grains in maize-wheat cropping system but higher content were found in ZT compared to CT plots. Similar results of no difference between zero and traditional cultivation in terms of the micronutrient concentration in grain of corn were obtained by Mehdi *et al.* (1999). The probable cause of these differences was the higher content of Fe and Zn in the soil of the ZT than on those with the CT (Rahman *et al.*, 2008; De Santiago *et al.*, 2008). Woźniak and Makarski (2012) demonstrated that the ZT system increased contents of total ash, Zn and Fe in maize and wheat over CT planting. Lavado *et al.* (2001) found that different tillage techniques affect the root absorption of macronutrients differentially in maize-wheat-soybean cropping system. The three crops were analysed for Fe, and Zn in various plant parts. Concentrations of both micronutrients were higher in grains as compared to root in all the three crops and at the same the ZT had a significantly higher concentration of both nutrients over CT in maize-wheat-soybean cropping system. Wozniak *et al.* (2014) conducted an experiment to assess the impact of crop rotation and tillage on grain quality of wheat. They found that the interaction of residue management practices and different tillage practices were significant in terms of micronutrient concentration in grain. The CT system increased Zn and Fe content of grain compared to RT and ZT which resulted from higher concentration of both of the nutrient in the soil under CT due to residue incorporation which in turn positively correlated with concentration of these two elements in wheat grain. Similarly, López-Bellido *et al.* (2001) also reported higher amount of Zn and Fe under CT compared to ZT planted maize in maize –wheat cropping system.

## CHAPTER-III

### MATERIAL AND METHODS

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The field experiment entitled “*Performance of maize (Zea mays L.) under long term tillage practices and diversified cropping systems*” was conducted at the research farm of ICAR-Indian Agricultural Research Institute, New Delhi during *kharif* 2014. This chapter deals in brief the experimental details of materials used, the observations taken and techniques used during the course of investigation.

#### 3.1. General details

##### 3.1.1. Location and soil of experimental site

The experiment was conducted at the research farm of ICAR-Indian Agricultural Research Institute, New Delhi, situated at 28<sup>0</sup>4' N latitude, 77<sup>0</sup>12'E longitude and 228.6 metres above mean sea level. The soil of the experimental site was sandy loam in texture and the samples taken from different depths before start and completion of the experiment were analysed for physical and chemical properties of the soil as well. The experimental field had an even topography and good drainage system.

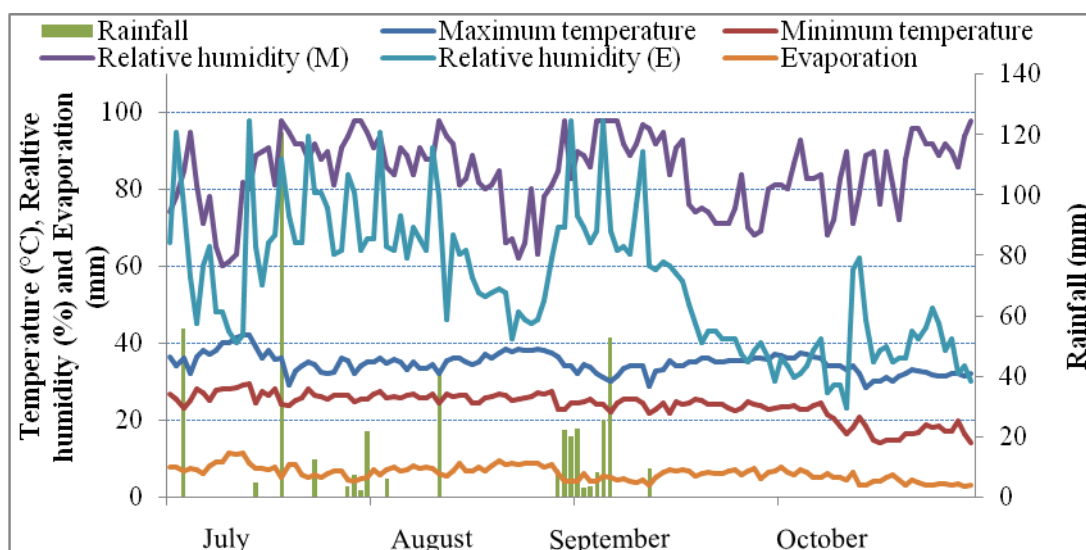
##### 3.1.2. Climate and weather conditions

Climatologically, Delhi attains a typical semi-arid and sub-tropical environment with extremes of cold and hot situations. May and June are the hottest months with mean temperature ranging from 41°C to 45 °C, whereas the mean minimum temperatures of the coldest months (December and January) varies between 1.9 °C and 5 °C. During December and January months the frost may be cited as common phenomenon. The daily maximum and minimum temperature tend to rise from the first fortnight of February and remain continue till June. The mean annual rainfall is about 650 mm, of which nearly 80 per cent is received during the monsoon period (July to September) and the remaining 20 percent during the October and May. The mean daily U.S. Weather Bureau Class ‘A’ open pan evaporation value reaches as high as 10.9 mm in June month and as low as 1.5 mm in January. The annual pan evaporation is about 850 mm. The mean wind velocity varies from 3.5 km/h in October to 7.6 km/h in the month of April. Maximum value (85 to 90 per cent) of mean relative humidity attains during the south-west monsoon period and the minimum (30 to 45 per cent) during the summer months.

The meteorological data of the experimental period recorded at the meteorological observatory of the ICAR-Indian Agricultural Research Institute, New Delhi are presented in Table 3.1 having monthly averages and Fig. 3.1 representing daily variations in these parameters. The weekly meteorological parameters also given in Appendix I.

**Table: 3.1.** Monthly variations in weather conditions during growth period of *kharif* maize (2014).

Month	Mean maximum temperature (°C)	Mean minimum temperature (°C)	Total rainfall (mm)	Mean relative humidity (%)	
				M	E
July	35.9	26.3	227.8	84.4	67.0
August	35.8	25.8	98.9	83.2	62.5
September	34.0	24.0	124.3	84.5	56.2
October	33.2	18.8	0.0	85.4	37.6
<b>Kharif season</b>	<b>34.7</b>	<b>23.7</b>	<b>451.0</b>	<b>84.4</b>	<b>55.8</b>



**Fig. 3.1.** Daily variations in weather conditions during growth period of maize in 2014.

### 3.1.3. Cropping history of experimental field

The cropping pattern being followed at the experimental field since last six years was maize in *kharif*, wheat, chickpea, mustard and maize during succeeding *rabi* season and mungbean and *Sesbania* crops in summer season.

### 3.2. Experimental details

The field experiment was conducted in split plot design (SPD) having 12 treatment combinations with 3 replications during *kharif* 2014.

**Table 3.2.** Treatments details

S. No.	Notations
<b>Main-plot:</b> <i>Tillage and crop establishment techniques (03)</i>	
1. Permanent Bed Planting	1. PB
2. Zero Tillage flat	2. ZT
3. Conventional Tillage flat	3. CT
<b>Sub-plot:</b> <i>Cropping systems (04)</i>	
1. Maize-Wheat-Mungbean	1. MWMB
2. Maize-Chickpea- <i>Sesbania</i>	2. MCS
3. Maize-Mustard-Mungbean	3. MMuMb
4. Maize-Maize- <i>Sesbania</i>	4. MMS

#### Experimental design and layout

Experimental design : Split-Plot Design

Total treatment combinations : 12

Replications : 3

Plot size : 6.0 m X 2.84 m = 17.04 m<sup>2</sup>

Total number of plots : 36

The plan of layout of the experiments is depicted in Fig.3.2.

#### Spacing between rows and crop variety

Maize: 67.5 cm in ZT and CT flat (one row of maize crop on each bed in PB)

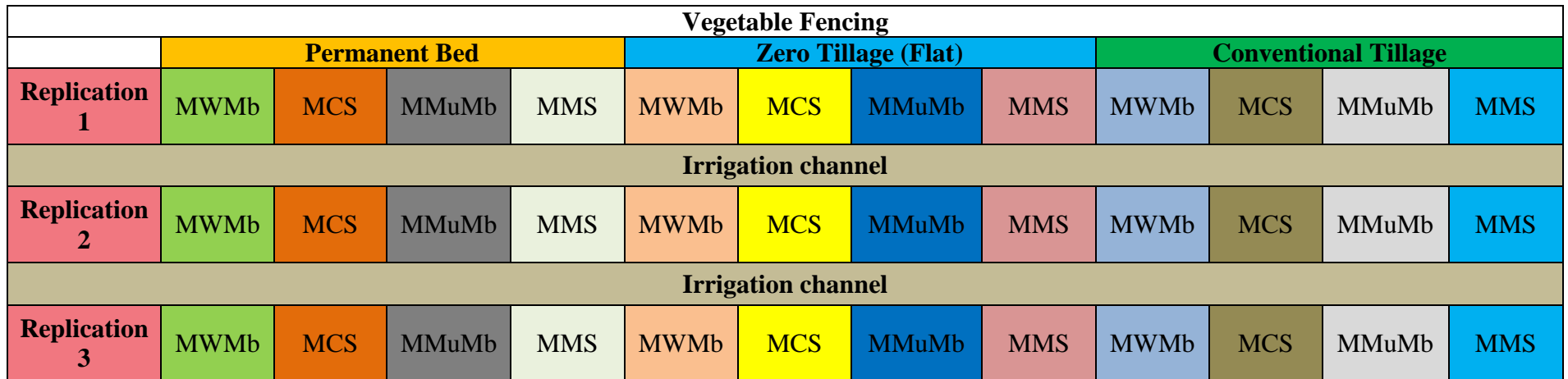
#### Variety

Maize: HQPM 1

### 3.3. Description of material used

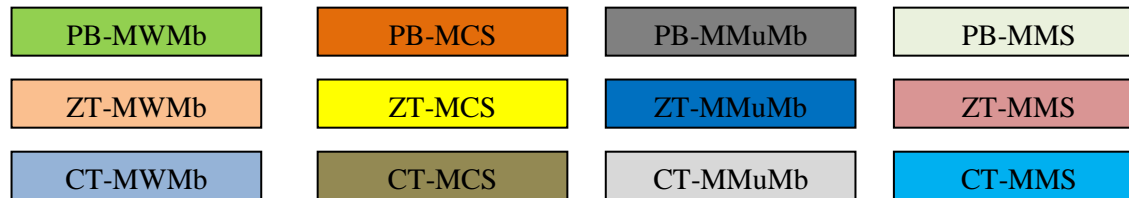
#### 3.3.1. Particulars about the maize variety HQPM 1

This is a yellow dent, late maturing single cross hybrid with average yield of 6.2 t/ha released in 2005 by CVRC for across the country cultivation. It is tolerant to frost/cold and resistant to *Maydis* leaf blight and common rust.



**Fig. 3.2.** Layout of plan of experiment

Legend:



### 3.3.2. Crop residues

The mungbean crop residue including stem comprises of air dried leaf and branches was weighed and applied in different plots as per the treatments of *kharif* season maize crop.

### 3.4. Field operations

The cultural operations carried out in the *kharif* maize crop during experimentation has been given in Table 3.3.

#### 3.4.1. Pre and post-sowing operations

##### *Herbicide application*

Tank mix solution of paraquat (Gramoxone 24%) and glyphosate (Round up 41%) was applied before sowing of the crop in the zero tillage plots to control grassy as well as broad leaf weeds.

##### *Land preparation*

The conventional tillage (CT) consisted of two pass of a disc harrow, followed by two pass of cultivator with planking in the last pass. Permanent raised beds were made with a bed planter at a distance of 67.5 cm from top of the one bed to top of the adjacent second bed with 37.5 cm top and 30 cm furrow and bed height of 8 inch for sowing of crop and shaping of beds. These permanent beds were reshaped before sowing of *kharif* season maize crop with bed planter. The zero tillage (ZT) consisted minimum soil disturbance, which accompanied by just opening the furrow (used for irrigation purposes), putting the seeds into furrow and covering the seeds in one operation.

##### *Fertilizer application*

Maize crop was given uniform application of 130:60:34 kg/ha of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O in ZT, flat and PB plots and 150:60:40 kg/ha of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O in CT plots. 1/3<sup>rd</sup> dose of N and full dose of P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O were applied at the time of sowing in furrow opened by pora. Remaining 2/3<sup>rd</sup> dose of N were applied in two equal splits at eight leaves stage (V8) and tasselling stages.

##### *Seed and sowing*

The maize variety HQPM 1 was dibbled at a spacing of 67.5 cm X 20 cm in conventional tillage flat and zero tillage flat plots. While one row of maize crop was established on top of the raised beds by keeping plant to plant spacing of 20 cm and irrigation was given in 30 cm furrow. The seed rate used for raising of crop was 20 kg/ha.

*Thinning and gap filling*

After three weeks of sowing extra plants from each row were thinned to maintain intra-row spacing. The gap filling was accomplished immediately after the germination in order to maintain optimum and uniform plant population.

**Table 3.3** Schedule of field operations during experimentation in maize.

<b>S. No.</b>	<b>Operation</b>	<b>Date of operation</b>
1.	Field preparation	28.06.2014
2.	Layout	01.07.2014
3.	Sowing	02.07.2014
4.	Thinning/gap filling	26.07.2014
5.	Fertilizer application	
	Basal dose	01.07.2014
	1 <sup>st</sup> split application of N	23.07.2014
	2 <sup>nd</sup> split application of N	19.08.2014
6.	Irrigation application	
	1 <sup>st</sup> irrigation	17.08.2014
	2 <sup>nd</sup> irrigation	26.08.2014
	3 <sup>rd</sup> irrigation	19.09.2014
	4 <sup>th</sup> irrigation	26.09.2014
7.	Weed management	
	<i>Herbicide application</i>	
	Pre-emergence	03.07.2014
	Protected spray	21.07.2014
	Hand weeding	
	First	16.08.2014
	Second	16.09.2014
8.	Plant protection measures	05.09.2014
9.	Harvesting	09.10.2014

*Weeding and inter-cultivation*

In conventional tillage treatments weed growth/population was checked by twice manual weeding at 3 and 5 weeks after sowing. It was done by hoeing the soil which besides checking weed growth provides good aeration to plant roots. In zero tillage treatments the weeds were managed by the application of herbicides. Atrazine (Atrataf 50% WP) as pre-emergence @ 1.5 kg a.i./ha in 600 litres of water was applied at one day after sowing of crop.

*Irrigation*

Irrigation was scheduled based on the crop water requirement and duration of dry spell or period without rainfall. To supplement the rainfall four irrigations were given during study period, respectively to maize crop.

### *Plant Protection measures*

After thinning carbofuron granules were placed in whorl of maize for control of *Chilo partellus*.

### *Harvesting and shelling*

The crop was harvested when cob sheath turns brownish and grains become hard. Net plot was considered by leaving two border rows one row each on both side of the plot. The cobs were harvested manually by plucking method and grains were separated from cob by hand shelling.

## **3.5. Biometric observations**

### **3.5.1. Growth parameters**

#### *Plant height (cm)*

The plant height of three tagged plants was measured at 30 days intervals from the ground level up to the base of the fully opened leaf at pre-taselling and up to the base of tassel at post-taselling stage.

#### *Dry matter accumulation (g/plant)*

Three plants from sampling rows uprooted and above ground portions were cut for observations. The sampled plants were dried in hot air oven at 65° c for 48 hours. Dry weight was expressed in g/ plant.

#### *Leaf area (cm<sup>2</sup>/plant)*

The leaf area of individual leaf was measured by leaf area meter (Model LICOR-3100). The area of each of the leaves on a plant was added (summed) to obtain the leaf area per plant.

#### *Leaf area index*

The leaf area of three plants was measured with the help of leaf area meter (Model LICOR-3100). The leaf area index/plant was calculated by using the following formula:

$$\text{Leaf area index (LAI)} = \frac{\text{Total leaf area/plant (cm}^2\text{)}}{\text{Ground area occupied/plant (cm}^2\text{)}}$$

#### *Crop growth rate (g/plant/day)*

Crop growth rate (CGR) was worked out on the basis of dry matter accumulation at 30 days interval with the help of following formula:

$$\text{CGR} = \frac{W_2 - W_1}{T_2 - T_1}$$

Where,

$W_1$  : dry weight at first stage (g)

$W_2$  : dry weight at second stage (g)

$T_1$  : Days at first stage

$T_2$  : Days at second stage

The CGR was expressed g/plant/day

*Relative growth rate (mg/g/day)*

Relative Growth Rate (RGR) expresses the dry weight increase in a time interval in relation to initial weight. It is calculated from the measurements taken at time  $T_1$  and  $T_2$ . In fact, RGR value is the slope of the line when  $\text{Log } W$  is plotted against  $T$ . Mathematically, RGR value was calculated as follows:

$$\text{RGR} = \frac{\text{Log}_e W_2 - \text{Log}_e W_1}{T_2 - T_1} \quad \text{mg/g/day}$$

*Days to germination*

After sowing of the crop days to germination was recorded when the germination was started and completed in all the plots of different treatments and used for calculating days to germination.

*Days to 50% Silking*

The date on which 50% plants in net plots produced silks was recorded and used for calculating days to silking stage.

*Days to maturity*

At this stage, the material inside the grain is solid and hard and does not yield to the pressure when we press the grain between thumb and index finger. Physiological maturity is marked by the formation of small black layer in the hilar region of the seed.

### **3.5.2. Yield attributes**

*Number of cobs per square metre*

Number of cobs per square metre were counted from 0.25 m<sup>2</sup> area randomly from four spots in the net plot, averaged and expressed as number of cobs per square

metre.

*Cob length (cm)*

Five cobs were randomly selected from each plot during harvest and their length from base to tip was measured and the mean value was recorded in cm.

*Cob girth (cm)*

The girth [circumference] of five cobs was measured at the middle portion of the cob and the mean value was recorded in cm.

*Cob weight (g)*

Five cobs were selected randomly from each plot and weight was taken. The average was calculated and expressed as cob weight in grams.

*Number of grain rows per cob*

The total number of grain rows were counted from the same cobs previously selected for weight of cobs were threshed and number of grain rows were recorded. The average value was expressed as number of grains rows/cob.

*Number of grain per cob*

The total numbers of grains were counted from the same cobs previously selected for weights of cobs were threshed and number of grains was recorded. The average value was expressed as number of grains/cob.

*100-grain weight*

From the final produce, about 100 g of sample was taken. One hundred grains were counted, weighed and expressed as 100-grain weight.

*Shelling percentage*

Five cobs were selected randomly from each plot and weight was taken after removing husks and silks. Grain weight was taken after shelling separately and shelling percentage was calculated using the formula:

$$\text{Shelling percentage} = (\text{Weight of grains} / \text{Weight of whole cob}) \times 100$$

**3.5.3. Yield**

*Cob yield kilogram per hectare*

After separating from stover, all the cobs from each plot were dried in the sun and threshed by a mechanical thresher. The cob yield was expressed as kg/ha.

*Grain yield kilogram per hectare*

After separating from stover and shelling of husk and silk, all the cobs from each plot were dried in the sun and threshed by a mechanical thresher. The grain yield was

adjusted to 15% moisture content and expressed as kg/ha.

#### *Stover yield kilogram per hectare*

The maize stover were cut from ground level from the net plot and weighed after sun drying. Final yield was expressed in kg/ha.

#### *Biological yield kilogram per hectare*

The weight of total harvested produce from net plot of each treatment was recorded after sun drying and expressed as biological yield kg/ha.

#### *Harvest index*

The harvest index was computed by dividing economic yield (grain yield of maize) by the respective biological yield (total produce) and was expressed as percentage.

$$\text{HI (\%)} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

### **3.6. Estimation of energetics**

#### *Energy efficiencies*

Energy efficiency, energy productivity and energy intensity were calculated by using the following formulae as suggested by Mittal and Dhawan (1988) and Singh *et al.* (1997).

$$\text{Energy efficiency} = \frac{\text{Energy output (MJ/ha)}}{\text{Energy input (MJ/ha)}}$$

$$\text{Net energy (MJ/ha)} = \text{Energy output (MJ/ha)} - \text{Energy input (MJ/ha)}$$

$$\text{Energy productivity (kg/MJ)} = \frac{\text{Output (grain + by-product) (kg/ha)}}{\text{Energy input (MJ/ha)}}$$

$$\text{Energy intensity (in economic terms MJ/^\wedge)} = \frac{\text{Energy output (MJ/ha)}}{\text{Cost of cultivation (^\wedge/ha)}}$$

The primary data collected on various inputs and management practices for *khariif* maize crop were used for computation of energy consumption, and it's various ratios. The energy output from the economic and by-product yield was also estimated. The loss of output was very negligible due to natural calamities and pests. Thus, the loss

or waste is not included.

### 3.7. Plant chemical analysis

Plant samples collected at harvest were dried in hot air oven at 60 °C for 6 hours. These oven-dried samples of plants as well as the air-dried sample of grain were ground to pass through 40 mesh sieve in a Macro-Wiley Mill and used for chemical analysis.

#### *Nitrogen content (%) and uptake (kg/ha)*

Nitrogen content (N) in grain and stover was determined by modified Kjeldahl method (Prasad *et al.*, 2006). N uptake was calculated by using the following expression:

N uptake (kg/ha) in grain/stover = [% N in grain/stover X grain/stover yield (kg/ha)]

Total uptake of N (kg/ha) = N uptake in grain + N uptake in stover

#### *Phosphorus content (%) and uptake (kg/ha)*

Phosphorus content (P) in grain and stover of the crop was determined by vanadomolybdophosphoric acid yellow colour method (Prasad *et al.*, 2006).

Total P uptake (kg/ha) was calculated by following expression:

P uptake (kg/ha) in grain/stover = [% P in grain/stover X grain/stover yield (kg/ha)]

Total uptake of P (kg/ha) = P uptake in grain + P uptake in stover

#### *Potassium content (%) and uptake (kg/ha)*

Potassium content (K) in grain and stover was determined by flame photometer (Prasad *et al.*, 2006). Potassium uptake was calculated by multiplying K content with the dry matter yield

K uptake (kg/ha) in grain/stover = [% K in grain/stover X grain/stover yield (kg/ha)]

Total uptake of K (kg/ha) = K uptake in grain + K uptake in stover.

#### *Iron and Zinc content in grain*

Iron (Fe) and Zinc (Zn) contents in maize grain were determined as per the procedure described by Prasad *et al.* (2007) and expressed on mg/kg dry matter basis.

#### *Crude protein content (%) in grain*

Crude protein content in maize grain was obtained by multiplying N concentration with a coefficient factor 6.25. This factor is based on the nitrogen content (16.0%) of the maize protein.

### 3.8. Soil analysis

#### 3.8.1. Physical properties of soil

##### *Bulk density ( $Mg/m^3$ )*

Bulk density of different surface and sub surface soil profiles (0-10, 10-20, 20-30, 30-40, 40-50 cm) was determined by the using of core sampler method (Piper,1950) from every experimental plot. The procedure used for determining the bulk density was as described by Mishra and Ahmad (1987).

##### *Hydraulic conductivity*

The hydraulic conductivity was determined in the laboratory by using of undisturbed soil core. The soil collected for bulk density in the core sampler was used for determining the hydraulic conductivity with constant head method (Mishra and Ahmad, 1987). The hydraulic conductivity (K) was calculated by using the formula:

$$K=QL/HAT$$

Where;

K= Hydraulic conductivity (cm/hr)

Q=Quantity of water collected (cc)

L=Flow length/length of sample (cm)

H=Loss in head (cm)

A=Cross sectional area of sample ( $cm^2$ )

T=Time interval (minute)

##### *Soil aggregation stability*

Aggregate stability was measured with the help of wet sieving techniques (Haynes, 1993). Fifty gram of air dried 2 to 6 mm soil aggregates/sample were transferred to the upper most of sieve set of a six sieves having 4, 2, 1, 0.5, 0.25 and 0.1 mm diameter apertures. The water level of iron tub was adjusted so that the aggregates on the upper sieve also just submerged at the height point of oscillation. The oscillation rate was 30 cycles per minute. The amplitude of the sieving action was 35 mm and the period of sieving was 10 minutes. The mean weight diameter (MWD) of aggregates was estimated by using the procedure and formula given by (Kemper and Roseneau,1986).

$$\text{Mean weight diameter} = \frac{\sum_{i=1}^{i=n} (X_i W_i)}{\sum_{i=1}^{i=n} W_i}$$

where,  $W_i$ , is the proportion of aggregates returned and the sieves in relation to the whole,  $X_i$  is the mean diameter of the class (mm), While the geometric mean diameter (GMD) was determined by using the following formula:

$$\text{Geometric mean diameter} = \exp \left( \frac{\sum_{i=1}^{i=n} W_i \log X_i}{\sum_{i=1}^{i=n} W_i} \right)$$

The line between macro- and micro- aggregates is commonly drawn at 0.25 mm (Oades and Waters, 1991).

#### *Soil Strength (kPa)*

Soil penetration resistance from different surface and sub surface soil profiles (0-10, 10-20, 20-30, 30-40, 40-50, 50-60 and 60-70 cm) was measured directly with the help of cone penetrometer (Rmik make CP40II) and expressed in kilo pascals (kPa).

### **3.8.2. Chemical properties**

#### *Total carbon and organic carbon (%)*

The soil samples (0-15, 15-30 and 30-45 cm depth) were collected in small size polythene bags from each plot of the experimental field at the start and at the end of experimentation period. The samples were air dried and the total carbon and organic carbon content from soil samples were estimated directly with the help of CHNS analyzer and TOC analyzer instruments, respectively.

#### *Available N, P and K (kg/ha)*

The soil samples were collected from three different depths (0-15, 15-30 and 30-45 cm soil profile) at the start and at the end of experimentation. The collected soil samples were air dried, ground and pass through 2 mm mesh sieve and were analysed for available N, P and K. The available N was estimated by using of alkaline  $\text{KMnO}_4$  method suggested by Subbiah and Asija (1956) and expressed in kg/ha. The available P content in soil was estimated with Olsen's method (Olsen *et.al.*, 1954). Normal ammonium acetate extraction (flame photometer) method as described by Jackson (1973) was used for estimation of available K and expressed in kg/ha.

### Soil pH

Soil pH was measured by using the method described by Piper, 1950 in which soil: water ratio is 1:2.5, respectively.

### 3.9. Water application, water use (ET), and water use efficiency computations

Soil moisture content in the profile (0-120 cm) was determined gravimetrically at initial and final stages of *Kharif* maize crop to study profile contribution of soil moisture in plant growth and development.

Evapo-transpiration (ET) was computed using the field water balance equation (Lenka et al., 2009 and Pradhan et al., 2014) as given below:

$$ET = (P+I+C) - (R+D+\Delta S) \dots \dots \dots \text{Eq (3.1)}$$

Where; ET is the evapo-transpiration (mm), *P* is the effective precipitation (mm), *I* is the irrigation (mm), *C* is the capillary rise (mm), *R* is the runoff (mm), *D* is the deep percolation (mm) and  $\Delta S$  is change in profile soil moisture (mm) at initial .

As the groundwater level was very low (8-10 m depth), *C* was assumed to be negligible. There was no runoff (*R*) from the experimental plots as they were bunded upto a sufficient height (40 cm height) and also no case of bund overflow was observed during the study period. As soil moisture studies were made up to a soil depth of 120 cm and the profile was sandy loam with loamy and clay loam layers having a high bulk density of 1.71-1.72 Mg/m<sup>3</sup> below 60 cm, deep percolation below the 120 cm profile (*D*) was assumed to be negligible (Lenka et al., 2009 and Pradhan et al., 2014).

Thus Eq. (3.1) simplifies to,

$$ET = (P+I) - \Delta S \dots \dots \dots \text{Eq(3.2)}$$

Precipitation data were collected from the meteorological observatory of ICAR-IARI, New Delhi and given in Table 3.1. The effective rainfall was calculated by using USDA SCS method (Cropwat 8.0). Irrigation was applied through surface irrigation at critical growth stages of the crop. A measured amount of water was supplied. The applied irrigation water was measured using a ‘parshall flume (3”)’ installed in the open channel under free flow conditions. The flow rate was calculated by using the equation 3.3.

$$Q = K \times 1000 \times (Ha/100)^{1.55} \dots \dots \dots \text{Eq(3.3)}$$

Where ,

*Q* = Flow rate in liter per second

$K$ = a fraction, which is function of throat width (0.1771 in our study)

$H_a$ = water depth in converging section (cm)

This discharge was corrected by measuring height in the middle of the throat ( $H_b$ ) of ‘parshall flume’ due to submergence. The percentage variation between  $H_a$  and  $H_b$  was used to measure the submergence and correction factor was subtracted from  $Q$  to get actual discharge (Savva and Fenken, 2002). The water applied in each plot was calculated by equation 3.4.

$$\text{Water applied (m}^3\text{/ha)} = \{(Q - Q_c) \times T\} * 10 / A \dots \dots \dots \text{Eq(3.4)}$$

Where,  $Q_c$  is correction factor for reduction in modular discharge due to submergence;  $T$  is time taken for irrigation of a plot (in seconds) and  $A$  is size of plot ( $\text{m}^2$ ). Changes in soil moisture content ( $\Delta S$ ) were calculated by soil moisture sampling by gravimetric method.

Water Use Efficiency (WUE) was computed as

$$\text{WUE} = (\text{Yield (kg/ha)} / (\text{ET (m}^3\text{)})) \dots \dots \dots \text{Eq(3.5)}$$

### 3.10. Economic analysis

The economic analysis in terms of gross and net returns and benefit: cost ratio (returns per rupee invested) was calculated on the basis of existing rate of inputs and output. Total cost included in the cost of input such as seeds, fertilizers, irrigation and various cultural operations like ploughing, sowing, weeding, harvesting, threshing, etc (Annexure-II). The rental value of land was also taken into consideration for cost of cultivation calculation. Returns were calculated by using the following formula expression:

Gross returns = value of the grain + value of stover

Net returns = Gross returns – Total costs

Benefit: cost ratio = Net returns/Total cost

### 3.11. Statistical analysis

The data recorded for different parameters were analysed with the help of analysis of variance (ANOVA) technique (Gomez and Gomez, 1984) for split-plot design using SAS 9.1 software (SAS Institute, Cary, NC). The least significant difference test was used to decipher the effect of treatments at 5% level of significance ( $P=0.05$ ). Critical difference (CD) values for different pair-wise comparison among the treatment effect were computed by using the given below formulas:

Difference between two A mean: eg.  $[(a_1) - (a_0)] \sqrt{2E_a/2r_\beta}$

Difference between two B mean: eg..  $[(b_1) - (b_0)] \sqrt{2E_b/2r_\alpha}$

Difference between two B mean at the same level of A eg.  $[(a_1b_1) - (a_1b_0)] \sqrt{2E_b/r}$

Difference between two A mean at the same level of B or at different level of B:-

e.g.  $[(a_1b_1) - (a_0b_1) - (a_0b_1)]$  or  $[(a_1b_1) - (a_0b_0)] \sqrt{2[(B-1)E_b + E_a]/r\beta}$

Both the main effect of A and the AB interaction: consequently the appropriate error is a weighted mean of  $E_a$  and  $E_b$ . This error also applies to the difference between two A mean which have different levels of B. In such cases the ratio of the treatment difference to its standard error does not follow the t- distribution. For practical purpose the approximate rule of section 4.14 may be used, through two methods given slightly too few significant results. Let  $t_a$ ,  $t_b$  be the significant level of + corresponding to the degree of freedom in  $E_a$  and  $E_b$ , respectively. The significance level of t is taken as:  $t = \frac{(B-1) E_b t_b + E_a t_a}{(B-1) E_b + E_a}$

## CHAPTER – IV

## EXPERIMENTAL RESULTS

The results of the field experiment entitled “*Performance of maize (Zea mays L.) under long term tillage practices and diversified cropping systems*” conducted at the research farm, ICAR-Indian Agricultural Research Institute, New Delhi during *kharif*, 2014 are presented in this chapter. Data on the effects of treatments on growth, yield attributes, yield, quality, nutrient uptake, input use efficiency and economics of *kharif* maize and soil physical and chemical properties were analyzed statistically to test the significance of the results. The results have been illustrated by appropriate tables and graphs as per necessity.

#### 4.1. Growth parameters

Maize crop responded differentially to various tillage/crop establishment practices and diversified maize based cropping systems after six cropping cycles at fixed site. The plant height, dry matter accumulation, leaf area and leaf area index (LAI) of *kharif* maize were influenced significantly due to different tillage/ crop establishment practices at all the growth stages, except at 30 days after sowing (DAS), while these parameters were not significantly influenced by diversified cropping systems (Table 4.1 & 4.2 and Fig. 4.1).

**Table: 4.1.** Effect of long term tillage practices and diversified cropping systems on emergence, plant height and leaf area of maize after six cropping cycles.

Treatments	Days to emergence	Plant height (cm)			Leaf area (cm <sup>2</sup> /plant)		
		30 DAS	60 DAS	At harvest	30 DAS	60 DAS	90 DAS
<i>Tillage practices</i>							
Permanent bed	4.3	59.1	169.2	189.4	3152	5588	4334
Zero tillage flat	5.2	57.1	169.9	190.3	3116	5679	4656
Conventional tillage	6.1	54.7	156.2	173.8	3016	5084	4004
SEm±	0.16	1.31	2.93	3.48	71.6	115.8	90.0
LSD (P=0.05)	0.6	NS	11.5	13.7	NS	454.6	353.5
<i>p</i> -value	0.003	0.178	0.050	0.048	0.036	0.003	0.006
<i>Cropping systems</i>							
MWMb	5.2	57.0	167.2	186.3	3214	5546	4401
MCS	5.1	58.3	171.6	188.4	3354	5652	4577
MMuMb	5.2	56.7	162.0	182.4	2935	5464	4324
MMS	5.1	55.8	159.6	180.8	2877	5139	4025
SEm±	0.20	1.40	3.30	3.62	133.1	162.8	186.0
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS
<i>p</i> -value	0.954	0.641	0.081	0.448	0.063	<.0001	<.0001
<i>p</i> -value interaction	0.297	0.641	0.030	0.846	0.403	0.036	0.039

Note: MWMb: Maize-Wheat-Mungbean, MCS: Maize-Chickpea-*Sesbainia*, MMuMb: Maize-Mustard-Mungbean, MMS: Maize-Maize-*Sesbania*.

However, these growth parameters of maize 30 DAS onward were maximum under conservation agriculture (CA) based zero tillage (ZT) planting which was statically at par with permanent bed (PB) planting and significantly higher over to conventional tillage (CT) planting after the six cropping cycles of *khariif* maize under diversified cropping systems at fixed site of experimentation. As compare to previous study year (before *khariif*, 2014) this growth parameters were lower in all the treatments due to unfavorable weather conditions during the experimental season (*khariif*, 2014). In general, at 60 DAS and at harvest the tallest crop plants were recorded under zero tillage planting with height of 169.9 and 190.3 cm, respectively. However, at initial growth stage (at 30 DAS) of *khariif* maize the maximum plant height (59.1 cm) was observed in PB plots.

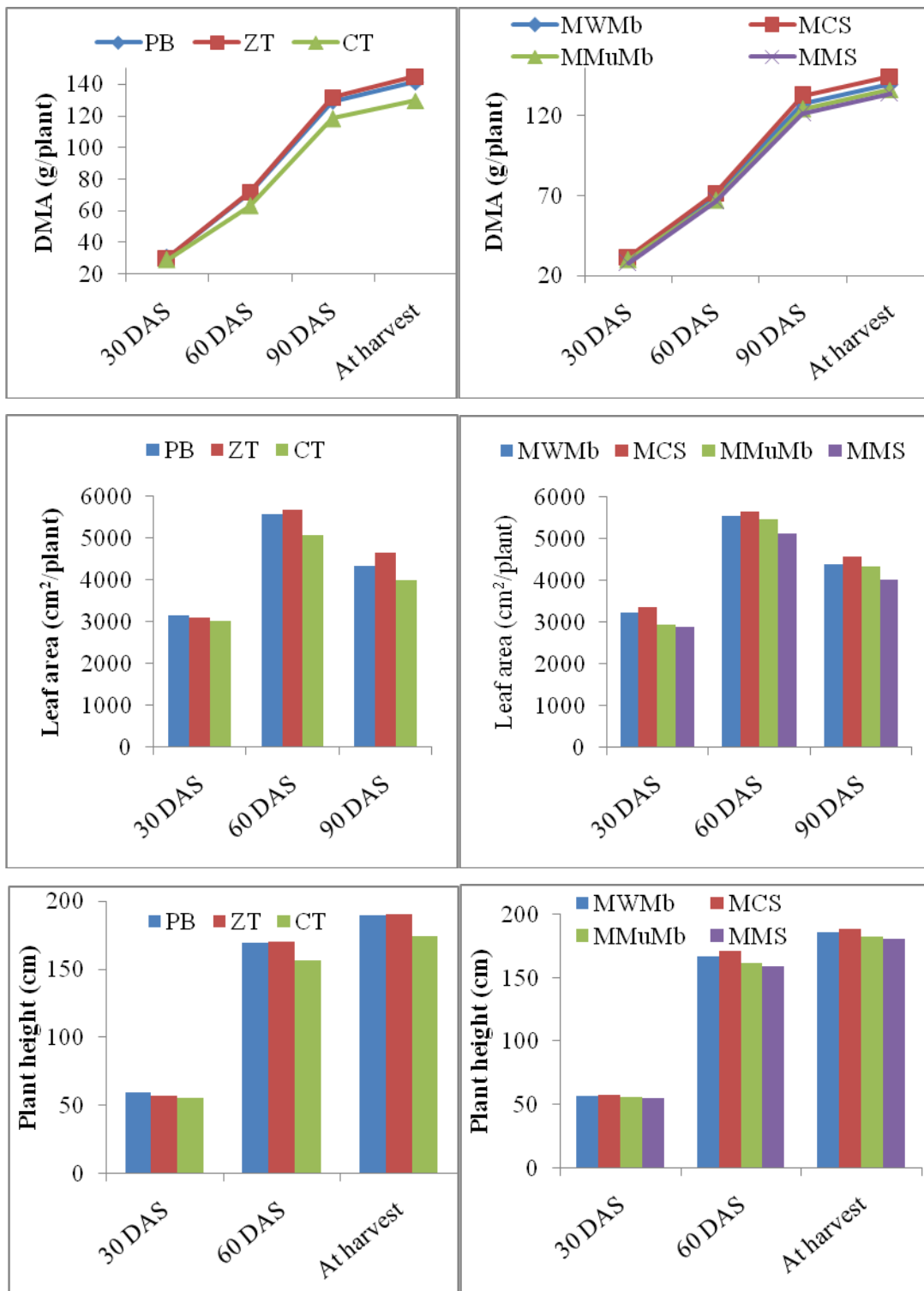
**Table: 4.2.** Effect of long term tillage practices and diversified cropping systems on dry matter accumulation and LAI of maize after six cropping cycles.

Treatments	Dry matter accumulation (g/plant)				Leaf area index		
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS
<i>Tillage practices</i>							
Permanent bed	30.4	71.3	129.2	141.5	2.35	4.17	3.23
Zero tillage flat	30.0	72.0	131.6	144.9	2.33	4.24	3.47
Conventional tillage	29.2	63.0	118.3	129.5	2.15	3.63	2.86
SEm±	1.12	1.34	2.68	2.68	0.053	0.085	0.067
LSD (P=0.05)	NS	5.27	10.51	10.42	NS	0.34	0.26
<i>p</i> -value	0.726	0.016	0.049	0.033	0.013	0.001	0.002
<i>Cropping systems</i>							
MWMb	30.2	70.1	127.3	139.6	2.36	4.10	3.24
MCS	31.6	71.5	132.3	144.6	2.47	4.15	3.37
MMuMb	29.8	67.0	124.1	136.4	2.16	4.03	3.18
MMS	27.8	66.3	121.6	133.8	2.12	3.77	2.97
SEm±	0.93	1.57	3.52	3.52	0.099	0.117	0.138
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS
<i>p</i> -value	0.067	0.096	0.194	0.194	0.061	<.0001	<.0001
<i>p</i> -value interaction	0.004	0.006	<.0001	<.0001	0.406	0.024	0.039

Note: MWMb: Maize-Wheat-Mungbean, MCS: Maize-Chickpea-*Sesbainia*, MMuMb: Maize-Mustard-Mungbean, MMS: Maize-Maize-*Sesbania*.

Across the treatments the dry matter accumulation rate was slow at early growth stages and at harvest, but increased linearly at maximum growth stages and peak of plant growth and development was observed at 60 and 90 DAS. Among the tillage practices the maximum dry matter accumulation (71.9, 131.6 and 144.9 g/plant) at 60, 90 DAS and at harvest stage was recorded in zero tillage plots which was significantly higher over conventional tillage plots and remain at par with PB planting. While the diversified maize based cropping systems were not shown any significant effect on dry matter accumulation of maize under different crop

establishment practice. Similarly, the leaf area and leaf area index (LAI) was also low at early growth stage (30 DAS), but it was increased on later plant growth stages with differential rates and reached maximum at 60 DAS, after that it start to decline under all the treatments.



**Fig. 4.1.** Effect of long term tillage practices and diversified cropping systems on dry matter accumulation (DMA), leaf area and plant height of maize grown after six cropping cycles.

At 60 days after sowing, the LAI values were found maximum (4.24) under ZT planting which was statistically at par with PB and significantly higher than CT, However like other growth parameters the *kharif* maize LAI was also not significantly influenced by different cropping systems treatments and the numerically maximum LAI value (4.15) was recorded in maize-chickpea-*sesbania* (MCS) system plots at 60 DAS. The interaction effect of tillage and cropping systems on maize growth parameters, leaf area and LAI at 30 DAS were non-significant ( $P>0.05$ ), while significant ( $P>0.05$ ) interaction effects were observed on dry matter accumulation (at 30, 60 90 DAS and at harvest), leaf area and LAI (at 60 and 90 DAS).

#### 4.2. Development parameter

The developmental parameters of maize (50% silking, days to maturity and reproductive period) were significantly influenced by different tillage and crop establishment practices.

**Table: 4.3.** Effect of long term tillage practices and diversified cropping systems on CGR, RGR and phenological stages of maize after six cropping cycles.

Treatments	CGR (g/plant/day)			RGR (mg/g/day)		Days to 50% silking	Days to maturity	Reproductive period
	0-30 DAS	30-60 DAS	60-90 DAS	30-60 DAS	60-90 DAS			
	<i>Tillage practices</i>							
Permanent bed	1.01	1.36	1.93	12.5	8.48	56.1	108.1	52.0
Zero tillage flat	1.00	1.39	1.99	12.7	8.78	56.6	107.8	51.3
Conventional tillage	0.97	1.13	1.84	11.1	8.97	59.2	109.3	50.1
SEm±	0.037	0.075	0.081	0.77	0.32	0.10	0.25	0.25
LSD (P=0.05)	NS	0.184	NS	NS	NS	0.4	1.0	1.00
<i>p</i> -value	0.726	0.121	0.491	0.396	0.588	<.0001	0.034	0.015
<i>Cropping systems</i>								
MWMb	1.01	1.33	1.91	12.2	8.40	57.2	108.3	51.1
MCS	1.05	1.33	2.03	11.9	8.92	57.1	108.0	50.9
MMuMb	0.99	1.24	1.90	11.7	8.98	57.2	108.6	51.3
MMS	0.93	1.28	1.84	12.7	8.67	57.6	108.7	51.1
SEm±	0.031	0.052	0.135	0.47	0.56	0.24	0.50	0.51
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
<i>p</i> -value	0.067	0.568	0.798	0.481	0.881	0.604	0.791	0.944
<i>p</i> -value interaction	0.004	0.002	<.0001	0.001	<.0001	0.111	0.150	0.018

Note: MWMb: Maize-Wheat-Mungbean, MCS: Maize-Chickpea-*Sesbania*, MMuMb: Maize-Mustard-Mungbean, MMS: Maize-Maize-*Sesbania*.

The minimum 56.1 days for 50% silking and maximum reproductive period of 52 days was recorded under PB, while days to maturity period 107.8 was minimum

under ZT plots which were significantly lower than the CT plots (Table 4.3). The interaction effect of tillage and cropping systems on maize developmental parameters were non-significant ( $P>0.05$ ).

#### 4.3. Physiological indices

The crop growth rate (CGR) and relative growth rate (RGR) of maize plant were not significantly influenced by different tillage practices at different growth intervals except at 30-60 DAS (Table 4.3). Similarly, these growth indices were not significantly influenced due to different cropping systems. However, gradual increase in CGR was recorded with periodic advancement of growth stages and the maximum CGR values were recorded at 60-90 DAS. Whereas, RGR value was highest in initial growth stage of the crop. The interaction effect of tillage and cropping systems on maize physiological indices were significant ( $P>0.05$ ).

#### 4.4. Yield attributes

Data on maize yield attributes *viz*; Cobs/m<sup>2</sup>, cob length, grain row/cob and grains/row are given in Table 4.4. The critical examination of these yield attributes data revealed that different tillage practices influenced significantly on maize yield attributes. However, the cob girth and 100-grain weight were statistically similar under various tillage as well as the cropping system treatments. While, all these yield attributes were not significantly influenced due to cropping system effect during the study period after the six maize cropping cycles at the same experimental site.

**Table: 4.4.** Effect of long term tillage practices and diversified cropping systems on yield attributes of maize after six cropping cycles.

Treatments	Cobs/m <sup>2</sup>	Cob length (cm)	Cob girth (cm)	Grain rows/cob	Grains/row	100- grains weight (g)
<i>Tillage practices</i>						
Permanent bed	7.7	17.7	12.9	13.4	34.2	26.7
Zero tillage flat	7.8	18.3	13.2	13.8	35.6	25.6
Conventional tillage	6.8	16.9	12.5	12.7	31.5	27.1
SEm±	0.17	0.27	0.13	0.19	0.77	0.44
LSD (P=0.05)	0.68	1.0	NS	0.7	3.0	NS
<i>p</i> -value	0.027	0.047	0.062	0.048	0.048	0.166
<i>Cropping systems</i>						
MWMb	7.4	17.7	13.1	13.7	34.0	25.9
MCS	7.6	18.1	13.0	13.2	34.5	26.2
MMuMb	7.3	17.4	12.8	13.1	33.8	26.8
MMS	7.2	17.2	12.6	13.0	32.8	27.0
SEm±	0.21	0.24	0.19	0.28	0.59	0.42
LSD (P=0.05)	NS	NS	NS	NS	NS	NS
<i>p</i> -value	0.695	0.057	0.347	0.342	0.288	0.311
<i>p</i> -value interaction	0.376	0.544	0.868	0.409	0.298	0.048

Note: MWMB: Maize-Wheat-Mungbean, MCS: Maize-Chickpea-*Sesbainia*, MMuMb: Maize-Mustard-Mungbean, MMS: Maize-Maize-*Sesbania*.

The maximum values of cobs/m<sup>2</sup> (7.8) cob length (18.3 cm), cob girth (13.2 cm), grain rows/cob (13.8) and grains/row (35.6) were recorded under ZT than rest of the crop establishment treatments, while CT resulted in minimum values of these yield attributes. Though these yield attributes were not significantly influenced due to diversified cropping systems, however the numerically higher values of cobs/m<sup>2</sup>, cob length, grain row/cob and grains/row were observed in maize-chickpea-*sesbania* (MCS) cropping system. The interaction effect of tillage and cropping systems on maize yield attributes were non-significant (P>0.05).

#### 4.5. Yield performance

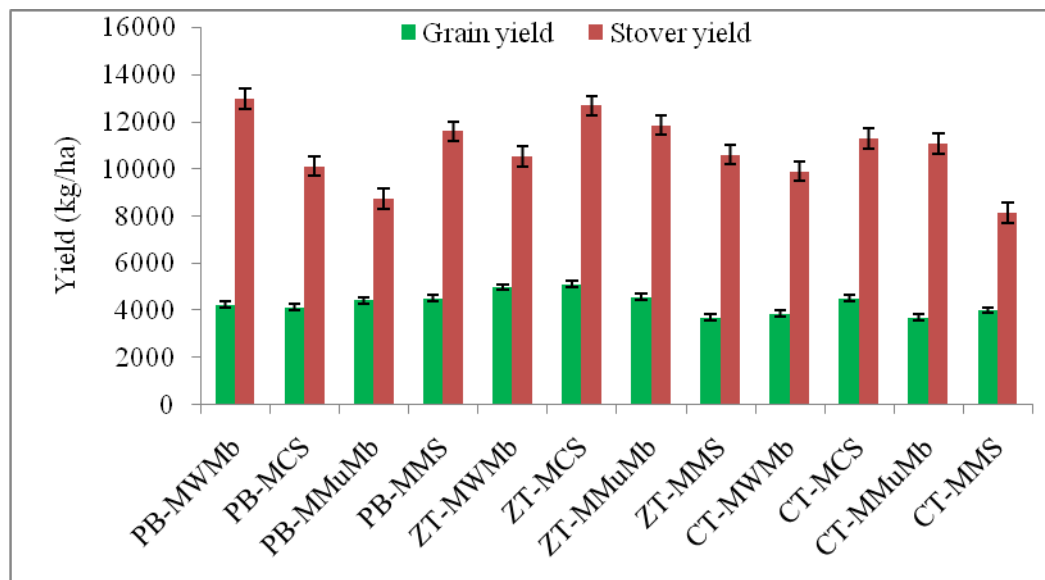
The grain, stover, cob and biological yields of maize were differed significantly due to different tillage practices and diversified maize based cropping systems, while the harvest index and shelling percentage were non-significant under all the treatments (Table 4.5 and Fig. 4.2). Grain, stover, cob and biological yields were significantly higher under ZT followed by PB during the experimentation. There was only a marginal non-significant difference in the harvest index (HI) and shelling percentage of maize under different tillage and crop establishment practices.

**Table: 4.5.** Effect of long term tillage practices and diversified cropping systems on yields and harvest index of maize after six cropping cycles.

Treatments	Grain yield (kg/ha)	Cob yield (kg/ha)	Stover yield (kg/ha)	Biological yield (kg/ha)	Shelling (%)	Harvest Index
<i>Tillage practices</i>						
Permanent bed	4328	5368	10847	16215	80.6	27.0
Zero tillage flat	4589	5939	11412	17351	77.3	26.5
Conventional tillage	4018	5169	10095	15264	77.8	26.5
SEm±	106.4	117.4	249.6	213.6	1.11	0.82
LSD (P=0.05)	417.5	461.1	980.0	838.6	NS	NS
<i>p</i> -value	0.047	0.022	0.049	0.006	0.196	0.881
<i>Cropping systems</i>						
MWMB	4366	5530	11131	16660	78.8	26.4
MCS	4582	5851	11352	17203	78.6	26.7
MMuMb	4225	5374	10549	15924	78.8	26.8
MMS	4075	5214	10107	15320	78.2	26.8
SEm±	103.7	123.4	277.3	347.1	1.75	0.67
LSD (P=0.05)	308.2	366.7	824.0	1031.5	NS	NS
<i>p</i> -value	0.018	0.012	0.021	0.007	0.993	0.960
<i>p</i> -value interaction	0.001	0.006	<.0001	0.0001	0.377	<.0001

Note: MWMB: Maize-Wheat-Mungbean, MCS: Maize-Chickpea-*Sesbainia*, MMuMb: Maize-Mustard-Mungbean, MMS: Maize-Maize-*Sesbania*.

The minimum yields were registered under CT planting. Critically examination of data revealed that conservation tillage based ZT and PB planting registered 14.2 & 7.7%; 13.0 & 7.5% and 13.7 & 6.2% increase in *kharif* maize grain, stover and biological yields over to continuous conventional tillage at fixed site after six cropping cycles, respectively.



**Fig. 4.2.** Interaction effects of long term tillage practices and diversified cropping systems on grain and stover yields of maize grown after six cropping cycles.

Among the diversified cropping systems the highest grain, stover, cob and biological yields of *kharif* maize were recorded with MCS system which were statically at par with MWMB system planting. Critically analysis of yields data revealed that planting of *kharif* maize in all the cropping sequence showed that MCS system registered 11.1, 8.5 & 4.9 % and 11.0, 7.6 & 2.0 % increase in grain and stover yields over to MMS, MMuMb and MWMB systems, respectively. The HI of *kharif* maize planted under different diversified cropping systems varied narrowly and remains statistically at par in all the cropping sequences. The interaction effect of tillage and cropping systems on maize grain, stover, cob and biological yields were significant ( $P > 0.05$ ).

#### 4.6. Nutrient content and uptake

The N, P, K content and uptake by grain & stover and Fe, Zn and protein content in maize grain were significantly influenced due to different tillage practices and cropping systems during the study at fixed site after six cropping cycles (Table 4.6 to 4.7 and Fig. 4.3). The maximum total (grain and stover) N, P, K uptake (134.7, 40.9 and 156.6 kg/ha), respectively, as well as the protein content (8.7 %) in maize grains was recorded when maize was sown in ZT, while minimum content and uptake of all

these nutrients and quality parameters was recorded with CT planting during *kharif*, 2014. While the lowest content of Fe (26.0 mg/kg DM) and Zn (14.8 mg/kg DM) in maize grain was recorded in CT plots.

**Table: 4.6.** Effect of long term tillage practices and diversified cropping systems on quality and nutrient uptake in maize after six cropping cycles.

Treatments	Protein content (%)	N content (%)		N uptake (kg/ha)		P content (%)		P uptake (kg/ha)	
		Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
<i>Tillage practices:</i>									
Permanent bed	8.55	1.51	0.547	65.0	59.4	0.334	0.205	15.0	22.3
Zero tillage flat	8.69	1.52	0.563	70.2	64.5	0.352	0.226	15.1	25.8
Conventional tillage	8.31	1.41	0.537	56.8	53.7	0.338	0.194	13.5	19.6
SEm±	0.066	0.014	0.004	1.68	1.49	0.010	0.004	0.32	0.94
LSD (P=0.05)	0.26	0.053	0.018	6.59	5.84	NS	0.016	1.26	3.71
<i>p</i> -value	0.035	0.008	0.036	0.012	0.017	0.499	0.012	0.041	0.024
<i>Cropping systems:</i>									
MWMb	8.48	1.48	0.538	65.0	59.9	0.348	0.210	15.0	23.4
MCS	8.96	1.58	0.551	72.2	62.3	0.334	0.216	15.1	24.5
MMuMb	8.22	1.42	0.556	60.1	59.3	0.328	0.207	13.8	22.1
MMS	8.40	1.44	0.552	58.6	55.2	0.356	0.199	14.3	20.2
SEm±	0.056	0.019	0.016	1.54	2.50	0.010	0.003	0.26	0.64
LSD (P=0.05)	0.17	0.055	NS	4.59	7.414	NS	0.009	0.76	1.91
<i>p</i> -value	<.0001	<.0001	0.861	<.0001	0.266	0.207	0.007	0.005	0.001
<i>p</i> -value interaction	0.204	0.874	0.003	0.001	0.002	0.003	<.0001	0.287	<.0001

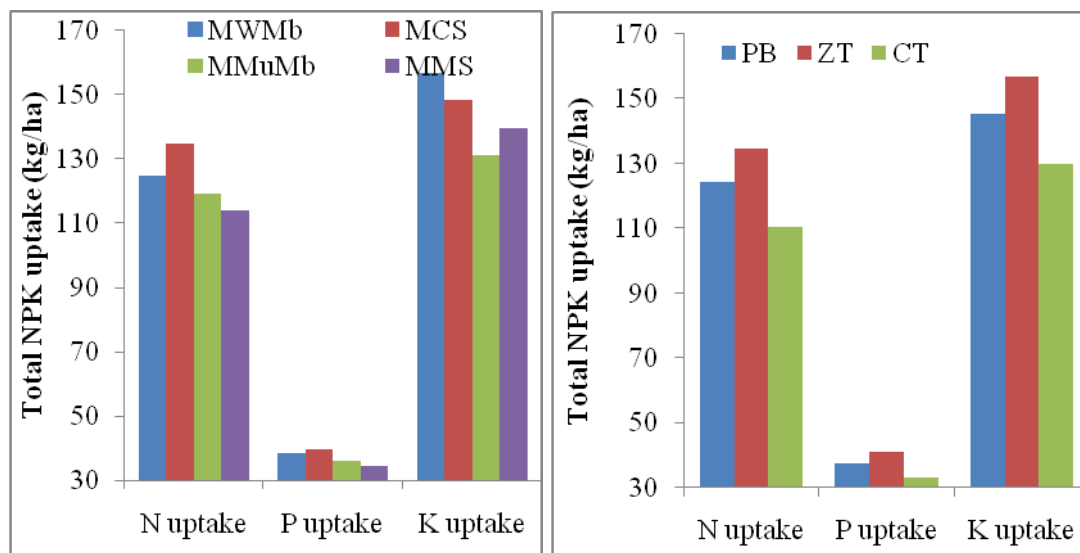
Note: MWMb: Maize-Wheat-Mungbean, MCS: Maize-Chickpea-*Sesbainia*, MMuMb: Maize-Mustard-Mungbean, MMS: Maize-Maize-*Sesbania*.

**Table: 4.7.** Effect of long term tillage practices and diversified cropping systems on nutrient content and uptake in maize after six cropping cycles.

Treatments	K content (%)		K uptake (kg/ha)		Total (grain + stover) uptake (kg/ha)			Fe content (mg/kg DM)	Zn content (mg/kg DM)
	Grain	Stover	Grain	Stover	N	P	K		
<i>Tillage practices:</i>									
Permanent bed	0.446	1.153	20.2	124.9	124.3	37.3	145.1	36.2	16.3
Zero tillage flat	0.483	1.198	20.7	135.9	134.7	40.9	156.6	33.8	16.0
Conventional tillage	0.427	1.138	17.0	112.8	110.5	33.1	129.9	26.0	14.8
SEm±	0.010	0.010	0.42	2.80	1.33	0.90	2.75	0.66	0.28
LSD (P=0.05)	0.040	0.038	1.66	10.97	5.21	3.52	10.8	2.58	1.10
<i>p</i> -value	0.042	0.026	0.007	0.011	0.001	0.009	0.006	0.001	0.044
<i>Cropping systems:</i>									
MWMb	0.450	1.233	19.5	137.2	125.0	38.4	156.7	31.3	15.9
MCS	0.476	1.119	21.5	126.8	134.6	39.6	148.2	37.7	17.3
MMuMb	0.428	1.078	18.0	113.0	119.3	35.9	131.0	28.9	14.1
MMS	0.454	1.221	18.4	121.2	113.8	34.5	139.5	30.2	15.5
SEm±	0.017	0.017	0.47	3.67	3.04	0.68	3.95	0.67	0.27
LSD (P=0.05)	NS	0.052	1.39	10.89	9.04	2.03	11.7	1.98	0.79
<i>p</i> -value	0.304	<.0001	0.0002	0.002	0.001	0.001	0.002	<.0001	<.0001
<i>p</i> -value interaction	0.006	<.0001	0.230	0.030	0.002	<.0001	0.055	0.0002	0.009

Note: MWMb: Maize-Wheat-Mungbean, MCS: Maize-Chickpea-Sesbainia, MMuMb: Maize-Mustard-Mungbean, MMS: Maize-Maize-Sesbania.

The accumulation of micronutrients (Fe and Zn) in *kharif* maize grain was maximum (36.2 and 16.3 mg/kg DM), respectively when crop was planted in PB plots.



**Fig. 4.3.** Effect of long term tillage practices and diversified cropping systems on total NPK uptake in maize grown after six cropping cycles.

Data pertaining to N, P, K content and uptake by maize grain & stover and Fe, Zn and protein content in grain were reflected that different diversified maize based cropping systems significantly influenced these parameters. The maximum N, P, K uptake by grain & stover and Fe, Zn and protein content was observed when *kharif* maize was sown in MCS sequence as compare to other cropping sequences. The planting of *kharif* maize in MCS sequence registered 18.2, 14.8 & 6.2% increase in total N, P and K uptake (grain + stover) over to MMS, respectively. Similarly, the maximum protein (8.96%), Fe (37.7 ppm) and Zn (17.3 ppm) content were also found in maize grain under MCS planting after six cropping cycles at fixed site.

#### 4.7. Energy relations

Total energy output, energy efficiency, energy productivity and energy intensity of *kharif* maize were significantly influenced due to different crop establishment practices (Table 4.8). The maximum net energy (197.3 thousand MJ/ha), energy efficiency (16.4), energy productivity (1.35 Kg/MJ) and energy intensity (8.50 MJ/Rs) of *kharif* maize were recorded under ZT planting. PB and ZT planting registered 10.1 & 16, 33.9 & 39.6, 32.3 & 39.9 and 14.7 & 21.0 % higher net energy, energy efficiency, energy productivity and energy intensity over to CT

planting, respectively. However, all these energy indices are statistically similar in both the CA-based tillage practices (ZT and PB).

Diversified maize based cropping systems also significantly influence the gross energy output, energy efficiency, energy productivity and energy intensity of *kharif* maize. The highest net energy (195.5 thousand MJ/ha), energy efficiency (15.3), energy productivity (1.26 Kg/MJ) and energy intensity (8.29 MJ/Rs) were recorded when *kharif* maize crop was planting in MCS system over to other diversified cropping sequences. However, after six cropping cycles at fixed site the lowest values of all these energy indices of *kharif* maize were observed in MMS system. The interaction effect of tillage and cropping systems on maize energy indicators were significant ( $P>0.05$ ).

**Table: 4.8.** Effect of long term tillage practices and diversified cropping systems on energy indicators of maize after six cropping cycles.

Treatments	Input energy (x 10 <sup>3</sup> MJ/ha)	Gross output energy (x 10 <sup>3</sup> MJ/ha)	Net energy (x 10 <sup>3</sup> MJ/ha)	Energy efficiency (output/input ratio)	Energy productivity (Kg/MJ)	Energy intensity (MJ/ha-INR)
<i>Tillage practices:</i>						
Permanent bed	12.7	199.2	186.5	15.7	1.28	8.06
Zero tillage flat	12.8	210.1	197.3	16.4	1.35	8.50
Conventional tillage	15.8	185.3	169.5	11.7	0.97	7.03
SEm±	-	2.55	2.55	0.20	0.017	0.103
LSD (P=0.05)	-	10.00	10.00	0.78	0.07	0.40
<i>p</i> -value	<.0001	0.006	0.004	0.0002	0.0002	0.001
<i>Cropping systems:</i>						
MWMB	13.8	203.3	189.5	15.0	1.23	8.08
MCS	13.8	209.2	195.5	15.3	1.26	8.29
MMuMb	13.8	194.0	180.2	14.2	1.17	7.69
MMS	13.8	186.2	172.5	13.8	1.13	7.40
SEm±	-	4.22	4.22	0.31	0.026	0.167
LSD (P=0.05)	-	12.54	12.54	0.92	0.08	0.50
<i>p</i> -value	-	0.006	0.006	0.009	0.009	0.007
<i>p</i> -value interaction	-	0.0001	0.0001	<.0001	<.0001	<.0001

Note: MWMB: Maize-Wheat-Mungbean, MCS: Maize-Chickpea-*Sesbainia*, MMuMb: Maize-Mustard-Mungbean, MMS: Maize-Maize-*Sesbania*.

#### 4.8. Water use and water use efficiency

The seasonal evapo-transpiration (ET) of maize varied significantly ( $P<0.05$ ) with different tillage practices (Table 4.9). The total water use was 13.7 % lower in PB plots and 9.1% lower in ZT plots compared to CT planting systems during the experimentation season. During the study period, ET decreased significantly with PB/ZT treatments ( $P<0.05$ ). PB/ZT plots had 9.1-13.7%, lowered ET, in maize crop

compared to CT, respectively. Similar to ET, water use efficiency of *kharif* maize was significantly ( $P<0.05$ ) affected by different tillage practices. The WUE of maize was maximum under PB/ZT (2.12-2.16 kg/ ha-m<sup>3</sup>), practices (Table 4.9). However, the WUE in CT plots was significantly ( $P<0.05$ ) lower, which might be due to the retention of residue at the soil surface in ZT system helped in reducing evaporation losses and hence conserving soil moisture.

**Table: 4.9.** Effect of long term tillage practices and diversified cropping systems on water use and water use efficiency of maize after six cropping cycles.

Treatments	Effective Rainfall (mm)	Water use (ET, mm)	Water use efficiency (kg/ha-m <sup>3</sup> )
<i>Tillage practices</i>			
Permanent bed	328	765	2.12
Zero tillage flat	328	806	2.16
Conventional tillage	328	886	1.72
SEm±	-	2.051	0.028
LSD (P=0.05)	-	8.05	0.11
<i>p</i> -value	-	<.0001	0.001
<i>Cropping systems</i>			
MWMB	328	819	2.05
MCS	328	814	2.12
MMuMb	328	819	1.95
MMS	328	823	1.88
SEm±	-	2.049	0.042
LSD (P=0.05)	-	6.09	0.13
<i>p</i> -value	-	0.042	0.004
<i>p</i> -value interaction	-	0.666	<.0001

*Note:* MWMB: Maize-Wheat-Mungbean, MCS: Maize-Chickpea-*Sesbainia*, MMuMb: Maize-Mustard-Mungbean, MMS: Maize-Maize-*Sesbainia*.

After six cropping cycles at fixed site the effect of cropping systems was also found to be significant ( $P<0.05$ ) on ET and WUE of maize. MCS treatment was statistically better than all other cropping system treatments. MCS/MWMB plots registered higher ET by 0.57-1.1% in maize, than MMuMb and MCS treatments. The maximum water use efficiency (2.12 kg/ ha-m<sup>3</sup>) recorded in MCS plots of maize which was significantly higher than MMuMb and MCS plots. However, the lowest water use efficiency (1.88 kg/ ha-m<sup>3</sup>) was observed in MMS plots of *kharif* maize. Similar to main effects the interaction effect of tillage and cropping systems was significant ( $P<0.05$ ) for WUE, and non-significant for ET.

#### 4.9. Economics

Data pertaining to gross returns, net returns and B:C ratio of maize are presented in (Table 4.10 and Fig. 4.4). There was significant ( $P<0.05$ ) interaction and main

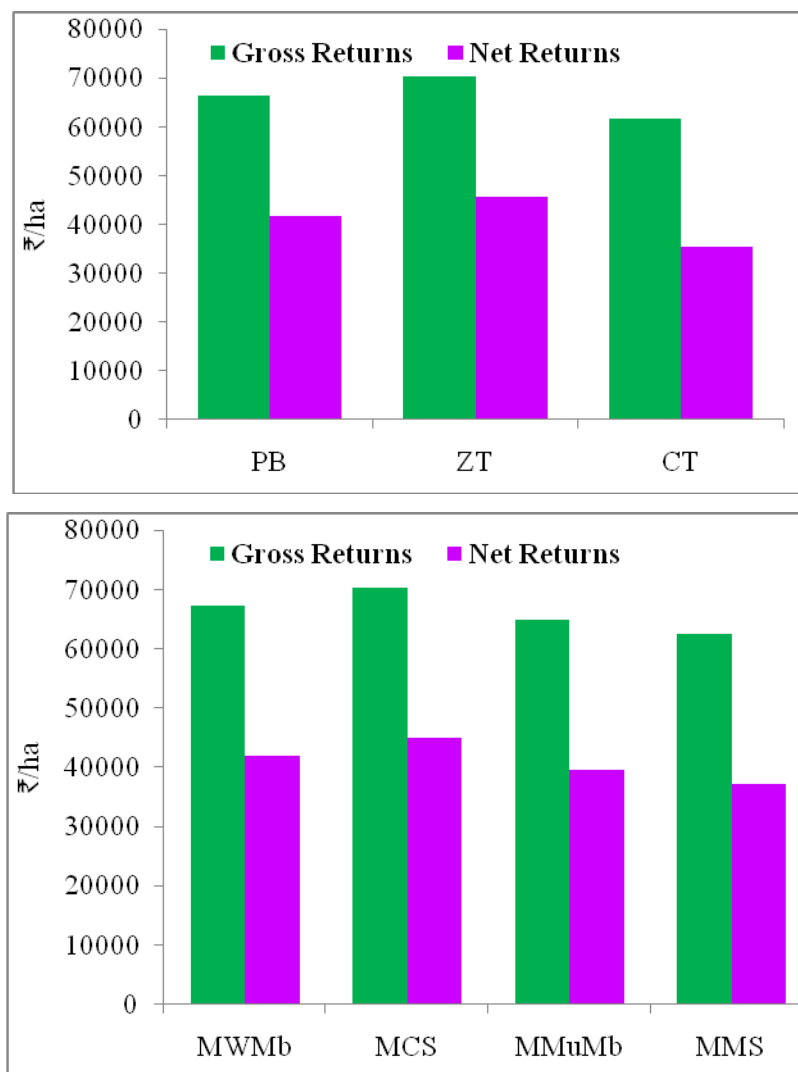
effects of tillage and cropping systems on gross and net returns (Table 4.10). The cost of cultivation of *kharif* maize crop under different tillage practices varied from minimum with ZT and PB ( $24.71 \times 10^3$  ₹/ha) to maximum under CT ( $26.36 \times 10^3$  ₹/ha), respectively. However, the *kharif* maize cost of cultivation was not varied with different cropping systems and remained same ( $25.26 \times 10^3$  ₹/ha) in all the cropping sequences.

**Table: 4.10.** Effect of long term tillage practices and diversified cropping systems on economics of maize after six cropping cycles.

Treatments	Gross returns (₹/ha)	Net returns (₹/ha)	BC ratio
<i>Tillage practices</i>			
Permanent bed	66456	41744	1.69
Zero tillage flat	70393	45681	1.85
Conventional tillage	61725	35363	1.34
SEm±	1275.5	1275.5	0.05
LSD (P=0.05)	5007.3	5007.3	0.205
<i>p</i> -value	0.022	0.012	0.005
<i>Cropping systems</i>			
MWMb	67213	41952	1.67
MCS	70235	44973	1.78
MMuMb	64838	39576	1.57
MMS	62478	37216	1.48
SEm±	1459.6	1459.6	0.06
LSD (P=0.05)	4336.8	4336.8	0.204
<i>p</i> -value	0.009	0.009	0.011
<i>p</i> -value interaction	0.001	0.001	0.001

*Note:* MWMb: Maize-Wheat-Mungbean, MCS: Maize-Chickpea-*Sesbainia*, MMuMb: Maize-Mustard-Mungbean, MMS: Maize-Maize-*Sesbania*.

The net returns and BC ratio were influenced significantly due to different tillage practices. The maximum net returns (45,681 ₹/ha) and BC ratio (1.85 ₹/₹ invested) were obtained under ZT planting of *kharif* maize, while minimum net returns (35,363 ₹/ha) and BC ratio (1.34 ₹/₹ invested) were obtained under CT, respectively. Similarly, the net returns and BC of *kharif* maize were also significantly differ when it was sown under diversified cropping systems. The highest net returns (44,973 ₹/ha) and BC ratio (1.78 ₹/₹ invested) were fetched with MCS sequence planting of *kharif* maize in 2014, which was statistically at par with MWMb system. The lowest net returns (37,216 ₹/ha) and BC ratio (1.48 ₹/₹ invested) was obtained in MMS system.



**Fig. 4.4.** Effect of long term tillage practices and diversified cropping systems on economic returns in maize grown after six cropping cycles.

#### 4.10. Soil physical properties

##### *Bulk density*

The effects of tillage practices were significant ( $P < 0.05$ ) on bulk density (BD) of 0-10, 10-20 and 20-30 cm soil depths, while in deeper soil layers (30-60 cm) it was non-significant (Table 4.11). In general BD was increased with increased in the soil depth and across the tillage practices the maximum BD values (1.63-1.67  $\text{Mg/m}^3$ ) were recorded at 30-40 cm soil depth. However, across the soil depths the higher BD was recorded in CT. The main effect of crop rotations and interaction effects of tillage and diversified crop rotations on soil BD were non-significant ( $P < 0.05$ ) for all soil depths (0-60 cm). Among the diversified cropping systems the BD values after harvest of *khariif* maize were lower in MCS sequence plots, and the maximum BD was observed in MMuMb plot in all the soil layers (0-60 cm).

**Table: 4.11.** Effect of long term tillage practices and diversified cropping systems on different soil layers bulk density after seven cropping cycles of maize.

Treatments	Bulk density (Mg/m <sup>3</sup> )					
	0-10 cm	10-20 cm	20-30 cm	30-40 cm	40-50 cm	50-60 cm
<i>Tillage practices</i>						
Permanent bed	1.46	1.54	1.58	1.64	1.60	1.60
Zero tillage flat	1.46	1.53	1.55	1.63	1.60	1.59
Conventional tillage	1.53	1.64	1.65	1.67	1.61	1.60
SEm±	0.003	0.003	0.005	0.007	0.003	0.006
LSD (P=0.05)	0.011	0.009	0.020	NS	NS	NS
<i>p</i> -value	0.0001	<.0001	0.0004	0.039	0.069	0.524
<i>Cropping systems</i>						
MWMB	1.46	1.55	1.57	1.63	1.60	1.60
MCS	1.48	1.57	1.58	1.64	1.60	1.60
MMuMb	1.50	1.58	1.62	1.67	1.60	1.60
MMS	1.48	1.57	1.59	1.64	1.60	1.59
SEm±	0.006	0.005	0.011	0.010	0.003	0.003
LSD (P=0.05)	0.016	0.014	0.032	NS	NS	NS
<i>p</i> -value	0.001	0.005	0.027	0.045	0.083	0.234
<i>p</i> -value interaction	0.285	0.983	0.528	0.123	0.023	0.649

Note: MWMB: Maize-Wheat-Mungbean, MCS: Maize-Chickpea-Sesbainia, MMuMb: Maize-Mustard-Mungbean, MMS: Maize-Maize-Sesbania.

### Soil strength

The main effects of tillage practices and crop rotations were significant ( $P < 0.05$ ) on penetration resistance (PR) up to 50 cm soil depth (Table 4.12) after harvest of 19<sup>th</sup> crop grown in different cropping sequences at same site. The PR across tillage and crop rotations treatments increased with depth (upto 40 cm) because of higher intrinsic BD in deeper soil layers. Among the different tillage plots the maximum penetration resistance (1805 to 2243kPa) was recorded at 30-40 cm. Moreover, PR decreased under ZT plots by 14.9 to 26.5 % and PB by 15.6 to 30.0% compared to CT in different layers of effective root zone (0-50 cm).

Similar to tillage practices, diversified crop rotations also significantly influenced the PR in soil profiles upto 50 cm depth. After harvest of 19<sup>th</sup> crop grown in continuous sequences with different crops at same site the highest penetration resistance (868 to 2227 kPa) was recorded in MMuMb system plots at all the soil depths (0-60 cm), which was significantly higher over to other three cropping systems plots. However, upto 40 cm soil depths the lowest penetration resistance (622 to 1790 kPa) was observed in MWMB sequence plots and below this depth (40-60 cm) it was lowest in MMS plots. The interaction effect of tillage and crop rotations on PR was significant ( $P < 0.05$ ) only for 0-10 cm soil layer.

**Table: 4.12.** Effect of long term tillage practices and diversified cropping systems on different soil layers penetration resistance after seven maize crops.

Treatments	Penetration resistance (kPa)					
	0-10 cm	10-20 cm	20-30 cm	30-40 cm	40-50 cm	50-60 cm
<i>Tillage practices</i>						
Permanent bed	661	1241	1446	1876	1802	1779
Zero tillage flat	689	1304	1465	1805	1713	1693
Conventional tillage	809	1773	1991	2243	2134	1920
SEm±	13.7	58.0	54.8	49.5	59.2	47.5
LSD (P=0.05)	53.9	227.8	215.0	194.3	232.5	NS
<i>p</i> -value	0.003	0.005	0.004	0.007	0.016	0.065
<i>Cropping systems</i>						
MWMb	622	1217	1355	1790	1798	1772
MCS	660	1501	1641	1954	1951	1849
MMuMb	868	1775	2043	2227	2042	1857
MMS	729	1265	1497	1927	1743	1712
SEm±	18.7	68.4	71.8	74.0	53.6	54.4
LSD (P=0.05)	55.5	203.2	213.5	219.7	159.3	NS
<i>p</i> -value	<.0001	<.0001	<.0001	0.005	0.003	0.225
<i>p</i> -value interaction	<.0001	0.956	0.879	0.915	0.978	0.928

Note: MWMb: Maize-Wheat-Mungbean, MCS: Maize-Chickpea-Sesbainia, MMuMb: Maize-Mustard-Mungbean, MMS: Maize-Maize-Sesbania

### Soil aggregation

The tillage and crop rotations had significant ( $P<0.05$ ) effect on water stable aggregates ( $>250\ \mu\text{m}$ ), mean weight diameter (MWD) and geometric mean diameter (GMD) for 0-15 and 15-30 cm soil depths (Table 4.13 and Table 4.14). In first soil profile (0-15 cm) the maximum water stable aggregates, MWD and GMD were recorded with PB plots, however in succeeding deeper soil layers (15-30 and 30-45 cm) these were maximum in ZT plots. ZT and PB plots showed 18 to 20.9% and 14.9 to 29.7% higher water stable aggregates (WSA), 34.4 to 37.8 % and 22.3 to 41.6% higher MWD, 24.5 to 26.5% and 16.7 to 31.5 % higher GMD compared to CT in 0-15 and 15-30 cm soil depth, respectively. Whereas, in 30-45 cm soil depth, WSA, MWD and GMD did not differed significantly ( $P<0.05$ ) by different tillage practices. The minimum values of water stable aggregates, MWD and GMD at all the soil depths were recorded under CT plots.

After harvesting of 19<sup>th</sup> diversified crops the diversified crop rotations significantly ( $P<0.05$ ) influenced the WSA, MWD and GMD, the highest were found in MCS rotation plots, which were 2.3 to 17.6%, 3.1 to 18.9 % and 5.1 to 16.2% (0-15 cm) and 6.7 to 24.4%, 1.4 to 13.8 % and 5.0 to 10.2% (15-30 cm) higher compared to MWMb, MMS and MMuMb rotations (Table 4.13 and Table 4.14). However, the significantly lower values of these parameters were recorded in

MMuMb system plots at all the soil depths. However, WSA, MWD and GMD were statistically at par in 30-45 cm soil layer across crop rotations. In general across the treatments (tillage and cropping systems) the soil water stable aggregates, mean weight diameter (MWD) and geometric mean diameter (GMD) were decreases with increasing soil depth. The interaction effect of tillage and crop rotations on WSA, MWD and GMD were non-significant ( $P < 0.05$ ).

**Table: 4.13.** Effect of long term tillage practices and diversified cropping systems on mean weight diameter and geometric mean diameter in different soil layers after seven maize crops.

Treatments	Mean weight diameter (mm)			Geometric mean diameter (mm)		
	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
<i>Tillage practices</i>						
Permanent bed	1.216	0.826	0.639	0.786	0.625	0.547
Zero tillage flat	1.183	0.908	0.667	0.756	0.667	0.565
Conventional tillage	0.858	0.676	0.635	0.598	0.536	0.534
SEm±	0.015	0.008	0.002	0.002	0.002	0.001
LSD (P=0.05)	0.136	0.104	NS	0.055	0.047	NS
<i>p</i> -value	0.003	0.008	0.210	0.001	0.004	0.389
<i>Cropping systems</i>						
MWMB	1.127	0.829	0.658	0.726	0.612	0.563
MCS	1.162	0.840	0.663	0.764	0.643	0.571
MMuMb	0.977	0.738	0.628	0.657	0.583	0.531
MMS	1.076	0.807	0.639	0.705	0.601	0.534
SEm±	0.013	0.005	0.005	0.003	0.002	0.002
LSD (P=0.05)	0.112	0.072	NS	0.055	0.040	NS
<i>p</i> -value	0.015	0.036	0.692	0.006	0.038	0.206
<i>p</i> -value interaction	0.975	0.983	0.807	0.349	0.864	0.996

Note: MWMB: Maize-Wheat-Mungbean, MCS: Maize-Chickpea-Sesbainia, MMuMb: Maize-Mustard-Mungbean, MMS: Maize-Maize-Sesbania.

#### *Saturated hydraulic conductivity*

The saturated hydraulic conductivity ( $K_{sat}$ ) of different soil layers were significantly influenced by different tillage practices. Tillage treatments had significant effect on  $K_{sat}$  for 0-15 and 15-30 cm soil layers. However, the tillage effect on  $K_{sat}$  was not observed for 30-45 cm soil layer (Table 4.14). Moreover, across the tillage and crop rotations, the  $K_{sat}$  decreased with increase in soil depths. The  $K_{sat}$  increased by 13.7 and 9.2% in PB plots and 10.2 and 10.1 % in ZT plots for 0-15 and 15-30 cm soil layers, respectively, compared to CT plots. The increase in  $K_{sat}$  under conservation agriculture practices (PB and ZT) was mainly attributed to decrease in bulk density and increase in effective pore volume because of better soil aggregation in these practices.

**Table: 4.14.** Effect of long term tillage practices and diversified cropping systems on different soil layers aggregation and saturated hydraulic conductivity after seven maize crops.

Treatments	Water stable aggregate (%)			Saturate hydraulic conductivity (cm/hr)		
	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
<i>Tillage practices</i>						
Permanent bed	69.1	58.7	54.4	1.043	0.950	0.704
Zero tillage flat	64.4	60.8	57.4	1.011	0.957	0.720
Conventional tillage	53.3	51.6	51.4	0.918	0.870	0.691
SEm±	31.6	37.2	19.7	0.019	0.018	0.022
LSD (P=0.05)	6.37	6.91	NS	0.076	0.070	NS
<i>p</i> -value	0.006	0.043	0.070	0.023	0.045	0.676
<i>Cropping systems</i>						
MWMB	64.8	58.5	55.9	1.011	0.940	0.720
MCS	66.2	62.4	56.4	1.019	0.942	0.723
MMuMb	56.3	50.2	51.0	0.932	0.889	0.669
MMS	61.6	57.1	54.2	1.001	0.932	0.709
SEm±	43.0	38.1	26.2	0.021	0.012	0.019
LSD (P=0.05)	6.49	6.12	NS	0.062	0.036	NS
<i>p</i> -value	0.024	0.005	0.142	0.033	0.021	0.215
<i>p</i> -value interaction	0.479	1.000	0.870	0.864	1.000	0.806

Note: MWMB: Maize-Wheat-Mungbean, MCS: Maize-Chickpea-*Sesbainia*, MMuMb: Maize-Mustard-Mungbean, MMS: Maize-Maize-*Sesbania*.

After harvesting of 19<sup>th</sup> crop grown in diversified crops sequences at fixed site, similar to tillage effects, the diversified crop rotations also significantly ( $P < 0.05$ ) affected the  $K_{sat}$  at 0-15 and 15-30 cm soil depths (Table 4.14). However,  $K_{sat}$  was not affected ( $P > 0.05$ ) by crop rotation at 30-45 cm soil depth. The  $K_{sat}$  increased by 9.3 and 5.9 % in MCS; 8.4 and 5.8 % in MWMB; 6.9 and 4.6 % in MMS in 0–15 and 15-30 cm soil layer, respectively, compared to MMuMb crop rotation. In general across the treatments (tillage and cropping systems) the hydraulic conductivity was decreases with increasing soil layers. The interaction effect of tillage and crop rotations was non-significant ( $P < 0.05$ ) on  $K_{sat}$  at all soil depths.

#### 4.11. Soil chemical properties

##### *Total and organic carbon*

Tillage practices had significant ( $P < 0.05$ ) effect on total soil carbon (TSC) and soil organic carbon (SOC) content of different soil layers (Table 4.15). The TSC and SOC content were significantly ( $P < 0.05$ ) higher in PB (17.5 to 20.2 and 21.5 to 31.9%) and ZT plots (15.5 to 20.9 and 21.5 to 31.7 %) than the CT plots for the soil depths 0-15 and 15-30 cm. However, the SOC content of PB, ZT and CT plots were statistically at par for the soil depth of 30-45 cm. In general both the carbon fractions were decreased in sub surface soil profiles under all the tillage practices.

**Table: 4.15.** Effect of long term tillage practices and diversified cropping systems on carbon content in different soil layers after seven maize crops.

Treatments	Total Soil Carbon (%)			Soil Organic Carbon (%)		
	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
<i>Tillage practices</i>						
Permanent bed	1.187	1.030	0.770	0.641	0.542	0.424
Zero tillage flat	1.167	1.035	0.785	0.640	0.550	0.430
Conventional tillage	1.011	0.856	0.723	0.486	0.446	0.410
SEm±	0.017	0.021	0.014	0.011	0.012	0.010
LSD (P=0.05)	0.066	0.084	NS	0.044	0.046	NS
<i>p</i> -value	0.003	0.007	0.077	0.001	0.006	0.396
<i>Cropping systems</i>						
MWMb	1.146	0.986	0.755	0.626	0.543	0.430
MCS	1.215	1.010	0.794	0.649	0.557	0.439
MMuMb	1.030	0.910	0.738	0.538	0.446	0.405
MMS	1.096	0.988	0.751	0.544	0.504	0.410
SEm±	0.019	0.019	0.021	0.013	0.012	0.015
LSD (P=0.05)	0.058	0.055	NS	0.040	0.034	NS
<i>p</i> -value	<.0001	0.007	0.279	<.0001	<.0001	0.351
<i>p</i> -value interaction	0.041	0.002	0.005	0.021	0.037	0.965

Note: MWMb: Maize-Wheat-Mungbean, MCS: Maize-Chickpea-*Sesbainia*, MMuMb: Maize-Mustard-Mungbean, MMS: Maize-Maize-*Sesbania*.

The effect of diversified maize based crop rotations on TSC and SOC contents were significant ( $P < 0.05$ ) for the surface soil layers (0-15 and 15-30 cm) (Table 15). Maximum TSC contents in both the soil depths was recorded in MCS sequence, which were 2.2 to 10.9 and 10.9 to 18.0% higher compared to MMuMb and MMS crop rotations, respectively. In all the soil depths MCS plots recorded higher carbon content over other crop rotations. Generally, across the treatments (tillage and cropping systems) the TSC and SOC content were decreases in sub-surface soil layers. The tillage and crop rotations had significant ( $P < 0.05$ ) interaction effect on TSC and SOC content of 0-15 and 15-30 cm soil layers.

#### *Available nutrients in soil*

The status of major nutrients, N, P and K were also significantly ( $P < 0.05$ ) influenced by different tillage practices in 0-15 and 15-30 cm soil depths (Table 4.16) after completion of 19<sup>th</sup> crops in sequence. The highest amount of N, P and K content (219.8, 24.9 and 203.1 kg/ha) in top soil surface (0-15 cm) was recorded under PB plots, however, in sub-surface soil layers (15-30 and 30-45 cm) depths the maximum amount of available N, P and K were recorded under ZT (204.3 and 165.0 and 17.5 and 9.6 and 179.5 and 126.5 kg/ha), respectively.

**Table: 4.16.** Effect of long term tillage practices and diversified cropping systems on available nutrients in different soil layers after seven maize crops.

Treatments	Available N (kg/ha)			Available P (kg/ha)			Available K (kg/ha)		
	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45
<i>Tillage practices</i>									
Permanent bed	219.8	196.8	160.4	24.9	16.7	9.4	203.1	174.1	126.4
Zero tillage flat	219.2	204.3	165.0	24.8	17.5	9.6	190.3	179.5	126.5
Conventional tillage	181.9	157.1	153.3	18.9	14.5	9.0	185.2	165.3	122.4
SEm±	5.21	4.37	3.73	0.65	0.36	0.26	2.68	2.45	2.59
LSD (P=0.05)	20.44	17.17	NS	2.56	1.41	NS	10.51	9.62	NS
<i>p</i> -value	0.011	0.003	0.198	0.005	0.010	0.347	0.021	0.036	0.500
<i>Cropping systems</i>									
MWMb	214.5	190.6	161.6	23.8	16.1	9.7	205.0	183.3	129.6
MCS	223.4	200.6	165.7	26.2	19.1	9.7	190.2	170.9	124.0
MMuMb	203.1	182.1	157.4	21.3	15.3	9.3	183.2	164.0	120.0
MMS	186.9	171.1	153.5	20.3	14.5	8.6	193.1	173.7	126.7
SEm±	4.43	3.77	6.28	0.89	0.54	0.45	4.41	4.39	4.16
LSD (P=0.05)	13.17	11.19	NS	2.64	1.60	NS	13.11	13.04	NS
<i>p</i> -value	0.0001	0.0002	0.5588	0.0008	<.0001	0.2379	0.0198	0.0434	0.4307
<i>p</i> -value interaction	0.813	0.978	0.999	0.756	0.305	0.725	0.927	0.449	0.061

*Note:* MWMb: Maize-Wheat-Mungbean, MCS: Maize-Chickpea-Sesbainia, MMuMb: Maize-Mustard-Mungbean, MMS: Maize-Maize-Sesbania.

In all the soil layers the minimum amount of available N, P and K were observed under CT plots. Moreover, the crop rotations significantly influenced the status of N, P and K in 0-30 cm soil depths (Table 4.16). At 0-15 and 15-30 cm depth increase in N (5.2-19.6%), P (10.2-31.7%) and K (5.5-11.9%) was found in MCS and MWMb compared to MMS and MMuMb plots. The lowest amount of available soil N and P K contents across the soil layers were recorded with MMS plots, while K was lowest with MMuMb plots. In general, the quantity of available N, P and K decreased with lower soil layers. However, the interaction effects of tillage and crop rotations were non-significant for N, P and K at all soil depths.

## CHAPTER-V

## DISCUSSION

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The experimental findings presented in previous chapter are discussed in this chapter. Attempts have been made to explain and confirm experimental results by establishing cause-effect relationship as far as possible and also citing experimental results supported by relevant finding of earlier workers, where ever it was felt necessary.

### **Weather conditions and crop growth**

Weather parameters play vital role in growth and development of crop plants. In general, the growth and productivity of *kharif* (rainy) season crops is directly correlated with season's weather conditions. A cursory appraisal of weather data of *kharif*, 2014 revealed that the mean maximum temperature was 34.7<sup>0</sup>C, and mean minimum temperature was 23.7 <sup>0</sup>C, with mean evaporation rate was 6.2 mm/day. In experimentation season 451 mm of rainfall received which was only 38% of previous year *kharif* season (2013). The long period average of annual rainfall at Delhi is 652 mm. During the study period the crop was suffered with prolong dry spells, high temperatures and high evaporation rate at reproductive stages. These adverse climatic conditions resulted reduction in potential yield of *kharif* maize crop. A close examination of weather data revealed that during the experimentation there was heavy rain immediately after sowing of crop and which also leads to poor germination and poor crop stand. Due to that the overall yield of maize crop was low in study period (*kharif*, 2014) as compared to previous year (*kharif*, 2013).

### **Growth parameters**

The different growth parameters *viz*, plant height, dry matter accumulation, leaf area, of maize was significantly differed at all the growth stages, except 30 DAS due to tillage and crop establishment practices. The highest values of all these growth parameters at 60 and 90 DAS of maize were observed in ZT flat planting, this might be due to better soil health and micro-environment created by continuous adoption of these resource conserving practices in diversified maize systems including legumes in sequence at fixed site since last six cropping cycles. However, the lowest values of these maize growth parameters were fetched with CT flat. The enhancement in growth is a function of better above and below ground environment in crop

production and similar finding was also reported under ZT and PB by Memon *et al.* (2014). Our findings of higher growth parameters of maize under ZT are in close agreement with earlier report of Jat *et al.* (2013). Ram (2006) also reported the higher values of plant height, dry matter accumulation, LAI, CGR and RGR under permanent beds with residue retention than no-residue in both ZT and CT practices. Similarly Tolk *et al.* (1999) reported that residue application with CA practices significantly improved all the growth parameters than no-residue under different tillage including bed planting, this might be due to improved soil physical environment; higher available soil moisture and nutrients, moderate soil temperature and lower evaporation losses from surface soil. The growth parameters were marginally higher under ZT and residue retention; this might be due to better soil health and micro-environment created by continuous adoption of these resource conserving practices. The CGR and RGR of maize did not significantly influence by different tillage practices at all the growth intervals, except between 30-60 DAS (coincides with grand growth phase of the crop). This enhancement of crop growth at later vegetative stages leads to higher values of all the growth parameters of maize. Yadav *et al.* (2005) also reported marginally higher growth parameters under CA based ZT planting than CT.

In our study the higher growth attributes of maize *viz.*, plant height, dry matter accumulation, leaf area and LAI of maize were recorded when it was sown in MCS cropping sequence. The exhaustive nature of maize plant to fetch higher yields and the growth extracts higher amount of nutrients from the soil is an expression of the soil nutrient availability. Thus, the inclusion of two legumes (chickpea and *Sesbania*) in MCS improved the residual soil fertility due to compound legume effect of both the legumes compared to one legume in other systems under study. Simultaneously, MCS system might help in enhancing the residual soil fertility and higher crop growth of maize compares to other system. The similar results of enhancement in maize growth parameters due to legumes inclusion were also reported by Memon *et al.* (2014) and Parihar (2014).

### **Yield attributes**

The CA based tillage practices (ZT and PB) lead to significant enhancement in yield attributes (grain rows/cob, grains/row, cobs/ha and cob length) of *kharif* maize raised after six diversified cropping cycles at fixed site in sandy loam soil of Indo-Gangetic

plains were reported over CT. At the same time the cob girth and 100-grains weight of maize were not significantly influenced by long-term effect of tillage practices which means these attributes are more genetically govern and needs other practices like genetic/breeding approaches, etc for their manipulation. In our study grain rows/cob, grains/row, cobs/ha and cob length were enhanced by ZT and PB over CT and these characters can be easily manipulated through manipulation in tillage management for higher maize yield.

The better crop growth at 30-60 DAS period under these CA practices lead to enhancement in crop CGR and RGR as well as the yield governing attributes of maize, because this is the crucial stages in deciding the number of grains/ row and grain rows/cob of the maize plant. The higher crop growth during this period might lead to increase the sink strength due to translocation of more photosynthates under ZT and PB practices. Hence, the superiority in yield attributes of maize with ZT and PB might be due to higher growth and better photosynthesis benefit derived by the crops during vegetative growth or panicle initiation period. Moreover, the maximum reproductive period of 52.0 and 51.3 days were recorded under PB and ZT, respectively which might help in better sink growth and ultimately resulted in higher yield attributes in our study. While working on maize the similar findings were also reported by Ahmad *et al.* (2010) and Parihar (2014).

However, the diversified cropping systems did not showed any significant effect on the grain rows/cob, grains/row, cobs/ha, cob length and 100-grains weight of maize crop plated after six diversified cropping cycles at fixed site. However, numerically higher values all these yield attributes of maize were recorded in MCS system over others and least values were under MMS cropping system plots. Similarly Raimbault and Vyn (1991) also reported the greater values of maize yield attributes where legumes incorporated in continuously grown maize under maize-legume system due to better physic-chemical properties of soil. Like CA practices the higher maize growth in MCS systems might lead to higher photosynthates translocation in sink and thus improved the sink strength. Being a nutrient exhaustive crop, the enhancement in maize yield attributes due to legume inclusion was also reported by several other workers; Tolk *et al.* (1999), Ram (2006) and Parihar (2014). Ojiem *et al.* (2014) reported that inclusion of legumes increased maize yield attributes due to better N supply.

## Yields

The adoption of CA practices significantly improved the grain, cob, stover and biological yields of maize after six cropping cycles at fixed site. However, irrespective of tillage and cropping systems treatments the shelling percentage and harvest index of maize were not significantly influenced and remained almost similar. It indicates that the tillage and cropping systems could not affect these parameters significantly because these parameters are genetically governed so here genetics play a major role. In our study the grain yield was 14.2 and 7.7 % higher under ZT and PB, respectively over CT practices. But the enhancement in stover yield was only 13.0 and 7.5 % in ZT and PB plots, respectively over to CT. It indicates that these CA based tillage practices (ZT and PB) leads to efficient utilization of source for higher sink (grain yield) advantage. It shows that CA practices improve the source-sink relationship. Though in our study the physiological indices (CGR and RGR) were not significantly influenced by the tillage practices both at early and later stage but during grand growth phase (30-60 DAS) significant difference in CGR lead to higher sink formation and better source-sink relationship. Moreover, the higher leaf area index (LAI) might helped in better photosynthesis and assimilation rate which resulted in more dry matter accumulation and better growth indices, these ultimately gave better performance of crop with regards to yield attributes under ZT and PB tillage practices. As under CA practices better growth parameters and yield attributes of maize were recorded in our study and these are directly correlated with grain, stover and biological yields of maize, might helped in enhancing the yields. Moreover, the higher reproductive period of the crop recorded in our study helped in proper grain filling upto the tip of the cob which in turn gave more yields under ZT and PB compared to CT. The growth parameters of maize were significantly higher under bed planting than CT, this might be due to better root growth (Aggarwal *et al.*, 2006 ), which might helped in better soil moisture extraction during dry periods and maintained the plant vigour. Growing of maize on permanent beds avoids the adverse effect of short-term water logging during heavy rains period and results in more efficient use of irrigation water and nutrients (Singh *et al.*, 2007). The higher yield of the maize in CA practices (ZT and PB) could be due to the compound effects of additional nutrients (Blanco-Canqui and Lal, 2008 and Kaschuk *et al.*, 2010) reduce competition for resources due to lesser weed

population (Ozpinar and Cay 2006 and Chauhan *et al.*, 2007), improved soil physical health (Jat *et al.*, 2013 ) and better water regimes (Govaerts *et al.*, 2009 ) with higher resource-use efficiency, aeration and efficient nutrient use over CT (Unger and Jones, 1998). Improved grain yield due to straw mulch in maize under no-tillage and permanent bed planting was also reported by Kumar *et al.* (2004) and Govaertz *et al.* (2005). However, in contrast to these findings, during initial two years maize yields were higher under CT compared to ZT in sandy loam soil (Chaudhary, 2011) and clay loam soil (Pal and Bhatnagar, 2014).

The diversified maize based cropping systems significantly influenced the cob, grain, stover and biological yields of maize. The grain yield increased by 4.9, 8.5 and 11.1% under MCS systems over MWMB, MMuMb and MMS, respectively. However, under same treatment the stover yield enhancement was much lower (2.0, 7.6 and 11.0%), which indicates that the inclusion of two legume in cropping sequence affects the nutrition of crop for better source-sink relationship. The source (photosynthetic area/biomass) of maize produced in lowest yielding cropping system (MMS) was also enough but it was not able to translate in the economic produce (grain yield) because of that the yield of maize was low in this system compared to other systems. The higher yield attributes and physiological indices of maize recorded under MCS lead to better crop growth which might help in enhancing maize yield over other systems. The enhancement in yield due to adoption of legumes in cropping systems was also reported by Sime *et al.* (2015) and Thierfelder *et al.* (2015). The inclusion of two legumes in maize based sequences enhances soil health (physical, chemical and biological properties), moisture availability, aeration and nutrient supplying capacity of soil due to legume effects, which helps in enhancing the yield and reducing the yield gaps of maize. Similar finding were also reported by (Pasuquin *et al.*, 2014).

### **Economics**

The net returns and BC ratio were significantly influenced due to different tillage practices. The maximum net returns (45,681 ₹/ha) and BC ratio (1.85 ₹/₹ invested) were recorded under ZT planting of *kharif* maize due to saving in labour, fuel, repair and machinery overhead charges, while minimum net returns (35,363 ₹/ha) and B C ratio (1.34 ₹/₹ invested) were obtained in CT. The returns to investment was much higher in ZT practices due to twin reasons *viz*; lower production cost by 1350 ₹/ha

and enhancement in yields, which lead to increase in net returns by 29% over CT. In our study ZT found to be economical as well as ecological viable option as compared to CT for maize. The similar results were also reported by Singh *et al.* (2014) at Udaipur. In contrast, Pal and Bhatnagar (2014) reported higher net returns in CT at Pantnagar due to lower yield of maize in heavy soil with ZT practices. Similarly, the net returns and B C ratio of maize were also differed significantly under diversified cropping systems and the highest net returns (44,973 ₹/ha) and B C ratio (1.78 ₹/₹invested) were fetched with MCS which was at par to MWMB and lowest was with MMS system planted maize. The higher net returns of maize planted under MCS system was due to that the inclusion of two legumes in this system provided an additional yields of maize compared to others cropping systems. The higher net returns with legume inclusion and their positive effects were also reported by Parihar *et al.* (2011), Khatri *et al.* (2014) and Paudel *et al.* (2015).

### **Nutrient uptake**

The different tillage and cropping systems made significant effect on N, P and K content and their uptake in maize crop grown after six cropping cycles at fixed site. The maximum total N, P and K uptake (134.7, 40.9 and 156.6 kg/ha) in maize stover and grain as well as the protein content (8.7%) in grains were recorded when crop was sown in ZT and minimum content and uptakes was in CT. The higher concentration of these nutrients in maize under CA practices might be due to better root development, which enhanced nutrient density in maize crop due to increased forage area for nutrient extraction under ZT and PB. Beside this, the retention of mungbean/*sesbania* residue recycled the nutrients in soil layers and ultimately enhances nutrient availability in crop root zone and which might leads to more nutrient uptake. In addition to this, the chelating forms of nutrients due to higher SOM content in ZT helps in retaining more nutrients with lesser losses of soil applied fertilizer nutrients.

The higher concentration of these nutrients along with higher yield ultimately leads to higher uptake (as uptake is derived by multiplication of nutrient concentration in grain and stover with respective yields). Moreover, these nutrients (NPK) are synergistic to each other in nature and uptake of one enhances the uptake of other as well. The higher concentration of N in grain caused enhancement in protein content of maize as this is one of the essential part of amino acid and basic

unit for protein synthesis. The similar finding of higher NPK uptake under ZT were also reported by Wani *et al.* (1995), Alam *et al.* (2014) and Naresh *et al.* (2014).

Beside this, in our study PB and ZT helped in increasing Fe and Zn density in *kharif* maize grain in the range of 33.8-36.2 and 16-16.3 mg/kg DM, respectively compared to low Fe (26.0 mg/kg DM) and Zn (14.8 mg/kg DM) content in CT plots. The more residues recycling and litter fall leads to higher Fe and Zn availability in crop root zone under CA compared to CT, which might increase the density of these nutrients in maize grain due to higher uptake. While in CT, all the residue got incorporated and goes in deeper soil layers than the effective root zone and thus creates the conducive situations for nutrients depletion in deeper soil zones (beyond the root zone). Both Fe and Zn are the critical nutrients for human and animal nutrition point of view and enhancement in their density might help in reducing hidden malnutrition. Thus, this indicates that the CA has potential for addressing the micronutrient malnutrition. Lavado *et al.* (2001), De Santiago *et al.* (2008) and Wozniak and Makarski (2012) were also reported the higher micro-nutrient concentration under ZT while Mehdi *et al.* (1999) and Gulbiak and Korzeniowska (2011) found similar micronutrient concentration under different tillage practices.

In our study maize planting in MCS sequence resulted highest nutrient uptake and the increase in total N, P and K uptake (grain + stover) by 18.2, 14.8 and 6.2% , respectively over to MMS planted crop. The maximum protein (8.96%), Fe (37.7 mg/kg DM) and Zn (17.3 mg/kg DM) content in maize grain was found under MCS planting crop after six cropping cycles at fixed site. The inclusion of deep rooted legumes with shallow rooted cereals in the systems might help in extraction of sub-surface nutrients to surface through leaf and twig fall. This in turn increases the nutrient availability in surface soil layers where maximum concentrations of maize roots were found. The higher nutrient availability might help in higher uptake of all the macro and micro nutrients (N, P, K, Fe and Zn). In addition to this the chelating agent forms due to adoption of legume/s in rotation helps in enhancing the Fe and Zn content in cereals which indicates that this might also be an option for biofortification in maize. The enhancement of NPK uptake due to inclusion of legumes has been earlier reported by Aziz *et al.* (2015) and Parihar (2014).

### **Input-use efficiencies**

Adoption of CA based management practices (ZT and PB) improved the water and energy use efficiencies in maize after six cropping cycles. The PB planting of *kharif* maize recorded highest water productivity (6.70 kg/ ha-mm) which was 27.9% higher over CT and found at par with ZT. The applied water was 18.6 and 11.7% lower in PB and ZT plots compared to CT, respectively with higher yields. Hence, the grain yield (output) was more with per unit of water applied in maize production under CA. The residue retention on soil surface decreases the evaporation losses which in turn increases soil moisture content and availability for crop growth in CA practices. The better root development in PB and ZT (Aggarwal *et al.*, 2006) leads to more water extraction by the crop and hence improved water productivity. The higher infiltration rate (Ferreras *et al.*, 2000) and hydraulic conductivity (Chen *et al.*, 2014) also maintains better water dynamics under PB and ZT practices compared to CT, which ultimately improves the water availability to crop plants. The enhancement in water productivity by adoption of ZT and PB practice over CT was also reported by Jat *et al.* (2005) and Parihar *et al.* (2011).

The *kharif* maize under MCS cropping sequence recorded the maximum water productivity (6.57 kg/ ha mm) which was significantly higher than MMS, but remained statistically at par to MWMB and MMuMB systems. Though the applied water was similar in all the treatments but the higher water productivity could be due to more yields of maize in MCS compared to other systems. Moreover, due to incorporation of two legumes added the additional amount of nutrients in root zone of maize which might lead to enhanced water productivity due to synergistic effect. Due to inclusion of two legumes in MCS system also leads to better soil physico-chemical conditions resulted in higher moisture storage and improved supply of water from the soil to maize crop, which ultimately resulted in higher yield and water productivity over the other systems. Our findings are in close conformity with Parihar *et al.* (2011) and Ram *et al.* (2011).

Adoption of ZT and PB in maize leads to higher energy efficiencies in our study than that of CT planting. The maize planting under CA practices (PB and ZT) resulted in higher net energy by 10-16%, energy efficiency by 34-40%, energy productivity by 32-40% and energy intensity by 15-21% over CT. The higher energy efficiencies might be due to two reasons; either due to less energy consumption by 3000 MJ/ha in CA compared to CT or due to higher production (which leads to more

energy output per unit of energy used) or both for production of maize. The energy accumulation capacity was higher in CA due to better crop growth environment in terms of higher nutrient availability, better root growth and modulation of climatic conditions with better water retention. The similar findings of higher energy output under CA were also reported by Chaudhary *et al.* (2006) and Parihar *et al.* (2011). The enhanced energy efficiency in CA practices compared to CT was also reported by Ram *et al.* (2010) and Parihar *et al.* (2011). Among the cropping systems, the highest net energy ( $195.5 \times 10^3$  MJ/ha), energy efficiency (15.3), energy productivity (1.26 Kg/MJ) and energy intensity (8.29 MJ/₹) were recorded when *kharif* maize crop was planted in MCS system over other cropping sequences. The energy efficient maize under MCS system was primarily due to higher yields compared to other systems, with same energy input and enhanced output per unit of input energy used. The reasons for higher productivity in this system discussed earlier under yield head. Thus, the higher productivity is one of the options for enhancing energy efficiencies of maize systems which was also reported by Parihar *et al.* (2011).

### **Soil physical properties**

The ZT and PB practices improved the soil physical properties with less penetration resistance and bulk density and improvement in aggregate stability. The BD of the soil at various depths, except in 40-60 cm soil profile (0-60 cm at 10 cm interval) was influenced significantly after 19<sup>th</sup> crop of maize. The more organic matter content and lesser trafficking of machinery and tractors in farm operations might lead to lower down the BD compared to CT. The similar findings of lower BD values were also reported by Yang and Wander (1999) and Salem *et al.* (2015). In contrast, some of the researchers also reported higher BD values in clay/silty loam soil under ZT (Kumar *et al.*, 2002 and Wilkens *et al.*, 2002).

Interestingly in our study, the soil BD was also significantly influenced due to different cropping systems (up to 40 cm soil profile) after taking 19<sup>th</sup> crop at same site. Among the diversified cropping systems, the BD values were lowest in MCS planted plots of maize and the maximum in MMuMb plots in all the soil layers. The higher BD may be due to lower soil organic carbon (SOC) content in this system compared to MCS system plots. Moreover, the roots of mustard might secrete some allelopathic substances/ secondary metabolites in root zone which further helped in reducing the soil biological activity and thus reduces the SOC. In contrast, the roots

of the chickpea and *sesbania* had lower C:N ratio due to that rapid/ better decomposition was took place leads to enhanced SOC as well as soil aggregation and which ultimately increases porosity and reduces BD of soil. The similar findings of lower BD due to pulses inclusion were also reported by Verhulst *et al.* (2011) and Thierfelder *et al.* (2012).

In our study the penetration resistance (PR) was also affected significantly by tillage practices except in 50-60 cm soil depth and it was recorded lower in all soil layers in CA practices. Thus, under ZT and PB the lesser PR values in effective root zone of maize crop (0-50 cm) found beneficial for better root growth. In sandy loam soil the higher soil organic carbon content in CA practices and lower BD both were contributed for lowering the penetration resistance which in turn helped in better root development compared to CT. Moreover, the compaction caused by plough pan development also enhances the resistance in soil which might also contribute for higher PR in repeated tilled soil. In contracts to this some workers reported higher penetration resistance in clay soil (Fabrizzzi *et al.*, 2005 and Afzalinia and Zabihi, 2013). However, some workers reported that CA practices reduce the penetration resistance (Yang and Wander, 1999).

In our study after harvest of 19<sup>th</sup> maize crop grown in continuous sequences with different crops at same site the highest penetration resistance (up to 2226 kPa) was recorded in MMuMb system plots at all the soil depths (0-60 cm), which was significantly higher over other three cropping systems. However, in upper surface soil layer ( up to 40 cm soil depths), the lowest penetration resistance (617 to 1789 kPa) was observed in MWMB sequence plots of maize and below 40 cm depth the PR was lowest in MMS plots. The organic matter content in soil has negative correlation with BD and PR, while BD has positive correlation with penetration resistance. Thus the high organic matter content and lower BD values in MCS system plots of *kharif* maize lowered the PR. The Bellakki *et al.*(1998) also reported similar findings.

The other soil physical properties *viz*; water stable aggregates (WSA), mean weight diameter (MWD) and geometric mean diameter (GMD) were significantly influenced due to different tillage practices adopted for planting 19<sup>th</sup> crop in sequences of different crops at same site in three soil layers. In 0-15 cm soil profile

maximum values of these parameters were recorded with PB plots, however, in succeeding deeper soil layers (15-30 and 30-45 cm) these parameters were maximum in ZT plots. The highest percentage of WSA, MWD and GMD were recorded in MCS plots at all the three different soil layers. However, the significantly lower values of the soil aggregation were recorded in MMuMb plots at all the soil depths. In general, across the treatments (tillage and cropping systems) the soil water stable aggregates, mean weight diameter (MWD) and geometric mean diameter (GMD) were decreased with increased soil depths.

The higher value of all these parameters was found in MCS system plots due to inclusion of two legumes which improve soil aggregation formation, biological activity and preserve more nutrients for plants due to more legume effect. Greater soil macro-aggregation in no-till systems due to reduced disturbance normally caused by ploughing has been reported by several authors (Filho *et al.*, 2002 and Pinheiro *et al.*, 2004). The crop residues retention on the soil surface lead to increase in soil organic carbon, which gives rise to improved soil aggregate stability (Limon-Ortega *et al.*, 2002). The retention of crop residues at the soil surface does not only increase the aggregate formation, but it also decreases the aggregates breakdown which reduces erosion susceptibility of aggregates against raindrop and wind erosion impact. Fresh residue forms the nucleation centre for the formation of new aggregates by creating hot spots of microbial activity (De Gryze *et al.*, 2005). Almost similar findings of improvement in MWD reported by Govaerts *et al.* (2007) and WSA by Beare *et al.* (1994) under ZT and PB compared to CT.

The saturated hydraulic conductivity ( $K$ ) was lower in deeper soil layers at 15–30 and 30-45 cm depths compare to top soil layer of 0–15 cm depth in all the treatments. The maximum value of  $K$  was measured under PB (1.45 cm/hr) in 0–15 cm soil profile, while in sub-surface profiles 15–30 and 30-45 cm soil depths it was maximum (1.22 and 1.13 cm/hr) with ZT, respectively. The highest  $K$  in all the three soil depths was recorded in MCS planted maize plots. However, the significantly lower values of  $K$  (1.33, 1.14 and 1.04 cm/hr) was recorded in MMuMb system plots at different soil depths, respectively. The higher value of  $K$  under ZT and PB were found due to greater number of macrospores and higher biological activity helps in formation of soil organic matter and increased soil  $K$ . In general across the treatments (tillage and cropping systems) the hydraulic conductivity was decreased

with sub-surface soil layers. The hydraulic conductivity of soil is more related with soil macro-pores (Rasse *et al.*, 2000) and disruption of macro-pores continuity by tilling of soil can reduce hydraulic conductivity (Logsdon *et al.*, 1990). The lower BD and penetration resistance and higher organic carbon found in ZT and PB practices while, MCS system might help in enhancing the soil hydraulic conductivity.

The higher value of  $K$  in MCS plots was due to inclusion of legumes which add organic matter and improve soil macro-aggregates, which facilitate easy movement of water in soil system compared to the other cropping system plots. However, Buschiazzo *et al.* (1998) in Argentinean pampas observed that a period of 2-3 years was not enough for recording tillage effect on hydraulic conductivity of sandy loam as well as in other soils. The similar finding of enhancement in  $K$  of soil due to CA practices reported widely by several workers while working in different agro-climatic conditions throughout the world (Osunbitan *et al.*, 2005; Bhattacharya *et al.*, 2006; Rasool *et al.* 2007 and Li *et al.*, 2011).

### **Soil chemical properties**

The soil nutrient balance after 19<sup>th</sup> crop planted in intensive maize systems was significantly differed with tillage and cropping systems. The slightly higher balance of available N and P in top soil layer (0-15 cm) was reported in PB which was at par to ZT. This might be due to more oxidation of organic material in top 15 cm soil layer of PB plots. But, in subsequent deeper soil layers N, P (15 to 45 cm depths, at 15 cm interval) and K (0-45 cm) content were higher in ZT plots which were at par to PB but significantly superior to CT plots.

The MCS system plots had higher available N and P in all the soil depths due to legume effect compared to other maize based sequences, while the available K was maximum with MWMb system. The lowest N and P across the different soil layers were recorded with MMS plots; however, K was lowest in MMuMb system. The recycling of the higher amount of previous crops residue due to higher biomass yield in these treatments lead to addition of more nutrients in ZT and PB practices compared to CT. While, in case of CT the stover/ straw get incorporated in deep soil layer and which leads to rapid decomposition due to anaerobic conditions and might also lead to leaching of mineralized nutrients in much deeper soil layers which in

turn reduces the available these nutrients in CT. Moreover, the chelating of these nutrients with organic matter in non-disturbed soil leads the improvement of soil nutrient status in different soil depths. In addition to this, the fungi present in the mungbean rhizosphere produces a glycoprotein 'glomalin' which entraps the nutrients in soil (Singh *et al.*, 2009) and thus causes enhancement of soil NPK status. The similar findings of enhancement in available nutrients due to CA practices in soil were also reported by Graham *et al.* (2002) Borie *et al.* (2006) and Wang *et al.* (2008) for N; Betro *et al.* (2007) and Malhi *et al.* (2011) for P and Du Preez *et al.* (2001) and Govaerts *et al.* (2007) for K. The enhancement in available NPK status due to ZT and PB practices was also reported by Parihar *et al.* (2011).

In our study we found build-up of carbon in soil due to CA practices and across the soil layers TC and SOC decreased with increasing soil depths. The carbon build up in soil was due to application of the more residues in ZT and PB than CT. Both TC and SOC were maximum under PB plots in upper soil layer (0-15 cm) while in deeper layers (15-45 cm) maximum in ZT plots. The adoption of CA practices (ZT and PB) enhanced SOC in different soil layers (0-15, 15-30 and 30-45 cm) in the range of 23 to 35% over CT in our study. Beside this, in our study ZT and PB also enhanced the TC in the range of 16 to 22% over CT. Tillage hastens SOM decomposition and reduces the carbon content by increasing the access of micro-organisms to SOM upon aggregate destruction (Six *et al.*, 1999 and Balasdent *et al.*, 2001). Aziz *et al.* 2015 also observed NT enhances the total carbon (30%), active carbon (10%) in corn-soybean-wheat-cowpea rotation. Moreover, the roots of the crops were also remained indicted in the root zone due to non-disturbance of the soil, which might facilitates movement of organic carbon in deeper root zones through capillaries formed due to the their decay. In addition to this, the more tillage increases the oxidation of SOM while ZT reduces it due to less mixing with soil (Thompson *et al.*, 2006). The enhancements in soil carbon content due to CA practices were also reported by Baker *et al.* (2007), Thomas *et al.* (2007) and Kaiser *et al.* (2014).

In all the soil depths MCS plots recorded higher carbon pools over to other cropping systems which might be due to narrow C:N ratio of legumes caused rapid decomposition of SOM and release & retention of more carbon in soil along with better aggregation. Thierfelder *et al.* (2012) also found 31% greater soil carbon by

inclusion of cowpea and sunhemp in maize systems. The positive effect of legume residue application in cereal cropping systems on soil carbon pools were also reported by Saha and Ghosh (2013).

## CHAPTER-VI

### SUMMARY AND CONCLUSIONS

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A field experiment was carried out at ICAR- Indian Agricultural Research Institute, New Delhi, India during Kharif, 2014 on sandy loam soil (Main Block 9 B research farm) to study the '*Performance of maize (Zea mays L.) under long term tillage practices and diversified cropping systems*' after six diversified cropping cycles at fixed site..

The important salient findings of the experiments are summarized as below:

1. Significant difference was observed in plant height, dry matter accumulation, leaf area and leaf area index (LAI) of maize at different crop growth stages among different tillage practices. The significantly higher values of these growth parameters were registered in ZT and PB at 60 DAS and at harvest over CT flat planting. However, the diversified cropping systems failed to show significant effect on these growth parameters.
2. Crop developmental parameters of maize (50 % silking, and days to maturity) were significantly influenced by different tillage practices and these were advanced by about two days in PB and ZT flat plots over CT flat, respectively. However, there is no variation observed in reproductive period, 50% silking and days to maturity due to different cropping systems.
3. The CGR was gradual increase with enhancement of growth stages with maximum values at 60-90 DAS while the RGR recorded a reverse trend in comparison to CGR. In most cases the maximum values of these indices were recorded in ZT and PB over CT, with respect to cropping system these were high under MCS plots over other cropping systems.
4. Cobs/m<sup>2</sup>, cob length, grain rows/cob and grains/row were significantly influenced due to conservation tillage practices. However, cob girth and 100-grains weight were statistically similar. Maximum values of cobs/m<sup>2</sup> (7.8), cob length (18.3 cm), grain rows/cob (13.8) and grains/row (35.6) were recorded under ZT, which was remain at par with PB and significantly higher over to CT. Non-significant effect of

diversified cropping systems was observed on cobs/m<sup>2</sup>, cob length, cob girth, grain rows/cob, grains/row and 100-grains weight of maize.

5. The ZT flat and PB registered increase of 14.2 and 7.7 % in grain, 13.0 and 7.5 % in stover and 13.7 and 6.2% in biological yields of *kharif* maize over CT at fixed site after six diversified cropping sequences. But the non-significant difference in harvest index and shelling (%) of maize was noticed under different tillage practices.
6. Amongst the diversified maize based cropping systems, highest grain, stover, biological yields and harvest index of maize was registered with MCS sequence plots, which is remain par with MWMB plots and significantly higher than MMuMb and MMS plots. The maize grain and stover yields in MCS sequence plots increased to the tune of 11.1, 8.5 and 4.9% and 11.0, 7.6 and 2.0% over to MMS, MMuMb and MWMB systems, respectively.
7. The maximum total N, P, K uptake (134.7, 40.9 and 156.6 kg/ha) as well as the protein content (8.7%) in maize grain were recorded in ZT, while these were minimum in CT. The accumulation of micronutrients (Fe and Zn) in maize grain was maximum (36.2 and 16.3 mg/kg DM, respectively) when crop was planted in PB plots and lowest under CT plots.
8. The *kharif* maize planted under MCS registered the highest amount of N, P, K content and uptake in stover & grain and protein (8.96%), Fe (37.7 ppm) and Zn (17.3 ppm) content in grain compared to other cropping systems plots.
9. The maximum net energy (197.3×10<sup>3</sup> MJ/ha), energy efficiency (16.4), energy productivity (1.35 kg/MJ) and energy intensity (8.50 MJ/Rs) of *kharif* maize were recorded under ZT planting which is remain at par with PB and significantly higher over to CT. PB and ZT planting registered 10.1 and 16, 33.9 and 39.6, 32.3 and 39.9 and 14.7 and 21.0 per cent higher net energy, energy efficiency, energy productivity and energy intensity, respectively over CT.
10. After six cropping cycles at fixed site the highest net energy (195.5 × 10<sup>3</sup> MJ/ha), energy efficiency (15.3), energy productivity (1.26 Kg/MJ) and energy intensity

(8.29 MJ/Rs) was recorded when *kharif* maize crop was planting in MCS system plots over other cropping sequences.

11. The highest water use efficiency (WUE) was obtained under ZT (2.16 kg/ha-m<sup>3</sup>), which was significantly higher than CT, but it remained statistically similar with PB plot. water use efficiency was also significantly influenced due to different cropping systems and maximum WUE (2.12 kg/ha-m<sup>3</sup>) of maize was recorded in MCS sequence plots.
12. The maximum net returns (45,681 ₹/ha) and B C ratio (1.85 ₹/₹ invested) were obtained under ZT flat planting of *kharif* maize, while minimum net returns (35,363 ₹/ha) and B C ratio (1.34 ₹/₹ invested) were obtained under CT, respectively.
13. The highest net returns (44,973 ₹/ha) and B C ratio (1.78 ₹/₹ invested) were fetched with MCS sequence plots planted maize, which is statistically at par with MWMB with net returns of (41,952 ₹/ha) and B C ratio of (1.78 ₹/₹ invested). However, the lowest net returns (37,216 ₹/ha) and B C ratio (1.48 ₹/₹ invested) was observed in MMS plots. The returns to investment was much higher in ZT practices due to twin reasons *viz*; lower production cost by 1350 ₹/ha and enhancement in yields, which lead to increase in net returns by 29% over CT.
14. The higher BD (1.53 to 1.67 Mg/m<sup>3</sup>) and penetration resistance ((809 to 2243 kPa) of different soil layers (0-60 cm) was recorded under CT after six maize cropping cycles. while these were lowest in ZT and PB. Among different soil layers and treatments the maximum BD and resistance were recorded at 30-40 cm soil depth.
15. The MWMB cropping sequence planted maize crop plots recorded the significantly lower BD (1.46 to 1.63 Mg/m<sup>3</sup>) and penetration resistance (622 to 1798 kPa), (PR) in different soil layers (0-60 cm at 10 cm interval). While the highest BD and PR of all the soil layers were observed under MMuMb plots.
16. The maximum TC (1.89), SOC (0.641 %), N (219.8 kg/ha), P (24.9 kg/ha) and K(203.1kg/ha) status recorded in PB plots in top soil profile (0-15 cm), while in sub-soil profiles (15-30 and 30-45 cm depths) these were higher in ZT plots (1.04

and 0.785 TC %, 0.550 and 0.430 SOC%, 204.3 and 165.0 N kg/ha and 17.5 and 9.6 P kg/ha) and 179.5 and 126.5 K kg/ha , respectively.

17. The adoption of ZT and PB enhanced SOC in different soil layers (0-15, 15-30 and 30-45 cm) in the range of 23 to 35% over CT in our study. Beside this, in our study ZT and PB also enhanced the TC in the range of 18 to 32% over CT.
18. The *kharif* maize planted under MCS plots registered the highest amount of TC, SOC and NPK content in all the soil layers (0-45 cm). These plots registered increase in TC by 2.2-18.0 %, SOC by 2.4-24.7% and available NPK by 4.2-31.7% in different soil layers compared to lowest soil health cropping sequences plots of maize.
19. The water stable aggregates, MWD GMD and saturated hydraulic conductivity were significantly influenced due to CA practices adopted for planting of 19<sup>th</sup> crops in different sequences at same site. In first soil profile layer (0-15 cm) the maximum water stable aggregates (69.1 %), MWD (1.216) and GMD (0.786) and saturated hydraulic conductivity (1.043 cm/hr) were recorded with PB plots, however, in succeeding deeper soil layers (15-30 and 30-45 cm) these were maximum in ZT plots.
20. After harvesting of 19<sup>th</sup> crop grown in diversified crops sequences at fixed site water stable aggregates, MWD GMD and hydraulic conductivity were differ significantly in soil surface and sub-surface profiles (0-15 and 15-30 cm) due to the different cropping sequences. The highest WSA (56-66%), MWD (0.663-1.162) GMD (0.571-0.764) and hydraulic conductivity (0.723-1.019 cm/hr) of all the three soil depths was recorded in MCS plots, respectively.

## **Conclusions**

- *Kharif* maize crop sown in conservation tillage based ZT and PB practices under diversified cropping systems resulted higher crop growth, yield attributes, yields, profitability, efficient nutrient use and quality.
- In long term experimentation the ZT and PB planting of maize under diversified cropping sequences improves the soil physical and chemical properties.

## सारांश

खरीफ 2014 के मौसम के दौरान भा.कृ.अनु.प.—भारतीय कृषि अनुसंधान संस्थान, नई दिल्ली, भारत की बलुई दोमट मृदा पर लगातार एक ही स्थान पर छः विविध सस्य चक्रों के बाद दीर्घकालीन जुताई क्रियाओं एवं विविध सस्य प्रणालियों के अन्तर्गत मक्का (जिया मेज एल.) के निष्पादन के अध्ययन के लिए एक प्रक्षेत्र प्रयोग किया गया। मक्का की शून्य जुताई एवं स्थाई शैया में परंपरागत जुताई की तुलना में अत्याधिक वृद्धि एवं उपज देखी गई लेकिन भुट्टे की मोटाई एवं 100—दानों का भार सांख्यिकीय रूप से समान रहा। परम्परागत जुताई वाली समतल शैया की तुलना में शून्य जुताई एवं स्थाई शैया में मक्का की 50 प्रतिशत सिल्विकिंग तथा पकने के दिनों में दो दिन की जल्दबाजी देखी गई। वृद्धि अवस्थाओं के आगे बढ़ने पर इसका अधिकतम मान बुवाई के 60—90 दिन बाद पाया गया जबकि अन्य अवस्थाओं में कमी दर्ज की गई। शून्य जुताई एवं स्थाई शैया में परम्परागत जुताई की तुलना में भुट्टे की उपज एवं दानों में क्रमशः 13.0 एवं 7.5 प्रतिशत तथा 14.2 एवं 7.7 प्रतिशत की बढ़ोतरी दर्ज की गई। उपज के गुणधर्म तथा उपज की मात्रा मक्का—चना—ढैंचा के क्रम में उगाई गई मक्का में सबसे ज्यादा पाये गये लेकिन कटाई सूचकांक एवं शेंलिंग प्रतिशत सभी सस्य प्रणाली खण्डों में समान पाया गया। अधिकतम कुल नत्रजन, फॉस्फोरस एवं पोटाश अवशोषण के साथ-साथ प्रोटीन (8.7 प्रतिशत), लोहा एवं जिंक की मात्रा मक्का की शून्य जुताई में क्रमशः 36.2 एवं 16.3 मि.ग्रा. प्रति कि.ग्रा. शुष्क भार पाई गई तथा यह मक्का—चना—ढैंचा सस्य प्रणाली खण्डों में भी अधिक थी। खरीफ मक्का में अधिकतम शुद्ध ऊर्जा ( $197.3 \times 10^3$  मेगा जूल/हे.), ऊर्जा दक्षता (16.4), ऊर्जा उत्पादकता (1.35 कि.ग्रा./मेगा जूल) एवं ऊर्जा गहनता (8.50 मेगा जूल/रू) शून्य जुताई के अन्तर्गत दर्ज की गई। अधिकतम जल उत्पादकता (2.16 कि.ग्रा./हे.— $\text{मि}^3$ .) स्थाई शैया के अन्दर पाई गई जो परम्परागत जुताई की तुलना में काफी अधिक थी लेकिन यह शून्य जुताई वाले भू-खण्ड के समान ही थी। अधिकतम शुद्ध लाभ (45,681 रू./हे.) एवं लाभ—लागत अनुपात (1.85 रू./रू. निवेशित) शून्य जुताई वाली खरीफ मक्का में देखा गया। शून्य जुताई प्रणाली के अन्तर्गत परम्परागत जुताई की तुलना में 1350 रू./हे. कम उत्पादन लागत तथा उपज में बढ़ोतरी के कारण शुद्ध लाभ 29 प्रतिशत अधिक था। सभी सस्य प्रणालियों में से मक्का—चना—ढैंचा में रोपण किये गये खण्ड से अधिकतम शुद्ध लाभ (44,973 रू./हे.) तथा लाभ—लागत अनुपात (1.78 रू./रू. निवेशित) प्राप्त किया गया जो मक्का—गेहूँ—मूँग के समान तथा मक्का—मक्का—ढैंचा में सबसे कम था। मक्का के सात सस्य चक्रों के उपरांत परम्परागत जुताई के अन्तर्गत विभिन्न मृदा तहों का अधिकतम स्थूल घनत्व (1.53 से 1.67 मेगा ग्रा./घन मी.) एवं भेदन प्रतिरोध सहिष्णुता (809 से 2243 किलो पास्कल) परम्परागत जुताई के अन्तर्गत दर्ज किया गया जबकि शून्य जुताई एवं स्थाई शैया में सबसे कम थे। विभिन्न मृदा तहों एवं उपचारों में से अधिकतम स्थूल घनत्व एवं भेदन प्रतिरोध 30—40 से.मी. मृदा गहराई पर दर्ज की गई। विभिन्न मृदा तहों में मक्का—चना—ढैंचा क्रम वाले खण्ड में सबसे कम स्थूल घनत्व (1.48 से 1.64 मि.ग्रा./घन मीटर) तथा भेदन प्रतिरोध (660 से 1954 किलो पास्कल)

दर्ज की गई जबकि ये मक्का-सरसों-मूँग खण्ड में अधिकतम थी। संरक्षित कृषि क्रियाएँ (शून्य जुताई एवं स्थाई शैया) अपनाने से विभिन्न मृदा तहों में मृदा कार्बनिक कार्बन (एसओसी) में 21 से 32 प्रतिशत तथा कुल कार्बन में 16 से 21 प्रतिशत तक परम्परागत जुताई की तुलना में बढ़ोतरी दर्ज की गयी। इसी तरह मक्का-चना-ढैंचा वाला खण्ड एन.पी.के. के स्तर को बढ़ाने के अलावा मृदा कार्बनिक कार्बन तथा कुल कार्बन को भी बढ़ाता है। शीर्ष मृदा प्रोफाइल में (0-15 से.मी.) अधिकतम जल स्थिर मृदा समुच्चय (69.1 प्रतिशत), औसत भार चौड़ाई, जी.एम.डी. (0.786) तथा जल चालकता (1.043 से.मी./घंटा) स्थाई शैया वाले खण्ड में दर्ज की गई। हालाँकि, निचली मृदा तहों में ये गुण शून्य जुताई खण्ड में अधिकतम तथा विभिन्न सस्य प्रणालियों में सबसे ज्यादा मक्का-चना-ढैंचा वाले क्रम में दर्ज की गई।

### ABSTRACT

A field experiment was carried out at ICAR- Indian Agricultural Research Institute, New Delhi, India during *Kharif*, 2014 on sandy loam soil to study the '*Performance of maize under long term tillage practices and diversified cropping systems*' with six cycles of diversified cropping system at fixed site. Significantly higher growth and yield attributes of maize was observed in ZT and PB over CT, but cob girth and 100-grains weight were remain statistically similar. The 50% silking, and days to maturity in maize were advanced by about two days in PB and ZT flat plots over to CT flat. The CGR values were gradually increased with enhancement in growth stages and maximum values were at 60-90 DAS, while the RGR recorded a reverse trend with CGR. ZT and PB increased grain yield by 14.2 and 7.7% in grain and 13.0 and 7.5% in stover yields over to CT, with respect to cropping system the yield attributes and yields were highest in MCS sequence planted maize but harvest index and shelling percentage remained similar in all the cropping systems. The maximum total N, P and K uptake as well as the protein (8.7%), Fe and Zn contents in maize grain (36.2 and 16.3 mg/kg DM, respectively) were recorded in ZT. Among the cropping system these were highest in MCS system plots as well. The maximum net energy ( $197.3 \times 10^3$  MJ/ha), energy efficiency (16.4), energy productivity (1.35 kg/MJ) and energy intensity (8.50 MJ/₹) were recorded under ZT planting. The highest water productivity was observed under ZT ( $2.16 \text{ kg/ha-m}^3$ ), which was significantly higher than CT, but it remained statistically similar with ZT flat. The maximum net returns (45,681 ₹/ha) and BC ratio (1.85 ₹/₹ invested) were observed under ZT planting. Under ZT practices the lower production cost by 1350 ₹/ha and enhancement in yields leads to increase in net returns by 29% over CT. Among the cropping systems plots the highest net returns (44,973 ₹/ha) and BC ratio (1.78 ₹/₹ invested) were fetched with MCS plots planted maize, which was statistically at par with MWMB and lowest in MMS plots. The higher BD (1.53 to 1.67  $\text{Mg/m}^3$ ) and penetration resistance (809 to 2243 kPa) of different soil layers (0-60 cm) was recorded under CT after seven maize cropping cycles, while these were lowest in ZT and PB. Among different soil layers and treatments the maximum BD and resistance were recorded at 30-40 cm soil depth. The MCS sequence plots of maize recorded significantly lower BD (1.48 to 1.64  $\text{Mg/m}^3$ ) and penetration resistance (660 to 1954 kPa), in different soil layers while these were highest under MMuMb plots. The adoption of CA practices (ZT and PB) enhanced organic carbon (SOC) in different soil layers by 21 to 32% and total carbon (TC) by 16 to 21% over CT. Among the cropping system MCS plot besides increasing soil NPK status also enhances the SOC and TC contents. In top soil profile (0-15 cm) the maximum water stable aggregates (69.1 %), MWD (1.216), GMD (0.786) and hydraulic conductivity (1.445 cm/hr) were recorded with PB plots, however, in succeeding soil layers these were maximum in ZT plots and among the cropping systems plots these were maximum in MCS sequence maize plots.

**Appendix I.** Mean weekly meteorological data during 2014.

Month	Std. week	Rainfall (mm)	Temperature (°C)		Relative humidity (M)	Relative humidity (E)	Evaporation (mm)
			Maximum	Minimum			
July	27	77.2	36.1	25.5	81.6	64.7	7.3
	28	0.0	40.2	27.9	69.9	54.9	9.8
	29	125.2	35.2	25.6	90.9	68.7	7.4
	30	12.4	33.8	26.4	88.9	74.3	5.9
Aug	31	40.6	34.6	25.9	93.7	74.4	5.5
	32	0.0	34.3	26.2	87.9	70.1	7.5
	33	41.7	34.9	25.6	88.4	61.3	6.9
	34	0.0	37.7	25.8	72.4	49.6	8.3
	35	51.2	36.7	25.3	81.1	63.1	6.8
Sep	36	115.0	32.1	24.1	93.9	72.7	4.7
	37	9.3	32.9	24.2	93.3	67.7	4.5
	38	0.0	35.1	24.2	81.0	50.3	6.5
	39	0.0	35.5	23.6	72.9	39.4	6.5
Oct	40	0.0	36.5	23.2	81.6	34.1	6.4
	41	0.0	35.0	21.1	80.4	31.6	5.3
	42	0.0	30.9	16.5	82.3	44.9	4.5
	43	0.0	32.1	17.1	89.3	42.0	3.6
	44	0.0	31.1	16.2	88.3	33.0	3.4

**Appendix II.** Treatment-wise cost of cultivation for one hectare maize crop in the experimentation during *kharif* 2014.

S. No.	Items	Rate	Amount (Rs.)	
A. Input			ZT & PB	CT
1. Land preparation and sowing	Disc harrow and cultivator	1050	450	2100
2. Seed	20 kg ha <sup>-1</sup>	110 kg ha <sup>-1</sup>	2200	2200
3. Thinning & gap filling	Labour (3 man days)	329 per man days	987	987
4. Fertilizer cost other than treatment	N: 150 kg ha <sup>-1</sup> (130 kg N) remaining is adjusted by DAP	11.76 per kg	1529	1529
	P: 60 kg P <sub>2</sub> O <sub>5</sub> ha <sup>-1</sup> (109 kg DAP)	22 per kg DAP	2398	2398
	K: 40 K <sub>2</sub> O kg ha <sup>-1</sup> (67 kg MOP)	16.80 per kg K <sub>2</sub> O	672	672
	ZnSO <sub>4</sub> . 2H <sub>2</sub> O: 10 kg	50 per kg	500	500
	Fertilizer application (3 man days)	329 per man days	987	987
5. Irrigation	Four irrigation	400 per irrigation	1600	1600
6. Insecticides	Chlorpyrifos 20 EC @ 1.5 liter ha <sup>-1</sup>	170 per liter	255	255
7. Manual weeding	Labour (4 man days)	329 per man days	1316	1316
8. Herbicides	Atrazine @ 1kg ha <sup>-1</sup>	290 per kg	290	290
	Labour (1 man days)	329 per man days	329	329
9. Watch and ward	15 man days	329 per man days	4935	4935
10. Harvesting	Labour (8 man days)	329 per man days	2632	2632
11. Shelling and cleaning	Labour (6 man days)	329 per man days	1974	1974
12. Bagging	Labour (2 man days)	329 per man days	658	658
13. Rental value of land	4 month	250 per month	1000	1000
Total			26362	24712
B. Output				
1. Main product	Grain	13100 per tone		
2. By-product	Stover	900 per tone		

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