STUDIES ON GREEN HOUSE GAS EMISSIONS AND CARBON SEQUESTRATION UNDER CONSERVATION AGRICULTURE IN MAIZE BASED CROPPING SYSTEMS

BY

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2005A28D

Dissertation submitted to Chaudhary Charan Singh Haryana Agricultural University, Hisar in partial fulfilment of the requirements for the degree of:

DOCTOR OF PHILOSOPHY
IN
AGRONOMY

DEPARTMENT OF AGRONOMY
COLLEGE OF AGRICULTURE
CCS HARYANA AGRICULTURAL UNIVERSITY
HISAR-125 004 (HARYANA)

2014

Certificate - I

This is to certify that this dissertation entitled, "**Studies on green house gas emissions and carbon sequestration under conservation agriculture in maize based cropping systems**" submitted for the degree of **Doctor of Philosophy** in the subject of Agronomy of Chaudhary Charan Singh, Haryana Agricultural University, Hisar, is a bonafide research work carried out by **Muli Devi Parihar, Admn. No. 2005A28D**, under my guidance and supervision and that no part of this dissertation has been submitted for any other degree.

The assistance and help received during the course of investigations have been fully acknowledged.

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CERTIFICATE-II

This is to certify that this dissertation entitled, "**Studies on green house gas emissions and carbon sequestration under conservation agriculture in maize based cropping systems"** submitted by **Muli Devi Parihar, Admn. No. 2005A28D** to Chaudhary Charan Singh Haryana Agricultural University, Hisar, in partial fulfilment of the requirements for the degree of **Doctor of Philosophy** in the subject of **Agronomy** has been approved by the Student's Advisory Committee after an oral examination on the same, in collaboration with an external examiner.

MAJOR ADVISOR **EXTERNAL EXAMINER**

HEAD OF THE DEPARTMENT

DEAN, POST- GRADUATE STUDIES

ACKNOWLEDGEMENT

"No bird can soar too high if it soars with its own wings……….". So I express my deep sense of gratitude with reverence to Dr. R.K. Nanwal, Professor, Department of Agronomy, CCS HAU, Hisar, the major advisor of my advisory committee for sagacious guidance and intellectual stimulation throughout the present study and in preparation of this manuscript. His scholarly suggestions, prudent adomitions, sustained interest, ungrudging help and affectionate behaviour have been a fountain of great inspiration to me.

I am grateful to my Co-Major Advisor, Dr. Pawan Kumar, Scientist, Department of Agronomy, for his continued support and encouragement throughout the whole period of my research. His timely guidance and suggestions cannot pass without mention.

My esteem and special acknowledgements are to Dr. Jagdev Singh, Professor and Head, Department of Agronomy, Dr. Dhindwal, Ex. Head, Department of Agronomy, Dr. R. P. Narwal, Ex. Director, Extension Education and Dr. Satish Kumar, Associate Dean PGS and all other member of the faculty.

I esteem it a privilege to record my profound sense of gratitude to Dr. S.K. Dhankar (Dean, PGS nominee), Department of Vegetable Science and also to the members of my advisory committee Dr. B.S. Duhan, Department of Soil Science, Dr. K.D. Sharma, Department of Botany and Plant Physiology, Dr. M.L. Jat, Sr. Cropping system agronomist, CIMMYT India, New Delhi, (external member) for providing enthusiastic encouragement, valuable guidance, suggestions and ready help during the entire course of investigation.

I am grateful to Dr. O.P. Yadav Director, DMR and Dr. R. Sai Kumar, Ex. Director DMR, New Delhi for their all kind of support to conduct my experiment successfully and also encouragement during the course of my study and investigation.

I feel gratified to record my cordial thanks to Dr. A.K. Singh, Pr. Scientist, Directorate of Maize Research (DMR), New Delhi and Dr. S.L. Jat, Scientist, DMR for their ready help whenever needed during the course of investigation.

Disction is not enough to express my cordial appreciation to Dr. Tek Sapkota, PDF, CIMMYT India, New Delhi, Dr. H.S. Jat, Scientist, (CSISA) CIMMYT India and Dr. J.M. Sutaliya Assistant Scientist, CIMMYT India, Dr. A.K. Parihar, Scientist, IIPR, Kanpur, Mr. Mukesh Choudhary, Scientist, IGFRI, Jhansi and Dr. B.R. Kuri, Research Associate, for their everlasting support and help during the research work and preparation of the manuscrip.

I off my sincere thanks to Dr. S.R. Kantwa, Sr. Scientist, IGFRI, Jhansi (UP) and Dr. Ghanshyam, AAO, Govt. of Rajasthan for their everlasting willing cooperation and help during the research work and preparation of the manuscript.

I sincerely acknowledge with heartfelt to all my friends, especially Anju, Dr. Rakesh, Krishna, R.N. Bhakar, Neelam, Babu Lal, Kamla, Indu, Prakash, Rakesh, Arvind, Kajod, Sarita, *Sangeeta Panday, Ramdhan, Vandana Choudhary, Ravindrnath, B.R. Gora, and B.R. Parihar whose cooperation and help in various ways brought this task to completion.*

I am void of words to express my sense of profuse reverence indebtedness and trustworthy affection to my in-laws and parents whose incessant love, dedicated efforts and everlasting inspiration were the great strength to me to accomplish higher studies.

I cannot find words to express my cordial appreciation to, my beloved husband Mr. Sanjay Singh Choudhary, my brothers C.M. Parihar and M.L. Parihar and Bhabhi's Santosh Hemlata, sister in-law Indu Singh and her husband Manish Kumar, brother in-law Karan Singh whose love and encouragement have been always and all ways to me. I feel pleasure to express my love and affection to my nephews Pankaj, Neeraj Yogesh, Ritesh and Dhairya whose smiles paved a way full of roses for me and will go on motivating me for a delightful future.

I express my thanks to Mr. Love Kumar Singh and Moonmoon Rai Research Associates, CIMMYT India and other field staff of the DMR, New Delhi for their precious service in conducting the experiment.

A very special word of appreciation goes to Mr. Sanjeev Kumar, DMR, New Delhi for typing this manuscript neatly and efficiently.

I am grateful to the CCAFS-CGIAR Research Programme and CIMMYT India, New Delhi, for granting me Research Scholarship supported under CCAFS during the course of investigation.

Last but not least, a million thanks to Almighty GOD, JAI BAJRANG BALI, who made me this task and made every job a success.

CCS HAU HISAR **(MULI DEVI PARIHAR)**
*Dated*__________________

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ABBREVIATIONS

CGR	: Crop growth rate
CSI	: Carbon sustainability index
CT	: Conventional tillage
CT-WR	: Conventional tillage- with residue
CT-WOR	: Conventional tillage- without residue
DAS	: Days after sowing
GHG	: Green house gases
GMD	: Grand mean diameter
LAI	: Leaf area index
MJ	: Mega joule
MWD	: Mean weight diameter
NAR	: Net assimilation rate
NUE	: Nitrogen-use efficiency
PB-WR	: Permanent bed-with residue
PB-WOR	: Permanent bed-without residue
R	: Crop residue
RGR	: Relative growth rate
RUE	: Resource use efficiency
SOC	: Soil organic carbon
SOM	: Soil organic matter
ZT	: Zero tillage
ZT-WR	: Zero tillage-with residue
ZT-WOR	: Zero tillage- without residue

CHAPTER-I

INTRODUCTION

Increasing world population, more particularly in South Asia will lead to higher demand of food, animal feed, fiber and fuel. India's food and feed security mainly depends on three major cereal crops *viz,* rice, wheat and maize. In recent years, with increasing competition for natural resources like land and water for human inhabitation and survival, meeting the global food demand for 9 billion strong populations will be a daunting task by the year 2050 .The target becomes more difficult when we keep in view of climate change and livelihood issues for farming communities. Food insecurity and loss of livelihood induced through climate change may even threaten the national security and it becomes an enigma for resource poor developing countries (Brown, 2008; FAO, 2006). The uncertainty about the pattern and impact of climate change on agriculture will challenge the sustainable development of the globe.

The climate of earth is a dynamic one promoting the evolution of various living forms and changing the structure and chemical composition of the atmosphere. Over the past few decades, acceleration in the human-induced changes in the climate of the earth has become the focus of scientific and social scrutiny. The gaseous composition of the atmosphere has undergone a significant change mainly through increased industrial emissions, fossil fuel combustion, widespread deforestation and burning of biomass as well as changes in land use and land management practices. These anthropogenic activities have resulted in an increased emission of radiatively active gases (Radiative forcing' is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the earth-atmosphere system and is an index of the importance of the factor as a potential climate change mechanism. Positive forcing tends to warm the surface while negative forcing tends to cool it) e.g., carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), popularly known as the 'greenhouse gases'. The atmospheric concentrations of carbon dioxide, methane and nitrous oxide were 280±6 ppm, 700±60 ppb and 270±10 ppb, respectively between the period 1000 and 1750 AD Today, these values have become 369 ppm, 1750 ppb and 316 ppb, respectively (IPCC, 2003). These greenhouse gases trap the outgoing infrared radiation from the earth's surface. The process, generally referred to as the greenhouse effect, adds to the net energy of the lower atmosphere and, therefore, results in atmospheric warming. The global mean annual temperature at the end of the 20th century has increased by 0.7º from that recorded at the end of the 19^{th} century. Diurnal temperature range has also decreased, with night time temperature increasing at twice the rate of day time maximum temperature. The 1990s were, on an average, the warmest decade of the earth since the starting of instrumental measurement of temperature in 1860's, and the twentieth century has been the warmest during the last 1000 years. Global warming, in turn, leads to regional changes in climate related parameters such as rainfall, soil moisture, and sea level. The extensive and frequent occurrence of climatic extremes such as droughts, heat and floods in the last decade in many parts of the world may be the fallout of this. The sea level has risen by 10-20 cm with regional variations (IPCC 2001). Similarly, snow cover is also believed to be gradually decreasing. The Inter-Governmental Panel on Climatic Change (IPCC) of the United Nations in its report for 2001 has projected using different models that the globally averaged temperature of the air above the earth's surface might rise by 1.4-5.8°C over the next 100 years (IPCC, 2001). The CO_2 levels are projected to increase to 388-399 478-1099 by 2100 using different models. For India, the area-averaged annual mean warming by 2020 is projected to be between 1.0 and 1.4°C and between 2.2 to 2.9°C by 2050. Relatively, the increase in temperature would be less in *kharif* (monsoon season) than in *rabi* (winter season). Agriculture accounts for approximately 10–12 per cent of total global anthropogenic emissions of greenhouse gases (GHG), which amounts to 60 per cent and 50 per cent of global nitrous oxide (N_2O) and methane (CH_4) emissions, respectively (Smith *et al.*, 2007). Methane is the second most important green house gas (GHG) after CO_2 and contributes 25% in global warming over an estimated period of 100 years. A single molecule of methane traps nearly 28 times as much heat, as does the CO_2 (IPCC, 2007). Methane emission measurement studies have indicated that the emission is mainly dependent on various parameters like frequency of water drainage (Baruah *et al.,* 1997), soil types (Cicerone *et al.,* 1992), soil temperature (Parashar *et al.,* 1991) apart from organic and inorganic fertilization (Xie *et al.,* 2010). George *et al.,* (1992) reported that in maize-wheat system the N dynamics are very different from rice-wheat and rice-rice system. Jat *et al.*, (2010) found that production systems under varied ecologies of South Asia revealed potential benefits of conservation agriculture-based crop management technologies in resource conservation, use efficiency of external inputs, yield enhancement, soil health improvement and adaptation to changing climates; The increase in N_2O since the pre industrial era now contribute a radiative forcing of + 0.16 $\pm$ 0.02 W m^2 and is due primarily to human activities, particularly agriculture and associated land use change. Current estimate are that about 40% of total N_2O emissions are anthropogenic but individual source estimates remain subject to significant uncertainties (IPCC, 2007). While Kroeze et al (1999) estimated approximately 17.6 Tg N_2O-N/year as total N_2O source strength (agriculture and other sources), the different estimates on agriculture – borne emission range from 1.4 to 18.9 Tg N_2O-N/year. Residue management in no-till systems (surface retention) help in regulates canopy temperature at the grain-filling stage to mitigate the terminal heat effects in wheat (Jat *et al.,* 2009), and significantly improves the C sustainability index (Jat *et al.,* 2011).

Sangar and Abrol (2005) found that conservation agriculture has emerged as a new paradigm to achieve goals of sustainable agricultural production. It is a major step towards transition to sustainable agriculture. Conservation agriculture (CA) involving continuous minimum mechanical soil disturbance, permanent organic soil cover with crop residues or cover crops and diversified, efficient & economical viable crop rotations provides opportunities for saving on inputs, improving resource use efficiency and mitigating GHGs emission and climate change adaptation. Conservation agriculture 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 (Wassmann *et al.*, 2009). It offers an opportunity for arresting and reversing the downward spiral of resource degradation, decreasing cultivation costs and making agriculture more resource – use-efficient, competitive and sustainable. It's potential to mitigate GHG potential is required to be further estimated in Indian perspective for assessing its suitability in the context of climate change. Sangar *et al.,* (2005) noticed that in Indo Gangetic Plains (IGP) with zero tillage technology, farmers were able to save on land preparation cost by about Rs. 2500/- ha and diesel consumption by 50-60 litres /ha. Lal (1994) noticed that soil compaction is caused by wheel traffic at the soil surface and formation of a plow-pan in surface layer. Hill and Cruse (1985) reported no significant effect of tillage methods (no tillage, ploughing tillage and minimum tillage) on bulk density of loess–derived Iowa soil. Mannering et al (1975) showed that as tillage intensity increase, soil aggregation decrease in Indian soil. Edwards et al (1998) concluded that no tillage effectively preserved the macro pores during the intercrop period, whereas tillage disrupted many of them. Alam *et al.*, (2005) reported that no tillage increase the proportion of macro aggregates (>2 mm) at 0-5 cm but not at 5-15 cm. The majority of SOC and SON storage under both CT and NT was observes in the largest aggregates size fractions (>2 mm, 250 ɥ m to 2 mm). The use of NT significantly improved soil aggregation and SOC and SON sequestration but not sub surface soil. Wright and Hons (2004) reported that NT management increased soil aggregation, produced higher concentrations of OC and N (sand free bases) in macro aggregates and stored soil organic carbon and SON in the 0-15 cm depth than CT. Doran (1980) found that the OC and Kjeldahl N content of surface soil (0-7.5 cm) with no till averaged 1.25 and 1.20 (25 and 20%) times higher respective for no tilled than for conventionally tilled soil.

A variety of options exists for mitigation of GHG emissions in agriculture. The most prominent options are improved crop and grazing land management (e.g., improved agronomic practices, nutrient use, tillage, and residue management), restoration of organic soils that are drained for crop production and restoration of degraded lands. Lower but still significant mitigation is possible with improved water and rice management; set-asides, land use change (e.g., conversion of cropland to grassland) and agro-forestry; as well as improved livestock and manure management. Many mitigation opportunities use current technologies and can be implemented immediately, but technological development will be a key driver ensuring the efficacy of additional mitigation measures in the future (IPCC, 2007).

The exact manner in which global warming is going to impact agriculture region wise is though not known but the broad indications are suggesting for increased frequency of heat waves, heavy and erratic precipitation along with prolonged dry spells. Recently in peninsular India area under rice-maize system is increasing at very faster rate due to less water availability for *rabi* rice and more profitability because of high yielding maize hybrids. Beside this, maize-wheat, maize-maize and maize-chickpea systems are also gaining popularity in Indo-Gangetic plains and central India due to declining water table and delayed rice transplanting which lead to heat stress in wheat. However, both rice and wheat are facing yield fatigues in the recent pasts resulting in declined total factor productivity. So, it is now crystal clear that resource degradation and climate change are emerging challenges. In this context, sustaining soil health, enhancing productivity and increasing the profitability on sustainable basis in long run needs urgent attention for food and nutritional security. Furhter, conservation agriculture practices (CA) presents a very promising opportunity for sustaining food security as a strategic platform by combating adverse effects of aberrant weather conditions and land degradation by buffering moisture and temperature and reducing the emission of global warming gaseous. 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 to quantify the green house gaseous emission potential of different emerging maize based cropping systems *viz*, maize-wheat, maize-maize and maize-chickpea under contrasting management practices. Hence, there is an urgent need to minimize losses due to climate with optimum use of nutrients and water under resource conserving practices to enhance production and sustain natural resource base. The proposed research work entitled "Studies on green house gas emissions and carbon sequestration under conservation agriculture in maize based systems" has been planned for execution at Directorate of Maize Research, New Delhi with following objectives:

1. To develop effective management practices for higher productivity and profitability in different maize based rotations under climate change.
2. To study the carbon sequestration potential of different conservation agriculture practices under various maize based systems.
3. To quantify the GHGs emissions reduction potential of conservation agriculture practices.

CHAPTER-II

REVIEW OF LITERATURE

An attempt has been made in this chapter to review the published literature pertaining to this investigation entitled "**Studies on green house gas emissions and carbon sequestration under conservation agriculture in maize based cropping systems**". Tillage refers to the different mechanical manipulations of the soil that are used to provide the necessary soil conditions favourable for crop growth. A proper tillage can alleviate the soil related constraints while improper tillage may leads to degradative processes, e.g., deterioration of soil structure, accelerated erosion, depletion of organic matter and fertility and disruption in cycles of water, organic carbon and plant nutrients (Lal, 1994). Sustaining production and productivity of any system is of paramount importance by improving the soil's physico-chemical and biological properties. Conventional tillage operations will alter these properties in every cropping cycle thereby affecting the soil system. Inefficient input use and management practices are leading to resource degradation, widespread contamination of surface and groundwater with connected health hazards. Resource conservation systems have drawn the attention of agronomists and other crop production scientists to devise innovative tillage and residue management techniques for efficient resource management and sustained productivity. Cultivation of agricultural soils has until relatively recently predominantly been achieved by inverting the soil using tools such as the plough. Continual soil inversion can in some situations 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). To combat soil loss and preserve soil moisture soil conservation techniques were developed in USA known as conservation tillage, this involves soil management practices that minimize the disruption of the soil's structure, composition and natural biodiversity, thereby minimizing erosion and degradation, control annual weed and seed bank but also water contamination (Anonymous, 2001).

Effect of conservation tillage practices and cropping systems

Maize

Growth and Yield

Various on-farm participatory trials revealed little or no difference in yield performance of zero-till maize when compared to best managed conventional crop (Gupta *et al.*, 2002a). Paliwal (2003) demonstrated how a successful zero-till maize crop could be grown using different management practices. Jat *et al.*, (2005) at Modipuram, Utter Pradesh reported that maize productivity was marginally higher with NT then CT practices. Similarly, Srivastava *et* *al.,* (2005) reported that the performance of QPM hybrids on a sandy loam soil was better under NT planting compared to CT with respect to yield, water productivity and profitability. A field experiment was conducted at PAU, Ludhiana by Ram *et al., (*2010) revealed that all the growth parameter (Plant height, dry matter accumulation and leaf area index), yield attributes (cobs/plant, grains/cob and 1000-grain weight) and yield performance of maize under different conventional and zero tillage practices were observed statistically at par. The yield of wheat, maize and soybean obtained under zero tillage were comparable to conventional tillage provided the seed were properly controlled (Mishra and Singh, 2005). Dhillon *et al.,* (1987) reported that the response of maize and wheat in sequence to different level of tillage (zero tillage and one/ four discing) for last 12 years that different tillage treatments had non-significant effect on grain yield of both the crops. Bachmann and Friedrich (2002) from Mongolia and Wall (2002) from Bolivia reported that no tillage with direct seeding of crop significantly increased the yield of crop. There was an average 17% yield increase across of soybean, maize and wheat crops compared to the conventionally tilled treatments. Pedersen and Lauer (2004) reported that the yields of wheat, maize and soybean obtained under zero tillage were comparable to conventional tillage provided the seeds were properly controlled. Contrarily, reduction in crop yield from no-tillage (Kaskarbayev *et al.,* 2002) against deep tillage amounted for 16% .Similarly, lower plant height, LAI, weight/cob, grain and stover yield of maize under minimum tillage then conventional tillage practices were reported by Singh *et al., (*2007) from IARI, New Delhi. Jat *et al.,* (2006) also reported marginally lower yields of maize under ZT than CT practices. The yield reduction in no-tillage had been explained by more weed infestation. However, water storage was higher in minimum or no-tillage treatments than conventionally tilled plots. Reducing the tillage practices resulted in lower grain yield of maize. Singh *et al.,* (2011) reported that mean decrease under minimum tillage was 6.8-12.1% in grain yield, and 5.9-17.1% in stover yield compared with conventional tillage.

Ram (2006) reported the higher values of plant height, dry matter accumulation, LAI, CGR and RGR under permanent bed with residue than no-residue under both ZT and CT practices. The similar results were also reported by Tolk *et al.,* (1999). A study conducted at IARI, New Delhi by Singh *et al., (*2009a) revealed that Bed planting significantly improved the yield of maize crop over flat planting. 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 conventional-tillage (CT) with an average productivity of 4.93 t/ha. Similarly, Srivastava *et al.,* (2005) reported that the performance of QPM hybrids on a sandy loam soil was better under FIRB and NT planting compare to CT with respect to yield, water productivity and profitability.

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). Ram *et al.*, (2005) reported that maize planted in trenches out yielded all over other methods of planting under early (May 20 and June 10) sown crop. However, under late sown (end June–early July) conditions, planting on raised beds or on ridges gave significantly higher yield than flat or trench sowing due to better drainage in bed planting. Aquino (1998) reported that farmers of Yaqui Valley obtained eight percent 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 during monsoon season at Ludhiana (India), Kaur and Mahay (2005a) obtained about 25% higher grain yield with one row per raised bed planting of maize than flat sowing. The higher yield in bed planting with one row per 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) conducted a field experiment on sandy loam soil in northern India and reported that yields of the highest yielding varieties were recorded an average 4 and 16% higher with permanent beds compared with CT and ZT-flat, respectively. Similarly, Singh *et al.,* (2007) reported relatively higher maize grain yield (6.9-14.6%) as compared with that of conventional tillage. Jat *et al.,* (2005) reported a notable increase in economic yield of maize being 19.2 and 28.9% with furrow irrigated raised bed (FIRB) planting (5.66 t/ha) compared to flat no-till (4.75 t/ha) and conventional till (4.39 t/ha) Planting systems, respectively.

Incorporation of legume stover (bambaranut, cow pea, groundnut, dry bean and soybean) compared to stover removal increased the total dry matter yield of maize (Svubure *et al.*, 2010). The total maize dry matter yield was greater even after legumes with stover removed (ranging from 4.41 to 9.91 t/ha) than after maize (2.16 to 2.26 t/ha) or one season fallow (1.57 to1.84 t/ha). 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 hundred-seed weight of maize on sandy soil environment of Nigeria. These treatments had 56-76% (when incorporated as green manure at 12 weeks) and 42.5- 61.49% (when incorporated as stover) of the total grain yield of maize produced by the inorganic fertilizer treatment, but gave significantly higher grain yield of maize than the natural fallow check

(Egbe and Ali, 2010).

Wheat

It has been reported that area planted with wheat adopting zero-till drill has been rapidly increasing and presently covered almost 2 million hectare in North-Western Plain Zone of India (Sangar *et al.,* 2005). McMaster *et al.,* (2002) found faster, more uniform and greater seeding emergence in zero tillage than in conventional tillage in 4 out of 6 years in the Central Great Plains, due to more favourable soil water levels in the seeding zone under zero tillage. Wilhelm *et al.,* (1989) recorded similar leaf area index, specific leaf weight, leaf area ratio, dry matter accumulation and grain yield but found the highest root weight of winter wheat in no-till treatment. Zero tillage led to improvement in growth and yield attributes, viz. plant height, effective tillers, grains/ear and 1000- grain weight, through the improvement was significant only for effective tillers were reported by Yadav *et al.,* (2005). Singh and Kushwaha (2000) studied the scope of zero tillage in wheat and reported that zero till had statistically similar plant dry matter accumulation, number of effective tillers, ear length, spikelets/spike, test weight, grain and straw yields as compared to conventional tillage. Studies conducted at PAU, Ludhiana by Kler *et al.,* (1992) reported slightly higher grains yield of wheat even after 10 year of continuous no-till rotation with maize, paddy, cotton and moong bean as compared to conventional tillage. Zhuang *et al.,* (1999) reported similarly yield of wheat under zero, minimum and conventional tillage. Kumar and Yadav (2005) and Gupta *et al.,* (2007) reported that yield performance of wheat was marginally better under ZT practices, this could be due to various favourable factors under ZT like proper placement of the seed in the narrow slit made by zero-seed drill, early emergence of wheat seedling and availability of higher moisture content which might helped the crop to compete with the crop sown under CT practices. Sen *et al.*, (2002) and Srivastava *et al.,* (2002) reported significantly higher yield of wheat under zero tillage than under conventional tillage system. Yadav *et al.,* (2005) reported that significantly higher (7.7%) grain yield of wheat was recorded with ZT in comparison to CT, and was mainly attributed to increase in effective tillers, grains/ear and 1000-grain weight in ZT. The conservational tillage (no-till) for wheat generally resulted in yields that were better than or equal to yields obtained with conventional tillage (Tripathi and chauhan, 2000; Nagarajan *et al.*, 2002; Mahey *et al.*, 2002; Yadav *et al.*, 2002a). Brar *et al.,* (2004a) reported from long term experiment that after 25 year wheat yield in maize–wheat sequence remained same in zero tillage and conventional tillage treatments. Mishra and Singh (2009) reported that variation in tillage systems did not influence the grain yield of wheat significantly except in 2002-03, where continuous ZT yielded significantly higher (5.13 t/ha) as compared to CT rotated with ZT (4.28 t/ha). Jat *et al.,* (2005) reported that productivity of maize-wheat system was marginally higher under NT than CT systems. Based on wheat and maize yield performance after 10 years of testing, Sayre *et al.,* (2005) reported yield improvements between 25-30% through adoption of zero-till seeding, appropriate rotations and residue retention as compared to the common practice of heavy tillage before seeding, mono-cropping and residue removal.

In Mexico, planting of wheat on beds and irrigation application in furrows had long been introduced. From a survey work it was concluded that by 1996, 90% of farmers in Mexico had adopted planting of wheat on raised beds. Sayre and Moreno (1997) reported that higher adoption of bed planting in Mexico was due to application of irrigation, less use of herbicides, insecticides and seed besides ease of mechanically cultivation. It was expected that in bed planting availability of nutrients of crop roots increase at optimum supply of water might be helpful in sustaining crop yield with less seed rate, less fertilizer and less water. In the Yaqui Valley in north-western Mexico, over the past 25 years more than 95% of the farmers have switched from using conventional technology and flood irrigation on the flat to planting raised beds (Aquino,1998). They were planted one to four rows on top of the bed, depending of the bed width and crop and irrigation water was applied in the furrows between the beds. Farmers had grown wheat on beds obtained 8% higher yields and saved nearly 25% in production costs, compared with the flood irrigation systems (Aquino, 1998). Bed planting provides a natural opportunity to reduce compaction by confining traffic to the furrow bottoms (Sayre, 2004). Kaur *et al.*, (2001a) reported that wheat grain yield was significantly higher under bidirectional and bed-planting methods than that unidirectional (22.5cm) and strip planting methods. Pulatov (2002) from Uzbekistan reported wheat grain yield 34.4, 39.6 and 35.7q/ha on zero tillage, bed planting and conventional flat planting. Kaur (2003) obtained higher grain yield and water-use efficiency of wheat under raised bed planting when the crop was planted on dry beds and irrigation was applied immediately after sowing and also when it was planted on beds prepared after applying pre-sowing irrigation. The dry sowing on beds following by irrigation helped to achieving higher germination count and tiller density. Tripathi *et al.,* (1999) at Mexico observed that raised beds gave significantly higher grain yield of wheat over conventional flat sowing by reducing the lodging score and increasing yield attributing characters. Beds confer additional advantages including reduced germination of *Phalaris minor*, reduced irrigation water requirement (30-50%), and reduced water lodging (Gill *et al.*, 1993). Tripathi *et al., (*1999) reported that bed planting of wheat reduced lodging (50-60%) as compared to flat sowing. Plant did not lodge in bed planting due to more silica content in bed sown wheat crop (Kaur *et al.,* 2001b). Similarly, many workers reported that wheat grown on beds with irrigation application in furrows resulted higher water-use efficiency and savings were recorded in cost of seed and irrigation application time (Dhillon *et al.*, 2000; Dhillon *et al.*, 2002; Singh *et al.*, 2002b). Yadav *et al.*, (2002b) also reported higher number of grains/spike and density of wheat planted on raised beds than conventionally sown wheat of flat. The lower tiller and spike density on beds were compensated by more grains/spike and higher grain weight (Dhillon *et al.*, 2004; Bhardwaj *et al.*, 2004; Sikka *et al.*, 2004).

However, Shivakumar and Mishra (2001) reported significantly higher shoot number, dry matter accumulation, number of ears and ear weight at harvest but non-significant difference in yield of wheat due to broad bed furrow sowing as compared to flat bed sowing. Singh *et al.,* (2001b) recorded less LAI, CGR and RGR in bed planted durum wheat than that bidirectional sowing but reported non-significant differences. Three rows per bed gave higher wheat grain yield under raised bed planting than that under conventional flat planting (Hobbs *et al.,* 1997; Khatri *et al.*, 2001). However Singh *et al.*, (2002a) reported that in timely sown wheat, there was non- significant difference in grain yield between two or three rows per bed. Nonetheless, under late sown conditions (December) three rows per bed resulted in significantly higher wheat yield than two rows per bed. Experiments conducted in different states of north western India showed that planting of two or three rows of wheat per bed produced grain yield similar to flat sowing. However, wheat sown on raised beds with three rows per bed out yielded than when sown with two rows per bed at Delhi (Aggarwal and Goswami, 2003). Mascagni and Sabbe (1990) reported by growing wheat on flat raised beds (76 inches wide) or on flat conventional beds that the seed bed type had no effect on grain yield. Similarly, Singh (1995) from Hisar, compared the ridge furrows system (1 row in the centre of furrow and 2 on the side of ridges) and flat bed system of planting wheat and obtained similar yield from flat conventional system and bed planted wheat. No significant differences in wheat yield were found between conventional tillage bed (CTB) straw incorporated and permanent bed (PB) systems where the residue was not burned (Sayre *et al.*, 2005). Ram *et al.,* (2010) reported that grain yield of wheat could not vary significantly among various treatments (different combinations of CT/ZT; flat/bed planting; residue/without residue). However, the effective tillers were less in bed planting treatments but higher grains/ear, and higher test weight compensated the low tiller density.

However, there are some situations where the performance of wheat on beds has been inferior to that on conventional tillage flats due to reduced tillering during vegetative stage due to water deficit stress in sandy loam soil (Sharma *et al.*, 2002). Ram (2006) reported that more soil temperature under beds than flat planting leads to lowers soil moisture and poor growth of the wheat crop. Yadav *et al.,* (2002b) reported potential problems with germination of wheat on beds due to rapid drying of soil surface in coarse-textured soils. Jat *et al.,* (2005) reported that the productivity of wheat was higher by 7.3 and 8.6% under flat no-till (5.56 t/ha) compared to no-till FIRB (5.18 t/ha) and flat conventional till planting (5.12 t/ha), respectively. They further reported that productivity of maize-wheat system was maximum (10.84 t/ha) under FIRB system of planting followed by NT and CT systems, respectively .Research findings over the past one and half decades has shown that wheat could be grown successfully on beds in North-West India, with similar or higher yield and lower irrigation water use than for conventional sowing (Dhillon *et al.*, 2000; Kaur *et al.*, 2001a; 2001b; Shivkumar and Mishra, 2001; Singh *et al.*, 2002b; Yadav *et al.*, 2002b; Kaur, 2003; Aggarwal and Goswami, 2003; Hobbs and Gupta, 2003; Sayre *et al.*, 2005).

Chickpea

Onyari *et al.,* (2010) reported tillage methods and sowing times independently influenced growth, biomass development, yield components and grain yield in Kabuli chickpea, Var ICCV-95423 under semi arid condition in Kenya. They also reported strip tillage was superior to conventional tillage in the parameters measured and time to 50% flowering and 50% maturity were not affected by tillage methods and sowing times. Chickpea (*Cicer arietinum L.*) is a hardy crop grown with residual moisture and on marginal soils that are unsuitable for other crops such as wheat (Saxena, 1984). In the early stages of growth most of the roots are confined to the surface layer of soil from 0-30 cm depths. As the surface soil dries out, root growth continues to deeper layers, where more moisture is available (Sheldrake and Saxena, 1979). Deep tillage or sub-soiling can be used to enhance axial root growth of chickpea by reducing soil strength (Allmaras *et al.*, 1998). The effects of tillage practice may vary, depending on the stage of growth of chickpea (Birch *et al.,* 1996). Dalal *et al.,* (1998) reported that early to mid sowing of the crop accompanied by zero tillage practice could enhance beneficial effects of chickpea in rotation with cereals. Birch *et al.,* (1996) observed that significant interaction between sowing time and tillage resulted in greater grain yield obtained from zero tillage than conventional tillage method. Dry matter (DM) accumulation of chickpea increased under all tillage treatments (Onyari *et al.,* 2010). In India Saxena (1984) reported a DM production range of 2950 to 6800 kg DM ha^{-1} while 4300 to 4800 kg DM ha^{-1} was reported by Kumar *et al.,* (2010). Kumar *et al.,* (2000) observed that availability of higher amounts of moisture during various stages of crop growth resulted in better crop growth (plant height and LAI), higher amounts of DM production and its translation to branches and thus grain yield. Flowering is a major adapative trait to survival and cultivation (Marx, 1985). It is estimated that major biotic and abiotic stresses reduce at least 50% realizable potential yield of chickpea in the major production areas of the world (Ryan, 1997). The time to physiological maturity is reported to range from 79 to 155 DAS by Kumar *et al.,* (1996) depending on the location and genotype. Abbas and Iraj, (2004) reported No-tillage chickpea yield was significantly higher (24-57%) than under reduced, minimum or conventional tillage. Felton and Marcellos (1997) stated that compared to cultivated fallows, chickpea yield was 10% greater following a no-tillage fallow after wheat. Lafond *et al.,* (1992) reported a 10% yield increase in filed pea with zero and minimum tillage. No-till, reduced tillage and Stubble retention system have been found to result in equivalent or even a higher crop yield compared to conventional tillage over a wide range of environment conditions (Francis *et al.*, 1987; Hodgson *et al.*, 1989; Hashemi-Dezfuli and Herbert, 1996).

Effect of residue management on crop productivity and soil fertility

Ram (2006) reported the higher values of plant height, dry matter accumulation, LAI, CGR and RGR of maize under permanent bed with residue than no-residue under both ZT and CT practices. Jat (2010) also reported the higher values of yield attributes of maize under residue applications with higher doses of N fertilizers. Ram *et al.*, (2010) reported higher yields of wheat under ZT with residue due to the cumulative effects of higher light interception more dry matter production, low soil and canopy temperature, more soil moisture, tillers, grains/ear and 1000-grain weight than no-residue application under ZT practices , as well as CT practices. Bakht *et al.,* (2009) reported that on average, crop residue incorporation increased the wheat grain yield by 1.31 times and straw yield by 1.39 times. Improved grain yield due to straw mulch in maize under no-tillage and permanent bed planting was also reported in earlier studies by Tolk *et al.,* (1999) ; Govaerts *et al.,* (2005). The similar results were also reported by Sen *et al.,* (2002); Mahey *et al.,* (2002); Brar *et al.,* (2004b) and Kumar *et al.,* (2004) in earlier studies. Wall (1999) from Bolivia reported that wheat yields were lowest under zero tillage without soil cover while the highest yields were obtained under no-tillage with soil cover. Talukder *et al.*, (2004) from Bangladesh reported that straw retention (50 to 100%) or permanent beds produced higher crop yields than straw removal. The retention of 50% straw significantly increased the grain yield of maize by 32% over straw removal. Similar effect was observed in rice and wheat. They suggested that straw retention on permanent bed planting could act as restorative management and would have positive impact on soil health based on 12 years experimentation, Govaerts *et al.,* (2005) reported that permanent bed planting along with rotation and residue retention had the advantages in yield potential of wheat and maize. Thus residue management under permanent bed planting and zero tillage improved the productivity of crops. The cereal-dominated crop rotation practices in India excessively deplete the organic matter and nutrient content of soil following the removal of crop residues. Due to economic considerations, major emphasis has been given in these agro-ecosystems to maximizing the grain yield (a fraction of total net productivity) rather than to the total biological productivity. The impact of previous crop residues on the level of soil fertility in the subsequent crop has received scant attention in crop production systems (Singh and Kushwaha, 2000). The application of organic matter in the form of plant residues has long been known to improve the properties of soils, especially the soil organic matter content (Blevins and Frye, 1993). The return of plant residues to soil improve soil structure (Martens, 2000), which is related to the amount and quality of the residues. Crop residues also reduce evaporation which is also important on soils that have low water holding capacities (Unger, 1994). Crop residue application aids nutrient recycling, improves soil structure, and accumulates organic matter in the soil, (Agboola and Unamma, 1991).

Soil physical parameters as influenced by conservation tillage practices and cropping systems

Bulk Density

Several research workers have reported the higher bulk density (BD) under ZT than CT practices (Kumar *et al.,* 2002; Meena and Behera, 2008; Bhattachaya *et al.,* 2008). Ram *et al.*, (2010) from Punjab reported higher BD values under continuous ZT practices than CT practice, but lower values of soil BD under residue applied treatments than without residue ZT practices in maize-wheat cropping system. Jat *et al.,* (2005) also reported lower BD values under raised beds then flat system due to looseness and lower soil compaction. Bautista *et al.,* (1996) working in a semi-arid ecosystem found that zero- tillage plus mulch reduced the BD. The similar results were also reported by Obalum and Obi (2010). Mean yearly soil BD at a depth of 0-200 mm was greater under NT (1.52 g/cm^3) than under CT (1.42 g/cm^3) when averaged across all crops (Franzluebbers *et al.,* 1995). Hu *et al.,* (2007) in their four years study at Luancheng, China reported that NT significantly increased the topsoil (0-5cm) BD, while reduced tillage maintained a lower BD as CT. Therefore, NT increased the topsoil BD remarkably, which indicated that the soil compactness under NT was increased after 4 years. Camara and Klein (2005) reported that soil chiselling under no-tillage decrease the bulk density and particle density. In a long-term experiment at a fixed site in Heinlongjiang province, China, five different tillage systems were compared for their effects on the BD. The treatment of reduced tillage had a lower BD in summer than the other treatments (Yu and Zhang, 2007). Across soil textures varying from sandy loam to clay loam, BD was greater under zero than under mould board tillage in the top 20 cm of the soil profile (Kay and Vanden Bygaart, 2002). Gal *et al.,* (2007) observed higher BD in the 0-30 cm layer under zero than under conventional tillage on a silty clay loam after 28 years, but no difference in the 30-100 cm layer. Tillage is temporary, and after tillage, soil rapidly settles, recovering its former BD (Lampurlanes and Cantero-Martinez 2003). Gwenzi *et al.,* (2009) stated that the conversion from conventional tillage to minimum tillage and no- tillage had no noticeable effects on BD even after six years. In another study, Bell and Raczkowski (2008) reported that no-tillage increased BD of a sandy loam soil from 1.3-1.5 g/cm^3 within a year due to natural setting and consolidation. Ozpinar and Cay (2005) found that minimum tillage systems provided lower BD at 0-20 cm due to loosening the surface soil by rotary tiller and disc, while conventional tillage had lower BD at 20-30 cm soil depth due to mould board plough. Verhulst *et al.,* (2011) in their study reported that most of the physical soil parameters measured were significantly affected by tillage-straw system, only BD showed no effect. Fabrizzi *et al.,* (2005) also showed higher BD and penetration resistance in NT experiments in

Argentina, but the values were below thresholds that could affect crop growth; Wheat yields were the same as in the tilled treatments. This experiment left residues on the surface in NT. The authors concluded that the experiment had a short time frame and more time was needed to assess the effect on BD.

Hydraulic conductivity

Hydraulic conductivity was lower with ZT than conventional practices due to higher BD and compaction in surface as well as sub surface layers has been reported by Singh *et al.,* (2002c). Ferreras *et al.,* (2000) found that infiltration and/or hydraulic conductivity were lower under NT than inversion tillage. Williams and Weil (2004) reported that hydraulic conductivity was higher on beds than flat system of planting. Residue as mulch on soil surface increases the hydraulic conductivity due to it adds the organic matter in the soil which improves the soil macro aggregates that might facilitate easy movement of water in the soil (Das *et al.*, 2001; Rasool *et al.,* 2007). Hydraulic conductivity and infiltration can be improved and evaporation can be decreased by no-tillage and crop residue cover (Li *et al.*, 2011). However, Buschiazzo *et al., (*1998) also observed that a period of 2-3 years was not enough for tillage to affect hydraulic conductivity of sandy loam and other soils in Argentinean pampas. Saturated hydraulic conductivity was found to be positively and significantly related with the total macro-pores of soil (Rasse *et al.*, 2000). Disruption of macro-pores continuity by tillage can reduce hydraulic conductivity (Logsdon *et al.*, 1990). Azooz and Arshad (1996) reported that the saturated hydraulic conductivity values were significantly greater in NT (0.36 to 3.0 cm/hr) than in (0.26 to 1.06 cm/hr). Bhattacharyya *et al.,* (2007) observed increments in hydraulic conductivity up to 45 cm depth after 8 years of farmyard manure application in a silty clay loam soil of India. Unsaturated hydraulic conductivity increased more with increasing matric potential (Less negative) in NT than in CT. Soil saturated hydraulic conductivity at 8 weeks after tillage decreased with increased intensity of soil manipulation by tillage the highest conductivity was recorded under no -tillage and the least under plough harrow (Osunbitan *et al.*, 2005). Saturated hydraulic conductivity 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 (Bhattacharya *et al.,* 2006). Rasool *et al.,* (2007) were reported higher hydraulic conductivity in fertilized plots (N_{120} P_{30} K_{30}) than control (no external sources of nutrients were applied).

Soil moisture

Increasing water storage within the soil profile is necessary to increase plant available soil water. The management of soil through tillage changes the water storage and evaporation losses. De vita *et al.,* (2007) stated that higher soil water content under no-till than under conventional tillage indicated the reduced water evaporation during preceding period. They also found that across growing season, soil water content under no-till was about 20% greater than under conventional tillage. However, Rashidi and Keshavarzpour (2007) reported that conventional tillage had higher moisture content than no-till and reduced tillage. They further stated that mouldboard plough and secondary tillage implements used in conventional tillage improved soil porosity and water holding capacity. Almaraz *et al.,* (2009) reported that the NT system had, in most of the cases, slightly higher moisture levels than CT but significant differences were not detected. The largest difference in soil water content (SWC) with NT compared with CT was at the 0-50 mm depth in all crops, averaging 32% greater in sorghum, 26% in wheat, and 13 % in soybean Franzluebbers *et al.,* (1996). Crop residue mulching can significantly reduce the soil evaporation and improve the soil water storage (Zhang *et al.*, 2007). Sharma *et al.,* (2011) reported that no-tillage retained the highest moisture followed by minimum tillage, raised bed and conventional tillage at different soil depths. Taser and Metinoglu (2005) and Munoz *et al.,* (2007) found that soil moisture content was greater under no-till than under conventional tillage at 0-15 cm soil depth because crop residue left on soil surface in no-till system protected against evaporation losses more effectively.

Soil Aggregation

Soil structure stability is the ability of aggregates to remain intact when exposed to different stresses. 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). Aggregated soil structure is the most desirable condition for plant growth, because it has a beneficial influence on soil moisture status, nutrient dynamics, and soil tilth (Hillel, 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. In a tillage comparison experiment, Fray *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.,* (1994a) reported that soil (0 to 5 cm layer) from CT plots had fever water stable aggregates (> 2mm; sand-free basis) and lower total C and N concentration than soil from adjacent plot under NT for the same length of time (13 years). 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; Pinheiro *et al.,* 2004). Wright and Hons (2004) reported that NT management increased soil aggregation, produced higher concentrations of soil organic carbon (SOC) and soil organic N (SON) in macro-aggregates and stored more soil SOC and SON in the 0-15 cm depth than CT. Numerous studies showed that no-tillage practices, with crop 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). Madari *et al.,* (2005) showed that NT with residue cover had higher aggregate stability, higher aggregate size values and total organic carbon in soil than CT in Brazil. Research on conservation agriculture showed that no-till with stubble retained treatment had more water stable aggregates (Zhang *et al.*, 2009). Retaining crop residues on the soil surface lead to a increase of soil organic carbon, which give rise to improved soil aggregate stability (Limon-Ortega *et al.*, 2002) and the return of biological diversity to the soil, particularly earthworms (Chan, 2001). The retention of crop residues at the soil surface does not only increase the aggregate formation, but it also decreases the breakdown of aggregates by reducing erosion and protecting the aggregates against raindrop impact, an effect that is lost when the residues are burned. Fresh residue forms the nucleation centre for the formation of new aggregates by creating hot spots of microbial activity where new soil aggregates are developed (De Gryze *et al.*, 2005).

Govaerts *et al.,* (2007) reported that soil from permanent raised beds (PB) with full residue retention had significantly higher mean weight diameter (MWD) for wet and dry sieving compared to conventionally tilled raised beds (CTB). 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). However, there was no significant difference in dry aggregate distribution between CTB-incorporated and PB-straw retained, but aggregates were weaker to resist water slaking in the CTB resulting in a lower MWD obtained through wet sieving and a higher dispersion index.

Reports in literature on the effect of residue on water stable aggregates (WSA) are also mixed. Unger (1997) found no difference in MWD of WSA between no-till and cultivated Torrentic Paleustolls in Texas. However, he observed that in some cases the percentage of small aggregates was larger in the no-till than on the plough till treatment. Beare *et al.,* (1994b) reported that plough till reduced the size of WSA compared with no-till on a well drained sandy clay loam in Athens. The use of NT significantly improved soil aggregation and SOC and SON sequestration in surface but not sub-surface soils (Wright and Hons, 2005). Crops can influence aggregation because the roots, especially fine roots, and organic substances released from roots may contribute to aggregate formation, Shrinkage and numerous small cracks Hillel (2004). Moreover, the C:N ratio and bio-chemical properties of crop residues that affect residue decomposition and SOM dynamics also influence soil aggregation Martens (2000). Cropping systems that include crop rotations are often beneficial for soil aggregation. Barley-forage rotation increased MWD by 6.7% in mould board ploughing system and 33.3% in chisel ploughing system, compared to the barley monoculture Bissonette *et al.*, (2001). Wright and Hons (2005) reported that a wheat-soybean rotation stored 36.7% more SOC and 40% more SON in the 5-15 cm layer under CT than a continuous monoculture soybean after 20 years. Better soil structure and soil physical properties, namely macro-porosity, aggregate stability and higher infiltration have been reported under conservation tillage, when compared with conventional tillage. However, little information on long term changes of these properties under conservation tillage is available. As many of these soil qualities are associated directly or indirectly with soil organic carbon levels, the lack of significant increase in the latter suggests that many of these improvements may not be sustainable in the long-term, particularly in dry areas (Chan *et al.*, 2003). In Brazil Marcolan *et al.*, (2007) reported that by tilling the soil at lime incorporation after four years of no-tillage, bulk density and porosity improved, but the aggregate stability decreased. They further reported that four years under no-tillage were necessary to recover the original aggregate stability condition. Soil physical attributes were more uniform in conventional tillage, but the aggregate stability in the surface layer was lower and was related to organic carbon content.

Seasonal variation in GHG emission

Generally, one or two distinct seasonal maxima are observed in tropical lowland rice fields, such as in irrigated rice, those are kept flooded during the entire growth season. The first maximum may occur within 4 weeks after flooding and is governed by methane production from soil organic matter and organic amendments (Neue *et al.*, 1994). This early maximum is pronounced in fields that received organic manure, whereas fields with low organic inputs generally show a gradual increase of emission rates in the early stage of the growing season. Ebullition is the dominant transport pathway in this stage when rice plants are still small or may not even be seeded or transplanted (Wassnamm *et al.*, 1995). Rice fields are mostly flooded for land preparation 2 – 4 weeks before transplanting so the initial peak of emission may be missed when monitoring CH_4 fluxes is only during crop growth.

Mitigation options for GHG (CH_4 & N_2O) emission.

Daming Li *et al.*, (2011) carried out field experiment to investigate the methane emission pattern in double-rice cropping system under conventional and no tillage in southeast China. They observed that the seasonal amount methane flux of late rice was reduced by 29% and 68% in the conventionally tilled and no-tilled treatment, respectively. The decrease of methane emission in the no-tillage treatment was attributed to lower dissolved organic carbon (DOC) content and higher soil bulk density.

No-till farming reduces the unnecessarily rapid oxidation of soil organic matter to CO_2 which is induced by tillage (Reicosky, 2008; Nelson *et al.*, 2009). Together with the addition of mulch as a result of saving crop residues in situ as well as through root exudation of carbon compounds directly into the soil during crop growth, there is a reversal from net loss to net gain of carbon in the soil, and the commencement of long-term processes of carbon sequestration (West and Post, 2002; Blanco-Canqui and Lal, 2008; CTIC/FAO, 2008). Making use of crop residues and the direct rhizospheric exudation of carbon into the soil represents the retention of much of the atmospheric C captured by the plants and retained above the ground. Some becomes transformed to soil organic matter of which part is resistant to quick breakdown (though still with useful attributes in soil), and represents net C-accumulation in soil, eventually leading to C-sequestration. Tillage, however, results in rapid oxidation to CO_2 and loss to the atmosphere.

Expanded across a wide area, CA has the potential to slow/reverse the rate of emissions of CO_2 and other greenhouse gases by agriculture. Studies in southern Brazil show an increase in carbon in the soil under CA. According to Testa *et al.,* (1992), soil carbon content increased by 47 % in the maize–lablab system, and by 116 per cent in the maize–castor bean system, compared to the fallow–maize cropping system which was taken as a reference. Although exceptions have been reported, generally there is an increase in soil carbon content under CA systems, as shown by the analysis of global coverage by West and Post (2002). In systems where nitrogen was applied as a fertilizer, the carbon contents increased even more. Baker *et al.,* (2007) found that crop rotation systems in CA accumulated about 11 t/ha of carbon after 9 years. Under tillage agriculture and with monoculture systems the carbon liberation into the atmosphere was about 1.8 t/ha per year of CO_2 (FAO, 2001b). With CA, reduced use of tractors and other powered farm equipment results in lower emissions. Up to 70 per cent in fuel savings have been reported (FAO, 2008). CA systems can also help reduce the emissions for other relevant greenhouse gases such as methane and nitrous oxides, if combined with other complementary techniques. Both methane and nitrous oxide emissions result from poorly aerated soils, for example from permanently flooded rice paddies, from severely compacted soils, or from heavy poorly drained soils. CA improves the internal drainage of soils and the aeration and avoids anaerobic areas in the soil profile, so long as soil compactions through heavy machinery traffic are avoided and the irrigation water management is adequate. The soil is a dominant source of atmospheric N_2O (Houghton *et al.*, 1997). In most agricultural soils biogenic formation of nitrous oxide is enhanced by an increase in available mineral N which, in turn, increases the rates of aerobic microbial nitrification of ammonia into nitrates and anaerobic microbial reduction (denitrification) of nitrate to gaseous forms of nitrogen (Bouwman, 1990; Granli and Bockman, 1994).

The rate of production and emission of N_2O depends primarily on the availability of a mineral N source, the substrate for nitrification or denitrification, on soil temperature, soil water content, and (when denitrification is the main process) the availability of labile organic compounds. These variables are universal and apply to cool temperate and also warm tropical ecosystems. Addition of fertilizer N, therefore, directly results in extra N_2O formation as an intermediate in the reaction sequence of both processes which leaks from microbial cells into the atmosphere (Firestone and Davidson, 1989). In addition, mineral N inputs may lead to indirect formation of N_2O after N leaching or runoff, or following gaseous losses and consecutive deposition of N_2O and ammonia. CA generally reduces the need for mineral N by 30–50 per cent, and enhances nitrogen factor productivity. Also, nitrogen leaching and nitrogen runoff are minimal under CA systems. Thus overall, CA has the potential to lower N_2O emissions (Parkin and Kaspar, 2006), and mitigate other GHG emissions as reported by Robertson *et al.,* (2000) for the mid-west USA and Metay *et al.,* (2007) for the Cerrado in Brazil. However, the potential for such results applying generally to the moist and cool UK conditions has been challenged, for example, by Bhogal *et al.,* (2007) and questions have been raised over their validity due to the depth of soil sampled, particularly for N_2O emissions and the overall balance of GHG emissions (expressed on a carbon dioxide (CO_2-C) equivalent basis).

A 1-year study was carried out by Bhatia *et al.*, (2012) to evaluate the impact of conventional and LCC-based urea application on emission of nitrous oxide, methane, and carbon dioxide in a rice–wheat system of the Indo-Gangetic Plains of India. Treatments consisted of LCC scores of $\leq$ 4 and 5 for rice and wheat and were compared with conventional fixed-time N splitting schedule. They observed that LCC-based urea application reduced nitrous oxide emission in rice and wheat. Their study showed that LCC based urea application can reduce GWP of a rice– wheat system by 10.5%.

Methane (CH_4) and nitrous oxide (N_2O) emissions from rice field in black soil were measured in situ by using static chamber techniques during crop growth season in 2001 (Yue *et al.*, 2005). The experiment fields were divided into three plots for three different treatments, one with continuous flooded and applying urea (CU), one with continuous flooded and applying slow-releasing urea (CS), and one with intermittent irrigation and applying urea (IU). Regression analyses showed that CH_4 emissions were closely related to methanogens population for all the three treatments. They found a positive correlation between denitrifiers population level and N_2O emission in the treatment of IU. Increasing organic matter stocks in soils reduce atmospheric carbon dioxide (CO_2), but they may also promote emissions of nitrous oxide (N_2O) by providing substrates for nitrification and denitrification and by increasing microbial O_2 consumption was observed by Nadine *et al.,* (2011). Smith and Conen (2004) stated that land use change and land management practices affect the net emissions of the trace gases methane (CH_4) and nitrous oxide (N_2O), as well as carbon sources and sinks. Changes in CH_4 and N_2O emissions can substantially alter the overall greenhouse gas balance of a system. Drainage of peat-lands for agriculture or forestry generally increases N_2O emission as well as that of CO_2, but also decreases CH_4 emission. Intermittent drainage or late flooding of rice paddies can greatly diminish the seasonal emission of CH_4 compared with continuous flooding. Changes in N_2O emissions following land use change from forest or grassland to agriculture vary between climatic zones, and the net impact varies with time. In many soils, the increase in carbon sequestration by adopting no-till systems may be largely negated by associated increases in N_2O emission. The promotion of carbon credits for the no-till system before we have better quantification of its net greenhouse gas balance is naive. Ahmed, *et al.*, (2009) showed that no-tillage system was an effective strategy to reduce GWP from rice paddies in central China and thus can serve as a good agricultural system for environmental conservation. While, Regina and Alakukku (2010) said that fluxes of CH_4 were negligible and not affected by no-till practice.

Zucong *et al.,* (2007) in their review paper stated that the effect of N application on CH_4 emission is N-form dependent. Nitrate-based fertilizers are able to mitigate CH_4 emission, but they are rarely applied to rice fields and generally not practicable to mitigate CH_4 emission because of their low use efficiency and stimulatory effect on N_2O emission. In contrast, the application of organic N stimulates CH_4 emission because additional organic carbon is supplied for CH_4 production. Introducing drainage periods during the crop cycle appears to be the most efficient management practice to reduce CH_4 emission from rice fields. It was extrapolated that introducing intermittent drainage period in 33 % of the poorly drained rice fields in China could reduce by 10 % the agricultural CH_4 emissions (9.9 ± 3.0 Tg) in this country (Kern *et al.*, 1997). It may also increase nitrification and N-losses by denitrification and the emission of N_2O, another greenhouse gas, during re-submersion of the soil (Bronson *et al.*, 1997; Cai *et al.*, 1997; Ratering and Conard, 1998).

Organic Carbon and Carbon Sequestration

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). Intensive tillage management has caused a significant loss of SOM and serious soil degradation (Liu *et al.*, 2010). 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 total organic carbon 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). Tillage practice 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 residue is incorporated through tillage (Dolan *et al.*, 2006; Jantalia *et al.*, 2007). Conservation agriculture, reduced/ zero tillage, crop rotation and retention of a rational amount of residue is a practice that leads to soil organic C sequestration. C sequestration is a strategy to achieve food security through improvement of soil quality (Lal, 2004). Most comprehensive field studies have shown that zero tillage results in greater accumulation of soil organic matter in surface layers (0-20 cm) than conventional tillage (Kern and Johnson, 1993; Govaerts, *et al.*, 2007). Zero- tillage, on the other hand, combined with permanent soil over, has been shown to result in a build-up of organic carbon in the surface layers (Lal, 2005). No-tillage 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 are generally 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 is associated with an increase in SOC concentration (Wilhelm *et al.*, 2004; Dolan *et al.*, 2006). Govaerts, *et al.*, (2007) reported that permanent raised beds with full residue retention increased soil organic matter content 1.4 times in the 0-5 cm layer compared to conventionally tilled raised beds with straw incorporated and it increased significantly with increasing amounts of residue retained on the soil surface for permanent raised beds. It can be hypothesized that conventional tillage with all plant residues incorporated by disking is actually a system that rapidly breaks down the organic C inputs, while C 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).

Thomas *et al.*, (2007) did not find a significant difference with SOC between zero and conventional tillage. Tillage treatments did not affect SOC significantly although OC values with conservation tillage were numerically higher than with conventional tillage but it may become significant when tillage is practiced over a longer period of time (Sharma and Acharya, 2000). Decomposition rates of soil organic matter are lower with minimal tillage 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 (both with residue retention) can sequester on average 48 ± 13g C m^2 /yr. 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. West and Post (2002) found that moving to zero tillage in wheat-Fallow rotations showed no significant increase in SOC and therefore, may not be a recommended practice for sequestering C. Likewise, Blanco-Canqui and Lal (2008) also found with some crops and some crop rotations decreased SOC in zero tillage compared to conventional tillage. The mechanisms that govern the balance between increased or no sequestration after conversion to zero tillage are not clear. Although more research is needed some factors that play a role can be distinguished. No till farming also reduces the unnecessarily repaid oxidation of soil organic matter to CO_2 which is induced by tillage (Nelson and Rosegrant 2009). Under tillage agriculture and with monoculture system the carbon liberation into the atmosphere in a year was about 1.8 t/ha of CO_2 (FAO, 2001). Baker *et al.*, (2007) found that crop rotation systems in conservation agriculture (CA) accumulated about 11 t/ha of carbon after 9 years. The reduced use of tractors and other powered equipment results in lower emissions. Up to 70% in fuel saving with CA have been reported by FAO (2008). Optimum levels of SOM can be managed through crop rotation, fertility maintenance including use of inorganic fertilizers and organic manures, tillage methods, and other cropping system components (Huggins *et al.*, 1995; Janzen *et al.*, 1998) . Organic carbon levels were significantly higher with direct drilling, compared to conventional cultivational (Chan *et al.*, 2002). It is not surprising to observe greater surface residue amount and C and N contents in NT than in CT because residues were left at soil surface in NT while they were incorporated into the soil in CT (Sainju *et al.*, 2006). Others reported an increase in SOC due to addition of organic sources of nutrients along with high inputs of NPK fertilizers (Bhandari *et al.*, 2002; Karumakaran, 2004). Crop residues provide a source of organic matter, so when returned to soil the residues increase the storage of organic C and N in soil, whereas their removal results in a substantial loss of organic C and N from the soil system (Malhi and Lemke, 2007). Lower concentration of soil TOC over years in the zero-N treatments (0 Kg N/ha) under CT compared to ZT was most likely due to a tillage effect, because tillage makes crop residues more accessible to soil microorganisms by incorporating them into soil, and subsequently results in faster oxidation/decomposition of organic matter. Previous research has indicated increase in the concentration of soil TOC with inputs of straw compared to when straw was removed (Nyborg *et al.*, 1995). N fertilizers increase the organic carbon content in the soil due to the sufficiency of nutrients provided by inorganic fertilizers, thereby increasing above ground and root biomass and hence organic matter (Rassol *et al.*, 2007). Narang *et al.,* (1999) have suggested application of 20-40 kg/ha higher N doses than recommended (120 kg N/ha) in wheat in straw amended fields during initial 1-2 years. Shah *et al.,* (2003) reported that SOC was increased by N inputs, from both fertilizer and by residue application. The similar results also reported by Singh *et al.*, (2009b). The effect of soil, crop, residue and fertilizer management practices on C sequestration in soil is additive. So, the total amount of organic C stored in the soil is the difference between C input (crop residues) and C output (C loss through gases from decomposition of crop residues, with few exceptions such as soil erosion). Therefore, one would expect a dramatic increase in organic carbon in soil from a combination of ZT, straw retention and proper/balanced fertilization (Malhi *et al.*, 2011a). The use of no–tillage management together with a moderate amount of crop residue (33%) and planted to leguminous species rapidly improved the soil organic carbon, biodegradable carbon fraction such as water soluble C and water soluble carbohydrate. Soil pH tends to be acidic under soybean–maize rotation compared with soybean mono culture and electrical conductivity was slightly affected by crop sequence, being lower under continues soybean (Roldan *et al.*, 2003). Total soil N mineralization was greater under leguminous residues compared to non leguminous crop and was significantly correlated with C/N ratio of the residues (Kumar and Goh, 2002). After two year of maize-wheat cropping cycle, improvement in organic C and $KMnO_4$-N over the initial values, particularly when legume residue were incorporated. The apparent N balance in soil was negative in sole maize-wheat but positive in sole legume-wheat system (Sharma and Behera, 2003).

Available 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.*, 2011a). Astier *et al.*, (2006) observed a significantly higher total N under zero tillage compared to conventional tillage in the highlands of Central Mexico. The same 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 resulted an increased % of total N. Soil structure disturbance due to tillage increases mineral nitrogen release from active and physically protected N pools (Kristensen *et al.*, 2000). Deep tillage causes an excessive level of nitrogen mineralization for cereals, with lodging as a result, and reduced tillage is a means of avoiding this (Riley, 1998). As reduced tillage 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_3-N in the conventional tillage system was larger as compared to the permanent system, total N was significantly higher under both zero tillage on the flat and permanent raised beds compared to conventional tillage 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 reduced tillage, 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 power of soil. Shafi *et al., (*2007) and Bakht *et al., (*2009) were also reported significant increase in N content of soil due to crop residue incorporation.

Previous research under long-term no-tillage (NT) management has shown higher amounts of available P in the surface thin layer (0-5 cm or less) under NT than CT due to P application and from decomposition of crop residues retained on the soil surface under ZT (Ismail *et al.*, 1994; Malhi *et al.*, 2011b). Gosai *et al.*, (2009) reported that available phosphorus of the soil varied remarkably along the crops growing duration, its depth and upon the tillage tool employed. Positive effect of returning crop residue in improving P fertility of soil and thus increasing potential for long-term sustainability of soil productivity was reported by Malhi *et al.*, (2011b). Verhulst *et al.*, (2009) reported that most 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 amounts of fertilizer were applied (P). No-till treatments have higher P, K and organic carbon concentrations in the superficial 0-2.5 cm soil layer and in runoff sediments than CT (Betrol *et al.*, 2007). It is well known that large amounts of K are 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 was 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 zero tillage compared to conventional tillage 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 zero tillage compared to conventional tillage, but this effect declined with depth. However, Duiker and Beegle (2006) found no effect of tillage on available K concentrations.

Water productivity as influenced by conservation tillage practices and cropping systems

The efficiency of conservation tillage to improve water storage is universally recognized. This is very important in arid and semi-arid zones, where management of crop residues is of prime importance to obtain sustainable crop productions (Lampurlanes and Cantero-Martinez, 2006). In rice-wheat systems in the Indo-Gangetic Plains, zero tillage is reported to save irrigation water in the range of 20-35% in the wheat crop compared to conventional tillage, reducing water usage by approximately one million I/ha (Gupta *et al.*, 2002a; Hobbs and Gupta, 2003).The savings arise because with zero tillage 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 no-tillage (Chauhan *et al.*, 2000) and bed planting (Kaur and Mahey, 2005; Ram *et al.*, 2010). Mrabet, (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. ZT combined with crop residue retention on the soil surface greatly reduce erosion and enhance water-use efficiency compared to CT (Johnson *et al.*, 2002). Jat *et al.*, (2005) reported that the water productivity (Kg grain/m^3 water) of either crop of maize and wheat was remarkably higher in FIRB planting (2.79 and 1.98) followed by no-till (1.74 and 1.89) and the lowest (1.36 and1.38) in conventional till system. But, the magnitude of increase in water productivity due to FIRB/no-till systems compared to conventional till planting was higher in maize than the wheat. Khan (2002) and Yadav *et al.,* (2002b) 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.

Economics

Tillage practices contribute greatly to the labour cost in any crop production system resulting to lower economic returns (Labios *et al.,* 1997). Low labour, animal or equipment requirements are major advantage of conservation tillage because it allows elimination of several operations, depending on the conservation tillage systems used. 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 identical. The use of ZT significantly reduces energy costs, mainly by reducing tractor operational costs associated with conventional methods (Erenstein and Farooq, 2009). Dhillon *et al.,* (2002) reported that wheat could be grown successfully under zero tillage on beds and flats, and thus allowing considerable saving in the cost of cultivation Rs. 412 through zero tillage as compared to conventional planting Rs1238 and with rotavator and conventional tillage Rs. 1373 in one hectare. 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 bed planting, conventional tillage and no-tillage treatments respectively and also showed usefulness and input saving in zero tillage and indicated higher output for bed planting technologies. Sayre and Limon- Ortega (2002) reported that permanent bed planting of wheat gave 48% higher returns over tilled beds. In addition to providing grain yield, zero tillage reduced the production costs (15-20%) by eliminating 4-8 tillage operations practiced under conventional tillage 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 a 20% increases 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. ZT technology proved to be a wise choice as it was reported to be economical as well as ecologically viable as compared with conventional tillage 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 zero tillage led to reduction in tillage cost form Rs 2000 to Rs 6500/ha, early sowing by 7-10 days in moist soil, less

Phalaris minor problem and proper placement of seed. The development and rapid adoption of direct drilling of wheat into rice stubble has been a major advance in reducing production costs, increasing yields and reducing greenhouse gas emissions (Hobbs and Gupta, 2003). Mishra and Singh (2009) reported that continuous ZT (ZT-ZT) generated higher net return (Rs. 28,085 and Rs. 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 soybean equivalent 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. It indicates that maize-wheat cultivation under NT has been more economical. Kar *et al.,* (2006) at Bhubaneswar (Orissa) recorded significantly highest net return (Rs. 61532) and B:C ratio (3.36) for sweet corn with application of 80 Kg N/ha followed by 60 and 40 kg N/ha. Gupta *et al., (*2007) also reported the higher net return and B:C ratio upto125 Kg N/ha in wheat. Jat (2010) reported that highest net returns (Rs 56198) and B:C ratio (3.80) of maize-wheat cropping system were obtained with 120 KgN/ha.

Sharma and Behera (2009) reported that ground nut was the more remunerative crop followed by green gram in grain legume – wheat cropping system. Total net returns and net returns per rupee invented were maximum in case of ground nut – wheat followed by green gram. Wheat cropping systems, resulting in overall profitability of the system. 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).

CHAPTER-III

MATERIAL AND METHODS

The field experiment entitled" *Studies on green house gas emissions and carbon sequestration under conservation agriculture in maize based cropping systems"* was conducted at research farm of Directorate of maize research (DMR), IARI, Pusa Campus, New Delhi during *kharif* and the following *rabi* seasons of 2012 –13 through 2013 –14 under collaborative research for Ph.D. student under CGIAR, CRPs on climate change, agriculture and food security (CCAFS) of CIMMYT. This chapter deals in brief the experimental details of materials used, the observations taken and techniques employed 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 Directorate of maize research (DMR), New Delhi. The research was carried out in collaboration with CIMMYT and was supported by CGIAR Research Programme on climate change, agriculture and food security (CCAFS). The experimental site was situated at 28^{0}4' N latitude, 77^{0}12'E longitude and 228.6 metres above mean sea level. Soil samples were taken before the start of the experiment which were analysed for physical and chemical properties of the soil (Table 3.3). The soil at site was sandy loam in texture with bulk density of 1.57 Mg/m^3, field capacity 16.87% (w/w) and infiltration rate 1.22 cm/hr. It had 0.45 % organic carbon, 158.4 kg $KMnO_4$ oxidizable N/ha, 12.6 kg 0.5 N $NaHCO_3$ extractable P/ha, 248.4 kg 1N NH_4OAc exchangeable K/ha, 7.5 pH and 0.32 dS/m EC at the start of the experiment. 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. The hottest months are May and June with mean temperature ranging from 41^{o}C to 45^{o}C, whereas the mean minimum temperatures of the coldest months (December and January) varies between 1.9^{o}C and 5^{o}C. Frost may be cited as the common phenomenon during the months of December and January. The daily maximum and minimum temperature tend to rise from the first fortnight of February and maintain the trend till the month of June. The mean annual rainfall is about 650 mm, of which nearly 80 per cent is received during the monsoon period from July to September and the rest during the period between October and May. The mean daily U.S. Weather Bureau Class ‘A’ open pan evaporation value reaches as high as 10.9 mm in the month of June and as low as 1.5 mm in the month of January. The annual pan evaporation is about 850 mm. The mean wind velocity varies from 3.5 km/hr during October to 7.6 km/hr during April. Mean relative humidity attains the maximum value 85 to 90 per cent during the south-west monsoon and the minimum 30 to 45 per cent during the summer months.

The meteorological data of the experimental period for two consecutive years were recorded at the meteorological observatory of the Indian Agricultural Research Institute, New Delhi are presented in

Table: 3.1. Monthly variations in weather conditions during growth period of *kharif* maize (2012 and 2013)

Month	Mean max. temp.(°C)		Mean min. temp. (°C)		Total rainfall (mm)		Mean relative humidity (%) (M)	
	2012	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**
July	36.5	35.6	27.3	23.6	139.8	459.8	78.8	92.3
August	32.5	34.0	25.7	24.2	274.0	521.9	86.9	98.0
September	33.4	34.5	24.0	23.8	57.0	108.1	86.5	88.0
October	32.6	31.5	16.1	19.2	11.0	109.0	87.6	93.6
Kharif season	33.8	33.9	23.3	22.7	481.8	1198.8	85.0	93.0

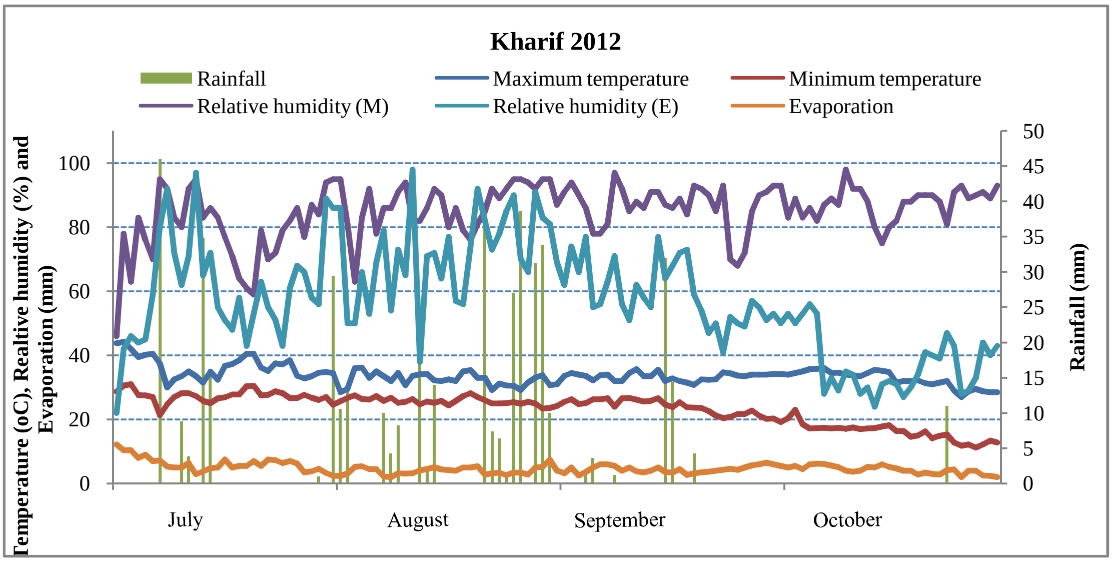


Fig. 3.1 Daily variations in weather conditions during growth period of maize in 2012.

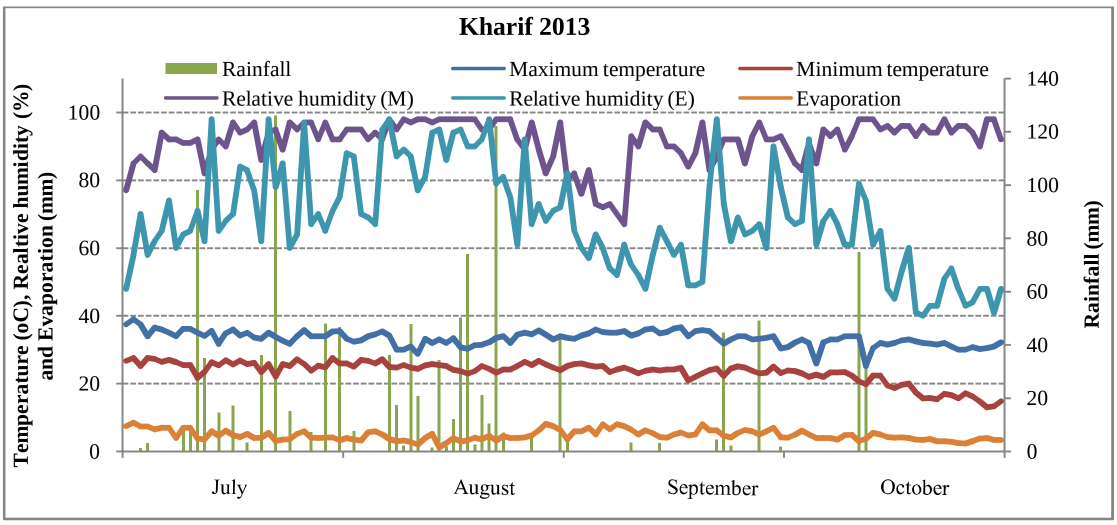


Fig. 3.2 Daily variations in weather conditions during growth period of maize in 2013.

Table: 3.2. Monthly variations in weather conditions during growth period of *rabi* wheat and chickpea (2012-13 and 2013-14).

Month	Mean max. temp. (°C)		Mean min. temp. (°C)		Total rainfall (mm)		Mean relative humidity (%) (M)	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
November	27.3	26.9	9.9	9.9	0.0	0.4	89.0	90.9
December	21.7	22.4	7.5	7.1	8.6	6.8	84.2	93.8
January	18.0	18.6	4.7	6.8	40.8	18.6	92.0	96.6
February	22.1	21.4	9.6	7.5	102.4	63.4	91.7	96.0
March	29.9	27.2	13.7	12.7	12.6	63.5	87.0	90.0
April	36.1	34.8	19.5	17.9	11.6	16.4	67.0	73.4
Rabi season	25.9	25.2	10.8	10.3	176.0	169.1	85.2	90.1

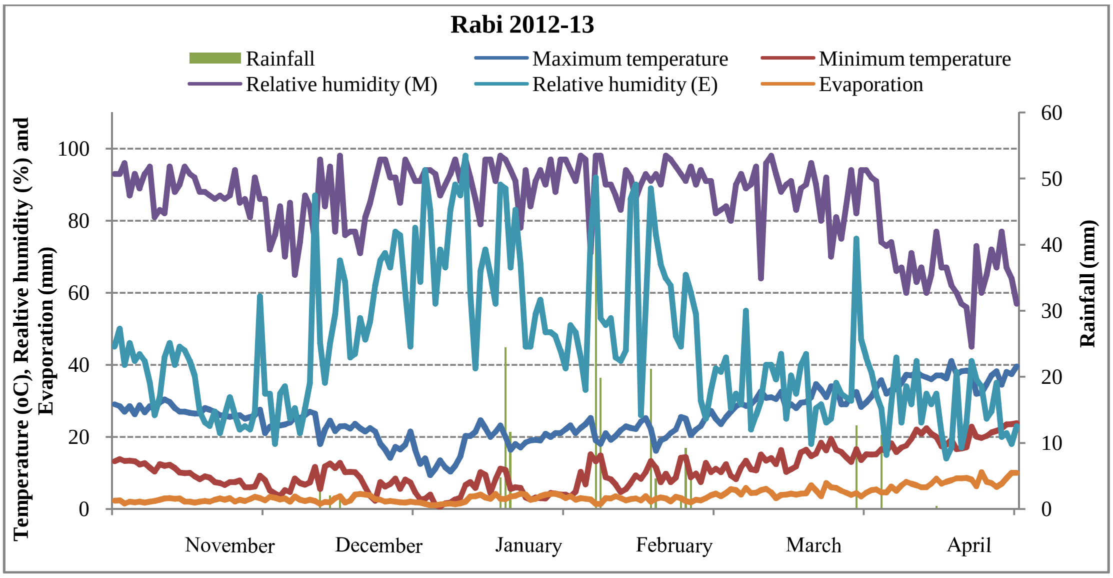


Fig. 3.3 Daily variations in weather conditions during growth period of wheat and chickpea in 2012–13

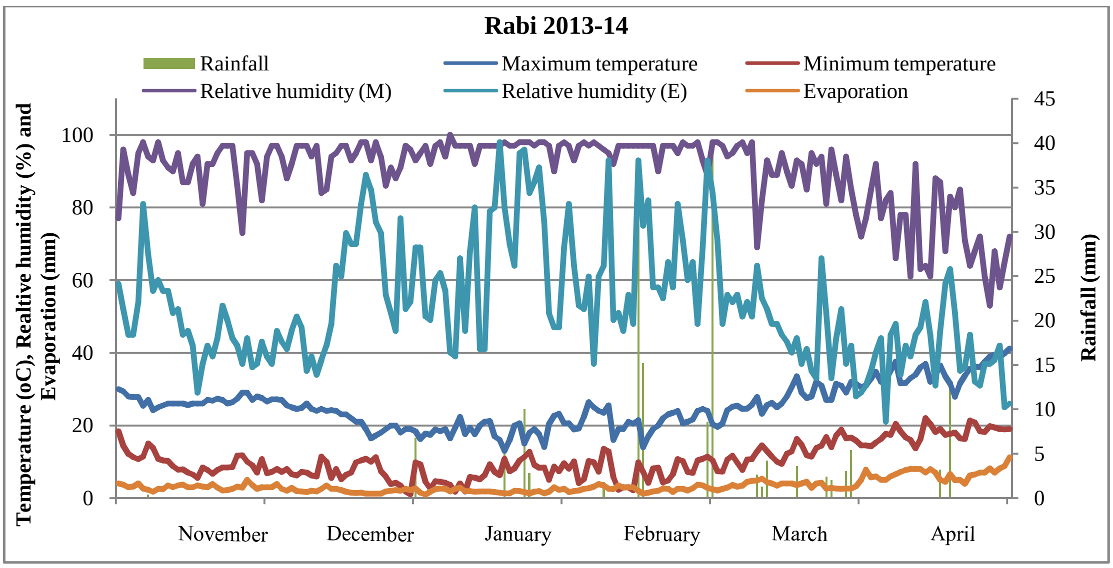


Fig. 3.4 Daily variations in weather conditions during growth period of wheat and chickpea in 2013–14

Table 3.3. Physico-chemical properties of soil at the experimental site

Particulars	Value
Mechanical composition: (Bouyoucos, 1962)	
1. Sand (%)	62.4
2. Silt (%)	15.6
3. Clay (%)	19.2
4. Textural class	
Sandy loam	
Physical properties:	
1. Bulk density (Mg/m^3) (Chopra and Kanwar, 1991)	1.58
2. Infiltration rate (cm/hr) (Bouwer, 1986)	1.22
3. Hydraulic conductivity (cm/hr) (Mishra and Ahamed, 1987)	1.12
4. Field capacity (% by weight) (Richards, 1954)	16.87
Chemical properties:	
1. pH (1:2.5; soil:water ratio) (Piper, 1950)	7.5
2. Electrical conductivity (dS/m) (Piper, 1950)	0.32
3. Organic C (%) (Walkley and Black, 1934)	0.38
4. Available N (kg/ha) (Subbiah and Asija, 1956)	147.41
5. Available P (kg/ha) (Olsen *et al*., 1954)	12.61
6. Available K (kg/ha) (Jackson, 1973)	208.42

3.1.3. Cropping history of the experimental field

The cropping pattern followed at the experimental field during the preceding years was maize crop in *kharif* and both wheat & chickpea during following *rabi* season for last five years period.

3.2. Experimental details

The field experiment was conducted in split plot design each having 12 treatment combinations with 3 replications during *kharif* 2012 and 2013. While it was conducted in randomized block design (RBD) with 3 replications in succeeding wheat and chickpea crops.

Table 3.4 Treatments detail

S. No.	Maize	Wheat and Chickpea.
Main plot: Tillage and crop establishment techniques – 06		
1.	Conventional Tillage flat with residue (CTWR) ;	1. CTWR
2.	Conventional Tillage flat without residue (CTWOR);	2. CTWOR
3.	Zero Tillage flat with residue (ZTWR);	3. ZTWR

4. Zero Tillage flat without residue (ZTWOR); 4. ZTWOR
5. Permanent Bed Planting with residue (PBWR); 5. PBWR
6. Permanent Bed Planting without residue (PBWOR); 6. PBWOR

Sub-plots (cropping systems): 02

1. Maize-Wheat (MW)
2. Maize-Chickpea (MC)

Experimental design and layout

	Permanent Bed		Zero Tillage (Flat)		Conventional Tillage	
	WR	WOR	WOR	WR	WR	WOR
Replication 1	Maize-Wheat	Maize-Chickpea	Maize-Chickpea	Maize-Wheat	Maize-Wheat	Maize-Chickpea
	Maize-Chickpea	Maize-Wheat	Maize-Wheat	Maize-Chickpea	Maize-Chickpea	Maize-Wheat
	Irrigation channel					
Replication 2	Maize-Chickpea	Maize-Wheat	Maize-Wheat	Maize-Chickpea	Maize-Chickpea	Maize-Wheat
	Maize-Wheat	Maize-Chickpea	Maize-Chickpea	Maize-Wheat	Maize-Wheat	Maize-Chickpea
Replication 3	Irrigation channel					
	Maize-Chickpea	Maize-Wheat	Maize-Chickpea	Maize-Wheat	Maize-Wheat	Maize-Chickpea
	Maize-Wheat	Maize-Chickpea	Maize-Wheat	Maize-Chickpea	Maize-Chickpea	Maize-Wheat
	PBWR	PBWOR	ZTWR	ZTWOR	CTWR	CTWOR

Fig. 3.5 Layout of plan of experiment

Experimental design : Split-Plot Design (in *kharif*); RBD (in *rabi* season)

Total treatment combinations : 12

Replications : 3

Plot size : 6.0 m X 2.84 m = 17.04 m^2

Total number of plots : 36

The plan of layout of the experiments is depicted in Fig.3.5.

Spacing between rows

Maize: 67.5 cm

Wheat: 18.5 cm in ZT & CT flat (three rows of wheat on each bed in PB)

Chickpea: 30 cm ZT & CT flat (two rows of chickpea on each bed in PB)

Varieties

Maize : HQPM 1

Wheat : HD 2967

Chickpea : Pusa 547

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 cultivation of across the country. It is tolerant to frost/cold and resistant to MLB and common rust.

3.3.2 Particulars about the wheat variety HD 2967

This variety is recommended for timely sown irrigated condition of North Western Plain Zone. Its average yield is 5.0 t/ha and was released in 2011 for cultivation. It possesses very high degree of resistance against most prevalent leaf rust disease. It has also better degree of resistance against leaf blight. It matures in 143 days.

3.3.3 Particulars about the Chickpea variety Pusa 547

This variety is recommended for Delhi, Haryana, Punjab, U.P. and Rajasthan states of the country. It is of medium maturity (135 days), tolerant to wilt, root rot and stunt diseases. Its average yield is 1.5-2.0 t/ha and was released in 2006 by CVRC for cultivation.

3.3.4 Crop residues

The mungbean crop residue including stem comprises of air dried leaf and branches was weighed and applied as per the treatments for *kharif* season crop. The maize residue after the manually harvest of crop was weighed and applied as per the treatments.

3.4 Field operations

The cultural operations carried out in the *kharif* maize, *rabi* wheat and Chickpea during experimentation has been given in Table 3.5, 3.6 and 3.7

3.4.1 Pre-sowing operations in maize, wheat and chickpea

Herbicide application

Tank mix solution of paraquat (Gramoxone 24%) and glyphosate (Round up 41%) was applied before sowing of the crops in the zero tillage treatments 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 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 during sowing of succeeding crops with bed planter during both years. The 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.

3.4.2. Maize

Fertilizer application

Maize crop was given uniform application of 150:80:60 kg/ha of N, P_2O_5 and K_2O. 1/3rd dose of N and full dose of P_2O_5 and K_2O were applied at the time of sowing in furrow opened by pora. Remaining 2/3rd dose of N were applied in two equal splits at eight leaves stage (V_8) and taselling 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 treatments. While one row of maize crop was established on top of the raised beds by keeping plant spacing of 20 cm and irrigation was given in 30 cm furrow. The seed rate of maize used was 20 kg/ha.

Thinning and gap filling

Extra plants in the rows were thinned to maintain intra-row spacing at three weeks after sowing. The gap filling was accomplished immediately after the germination in order to maintain optimum and uniform plant population.

Weeding and inter-cultivation

In conventional tillage treatments weed growth was checked by manual weeding twice 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 gap in rainfall. To supplement the rainfall three and one irrigations were given during first and second year, respectively to maize crop.

Plant Protection measures

Tank mix solution of chlorpyrifos (20 EC) and endosulfan (Thiodone @ 0.03%) was sprayed once in the standing crop in order to control termite infestation.

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.

Table 3.5 Schedule of field operations during experimentation in maize.

S. No.	Operation	2012	2013
1.	Field preparation	10.08.2012	03.07.2013
2.	Layout	18.08.2012	06.07.2013
3.	Sowing	19.08.2012	08.07.2013
4.	Thinning/gap filling	12.09.2012	27.07.2013
5.	Fertilizer application		
	Basal dose	18.08.2012	08.07.2013
6.	1st split application of N	20.09.2012	29.07.2013
	2nd split application of N	24.10.2012	03.09.2013
7.	Irrigation application		
	1st irrigation	29.08.2012	10.09.2013
	2nd irrigation	22.09.2012	-
	3rd irrigation	08.10.2012	-
8.	Weed management		
	Herbicide application		
	Pre-emergence	20.08.2012	09.07.2013
	Protected spray	-	-
	Hand weeding		
	First	18.09.2012	27.07.2013
	Second	15.10.2012	21.08.2013
9.	Plant protection measures	08.10.2012	29.07.2013
10.	Harvesting	24.11.2012	18.10.2013

3.4.3. Wheat

Fertilizer application

Wheat crop was given uniform application of 120:60:40 kg/ha of N, P_2O_5 and K_2O. Half dose of N and full dose of P_2O_5 and K_2O were applied at the time of sowing of wheat. Remaining half nitrogen was applied as top dressing after first irrigation at CRI stage.

Seed treatment

Seed treatment was done with chlorpyrifos (20 EC @90 ml/100 kg seed + 5 liter water) before last night of sowing of crop.

Seed sowing

The wheat (cv. HD 2967) crop was sown at a spacing of 18 cm X 5 cm (R x R and P x P) in conventional tillage flat and zero tillage flat treatments by multi-crop planter. While bed-planter was used to establish three rows of wheat crop on top of the raised beds by keeping plant spacing of 5 cm and irrigation was given in furrow. The seed rate of wheat used for sowing on beds and flats was 100 kg/ha.

Gap filling

The gap filling was accomplished in wheat immediately after the germination in order to maintain uniform optimum plant population.

Weed management

Tank mix solution of isoproturon (75 WP at 1 kg a.i./ ha) and 2,4-D sodium salt (80 WP at 0.5 kg a.i ./ha) was applied to control grassy as well as broad leaf weeds after 35 days of sowing of crop.

Irrigation

The wheat crop was totally dependent on irrigation and water was applied at critical stages of crop growth. Uniform supply rate of irrigation water was maintained and time taken to irrigate the flat and bed planted wheat crop was recorded with the help of stop watch for calculating water use.

Harvesting and threshing

At maturity plants from net plots were harvested separately and produce was left in the field for some days to get dried. Bundle weight was recorded. Threshing was done by using ALMACO Pullman Thresher. Each net plot grains were cleaned and weighed for estimation of yield and was expressed in t/ha. The weight of straw was recorded by subtracting grain weight from buddle weight.

Table 3.6 Schedule of field operations during experimentation in wheat

S. No.	Operation	2012-13	2013-14
1.	Field preparation	25.11.2012	19.11.2013
2.	Layout	25.11.2012	22.11.2013
3.	Sowing	26.11.2012	25.11.2013
4.	Gap filling	-	-
5.	Fertilizer application		
	Basal dose	26.11.2012	25.11.2013
	1st split application of N	14.01.2013	31.01.2014
	2nd split application of N	06.02.2013	24.02.2014
6.	Irrigation application		
	1st irrigation	10.12.2012	16.12.2013
	2nd irrigation	05.01.2013	06.01.2014
	3rd irrigation	15.01.2013	29.01.2014
	4th irrigation	05.03.2013	22.03.2014
7.	Weed management		
	Post emergence	02.01.2013	18.12.2013
8.	Harvesting	15.04.2013	10.04.2014

3.4.4. Chickpea

Fertilizer application

Chickpea crop was given uniform application of 30:60 kg/ha of N and P_2O_5 .Full dose of N and P_2O_5 were applied at the time of sowing of the crop.

Seed inoculation

The seed of chickpea were inoculated with specific and efficient *Rhizobium* strain as per the standard procedure. To inoculate the seed, 10% of jaggary solution was prepared in one litre of water. The solution was boiled and then cooled. The inoculants were mixed with the cooled solution thoroughly. The seeds were heaped on a clean surface and the inoculants slurry was poured and mixed. The inoculated seeds were dried in shade and sown immediately.

Seed sowing

Chickpea seeds were sown at the rate of 75 kg/ha at a spacing of 30 cm in conventional tillage flat and zero tillage flat treatments by multi-crop planter. While bed-planter was used to establish three rows of chickpea crop on top of the raised beds.

Thinning and gap filling

Extra plants in the rows were thinned to maintain the intra-row spacing. The gap filling was accomplished immediately after the germination in order to maintain optimum and uniform plant population.

Weed management

The weeds in chickpea were controlled by pre emergence application of Pendimethalin (1.0 kg a.i. /ha) and one manual hand weeding.

Irrigation

The *rabi* chickpea crop was entirely supported by irrigation water and water was applied at critical stages of crop growth. Uniform supply rate of irrigation water was maintained and time taken to irrigate the flat and bed planted chickpea crop.

Harvesting and threshing

At maturity plants from net plots were harvested separately and produce was left in the field for some days to get dried. Threshing was done by using ALMACO Pullman Thresher. Each net plot seed were cleaned and weighed for estimation of seed yield in t/ha. The weight of stover was recorded separately and used for estimating the biological yield.

Table 3.7 Schedule of field operations during experimentation in chickpea.

S. No.	Operation	2012-13	2013-14
1.	Field preparation	25.11.2012	18.10.2013
2.	Layout	25.11.2012	19.10.2013
3.	Sowing	25.11.2012	21.10.2013
4.	Basal fertilizer application	26.11.2012	21.10.2013
5.	Irrigation application		
	1st irrigation	10.12.2012	31.10.2013
	2nd irrigation	05.01.2013	06.12.2013
	3rd irrigation	12.03.2013	05.04.2014
6.	Weed management		
	Pre-emergence	21.11.2012	22.10.2013
	Hand weeding	18.12.2012	18.11.2013
7.	Harvesting	28.04.2013	03.04.2014

3.5. Biometric observations

3.5.1 Maize

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^{o} c for 48 hours. Dry weight was expressed in g/ plant.

Leaf area (cm^{2}/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:

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

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/m^2/day

Relative growth rate (g/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 Log W is plotted against T. Mathematically, RGR value was calculated as follows:

$$RGR = \frac{Log_e W_2 - Log_e W_1}{T_2 - T_1} \text{ g/g/day}$$

Net assimilation rate (g/cm^{2}leaf area/day)

It is the net gain of assimilate per unit leaf area time. It represents the photosynthetic efficiency of leaves. The following formula was used to calculate the NAR.

$$NAR = \frac{(W_2 - W_1)(\text{In } LA_2 - \text{In } LA_1)}{(T_2 - T_1)(LA_2 - LA_1)} \quad \text{g/cm2leaf area/day}$$

Where, W_1 and W_2 are the dry weights recorded at time T_1 and T_2, respectively. LA_2 and LA_1 are the area values recorded at times T_2 and T_1.

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.

Number of cobs per square metre

Number of cobs per square metre row length were counted from 0.5 m^2 area randomly from four spots in the net plot, averaged and expressed as number of cobs per metre row length.

Cob length (cm)

Five cobs were randomly selected from each plot during harvest and their length from base to tip of the cob 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 per cob

The total number of grains were counted from the same cobs previously selected for weight 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:

Shelling percentage = Weight of grains/ Weight of whole cob x100

Grain yield tonne per hectare

After separating from stalk 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 t ha^{-1}.

Stover yield tonne per hectare

The maize stalk were cut from ground level from the net plot and weighed after sun drying. Final yield was expressed in t ha^{-1}.

Biological yield tonne per hectare

The weight of total produce harvested from net plot of each treatment was recorded after sun drying and expressed as biological yield in t ha^{-1}.

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.

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

3.5.2 Wheat

Plant height (cm)

Five plants from sampling rows were randomly selected and tagged for all the periodic height observations and their height was measured from the ground level to the tip of flag leaf at every 30 days intervals.

Number of tillers per meter row length

Number of effective and ineffective tillers (ear bearing and non ear bearing tillers) were counted from 0.25 m^2 area randomly from four spots in the net plot, averaged and expressed as number of tillers per square meter area.

Leaf area (cm^2/plant)

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

Leaf area index

The crop leaves were stripped off from their base from the collected samples for dry matter accumulation. Total area of all the leaves was determined with the help of leaf area meter (Model LI-COR-3100). LAI was expressed as the ratio of leaf area to the land area occupied by the plant and the leaf area index/plant was calculated by using the following formula:

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

Dry matter accumulation (g/m^2)

In wheat, 0.25 m^2 area was selected after leaving the first row from either side of the plot for the measurement of dry matter accumulation. The samples were sun dried first and then in an oven at 65^0C till the constant weight arrived. The dry weight was expressed as g m^{-2}.

Crop growth rate (g/m^2/day)

$$CGR = \frac{W_2 - W_1}{T_2 - T_1} \text{g/m}^2\text{/day}$$

Where, W_1 and W_2 are the dry weights recorded at time T_1 and T_2, respectively. T_1 and T_2 are time in days.

Relative growth rate (g/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 Log W is plotted against T. Mathematically. RGR value was calculated as follows:

$$RGR = \frac{Log_e W_2 - Log_e W_1}{T_2 - T_1} \text{ g/g/day}$$

Net assimilation rate (g/m^{2}leaf area/day)

It is the net gain of assimilate per unit leaf area time. It represents the photosynthetic efficiency of leaves. The following formula was used to calculate the NAR.

$$NAR = \frac{(W_2 - W_1)(In\ LA_2 - In\ LA_1)}{(T_2 - T_1)(LA_2 - LA_1)} \text{ g/m2 leaf area/day}$$

Where, W_1 and W_2 are the dry weights recorded at time T_1 and T_2, respectively. LA_2 and LA_1 are the area values recorded at times T_2 and T_1.

Spike length (cm)

Length of spike was measured in centimetre from the randomly selected five plants averaged and expressed as length of spikes.

Grains per spike

Ten ear heads from sampled plants were randomly selected; threshed and number of grains was counted. The average value was worked out to obtain the number of grains / spike.

Number of effective tillers per square meter

Number of effective tillers (ear bearing tillers) were counted from 0.25 m^2 area randomly from four spots in the net plot, averaged and expressed as number of effective tillers per square meter area.

1000-grain weight (g)

A representative sample of grains was taken from the produce of the each plot after drying and cleaning and weight of 1000-grains recorded and was expressed in grams.

Grain yield tonne per hectare

The net plots, leaving two border rows directions and half meter on opposite directions of the plots were harvested and kept for sun drying for some days in the field and then the total biomass yield was recorded. After threshing, cleaning and drying the grain, grain yield was recorded.

Straw yield tonne per hectare

The weight of straw was obtained by subtracting the grain weight from the total biomass recorded before threshing. The straw yield finally adjusted on oven dry weight basis after deducting moisture content determined by taking one kg separate sample.

Biological yield tonne per hectare

After harvesting of net plot area, total biomass was recorded by weighing the total weight of air dried bundle of wheat crop t/ha.

Harvest index

Harvest index was computed by dividing the grain yield by the total biological yield and was expressed in percentage.

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

3.5.3 Chickpea

Plant height (cm)

Five plants were tagged at randomly from the sampling row and height of these plants was recorded from the ground level to the tip of plant at 40 days intervals.

Number of branches per plant

Those branches which originated from the main stem of the five sampled plants was counted and averaged to express branches per plant.

Dry matter accumulation per plant

Five plants per plot were selected and cut from ground level from sampled row at 40 days intervals. These plants were first air-dried followed by oven dried at 65^0c for 24 hours and weighed. Dry matter accumulation was expressed as g/plant.

Days to 50% flowering

The date on which 50% plants produced flowers was recorded and used for calculating days to flowering stage.

Number of pods per plant

The pods from the five sampled plants were separated and filled pods were counted and expressed as number of pods/plant.

Number of seeds per pod

The number of seed per pod was calculated by dividing the total number of seeds obtained from five sampled plants by total number of pods from these plants.

100-seed weight (g)

A random sample of seed was taken from the produce of the net plot, 100-seed from each sample were counted manually and their weight was recorded.

Seed yield tonne per hectare

The total produce from the net plot area was cleaned and weighed to compute the seed yield in tonne per hectare.

Stover yield tonne per hectare

Before threshing, the total biological yield from net plot area was recorded. The stover yield per plot was obtained by deducting the seed yield per plot from the biological yield.

Biological yield tonne per hectare

After harvesting net plot area, total biomass was recorded on air dry weight basis from chickpea crop t/ha.

Harvest index

The economic yield (seed yield of chickpea) was divided by the respective biological yield (total produce) to work out the harvest index by using following formula:

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

3.6 GHG sampling and measurements:

GHG sampling protocols

GHG (CH_4, CO_2 & N_2O) fluxes were monitored taking manual sampling. The assembly consisted of semi permanently installed gas chambers which were removed only when field operations occurred i.e. tillage, seeding or harvesting. The chambers were placed back in the ground as soon as possible after completion of each field operation, so that at least 24 hours time period could remain between the gas chambers installation and gases flux measurements. These installed gas chambers were made up of tin (Inner and outer diameter – 0.43 m and 0.53 m, respectively and height 0.30 m) with a circular channel to hold the plastic bucket (volume 0.1 m^3) and filled with water to provide air-tight conditions. The plastic buckets were fabricated manually, which were placed over each gas chamber at the time of sampling and GHG sampling was done through the sampling port, which was covered with a sleeve type septa to ensure full air tight condition (no entry of external air). For thermal insulation each of these plastic buckets was painted with white colour from outside to serve the purpose of reflective covering for minimizing the internal heating by solar radiation. Each bucket had a digital thermometer installed on the top the bucket for recording inside temperature during GHG sampling. A computer cabinet fan was installed inside each bucket along with an external power supply with 9 volts battery system on the top of the bucket. At the time of sampling, the cabinet fan was switched on, for uniform mixing of inside air masses of the bucket during sampling. All the vents and openings were sealed with adhesive to make the assembly airtight.

GHG sample collection

An evacuated and airtight 30 ml glass vial was used for GHG collection and storage. Glass vials were evacuated using a vacuum pump at suction of 20 lbs inch-2. A 50 ml BD disposable syringe with three-way leur lock was used for collection of GHG samples from the headspace of each bucket through the sampling port. From this syringe, 50 ml of the gas was injected into the pre-evacuated vials, which was over pressurized so that if any gas leakage exists, there would not be contamination from ambient air.

GHG sampling frequency

To cover the best scenario of GHG fluxes throughout the crop season, the GHG sampling frequency was designed as

- Before and after tillage operations.
- After application of fertilizer (basal/broadcast/foliar) for seven consecutive days.
- For the rest of the crop growth period samples were taken at once in a week.

At each sampling date, GHG samples were collected at 0, 10, 20 and 30 minutes interval from each gas chamber and same were stored in evacuated glass vials with proper labelling (date of sampling, plot number and time of sampling, etc). Samplings on different dates from maize, wheat and chickpea were recorded during *kharif* and *rabi* (2012-13 and 2013-14).

GHG analysis

Collected samples were analyzed for GHG (CH_4, N_2O and CO_2,) using a Gas Chromatograph (Bruker Gas Chromatograph) (Figure) equipped with Flame Ionization Detector (FID), Thermal conductivity detector (TCD) and Electron Capture Detector (ECD). Standards for methane, nitrous oxide and carbon dioxide were imported through Linde Engineering India Pvt. Ltd. Gas chromatograph was calibrated periodically using 10 ppm CH_4 in balance with 2 ppm N_2 and N_2O, 1 ppm in balance with 5 ppm nitrogen. Zero Air, Hydrogen, Nitrogen, and Helium were used as carrier gas for the Gas Chromatograph. The Gas chromatograph facility was installed under the premises of the Directorate of maize research, IARI, New Delhi, under the aegis of CIMMYT, India.

GHG calculations

Fluxes of GHGs (CH_4, N_2O and CO_2) were calculated by linear regression. All data were checked for linearity by visual inspection during data analysis. Gas concentrations in ppm, at each sampling (0, 10, 20 and 30 minutes after chamber deployment) were converted into mole of gas by using ideal gas law taking air temperature into account. The mole unit of gas was then converted into weight of gas considering the molecular weight of that particular gas. Linear regression was performed considering sampling time as independent variable and gas concentration as dependent variable to calculate the rate of gas emission per unit of time to come up with the flux per unit area per day. The fluxes in between two sampling dates were estimated by linear interpolation. The gas fluxes of all days in crop season were summed up to calculate cumulative emission during whole crop season.

Calculation of methane flux

Cross sectional area of the chamber = Am^2 = (π x radius^2)

Head space (bucket + chamber height) = H m

CH_4 concentration at time ‘0’ = C_0 ppmv

CH_4 concentration after time‘t’ = C_t ppmv

Change in concentration of CH_4 in time‘t’ = (C_t – C_0) ppmv

Volume of CH_4 evolved in time'tʼ = $(C_t – C_0)$ x 1000 x A x H. (Lt)

When time'tʼ is in minutes, then flux (F) is:- $\frac{[(C_t-C_0) \text{ x A x H}]}{\text{A x t}}$

Or, say Y ml m^{-2} min^{-1}

Flux = $\frac{\text{Y x 16 } (g\ m^{-2}\ min^{-1}) = \text{Y x 16 x 60 x 1000 } (mg\ m^{-2}\ hr^{-1})}{22400 \qquad\qquad 22400}$

Where, 16 is the molecular weight for methane.

Hence Flux (F) = $\frac{[(C_t-C_0) \text{ x H x 42.857] } mg\ m^{-2}\ hr^{-1}}{t}$

For N_2O, the molecular weight of 44 was be taken for calculating the flux values

Calculation of Global warming potential

Global-warming potential (GWP) is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide. A GWP is calculated over a specific time interval, commonly 20, 100 or 500 years. GWP is expressed as a factor of carbon dioxide whose GWP is standardized to 1 (IPCC, 2007). A high GWP correlates with a large infrared absorption and a long atmospheric lifetime. Just as radiative forcing provides a simplified means of comparing the various factors that are believed to influence the climate system to one another, global-warming potentials (GWPs) are one type of simplified index based upon radiative properties that can be used to estimate the potential future impacts of emissions of different gases upon the climate system in a relative sense. GWP is based on a number of factors, including the radiative efficiency (infrared-absorbing ability) of each gas relative to that of carbon dioxide, as well as the decay rate of each gas (the amount removed from the atmosphere over a given number of years) relative to that of carbon dioxide. The GWP is defined as the ratio of the time-integrated radiative forcing from the instantaneous release of 1 kg of a trace substance relative to that of 1 kg of a reference gas. Where TH is the time horizon over which the calculation is considered;

$$GWP(x) = \frac{\int_0^{TH} a_x \cdot [x(t)]\, dt}{\int_0^{TH} a_r \cdot [r(t)]\, dt}$$

Where, a_x is the radiative efficiency due to a unit increase in atmospheric abundance of the substance (i.e., $Wm^{-2}\ kg^{-1}$) and [x(t)] is the time-dependent decay in abundance of the substance following an instantaneous release of it at time t=0. The denominator contains the corresponding quantities for the reference gas (i.e. CO_2). The radiative efficiencies a_x and a_r are not necessarily constant over time. While the absorption of infrared radiation by many greenhouse gases varies linearly with their abundance, a few important ones display non-linear behaviour for current and likely future abundances (e.g., CO_2, CH_4, and N_2O). For those gases, the relative radiative forcing will depend upon abundance and hence upon the future scenario adopted.

3.7 Estimation of Carbon Sustainability Index

Carbon input (MJ/ha)

The carbon equivalence as suggested by Lal, 1994.for various inputs v*iz*; chemical fertilizer (NPK), diesel, tillage, lubricants, machinery and agro-chemical, etc were used for estimation of carbon total inputs and outputs (expressed in MJ/ha).

Carbon output (MJ/ha)

Three components of C output included for conversion in carbon equivalent:

i. Grain /seed yield,

ii. Straw/stover yield, and

iii. Root biomass

Carbon Sustainability Index

Sustainability Indices for both the years were calculated by dividing the difference between the total C output and C input by C input (Lal, 2004).

Cs = (Co – Ci) / Ci

Cs – Sustainability Index

Co – Carbon Output

Ci – Carbon Input

3.8 Soil analysis

3.8.1 Physical properties of soil

Bulk density (Mg/m^3)

Bulk density of surface (0-15 cm) and sub surface (15-30 cm) soil was determined by the core sampler method (Piper, 1950) from each plot. The procedure for determining bulk density was followed as described by Mishra and Ahmad (1987).

Hydraulic conductivity

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

$$K=QL/HAT$$

Where,

K=Hydraulic conductivity (cmhr^{-1})

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 using wet sieving techniques (Haynes, 1993). Fifty gram of air dried 2 to 6 mm soil aggregates were transferred to the upper most of a set of a six sieves having 4, 2, 1, 0.5, 0.25 and 0.1 mm diameter apertures. The water level was adjusted so that the aggregates on the upper sieve also just submerged at the height point of oscillation. The oscillation rate was 25 cycles/minute. The amplitude of the sieving action was 35 mm and the period of sieving was 15 minutes. The mean weight diameter (MWD) of aggregates were determined using the procedure given by (Kemper and Roseneau, 1986) MWD = $\sum$ Xi. Wi where, Wi, is the proportion of aggregates returned and the sieves in relation to the whole, Xi is the mean diameter of the class (mm). The line between macro- and micro- aggregates is commonly drawn at 0.25 mm (Oades and Waters, 1991).

3.8.2 Chemical properties

Organic carbon (%)

The soil samples (0-15 cm depth) were collected in small polythene bags from each plot of the experimental field at the initial and at the end of experimentation period. The samples were air dried and organic carbon content in soil samples were determined by Walkley and Black (1934).

Available N, P and K (Kg/ha)

The soil samples were collected from 0-15 cm soil profile at the initial and at the end of experimentation period. The soil samples were air dried, ground and passed through 2 mm mesh sieve and were analysed for available N, P and K. The available N was estimated by alkaline $KMnO_4$ method suggested by Subbiah and Asija (1956) and expressed in Kg/ha. The available P content in soil was estimated by Olsen's method (Olsen *et.al*., 1954). Available K was determined using neutral normal ammonium acetate extraction (flame photometer) method as described by Jackson (1973) and expressed in Kg/ha.

3.9 Irrigation water productivity (Kg/ha-mm)

Irrigation water-productivity (kg/ha-cm) was calculated as the grain/seed yield (kg/ha) divided by the irrigation water applied (ha-cm) (Ibragimov *et al.*, 2011).

$$\text{Irrigation water productivity} = \frac{\text{Grain yield (kg/ha)}}{\text{Irrigation water applied (ha-cm)}}$$

3.10 Economic analysis

The economic analysis in terms of gross and net returns and benefit: cost ratio (returns per rupee invested) was worked out on the basis of existing rate of inputs and output (Annexure-

II). Total variable cost included in the cost of input such as seeds, fertilizers, irrigation and various cultural operations such as ploughing, sowing, weeding, harvesting, threshing etc. The rental value of land was also considered in the cost of cultivation. Returns were calculated by using the following formula expression:

Gross returns = Value of the grain/seed + Value of straw/stover

Net returns = Gross returns – Total variable costs

Benefit: cost ratio = Net returns/Total variable 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, 1983) for split plot design and randomized block design using SAS 9.1 software (SAS Institute, Cary, NC). The Tukey procedure was used where ANNOVA was significant and results are presented at 5% level of significance (P=0.05).

CHAPTER-IV

EXPERIMENTAL RESULTS

The results of the field experiment entitled "*Studies on green house gas emissions and carbon sequestration under conservation agriculture in maize based cropping systems*" conducted at the Research Farm, Directorate of Maize Research, Pusa, New Delhi for two consecutive years during 2012-13 and 2013-14 are presented in this chapter. Data on the effects of treatments on growth, yield attributes and yield, plant quality, nutrient uptake, carbon budgeting, GHGs emission and economics of cropping system were analyzed statistically to test the significance of the results. Appropriate tables and graphs have been used to illustrate the results where necessary.

4.1 Maize

4.1.1 Growth parameters

The plant height, dry matter accumulation, leaf area and leaf area index (LAI) of maize were influenced significantly due to different conservation tillage practices at all the growth stages, except at 30 DAS during both the years of studies while cropping system did not influenced these parameters (Table 4.1 to 4.4 and Fig. 4.1). However, growth parameters of the maize were better during 2013 in comparison to 2012 due to favorable weather conditions. In general, crop was grown with residue performed better than without residue irrespective of tillage practices and the years. Tallest plants were recorded at 90 DAS under PB-WR (173.13 cm) during 2012 and ZT-WR (177.12 cm) practice during 2013, respectively. Dry matter accumulation rate was slow at early growth stages, but at peak growth and plant development (60 and 90 DAS) it accelerated tremendously during both the years. During 2012, the maximum dry matter accumulation (131.17 g/plant) was recorded in PB-WR while in 2013 ZT-WR treatment recorded maximum dry matter accumulation at 90 DAS. Similarly, at early growth stage (30 DAS) leaf area and LAI was low, but it was increased on later stages and reached maximum at 60 DAS and then reduced during both the year. At 60 DAS, the LAI values were found maximum (4.30) under PB-WR during 2012 while ZT-WR treatment recorded maximum LAI (4.60) during 2013. In most cases the minimum values of these growth parameters were recorded under CT-WOR practices at all the stages of crop growth.

4.1.2 Growth indices

The crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR) were influenced significantly by conservation tillage at all three intervals except at 0-30 DAS during both the years (Table 4.5 to 4.7). However, growth indices were not significantly influenced due to cropping system during both the years. CGR recorded gradual increase with enhancement of growth stages with maximum values at 60-90 DAS while the RGR recorded

Table: 4.1. Effect of conservation tillage practices and cropping systems on maize plant height (cm)

Treatments	30 DAS		60 DAS		90 DAS	
	2012	2013	2012	2013	2012	2013
Conservation tillage practices:						
PB-WR	55.70	64.00	171.81	173.54	173.13	174.70
PB-WOR	51.50	61.05	160.88	165.37	163.95	168.13
ZT-WR	55.39	63.67	169.72	174.60	172.77	177.12
ZT-WOR	50.72	60.58	157.48	163.03	161.56	165.98
CT-WR	54.65	60.20	168.46	169.54	170.74	172.57
CT-WOR	50.11	58.22	151.49	152.70	154.68	152.95
SEm±	1.521	3.479	3.989	4.321	3.904	4.420
LSD (P=0.05)	NS	NS	12.562	13.623	12.311	13.944
Cropping systems:						
Maize-Wheat	51.71	59.83	161.87	165.41	165.88	167.16
Maize-Chickpea	54.31	62.74	164.74	167.51	166.40	169.99
SEm±	1.542	1.825	1.492	1.202	1.987	2.645
LSD (P=0.05)	NS	NS	NS	NS	NS	NS

Table: 4.2. Effect of conservation tillage practices and cropping systems on maize leaf area (cm^2/plant)

Treatments	30 DAS		60 DAS		90 DAS	
	2012	2013	2012	2013	2012	2013
Conservation tillage practices:						
PB-WR	3043.17	3165.53	5761.17	5946.24	4295.07	4609.24
PB-WOR	2930.33	2963.42	5415.50	5665.11	4013.07	4265.74
ZT-WR	3006.00	3267.11	5535.67	6159.74	4068.40	4467.61
ZT-WOR	2902.83	2942.87	5371.50	5684.11	3900.90	4244.61
CT-WR	2953.33	3090.07	5494.00	5875.54	4042.57	4354.04
CT-WOR	2871.67	2890.33	4895.83	5417.26	3673.73	3927.76
SEm±	121.641	94.689	148.762	135.255	105.835	122.164
LSD (P=0.05)	NS	NS	468.692	426.142	333.444	384.881
Cropping systems:						
Maize-Wheat	2876.06	2976.88	5298.44	5678.63	3885.72	4239.30
Maize-Chickpea	3026.39	3129.56	5526.11	5904.03	4112.19	4383.70
SEm±	70.240	82.291	123.883	76.386	95.297	48.154
LSD (P=0.05)	NS	NS	NS	NS	NS	NS

Table: 4.3. Effect of conservation tillage practices and cropping systems on maize dry matter accumulation (g/plant).

Treatments	30 DAS		60 DAS		90 DAS	
	2012	2013	2012	2013	2012	2013
Conservation tillage practices:						
PB-WR	33.23	36.95	69.38	71.90	131.17	143.83
PB-WOR	32.00	34.63	66.88	66.45	122.67	131.83
ZT-WR	33.27	37.68	69.15	72.62	130.00	146.00
ZT-WOR	31.42	34.68	66.72	65.25	121.00	128.83
CT-WR	33.02	35.57	67.97	70.47	127.83	137.67
CT-WOR	29.17	34.23	60.13	63.22	118.33	123.33
SEm±	1.287	1.287	1.669	1.931	2.857	3.458
LSD (P=0.05)	NS	NS	5.264	6.084	9.002	10.891
Cropping systems:						
Maize-Wheat	31.16	35.23	64.84	67.32	123.06	133.39
Maize-Chickpea	32.87	36.02	68.57	69.31	127.28	137.11
SEm±	0.644	0.679	1.499	0.898	1.478	2.327
LSD (P=0.05)	NS	NS	NS	NS	NS	NS

Table: 4.4. Effect of conservation tillage practices and cropping systems on maize leaf area index (LAI).

Treatments	30 DAS		60 DAS		90 DAS	
	2012	2013	2012	2013	2012	2013
Conservation tillage practices:						
PB-WR	2.27	2.36	4.30	4.44	3.21	3.44
PB-WOR	2.19	2.21	4.04	4.23	2.99	3.18
ZT-WR	2.24	2.44	4.13	4.60	3.04	3.33
ZT-WOR	2.17	2.20	4.01	4.24	2.91	3.17
CT-WR	2.20	2.31	4.10	4.38	3.02	3.25
CT-WOR	2.14	2.16	3.65	4.04	2.74	2.93
SEm±	0.092	0.071	0.113	0.099	0.078	0.092
LSD (P=0.05)	NS	NS	0.354	0.323	0.251	0.294
Cropping systems:						
Maize-Wheat	2.15	2.22	3.95	4.24	2.90	3.16
Maize-Chickpea	2.26	2.34	4.12	4.41	3.07	3.27
SEm±	0.050	0.064	0.092	0.057	0.071	0.035
LSD (P=0.05)	NS	NS	NS	NS	NS	NS

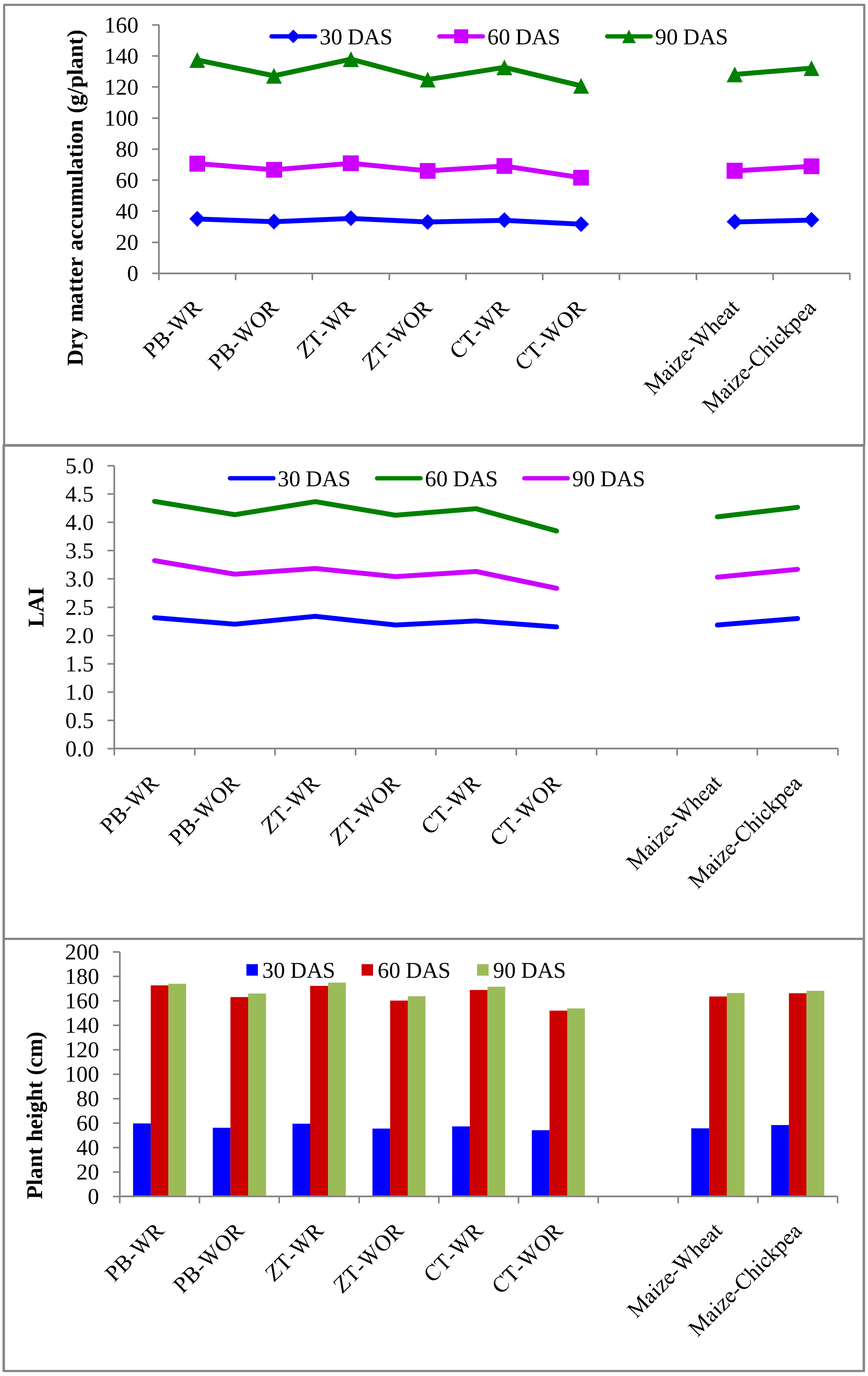


Fig.4.1. Effect of conservation tillage practices and cropping systems on maize growth parameters (mean of two years).

a reverse trend in comparison to CGR. In most cases the maximum values of these indices were recorded in ZT-WR.

Table: 4.5. Effect of conservation tillage practices and cropping systems on maize crop growth rate (g/plant/day)

Treatments	0-30 DAS		30-60 DAS		60-90 DAS	
	2012	2013	2012	2013	2012	2013
Conservation tillage practices:						
PB-WR	1.11	1.23	1.21	1.17	2.06	2.40
PB-WOR	1.07	1.15	1.16	1.06	1.86	2.18
ZT-WR	1.11	1.26	1.20	1.16	2.03	2.45
ZT-WOR	1.05	1.16	1.18	1.02	1.81	2.12
CT-WR	1.10	1.19	1.17	1.16	2.00	2.24
CT-WOR	0.97	1.14	1.03	0.97	1.94	2.00
SEm±	0.042	0.042	0.035	0.028	0.057	0.078
LSD (P=0.05)	NS	NS	0.114	0.102	0.171	0.243
Cropping systems:						
Maize-Wheat	1.04	1.17	1.12	1.07	1.94	2.20
Maize-Chickpea	1.10	1.20	1.19	1.11	1.96	2.26
SEm±	0.021	0.021	0.021	0.028	0.057	0.064
LSD (P=0.05)	NS	NS	NS	NS	NS	NS

Table: 4.6. Effect of conservation tillage practices and cropping systems on maize relative growth rate (mg/g/day)

Treatments	0-30 DAS		30-60 DAS		60-90 DAS	
	2012	**2013**	**2012**	**2013**	**2012**	**2013**
Conservation tillage practices:						
PB-WR	50.698	52.166	10.647	9.695	9.191	10.305
PB-WOR	50.079	51.299	10.608	9.435	8.818	9.908
ZT-WR	50.694	52.467	10.592	9.503	9.164	10.138
ZT-WOR	49.673	51.121	11.050	9.203	8.729	9.920
CT-WR	50.574	51.622	10.462	9.905	9.174	9.511
CT-WOR	48.735	51.144	10.453	8.845	9.919	9.635
SEm±	0.6292	0.5451	0.1064	0.1981	0.2123	0.1634
LSD (P=0.05)	NS	NS	0.3431	0.6342	0.6821	0.5011
Cropping systems:						
Maize-Wheat	49.685	51.426	10.585	9.403	9.344	9.936
Maize-Chickpea	50.466	51.847	10.685	9.459	8.987	9.869
SEm±	0.3112	0.2761	0.0503	0.0994	0.1414	0.1771
LSD (P=0.05)	NS	NS	NS	NS	NS	NS

Table: 4.7. Effect of conservation tillage practices and cropping systems on maize net assimilation rate (mg/cm^2/day)

Treatments	0-30 DAS		30-60 DAS		60-90 DAS	
	2012	2013	2012	2013	2012	2013
Conservation tillage practices:						
PB-WR	1.280	1.360	0.124	0.116	0.177	0.199
PB-WOR	1.270	1.360	0.125	0.112	0.173	0.192
ZT-WR	1.300	1.370	0.126	0.112	0.186	0.202
ZT-WOR	1.250	1.360	0.128	0.106	0.173	0.187
CT-WR	1.300	1.360	0.124	0.117	0.185	0.190
CT-WOR	1.170	1.370	0.118	0.105	0.201	0.189
SEm±	0.0642	0.0713	0.0004	0.0003	0.0071	0.0034
LSD (P=0.05)	NS	NS	0.0012	0.0011	0.0131	0.0102
Cropping systems:						
Maize-Wheat	1.250	1.380	0.124	0.112	0.187	0.194
Maize-Chickpea	1.270	1.350	0.125	0.111	0.178	0.192
SEm±	0.0352	0.0421	0.0013	0.0011	0.0011	0.0021
LSD (P=0.05)	NS	NS	NS	NS	NS	NS

4.1.3 Development parameter

There was variation in days to 50 % silking due to different tillage and crop establishment techniques. The minimum 56.83 and 57 days for 50 % silking under ZTWR while it was maximum of 57.63 and 58.83 days under CTWOR treatment during both years, respectively (Table 4.8).

4.1.4 Yield attributes

Cobs/m^2 and grains/cob were significantly influenced due to conservation tillage practices. However, cob length, cob girth, grains row/cob, and 100-grain weight were statistically similar. The yield attributes were not significantly influenced due to cropping system during both the years of study (Table 4.8 to 4.9 and Fig. 4.2). Maximum values of cobs/m^2 (7.33 and 8.17) and grains/cob (429.83 and 519.17) were recorded under ZT-WR than rest of the treatments, while minimum values were obtained under CT-WOR.

4.1.5 Yield performance

The grain, stover, cob and biological yields of maize were differed significantly due to different conservation tillage practices, while harvest index was non-significant during both the years of study. Cropping system did not influenced significantly yield attributes and harvest index of maize during both the years (Table 4.10 and Fig. 4.2). Grain, stover, cob and biological yields were significantly higher under ZT-WR followed by PB-WR during both the years except stover yield during 2013 which was higher under ZT-WOR. The minimum values of these traits were registered under CT-WOR. Data revealed that ZT-WR registered 22.4, 20.0 and 18.5 %; 24.3, 12.8 and 14.4% increase in grain, stover and biological yields during 2012 and 2013, respectively. There was only a marginal non-significant difference in the harvest index (HI) of maize under different tillage and crop establishment practices in both the years. The HI varied narrowly from 25.95 to 28.65% in year 2012 and from 26.90% under PB-WOR to 29.17% under ZT-WOR in year 2013. In comparison between PB-WR (or WOR) and ZT-WR (or WOR) both were resulted statistically similar grain, stover and biological yields.

4.1.6 Nutrient uptake

The nutrient uptake by grain and stover of maize crop was significantly influenced due to conservation tillage practices during both the years of study (Table 4.11 and Fig. 4.3). The maximum nutrient uptake in grain and stover were recorded with ZT-WR, while minimum was recorded with CT-WOR during both the years. Application of residue significantly improved the nutrient uptake in grain as well as in stover irrespective of tillage over no residue in most of the cases. ZT-WR was significantly increased the N uptake in grain and straw. The percent increase in N uptake by grain and straw were 16.2 and 30.3 during 2012; 19.7 and 38.3 during 2013 over CT-WOR, respectively. Similar trend was found in P and K uptake by grain and straw during both the years of study.

Table: 4.8. Effect of conservation tillage practices and cropping systems on maize phenological stages and yield attributes

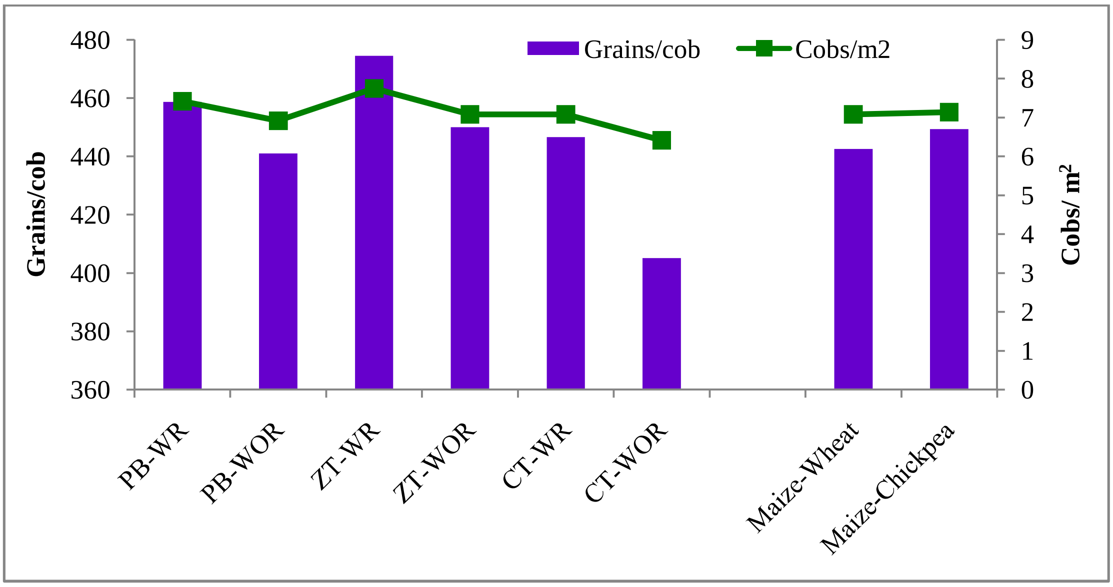
Treatments	Days to 50% silking		Days to maturity		Cobs/m^2 (at harvest)		100-grain weight (g)	
	2012	2013	2012	2013	2012	2013	2012	2013
Conservation tillage practices:								
PB-WR	57.00	57.17	107.50	107.67	7.17	7.67	26.77	27.17
PB-WOR	57.33	57.67	107.00	108.00	6.67	7.17	27.10	27.67
ZT-WR	56.83	57.00	107.00	107.17	7.33	8.17	25.67	27.00
ZT-WOR	57.17	57.67	106.67	107.83	6.67	7.50	27.77	27.33
CT-WR	57.67	58.33	108.50	108.83	6.83	7.33	26.80	28.17
CT-WOR	57.67	58.83	108.00	109.17	6.00	6.83	27.97	28.50
SEm±	0.219	0.474	0.410	0.502	0.219	0.233	0.714	0.926
LSD (P=0.05)	NS	NS	NS	NS	0.702	0.744	NS	NS
Cropping systems:								
Maize-Wheat	57.22	58.06	107.39	108.39	6.78	7.39	27.48	27.67
Maize-Chickpea	57.33	57.50	107.50	107.83	6.78	7.50	26.54	27.61
SEm±	0.156	0.184	0.233	0.233	0.163	0.127	0.438	0.552
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Table: 4.9. Effect of conservation tillage practices and cropping systems on maize yield attributes

Treatments	Cob length (cm)		Cob girth (cm)		Grain row/cob		Grains/cob	
	2012	2013	2012	2013	2012	2013	2012	2013
Conservation tillage practices:								
PB-WR	17.17	18.02	13.03	13.22	13.07	13.53	417.33	500.00
PB-WOR	16.39	17.57	13.15	13.48	13.42	13.70	403.00	479.00
ZT-WR	17.24	18.17	13.07	13.03	12.97	13.33	429.83	519.17
ZT-WOR	16.89	17.75	13.10	13.23	13.36	13.53	404.83	495.33
CT-WR	17.09	17.48	13.02	13.40	13.12	13.62	416.17	477.00
CT-WOR	16.26	17.13	13.48	13.62	13.45	13.83	363.83	446.5
SEm±	0.417	0.212	0.219	0.255	0.198	0.177	11.542	12.192
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	36.362	38.424
Cropping systems:								
Maize-Wheat	16.57	17.59	13.21	13.33	13.17	13.69	404.78	480.44
Maize-Chickpea	17.11	17.78	13.07	13.33	13.29	13.49	406.89	491.89
SEm±	0.481	0.127	0.134	0.099	0.113	0.134	5.198	6.153
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Table: 4.10. Effect of conservation tillage practices and cropping systems on maize yields and harvest index

Treatments	Cob yield (t/ha)		Grain yield (t/ha)		Stover yield (t/ha)		Biological yield (t/ha)		Harvest index (%)	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Conservation tillage practices:										
PB-WR	5.91	6.69	4.85	5.57	11.86	12.73	17.78	19.43	27.29	28.65
PB-WOR	5.30	6.43	4.23	5.26	10.97	13.14	16.27	19.58	25.95	26.90
ZT-WR	6.13	7.15	5.09	5.89	11.94	13.05	18.07	20.20	28.18	29.17
ZT-WOR	5.69	6.71	4.55	5.46	10.60	13.31	16.29	20.01	28.07	27.32
CT-WR	5.69	6.26	4.65	5.24	10.55	12.83	16.24	19.10	28.65	27.41
CT-WOR	5.30	6.07	4.16	4.74	9.95	11.57	15.25	17.65	27.36	26.95
SEm±	0.163	0.205	0.149	0.141	0.283	0.325	0.332	0.453	0.813	0.714
LSD (P=0.05)	0.522	0.641	0.473	0.443	0.906	1.021	1.0431	1.424	NS	NS
Cropping systems:										
Maize-Wheat	5.64	6.46	4.59	5.31	10.82	12.69	16.46	19.15	27.84	27.69
Maize-Chickpea	5.71	6.64	4.59	5.41	11.13	12.86	16.84	19.50	27.33	27.78
SEm±	0.067	0.097	0.088	0.103	0.241	0.211	0.251	0.234	0.622	0.601
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS



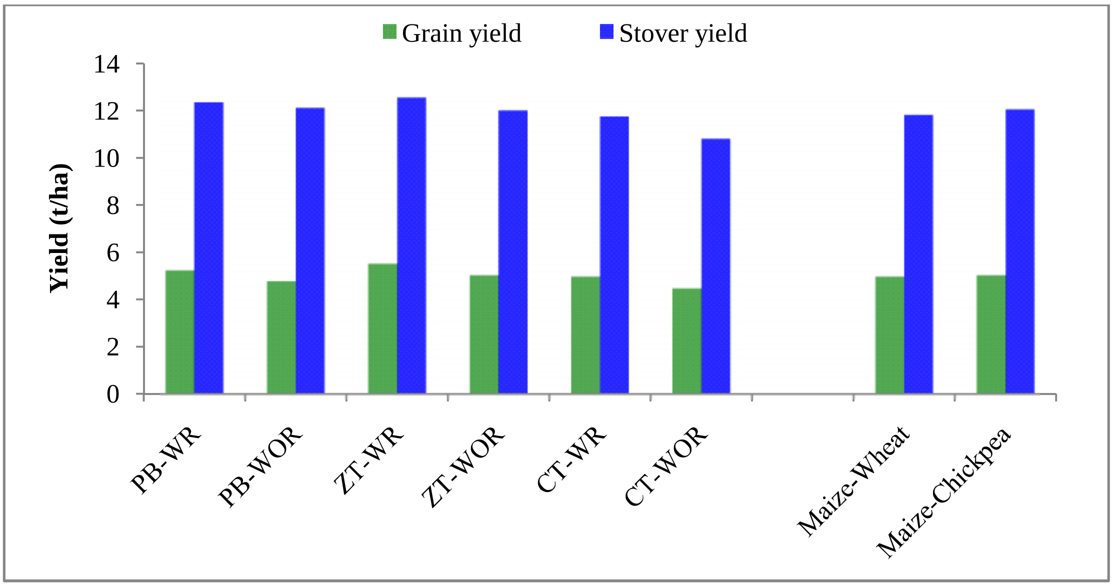


Fig.4.2. Effect of conservation tillage practices and cropping systems on yield attributes and yields in maize (mean of two years).

4.1.7 Carbon budgeting and C sustainability index

The total C-input output and CSI estimated for maize was influenced due to conservation tillage practices and cropping system (Table 4.12 and Fig. 4.4). The maximum C-input was estimated under CT-WR with 373.79 MJ/ha during both the year. Whereas, minimum C-input was recorded under PB-WOR. Similarly maximum C-output was recorded under ZT-WR (7899.76 and 8784.60 MJ/ha), whereas minimum under CT-WOR (6574.72 and 7567.74 MJ/ha). Both the cropping system were recorded same C-input (316.64 and 314.34 MJ/ha) during 2012 and 2013, respectively. Among cropping system maize–chickpea recorded highest C- output (7294.46 and 8475.80 MJ/ha) during both the years. CSI was also higher under ZT-WR (24.87) during 2012 and ZT-WOR (29.02) during 2013. Cropping system did not influenced CSI but was maximum under maize-chickpea cropping system during both the years.

4.1.8 Nutrient use efficiency

Nutrient use efficiency (NUE) in maize was significantly influenced with different conservation tillage practices (Table 4.12 and Fig. 4.3). Significantly higher values of NUE was found under ZT-WR (21.82 and 25.60 kg grain/ kg NPK applied during 2012-13 and 2013-14, respectively) over all other treatments except PB-WR.

4.1.9 Water productivity

Water productivity of maize was significantly influenced by conservation tillage practices and cropping system during both the years (Table 4.12 and Fig. 4.4). The highest water productivity was observed under PB-WR (4.85 and 5.57 kg/ha-mm; during 2012 and 2013, respectively), which was significantly higher than CT-WOR and ZT-WR, but it remained statistically similar with other treatments in both the years. Similarly, the lowest water productivity was recorded under CT-WOR (3.20 and 3.64 kg/ha-mm) during 2012 and 2013, respectively. Water productivity was not significantly influenced due to different cropping system in both the years. Slightly higher water productivity was recorded under maize-chickpea system (4.11 and 4.85 kg/ha-mm) as compare to maize-wheat (4.10 and 4.76 kg/ha-mm) during both the years.

4.1.10 Economics

Data pertaining to cost of cultivation, gross returns, net returns and B:C ratio of maize are presented in (Table 4.13 and Fig. 4.4) . The cost of cultivation of maize crop under different conservation tillage and cropping system varied from minimum with ZT-WOR and PB-WOR (22.11 x 10^3 and 23.32 x10^3 ₹/ha) to maximum under CT-WR (25.09 x 10^3 and 26.42 x 10^3 ₹/ha) in year 2012 and 2013, respectively. The cost of cultivation of maize under both the cropping system was same which were 23.33 x 10^3 and 24.59 x 10^3 ₹/ha during 2012 and 2013, respectively.

The net returns and B:C ratio were influenced due to different conservation tillage and cropping system. The maximum net returns and B:C ratio were recorded under ZT-WR (28.48 x 10^3 ₹/ha and 1.21) during 2012 and (34.80 x 10^3 and 1.40), while minimum net returns and B:C ratio were obtained under CT-WOR (18.96 x 10^3 ₹/ha and 0.80) during 2012 and 2013 (23.83 x 10^3 ₹/ha and 0.95), respectively. Gross returns from maize cultivation recorded the similar trend as it was with net returns. In general, with residue gave 20.8, 17.2 and 16.8% higher net returns over without residue during 2012, while 2.6, 5.9 and 15.5% higher under PB, ZT and CT, respectively during 2013. Slightly higher gross returns,

Table: 4.11. Effect of conservation tillage practices on maize nutrient uptake

Treatments	Nitrogen (kg/ha)				Phosphorus (kg/ha)				Potassium (kg/ha)			
	Grain		Stover		Grain		Stover		Grain		Stover	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Conservation tillage practices:												
PB-WR	63.77	73.27	41.16	44.55	14.57	16.49	12.00	13.36	20.57	25.70	91.04	93.13
PB-WOR	57.69	71.10	35.39	38.42	12.83	15.77	9.95	11.91	18.19	23.17	82.56	85.19
ZT-WR	65.18	76.48	42.30	45.75	15.14	17.34	12.23	13.88	20.95	25.17	93.00	95.21
ZT-WOR	58.03	71.55	35.74	39.93	13.40	16.10	10.46	12.04	19.30	24.34	83.19	85.68
CT-WR	62.83	70.80	37.00	40.38	13.00	14.52	10.71	13.25	19.94	23.00	84.25	87.58
CT-WOR	56.07	63.89	32.46	33.07	11.55	13.19	9.84	10.87	17.03	19.79	75.34	78.25
SEm±	1.294	1.662	0.948	1.584	0.396	0.438	0.467	0.530	0.679	0.842	1.733	3.048
LSD (P=0.05)	4.072	5.241	2.993	4.991	1.301	1.384	1.482	1.673	2.151	2.664	5.464	9.611
Cropping systems:												
Maize-Wheat	61.06	71.47	36.79	39.76	13.23	15.30	10.90	12.24	19.19	23.43	84.11	86.73
Maize-Chickpea	60.14	70.90	37.90	40.93	13.60	15.83	10.83	12.86	19.47	23.62	85.69	88.29
SEm±	0.877	1.591	0.728	0.806	0.403	0.219	0.205	0.375	0.467	0.537	2.192	1.803
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

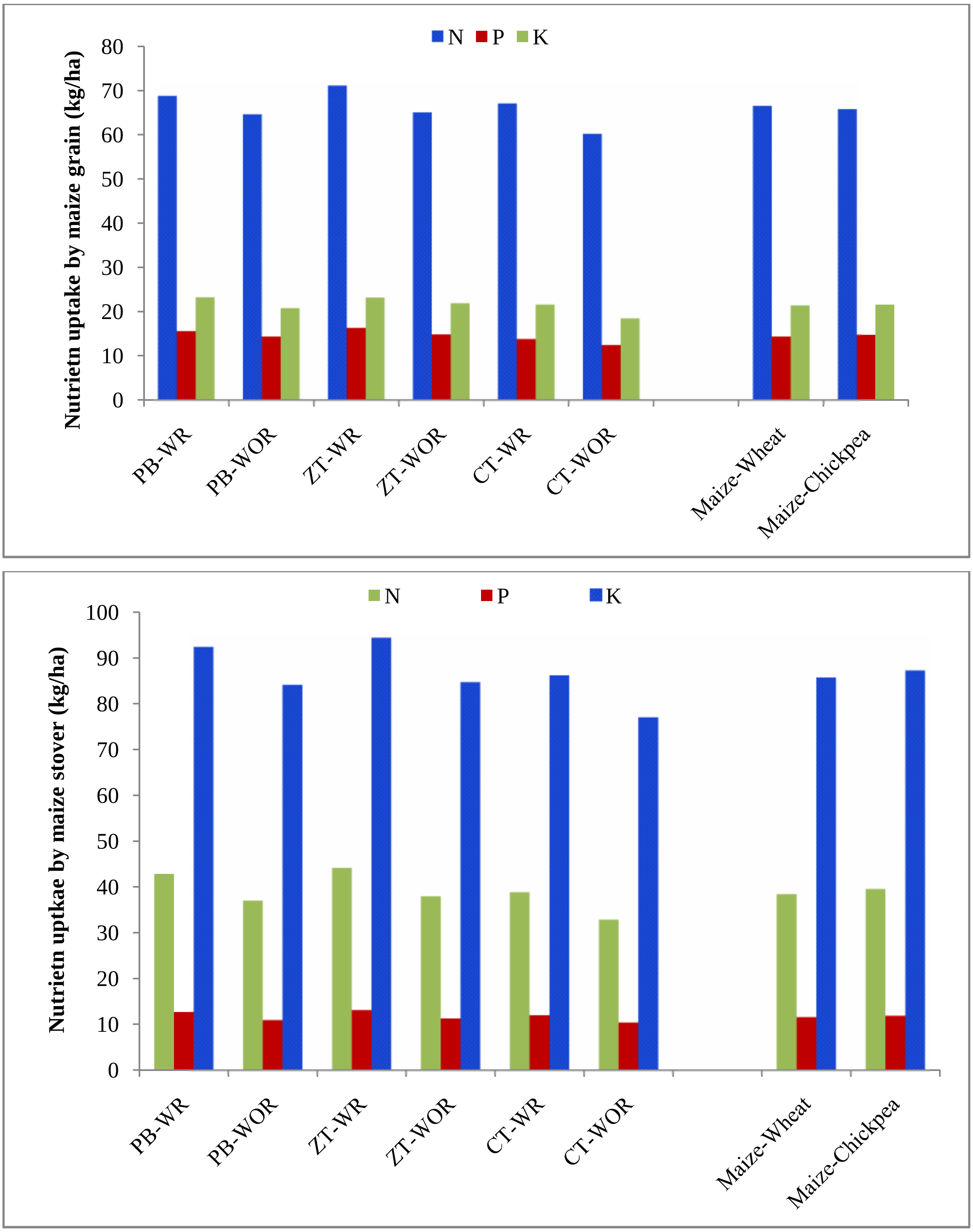


Fig.4.3. Effect of conservation tillage practices and cropping systems on NPK uptake by maize (mean of two years).

net returns and B:C ratio were recorded under maize-chickpea cropping system in comparison to maize-wheat during both the years.

Table: 4.12. Effect of conservation tillage practices and cropping systems on CSI, NPK and water productivity in maize

Treatments	Total C-input (MJ/ha)		Total C-output (MJ/ha)		Carbon sustainability index (CSI)		Total NPK productivity (kg grain /kg NPK applied)		Water productivity (kg/ha-mm)	
	2012	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**
Conservation tillage practices:										
PB-WR	302.82	299.37	7754.54	8491.30	24.61	27.36	20.81	24.20	4.85	5.57
PB-WOR	291.02	287.57	7050.90	8538.49	23.23	28.69	18.14	22.86	4.23	5.26
ZT-WR	305.32	301.87	7899.76	8784.60	24.87	28.10	21.82	25.60	4.62	5.35
ZT-WOR	293.52	290.07	7026.95	8708.27	22.94	29.02	19.52	23.74	4.14	4.96
CT-WR	373.79	373.79	7052.19	8384.77	17.87	21.43	18.60	20.95	3.58	4.03
CT-WOR	333.39	333.39	6547.72	7567.74	18.64	21.70	16.64	18.95	3.20	3.64
SEm±	-	-	151.605	172.199	0.460	0.559	0.622	0.587	0.134	0.120
LSD (P=0.05)	-	-	477.641	542.531	1.451	1.754	1.962	1.854	0.421	0.393
Cropping systems:										
Maize-Wheat	316.64	314.34	7149.56	8349.26	21.78	25.85	19.24	22.49	4.10	4.76
Maize-Chickpea	316.64	314.34	7294.46	8475.80	22.27	26.25	19.27	22.94	4.11	4.85
SEm±	-	-	116.938	98.975	0.375	0.318	0.375	0.446	0.085	0.092
LSD (P=0.05)	-	-	NS	NS	NS	NS	NS	NS	NS	NS

Table: 4.13. Effect of conservation tillage practices and cropping system on maize economics

Treatments	Gross returns (x 10^3 Rs/ha)		Net returns (x 10^3 Rs/ha)		B C ratio (Net returns Rs/Re invested)		Cost of cultivation (x 10^3 Rs/ha)	
	2012	2013	2012	2013	2012	2013	2012	2013
Conservation tillage practices:								
PB-WR	67.07	83.75	26.45	31.86	1.13	1.29	23.49	24.77
PB-WOR	58.99	80.05	21.90	31.04	0.99	1.33	22.11	23.32
ZT-WR	69.90	88.21	28.48	34.80	1.21	1.40	23.49	24.77
ZT-WOR	62.46	82.83	24.31	32.86	1.10	1.41	22.11	23.32
CT-WR	63.60	79.51	22.15	27.52	0.88	1.04	25.09	26.42
CT-WOR	57.35	71.91	18.96	23.83	0.80	0.95	23.71	24.97
SEm±	1.778	1.890	1.280	1.236	0.057	0.050	-	-
LSD (P=0.05)	5.603	5.955	4.034	3.895	0.172	0.152	-	-
Cropping systems:								
Maize-Wheat	63.07	80.29	23.57	29.81	1.01	1.22	23.33	24.59
Maize-Chickpea	63.38	81.80	23.84	30.82	1.03	1.26	23.33	24.59
SEm±	1.039	1.327	0.749	0.848	0.053	0.052	-	-
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	-	-

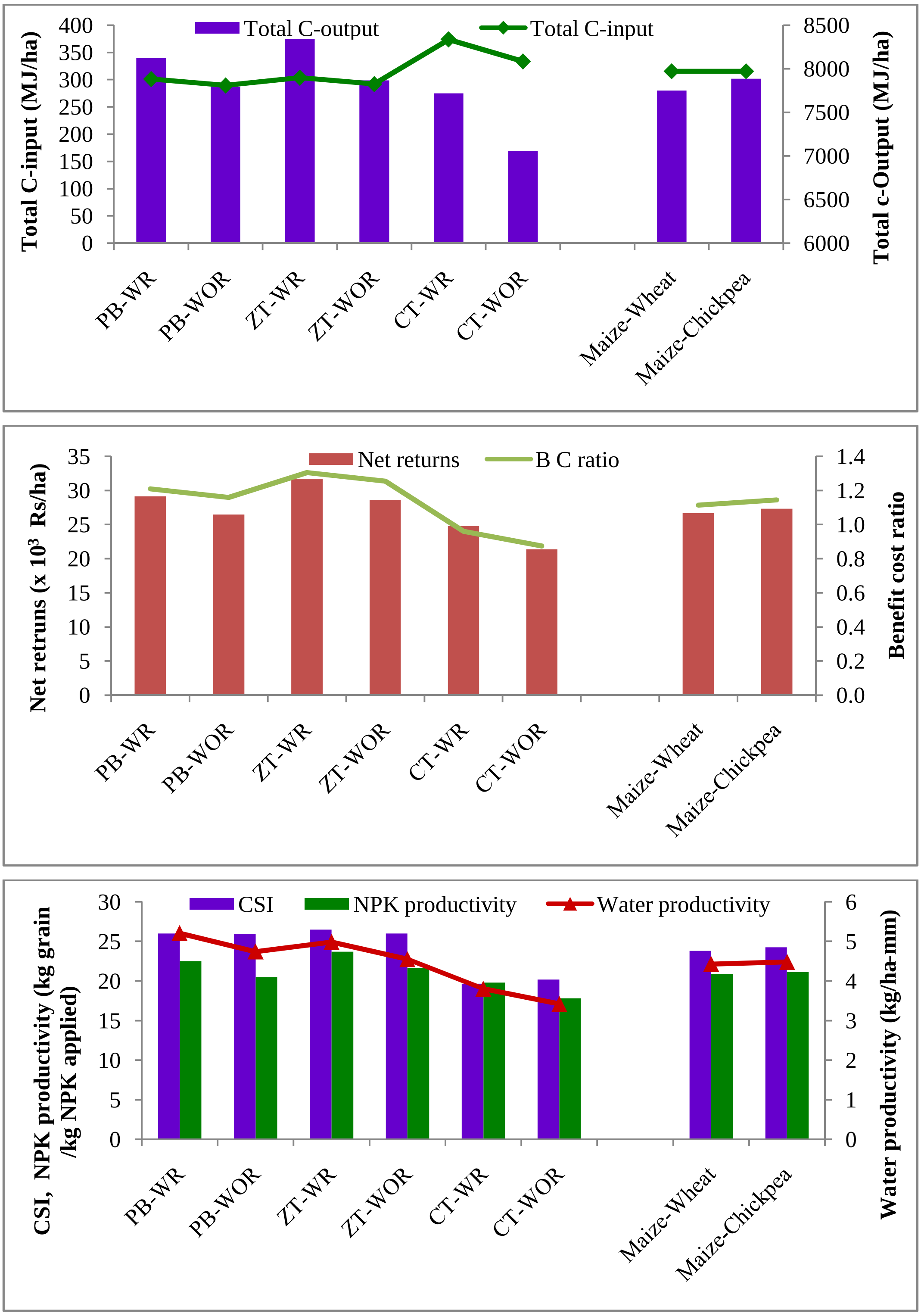


Fig.4.4. Effect of conservation tillage practices and cropping systems on carbon sustainability index (CSI), NPK and water productivity and economics in maize (mean of two years).

followed by ZT-WR (415.33 and 424.67 m^2) while lowest under CT-WOR (330.33 and 337.33/m^2) during 2012-13 and 2013-14, respectively.

4.2 Wheat

4.2.1 Growth parameters

Plant height, dry matter accumulation (DMA), leaf area and leaf area index (LAI) were influenced significantly due to conservation tillage practices at all the growth stages of wheat except 30 DAS during both the years of study (Table 4.14 to 4.17 and Fig. 4.5). The rate of increase of plant height was high upto 90 DAS after this stage there was slight increased in plant height. However, the tallest plants (84.00 and 88.57 cm) were recorded at harvest under PB-WR practice during both the years. While shortest plant was recorded under CT-WOR. 4Dry matter accumulation rate was slow at early growth stages, but at peak growth and plant development (60 and 90 DAS) it accelerated tremendously during both the years. At harvest the maximum dry matter accumulation (1038.82 and 1049.65 g/m^2) was recorded in PB-WR treatment during 2012-13 and 2013-14, respectively. Similarly, at early growth stage (30 DAS) leaf area and LAI were low, but it was increased on later stages and reached maximum at 90 DAS during both the year. At 90 DAS, the LAI values were found maximum (1.52 and 1.55) under PB-WR treatment during both the years, respectively. In most cases the minimum values of these growth parameters were recorded under CT-WOR practices at all the stages of crop growth.

4.2.2 Growth indices

Crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR) were influenced significantly at all the intervals except 30 DAS due to conservation tillage practice during both the years of study (Table 4.18 to 4.20). CGR and NAR recorded a gradual increase with enhancement of growth stages with maximum values at 60-90 DAS. The maximum CGR (17.90 and 18.46 g/m^2/day) were recorded at 60-90 DAS under PB-WR practice during both the years. Whereas, the RGR recorded a reverse trend in comparison to CGR, maximum value was found at 0-30 DAS.

4.2.3 Development parameters

There was no variation in days to 50% anthesis and days to maturity due to conservation tillage practices during both the years of study (Table 4.21).

4.2.4 Yield attributes

The yield attributes, viz. tillers/m^2 and effective tillers/m^2 and were influenced significantly by conservation tillage practices, while spike length, grains/spike and 1000-grain weight of wheat were not influenced significantly during both the years of study (Table 4.21 & 4.22 and Fig. 4.6). Most of these characters attained maximum value under PB-WR treatment, while minimum under CT-WOR practices during both the years of study. Highest number of tillers (452.33 and 472.67/m^2) were recorded under PB-WR during both the years of study. The maximum value of effective tillers were observed under PB-WR (431.33 and 433.67/m^2)

Table: 4.14. Effect of conservation tillage practices on wheat plant height (cm).

Treatments	30 DAS		60 DAS		90 DAS		At harvest	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Conservation tillage practices:								
PB-WR	24.97	30.33	43.10	51.83	79.70	83.67	84.00	88.57
PB-WOR	22.63	27.50	40.37	49.35	78.00	81.17	79.17	85.33
ZT-WR	23.53	29.53	42.77	51.17	79.50	83.17	83.17	87.00
ZT-WOR	21.93	27.50	39.20	48.17	77.47	80.97	78.97	84.57
CT-WR	21.77	26.50	40.57	50.77	76.67	80.27	80.27	82.47
CT-WOR	20.87	25.27	35.93	43.93	66.00	70.00	70.00	74.10
SEm±	1.075	1.330	1.413	1.573	2.743	2.707	2.700	2.785
LSD (P=0.05)	NS	NS	4.453	4.955	8.641	8.527	8.507	8.775

Table: 4.15. Effect of conservation tillage practices on wheat dry matter accumulation (g/m^2)

Treatments	30 DAS		60 DAS		90 DAS		At harvest	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Conservation tillage practices:								
PB-WR	41.29	48.79	151.26	155.40	688.32	703.07	1038.82	1049.65
PB-WOR	39.40	45.04	139.71	146.56	653.10	682.61	978.56	1026.14
ZT-WR	39.84	46.94	148.49	151.72	681.00	697.12	1030.06	1044.68
ZT-WOR	38.02	44.73	137.53	144.48	644.59	673.89	976.64	1024.73
CT-WR	37.75	42.33	138.01	141.60	646.93	666.08	995.74	1010.52
CT-WOR	36.73	41.19	128.68	133.55	571.74	597.70	871.86	877.36
SEm±	2.313	2.603	4.437	4.201	21.946	19.576	32.064	30.342
LSD (P=0.05)	NS	NS	13.979	13.236	69.142	61.675	101.021	95.588

Table: 4.16. Effect of conservation tillage practices on wheat leaf area (cm^2/plant)

Treatments	30 DAS		60 DAS		90 DAS	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Conservation tillage practices:						
PB-WR	97.13	98.51	283.98	294.90	494.88	509.98
PB-WOR	94.79	96.66	270.56	285.65	469.00	472.48
ZT-WR	96.20	98.05	279.81	293.05	483.54	497.13
ZT-WOR	93.20	95.74	273.80	282.59	470.01	470.64
CT-WR	95.28	95.28	275.19	287.50	476.31	478.65
CT-WOR	92.50	94.28	239.26	254.26	404.00	442.96
SEm±	5.410	6.214	8.742	7.917	16.626	12.243
LSD (P=0.05)	NS	NS	27.543	24.939	52.381	38.569

Table: 4.17. Effect of conservation tillage practices on wheat leaf area index (LAI)

Treatments	30 DAS		60 DAS		90 DAS	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Conservation tillage practices:						
PB-WR	0.70	0.71	1.35	1.42	1.52	1.55
PB-WOR	0.68	0.70	1.27	1.36	1.43	1.35
ZT-WR	0.69	0.71	1.32	1.41	1.47	1.47
ZT-WOR	0.67	0.69	1.30	1.35	1.41	1.36
CT-WR	0.69	0.69	1.30	1.39	1.48	1.38
CT-WOR	0.67	0.68	1.06	1.22	1.19	1.34
SEm±	0.042	0.042	0.056	0.037	0.055	0.044
LSD (P=0.05)	NS	NS	0.176	0.118	0.174	0.139

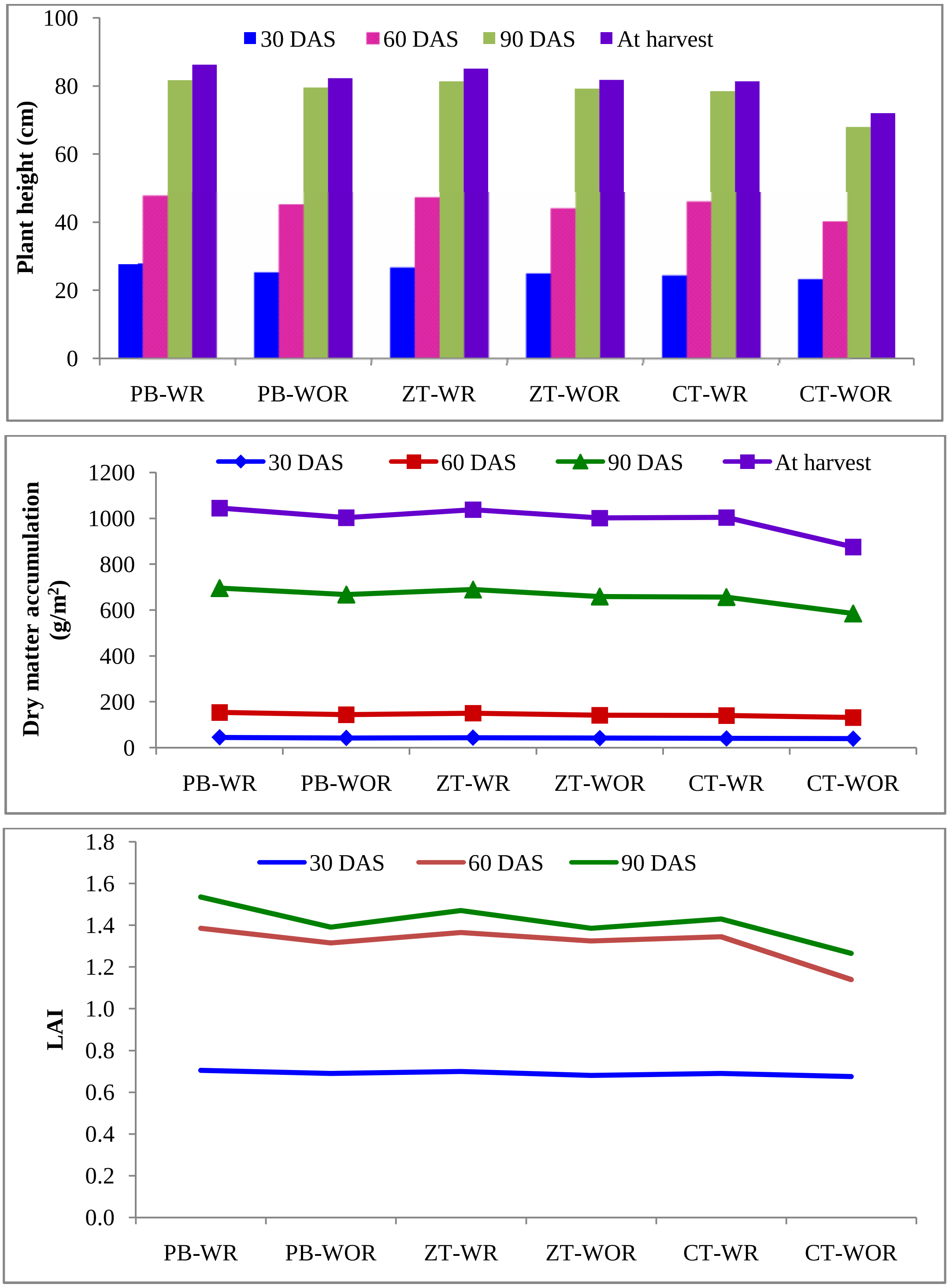


Fig.4.5. Effect of conservation tillage practices on wheat growth parameters (mean of two years).

recorded under CT-WOR (1.85 and 1.42 kg/ha-mm) during 2012-13 and 2013-14, respectively.

4.2.10 Economics

Data pertaining to cost of cultivation, gross returns, net returns and B:C ratio of wheat crop are presented in (Table 4.26 and Fig. 4.8). The maximum cost of cultivation was recorded

Table: 4.18. Effect of conservation tillage practices on wheat crop growth rate (g/m^2/day)

Treatments	0-30 DAS		30-60 DAS		60-90 DAS	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Conservation tillage practices:						
PB-WR	1.38	1.63	3.67	3.55	17.90	18.46
PB-WOR	1.31	1.50	3.34	3.38	17.11	17.87
ZT-WR	1.33	1.56	3.62	3.49	17.75	18.18
ZT-WOR	1.27	1.49	3.32	3.33	16.90	17.65
CT-WR	1.26	1.41	3.34	3.31	16.96	17.48
CT-WOR	1.22	1.37	3.07	2.98	14.77	15.11
SEm±	0.078	0.085	0.105	0.098	0.551	0.612
LSD (P=0.05)	NS	NS	0.329	0.307	1.735	1.928

Table: 4.19. Effect of conservation tillage practices on wheat relative growth rate (mg/g/day)

Treatments	0-30 DAS		30-60 DAS		60-90 DAS	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
Conservation tillage practices:						
PB-WR	53.80	56.23	18.82	17.07	21.93	21.86
PB-WOR	53.22	55.11	18.34	17.07	22.32	22.29
ZT-WR	53.31	55.64	19.05	17.06	22.06	22.07
ZT-WOR	52.63	55.06	18.65	17.01	22.36	22.31
CT-WR	52.54	54.22	18.80	17.52	22.37	22.41
CT-WOR	52.12	53.82	16.69	14.69	18.61	18.70
SEm±	0.001	0.001	0.438	0.496	0.651	0.744
LSD (P=0.05)	NS	NS	1.380	1.561	2.053	2.345

Table: 4.20. Effect of conservation tillage practices on wheat net assimilation rate (mg/cm^2/day)

Treatments	0-30 DAS		30-60 DAS		60-90 DAS	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
			Conservation tillage practices:			
PB-WR	28.22	32.93	9.14	8.62	20.49	20.41
PB-WOR	27.43	30.82	8.68	8.44	20.62	20.91
ZT-WR	27.46	32.03	9.15	8.53	20.73	20.46
ZT-WOR	27.11	31.05	8.62	8.41	20.22	20.79
CT-WR	26.23	29.62	8.57	8.28	20.11	20.35
CT-WOR	26.40	29.01	7.28	7.06	17.47	17.32
SEm±	0.002	0.002	0.264	0.274	0.536	0.655
LSD (P=0.05)	NS	NS	0.831	0.866	1.689	2.063

Table: 4.21. Effect of conservation tillage practices on wheat phenological stages and yield attributes

Treatments	Days to 50% anthesis		Days to maturity		Tillers/m^2		Effective tillers/m^2	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
Conservation tillage practices:								
PB-WR	104.00	102.33	136.00	135.67	452.33	472.67	431.33	433.67
PB-WOR	104.33	103.00	137.33	136.33	429.00	438.33	377.33	385.33
ZT-WR	104.33	102.67	136.33	136.00	447.33	453.00	415.33	424.67
ZT-WOR	104.67	103.67	137.33	136.33	393.67	398.00	359.67	370.67
CT-WR	105.67	104.00	139.00	137.00	413.00	418.33	382.33	391.33
CT-WOR	106.00	104.33	140.00	137.67	363.33	377.67	330.33	337.33
SEm±	0.460	0.509	0.849	0.587	15.318	18.847	18.840	0.460
LSD (P=0.05)	NS	NS	NS	NS	48.268	59.383	59.361	58.477

Table: 4.22. Effect of conservation tillage practices on wheat yield attributes

Treatments	Spike length (cm)		Grains/spike		1000-grain weight (g)	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Conservation tillage practices:						
PB-WR	10.43	10.93	49.33	53.87	38.30	41.50
PB-WOR	9.93	10.60	43.67	47.33	40.33	42.17
ZT-WR	10.17	10.83	44.67	50.10	38.27	41.90
ZT-WOR	9.80	10.17	42.00	45.67	39.07	42.40
CT-WR	10.13	10.37	43.00	47.93	40.13	42.97
CT-WOR	9.50	9.83	39.67	40.47	40.47	43.07
SEm±	0.545	0.453	2.694	2.631	1.478	1.485
LSD (P=0.05)	NS	NS	NS	NS	NS	NS

4.2.5 Yield performance

Grain, straw, and biological yields except harvest index of wheat were influenced significantly by conservation tillage practices during both years of study. (Table 4.23 and Fig. 4.6). The maximum grain, straw and biological yield were recorded under PB-WR treatment, which were 22.3, 26.9 and 24.3 % higher during 2012-13 and 27.3, 20.6 and 23.4% higher during 2013-14 over CT-WOR, respectively. The grain, straw and biological yield under PB-WR were at par with all other treatments except CT-WOR. Application of residue irrespective of tillage practices improved grain yield but could not reached to significant level except in CT during 2012-13.

4.2.6 Nutrient uptake

Data on N, P and K uptake by wheat as influenced by conservation tillage practices are presented in (Table 4.24 and Fig. 4.7). Conservation tillage significantly influenced the N, P and K uptake in grain and straw during both the years of investigation. Maximum N uptake in grain (64.84 and 68.38 kg/ha) and straw (31.73 and 35.81 kg/ha) was found under ZT-WR and PB-WR, respectively during both the years of study. Similar trend eas found P uptake by grain and straw. Whereas, highest K uptake in grain (23.73 and 25.39 kg/ha) and straw (90.45 and 102.37 kg/ha) were found under PB-WR during both the years of study.

4.2.7 Carbon budgeting and C sustainability index

The total C-input output and CSI estimated of wheat were influenced by conservation tillage practices (Table 4.25 and Fig. 4.8). The maximum C-input was estimated under CT-WR with 223.12 and 223.33 MJ/ha during 2012-13 and 2013-14, respectively. Whereas, minimum C-input was recorded under ZT-WOR. Similarly maximum C-output was recorded under PB-WR (4595.22 and 5057.22 MJ/ha), whereas minimum under CT-WOR (3694.49 and 4099.16 MJ/ha). CSI was higher under ZT-WR (18.13 and 21.56) during 2012-13 and 2013-14, respectively.

4.2.8 Nutrient use efficiency

Nutrient use efficiency (NUE) in wheat was significantly influenced with different conservation tillage practices (Table 4.25). Significantly higher values of NUE was found under PB-WR (22.51 and 24.66 kg grain/ kg NPK applied) over CT-WR and CT-WOR and remained at par with all other treatments during 2012-13 and 2013-14, respectively.

4.2.9 Water productivity

Water productivity of wheat was significantly influenced by conservation tillage practices during both the years (Table 4.25 and Fig. 4.8). The highest water productivity was observed under PB-WR (2.94 and 2.35 kg/ha-mm; during 2012 and 2013, respectively), which was significantly higher over CT-WOR, CT-WR and ZT-WOR, but it remained statistically similar with other treatments in both the years. Similarly, the lowest water productivity was

Table: 4.23. Effect of conservation tillage practices on wheat yields and harvest index.

Treatments	Grain yield (t/ha)		Straw yield (t/ha)		Biological yield (t/ha)		Harvest index (%)	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Conservation tillage practices:								
PB-WR	4.41	4.71	5.71	6.43	10.12	11.14	43.58	42.28
PB-WOR	4.11	4.34	5.56	5.77	9.67	10.11	42.42	44.85
ZT-WR	4.30	4.53	5.62	6.16	9.90	10.69	43.40	40.61
ZT-WOR	4.08	4.21	5.55	5.68	9.63	9.88	42.36	42.57
CT-WR	4..17	4.24	5.74	5.73	9.91	9.97	42.09	42.51
CT-WOR	3.61	3.70	4.50	5.33	8.14	9.03	44.36	40.91
SEm±	0.141	0.184	0.198	0.177	0.311	0.205	0.762	1.775
LSD (P=0.05)	0.454	0.592	0.636	0.567	0.986	0.654	NS	NS

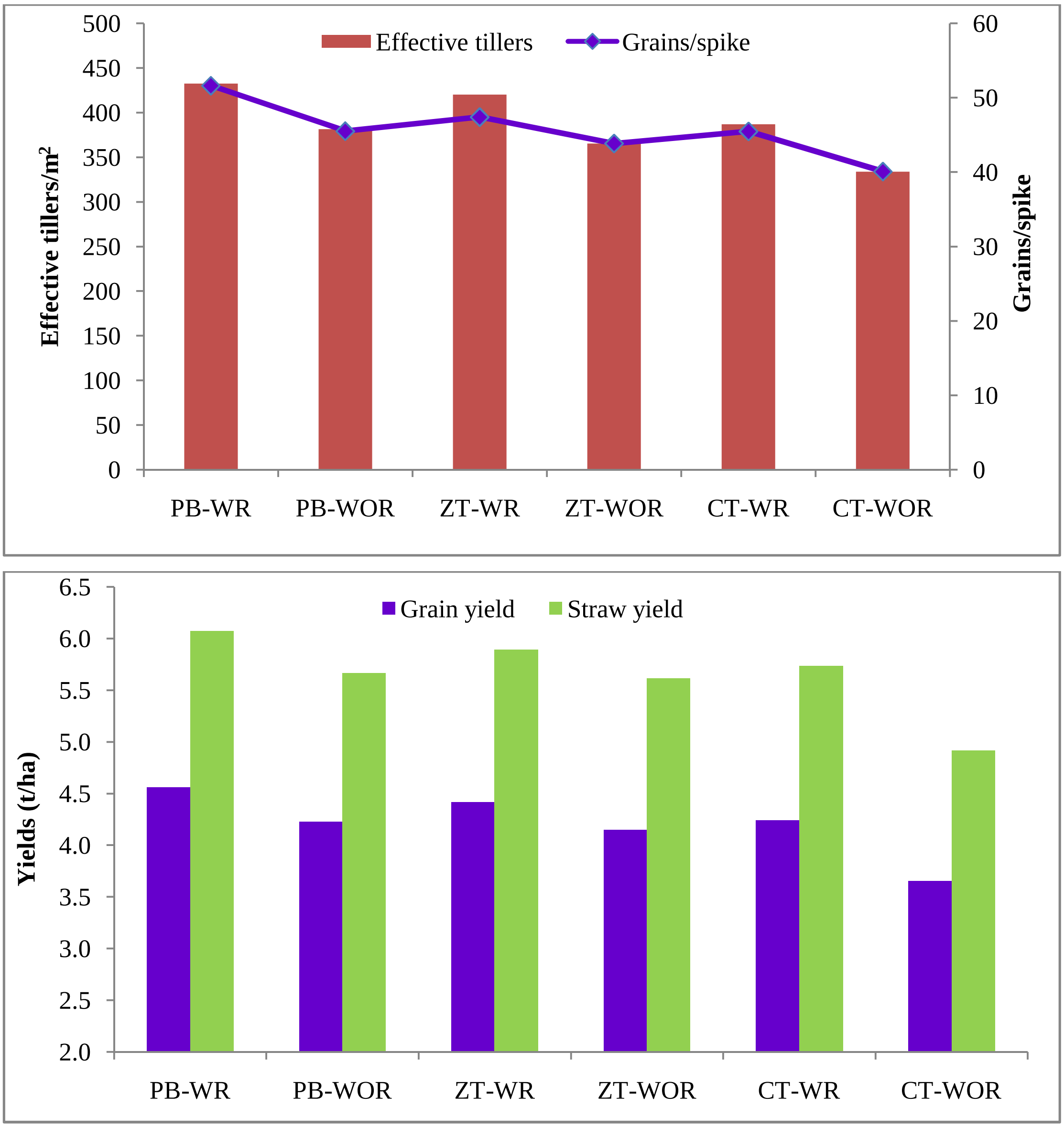


Fig.4.6. Effect of conservation tillage practices on yield attributes and yields in wheat (mean of two years).

under CT-WR (25.70 x 10^3 and 27.31 x 10^3 ₹/ha). While, it recorded minimum under PB-WOR (20.88 x 10^3 and 22.09 x 10^3 ₹/ha), which was also exactly similar with ZT-WOR during 2012-13 and 2013-14, respectively. The gross returns were influenced significantly due to various conservation tillage practices during both the years. The maximum gross returns were recorded under PB-WR (64.12 x 10^3 and 75.57 x 10^3 ₹/ha) during both the years, respectively, while it was recorded minimum under CT-WOR (52.28 x 10^3 and 59.73 x 10^3 ₹/ha) during 2012-13 and 2013-14, respectively. The maximum net returns was

Table: 4.24. Effect of conservation tillage practices on wheat nutrient uptake

Treatments	Nitrogen (kg/ha)				Phosphorus (kg/ha)				Potassium (kg/ha)			
	Grain		Straw		Grain		Straw		Grain		Straw	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Conservation tillage practices:												
PB-WR	61.86	65.99	31.73	35.81	15.46	16.52	2.40	2.70	23.73	25.39	90.45	102.37
PB-WOR	59.74	63.06	30.41	31.51	14.75	15.53	2.22	2.30	21.04	22.25	85.17	88.49
ZT-WR	64.84	68.38	30.34	33.55	15.77	16.64	2.36	2.61	22.58	23.75	89.24	98.18
ZT-WOR	60.00	61.94	27.89	28.50	14.78	15.24	2.22	2.26	20.97	21.54	85.43	87.19
CT-WR	59.72	60.66	30.28	31.46	15.69	15.91	2.33	2.33	21.49	21.67	86.46	90.71
CT-WOR	53.15	55.07	25.76	26.75	13.47	14.08	1.87	2.20	18.44	18.92	78.61	84.04
SEm±	2.091	2.187	1.151	1.291	0.470	0.417	0.096	0.088	0.918	0.552	2.159	3.313
LSD (P=0.05)	6.592	6.891	3.634	4.072	1.482	1.314	0.301	0.281	2.892	1.741	6.803	10.444

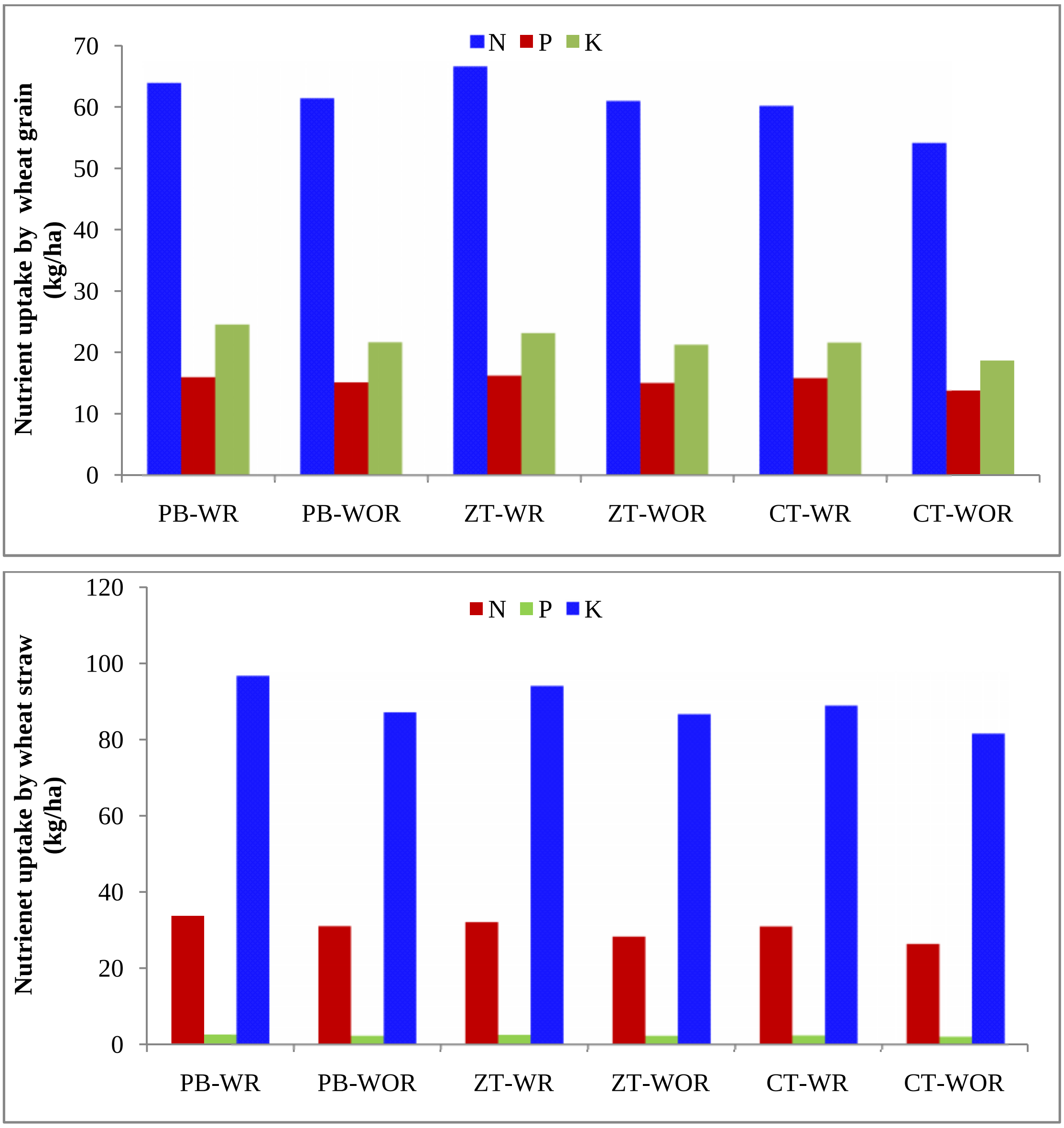


Fig.4.7. Effect of conservation tillage practices on NPK uptake by wheat (mean of two years).

produced under PB-WR (40.32 x 10^3 and 50.16 x 10^3 ₹/ha) during both the years, respectively, which was significantly higher over CT-WOR (29.50 x 10^3 and 35.73 x 10^3 ₹ /ha), but remained statistically similar with all other treatments. The B:C ratio was influenced significantly due to various conservation tillage practices. The maximum B:C ratio was recorded under PB-WOR (1.87 and 2.14) followed by ZT-WOR (1.86 and 2.05) during 2012-13 and 2013-14, respectively. The minimum B:C ratio was recorded with CT-WOR (1.30 and 1.49) during 2012-13 and 2013-14, respectively.

Table: 4.25. Effect of conservation tillage practices on CSI, NPK and water productivity in wheat

Treatments	Total C-input (MJ/ha)		Total C-output (MJ/ha)		Carbon sustainability index (CSI)		Total NPK productivity (kg grain/kg NPK applied)		Water productivity (kg/ha-mm)	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Conservation tillage practices:										
PB-WR	188.96	185.67	4595.22	5057.22	17.12	20.15	22.51	24.66	2.94	2.35
PB-WOR	183.31	180.10	4390.51	4591.05	16.41	19.37	20.95	22.74	2.74	2.17
ZT-WR	188.89	185.72	4504.59	4855.54	18.13	21.56	21.92	23.72	2.60	2.06
ZT-WOR	182.77	179.55	4374.26	4487.57	17.14	19.98	20.82	22.04	2.47	1.91
CT-WR	223.12	223.33	4499.86	4527.68	12.64	14.94	18.96	19.27	2.14	1.63
CT-WOR	217.10	217.27	3694.49	4099.16	12.78	14.73	16.41	16.80	1.85	1.42
SEm±	-	-	140.345	93.138	0.523	0.471	0.700	0.935	0.086	0.081
LSD (P=0.05)	-	-	442.172	293.443	1.647	1.484	2.207	2.946	0.271	0.257

Table: 4.26. Effect of conservation tillage practices on wheat economics.

Treatments	Gross returns (x 10^3 Rs/ha)		Net returns (x 10^3 Rs/ha)		B C ratio (Net returns Rs/Re invested)		Cost of cultivation (x 10^3 Rs/ha)	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
Conservation tillage practices:								
PB-WR	64.12	75.57	40.32	50.16	1.69	1.97	23.80	25.41
PB-WOR	60.01	69.45	39.13	47.35	1.87	2.14	20.88	22.09
ZT-WR	62.53	72.66	38.73	47.25	1.63	1.86	23.80	25.41
ZT-WOR	59.65	67.43	38.78	45.34	1.86	2.05	20.88	22.09
CT-WR	61.07	67.94	35.37	40.62	1.38	1.49	25.70	27.31
CT-WOR	52.28	59.73	29.50	35.73	1.30	1.49	22.78	24.00
SEm±	2.008	2.527	2.013	2.532	0.089	0.104	-	-
LSD (P=0.05)	6.327	7.962	6.327	7.962	0.281	0.328	-	-

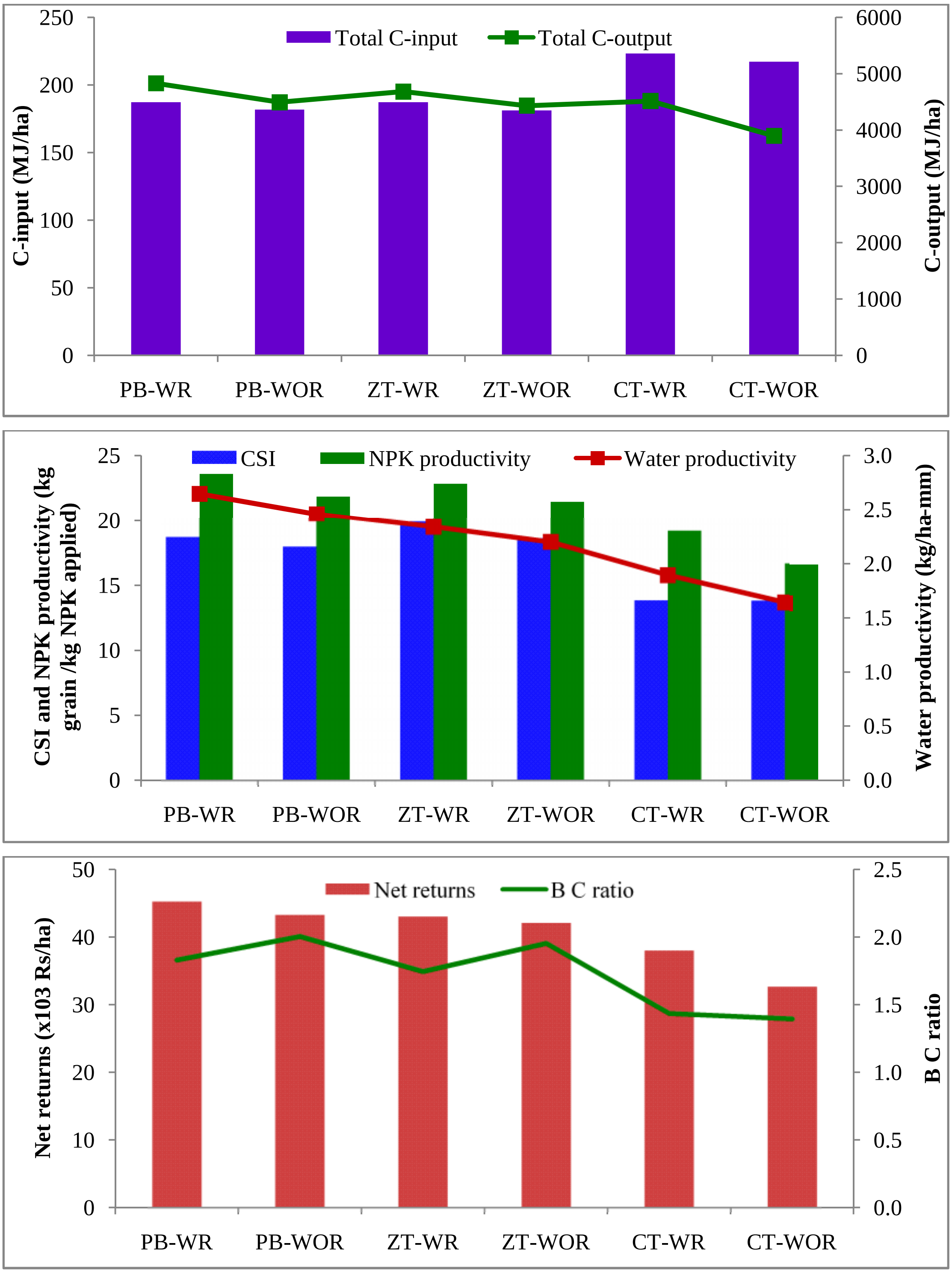


Fig.4.8. Effect of conservation tillage practices on carbon sustainability index (CSI), NPK and water productivity and economics in wheat (mean of two years).

experimentation. A perusal of data presented in Table 4.31 and Fig. 4.10 indicates that none of the treatment significantly affected the harvest index of chickpea during both the years of investigation.

4.3 Chickpea

4.3.1 Growth parameters

Plant height, branches/plant and dry matter accumulation (DMA), were influenced significantly due to conservation tillage practices at all the growth stages of chickpea except at 40 DAS during both the years of study (Table 4.27 to 4.29 and Fig. 4.9). The tallest plant of chickpea at harvest was recorded under PB-WR (62.13 and 67.53 cm) followed by ZT-WR, while lowest was under CT-WOR during both the years of experimentation. Branches/plant increased at later stages, after 120 days of sowing, there was marginally increased in number of branches. Maximum branches/plant was recorded under ZT-WR at all the growth stages during both the years, which were at par with PB-WR, PB-WOR and ZT-WOR. In chickpea, significantly higher dry matter accumulated under ZT-WR at all the growth stages over CT-WOR except 40 DAS.

4.3.2 Development parameters

There was significant variation in days to maturity due to conservation tillage practices during both the years of study, while days to 50% flowering did not significantly influenced (Table 4.30). Plant grown on PB-WR was matured 5 and 4 days early in comparison to CT-WOR during 2012-13 and 2013-14, respectively.

4.3.3 Yield attributes

The yield attributes, viz. pods/plant and seeds/pod were influenced significantly by conservation tillage practices, while 100-seed weight of chickpea were not influenced significantly during both the years of study (Table 4.30 and Fig. 4.10). Pods/plant and seeds/pod were maximum under ZT-WR, while minimum under CT- WOR practices during both the years of study. Highest numbers of pods/plant (72.67 and 77.33) were recorded under ZT-WR in 2012-13 and PB-WR during 2013-14. The maximum number of seeds/pod were observed under ZT-WR (1.73 and 1.93) followed by PB-WR (1.67 and 1.93) while lowest under CT-WOR (1.27 and 1.40) during 2012-13 and 2013-14, respectively.

4.3.4 Yield performance

It is explicit from the data (Table 4.31 and Fig. 4.10) that conservation tillage practices significantly enhanced the seed, stover and biological yield of chickpea during both the years of investigation. The maximum seed yield (2.13 and 2.46 t/ha) was obtained under ZT-WR followed by PB-WR (2.01 and 2.24 t/ha), along with the minimum under CT-WOR (1.78 and 1.75 t/ha) during 2012-13 and 2013-14, respectively. Further, ZT-WR gave significantly higher seed yield by 19.6 and 40.5% over CT-WOR in 2012-13 and 2013-14, respectively. The significantly higher stover yield of chickpea was recorded under ZT-WR but, it was statistically at par with all other treatments except CT-WR and CT-WOR. The maximum biological yield was obtained with ZT-WR followed by PB-WR during both the years of

Table: 4.27. Effect of conservation tillage practices on chickpea plant height (cm)

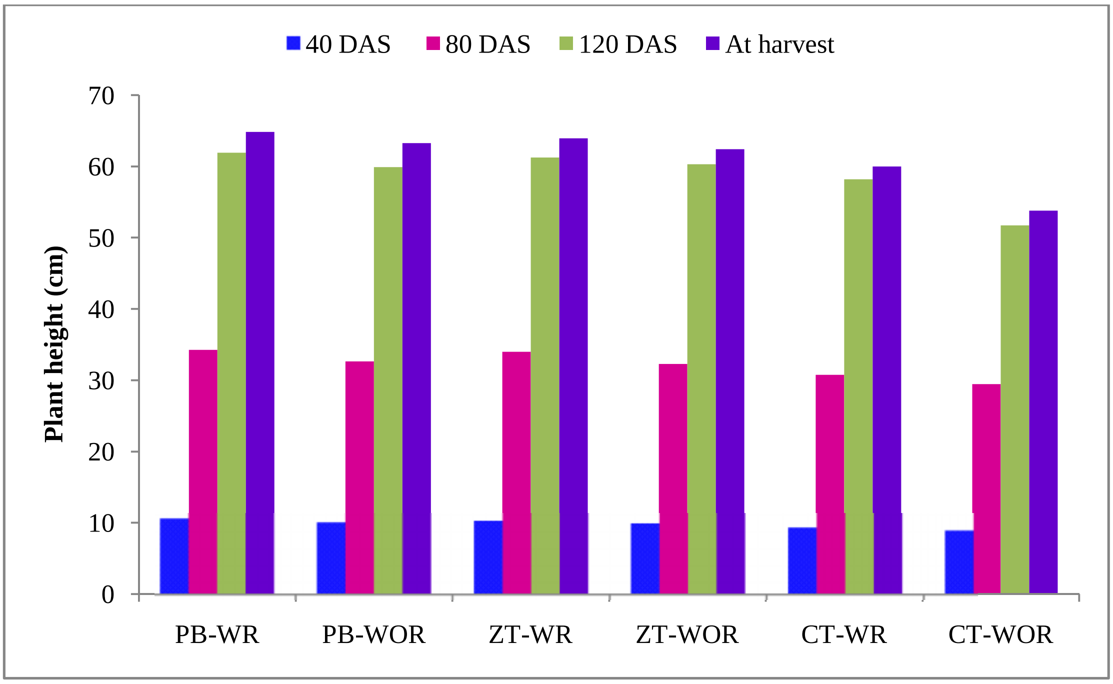
Treatments	40 DAS		80 DAS		120 DAS		At harvest	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
Conservation tillage practices:								
PB-WR	9.93	11.13	33.43	35.10	59.57	64.23	62.13	67.53
PB-WOR	9.47	10.60	31.77	33.50	57.93	61.90	60.87	65.68
ZT-WR	9.60	10.90	33.23	34.77	59.33	63.20	61.70	66.20
ZT-WOR	9.40	10.33	31.47	33.13	58.83	61.80	60.67	64.13
CT-WR	8.93	9.70	29.53	31.97	56.73	59.63	58.30	61.70
CT-WOR	8.53	9.23	28.90	30.03	50.10	53.33	51.83	55.77
SEm±	0.339	0.453	0.935	1.029	1.837	2.108	2.103	2.277
LSD (P=0.05)	NS	NS	2.946	3.241	5.786	6.641	6.627	7.174

Table: 4.28. Effect of conservation tillage practices on chickpea branches per plant.

Treatments	40 DAS		80 DAS		120 DAS		At harvest	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Conservation tillage practices:								
PB-WR	5.00	6.00	12.33	14.00	15.67	16.33	16.33	17.33
PB-WOR	4.67	5.67	11.67	13.33	15.00	15.67	15.33	16.67
ZT-WR	6.00	6.67	13.00	14.67	16.00	16.67	16.67	18.00
ZT-WOR	5.00	5.33	11.67	13.67	15.00	15.67	15.67	17.00
CT-WR	4.67	5.33	11.00	13.33	13.33	13.67	14.00	14.33
CT-WOR	4.33	4.67	10.00	12.00	12.00	13.00	12.67	13.67
SEm±	0.325	0.417	0.481	0.460	0.615	0.644	0.764	0.863
LSD (P=0.05)	NS	NS	1.512	1.448	1.937	2.020	2.411	2.720

Table: 4.29. Effect of conservation tillage practices on chickpea dry matter accumulation (g/plant)

Treatments	40 DAS		80 DAS		120 DAS		At harvest	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Conservation tillage practices:								
PB-WR	0.83	0.85	4.93	5.33	14.58	15.77	18.82	19.06
PB-WOR	0.78	0.82	4.77	5.13	14.20	15.19	17.99	18.47
ZT-WR	0.84	0.87	5.00	5.57	15.03	16.22	19.10	19.39
ZT-WOR	0.77	0.83	4.87	5.20	14.33	15.38	18.12	18.87
CT-WR	0.75	0.76	4.63	5.07	14.26	15.10	18.05	18.16
CT-WOR	0.73	0.74	4.10	4.50	12.79	13.00	15.93	15.50
SEm±	0.028	0.035	0.170	0.187	0.407	0.563	0.603	0.645
LSD (P=0.05)	NS	NS	0.535	0.591	1.282	1.773	1.898	2.032



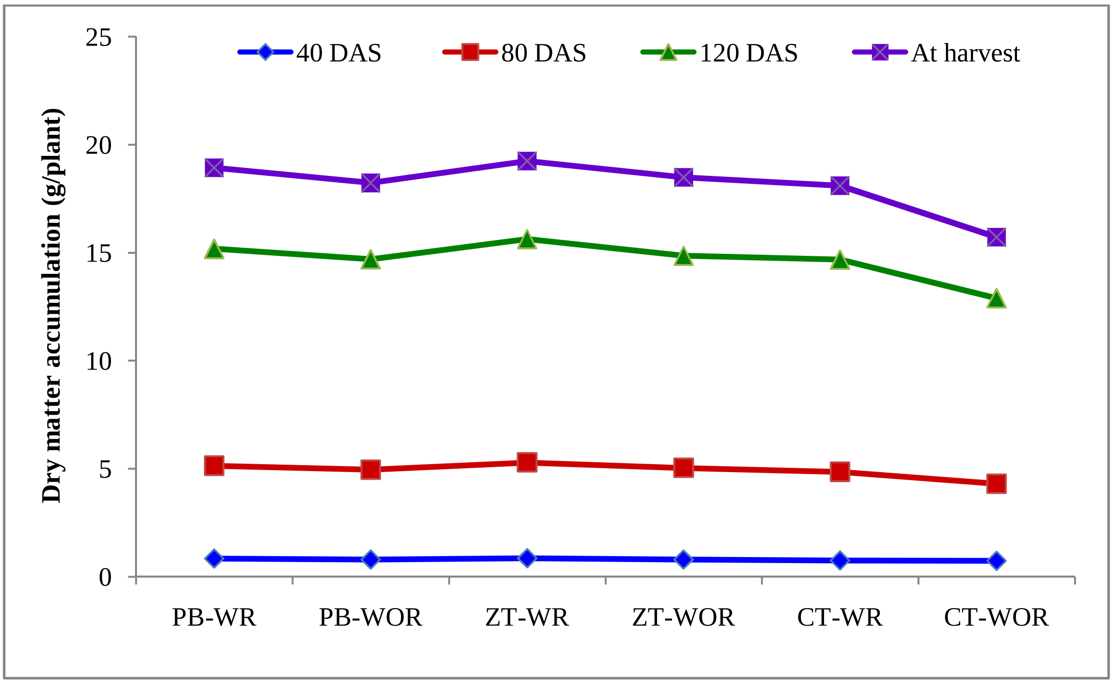


Fig.4.9. Effect of conservation tillage practices on chickpea growth parameters (mean of two years).

Table: 4.30. Effect of conservation tillage practices on chickpea phenological stages and yield attributes

Treatments	Days to 50% flowering		Days to maturity		Pods/plant		Seeds/pod		100-seed weight (g)	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Conservation tillage practices:										
PB-WR	120.00	123.33	152.00	159.67	72.00	77.33	1.67	1.93	22.33	23.00
PB-WOR	120.33	124.00	152.67	160.33	64.67	69.33	1.47	1.80	23.00	24.00
ZT-WR	120.00	122.67	153.00	159.33	72.67	76.00	1.73	1.93	21.67	23.33
ZT-WOR	120.67	123.00	154.00	160.00	67.33	68.67	1.53	1.87	23.33	24.00
CT-WR	122.00	124.33	155.67	162.67	58.67	62.00	1.40	1.67	23.67	24.67
CT-WOR	123.00	125.00	157.33	163.67	52.67	56.00	1.27	1.40	24.33	26.00
SEm±	0.898	0.537	0.983	0.778	3.905	3.378	0.078	0.099	0.778	0.912
LSD (P=0.05)	NS	NS	3.092	2.456	12.303	10.643	0.246	0.319	NS	NS

Table: 4.31. Effect of conservation tillage practices on chickpea yields and harvest index

Treatments	Seed yield (t/ha)		Stover yield (t/ha)		Biological yield (t/ha)		Harvest index (%)	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
Conservation tillage practices:								
PB-WR	2.01	2.24	5.17	5.99	7.18	8.24	28.02	27.29
PB-WOR	1.83	2.07	4.86	5.63	6.69	7.69	27.34	26.97
ZT-WR	2.13	2.46	5.45	6.32	7.58	8.79	28.11	28.01
ZT-WOR	1.88	2.17	5.08	5.73	6.95	7.90	27.03	27.44
CT-WR	1.80	1.93	4.58	5.53	6.38	7.46	28.21	25.90
CT-WOR	1.78	1.75	4.54	5.42	6.27	7.17	27.71	24.37
SEm±	0.071	0.078	0.184	0.184	0.212	0.191	0.863	0.983
LSD (P=0.05)	0.222	0.243	0.581	0.572	0.674	0.593	NS	NS

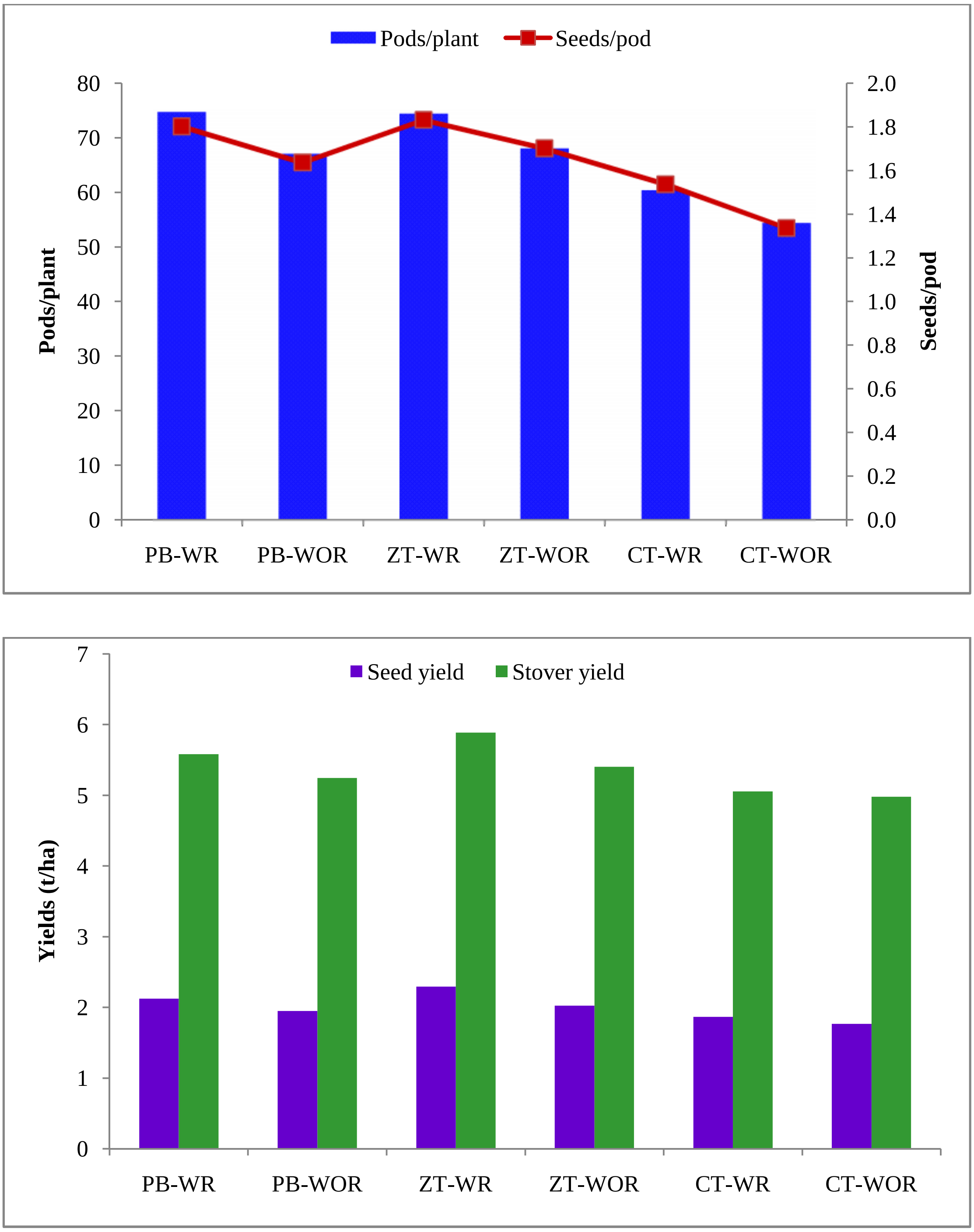


Fig.4.10. Effect of conservation tillage practices on yield attributes and yields in chickpea (mean of two years).

4.3.5 Nutrient uptake

The nutrient uptake by seed and stover of chickpea crop was significantly influenced due to conservation tillage practices during both the years of study (Table 4.32 and Fig. 4.11). The maximum nutrient uptake in seed and stover were recorded with ZT-WR during both the years. ZT-WR was significantly increased the N uptake in seed and straw. The percent increase in N uptake by seed and straw were 20.9 and 14.4 during 2012; 26.9 and 26.7 during 2013 over CT-WOR, respectively. Similar trend was found in P and K uptake by seed and straw during both the years of study

4.3.6 Carbon budgeting and C sustainability index

The total C-input output and CSI estimated of chickpea were significantly influenced by conservation tillage practices (Table 4.33 and Fig. 4.12). The maximum C-input was estimated under CT-WR with 223.12 and 223.33 MJ/ha during 2012-13 and 2013-14, respectively. Whereas, minimum C-input was under ZT-WOR. Similarly maximum C-output was recorded under ZT-WR (3614.28 and 4190.17 MJ/ha), whereas minimum under CT-WOR (2991.30 and 3418.54 MJ/ha). CSI was higher under ZT-WR (18.13 and 21.56) during 2012-13 and 2013-14, respectively.

4.3.7 Nutrient use efficiency

Nutrient use efficiency (NUE) in chickpea was significantly influenced with different conservation tillage practices (Table 4.33 and Fig. 4.12). Significantly highest values of NUE was found under ZT-WR (21.94 and 27.05 kg grain/ kg NPK applied) over CT-WR and CT-WOR and remained at par with all other treatments during both the years.

4.3.8 Water productivity

Water productivity of chickpea was significantly influenced by conservation tillage practices during both the years (Table 4.33 and Fig. 4.12). The highest water productivity was observed under PB-WR (1.82 kg/ha-mm) during 2012 and ZT-WR (2.05 kg/ha-mm) during 2013, which was significantly higher over CT-WOR, but it remained statistically similar with other treatments in both the years. Similarly, the lowest water productivity was recorded under CT-WOR (1.24 and 1.25 kg/ha-mm) during 2012-13 and 2013-14, respectively.

4.3.9 Economics

Data pertaining to cost of cultivation, gross returns, net returns and B:C ratio of chickpea crop are presented in (Table 4.34 and Fig. 4.12). The maximum cost of cultivation was recorded under CT-WR (20.90 x 10^3 and 22.53 x 10^3 ₹/ha). While, it recorded minimum under PB-WOR (16.73 x 10^3 and 17.97 x 10^3 ₹/ha), which was also exactly similar with ZT-WOR during 2012-13 and 2013-14, respectively. The gross returns were influenced significantly due to various conservation tillage practices during both the years. The maximum gross returns were recorded under ZT-WR (65.85 x 10^3 and 81.94 x 10^3 ₹/ha) during both the years, respectively, while it was recorded minimum under CT-WOR (53.86 x 10^3 and 59.32 x 10^3 ₹/ha) during 2012-13 and 2013-14, respectively. The maximum net returns was produced under ZT-WR (62.30 x 10^3 and 44.56 x 10^3 ₹/ha) during 2012-13 and 2013-14, respectively, which was significantly higher over CT-WOR (41.34 x 10^3 and 34.65 x 10^3 ₹/ha) and CT-WR, but remained statistically similar with all other treatments. The B:C ratio was influenced significantly due to various conservation tillage practices. The maximum B:C ratio was recorded under ZT-WOR (3.33 and 2.25) during 2012-13 and 2013-14, respectively. The minimum B:C ratio was recorded with CT-WR (2.11 and 1.47) during 2012-13 and 2013-14, respectively.

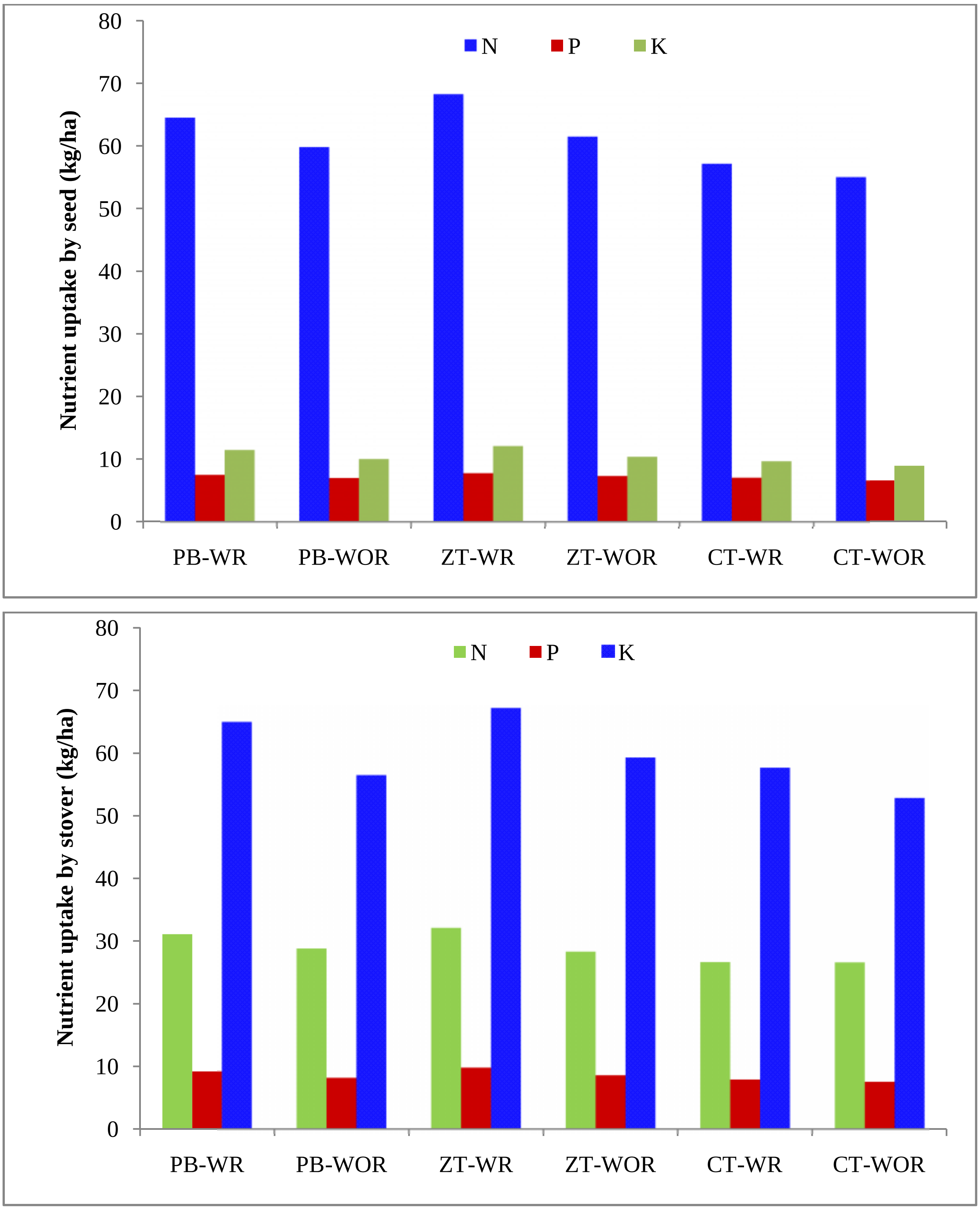


Fig.4.11. Effect of conservation tillage practices on NPK uptake by chickpea (mean of two years).

Table: 4.32. Effect of conservation tillage practices on chickpea nutrient uptake

Treatments	Nitrogen (kg/ha)				Phosphorus (kg/ha)				Potassium (kg/ha)			
	Seed		Stover		Seed		Stover		Seed		Stover	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Conservation tillage practices:												
PB-WR	60.47	68.22	28.77	33.40	7.04	7.87	8.91	9.42	10.79	12.11	62.06	67.42
PB-WOR	57.20	62.14	26.68	30.69	6.60	7.39	7.98	8.27	9.37	10.58	54.41	58.15
ZT-WR	64.11	72.04	29.55	34.44	7.39	8.10	9.47	10.10	11.16	12.99	64.28	69.66
ZT-WOR	59.39	63.26	25.48	30.95	6.70	7.87	8.33	8.81	9.62	11.13	58.10	60.09
CT-WR	55.41	58.54	24.30	28.76	6.77	7.28	7.70	8.01	9.27	9.97	55.41	59.47
CT-WOR	53.01	56.76	25.82	27.18	6.49	6.68	7.30	7.77	8.90	8.96	50.93	54.39
SEm±	1.654	3.151	1.105	1.351	0.149	0.259	0.234	0.431	0.335	0.644	2.225	2.760
LSD (P=0.05)	5.212	9.929	3.481	4.256	0.467	0.815	0.739	1.361	1.055	2.027	7.011	8.695

Table: 4.33. Effect of conservation tillage practices on CSI, NPK and water productivity in chickpea

Treatments	Total C-input (MJ/ha)		Total C-output (MJ/ha)		Carbon sustainability index (CSI)		Total NPK productivity (kg seed/kg NPK applied)		Water productivity (kg/ha-mm)	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Conservation tillage practices:										
PB-WR	188.96	185.67	3424.71	3927.46	17.12	20.15	20.69	24.65	1.82	2.04
PB-WOR	189.31	186.10	3192.21	3669.13	15.86	18.72	18.88	22.73	1.67	1.88
ZT-WR	188.89	185.72	3614.28	4190.17	18.13	21.56	21.94	27.05	1.77	2.05
ZT-WOR	188.77	185.55	3315.41	3766.90	16.56	19.30	19.35	23.84	1.56	1.81
CT-WR	223.12	223.33	3042.37	3559.04	12.64	14.94	16.36	17.57	1.29	1.38
CT-WOR	223.10	223.27	2991.30	3418.54	12.41	14.31	15.80	15.87	1.24	1.25
SEm±	-	-	101.885	89.938	0.516	0.465	0.716	0.818	0.060	0.064
LSD (P=0.05)	-	-	321.002	283.363	1.625	1.463	2.255	2.579	0.189	0.204

Table: 4.34. Effect of conservation tillage practices on chickpea economics

Treatments	Gross returns (x 10^3 Rs/ha)		Net returns (x 10^3 Rs/ha)		B C ratio (Net returns Rs/Re invested)		Cost of cultivation (x 10^3 Rs/ha)	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
Conservation tillage practices:								
PB-WR	62.14	74.97	55.32	40.85	2.82	1.92	19.65	21.28
PB-WOR	56.88	69.25	52.52	38.91	3.14	2.17	16.73	17.97
ZT-WR	65.85	81.94	62.30	44.56	3.17	2.09	19.65	21.28
ZT-WOR	58.39	72.41	55.68	40.42	3.33	2.25	16.73	17.97
CT-WR	55.65	65.07	44.17	33.12	2.11	1.47	20.90	22.53
CT-WOR	53.86	59.32	41.34	34.65	2.30	1.80	17.98	19.22
SEm±	2.060	2.251	2.251	2.060	0.126	0.105	-	-
LSD (P=0.05)	6.491	7.093	7.093	6.491	0.397	0.330	-	-

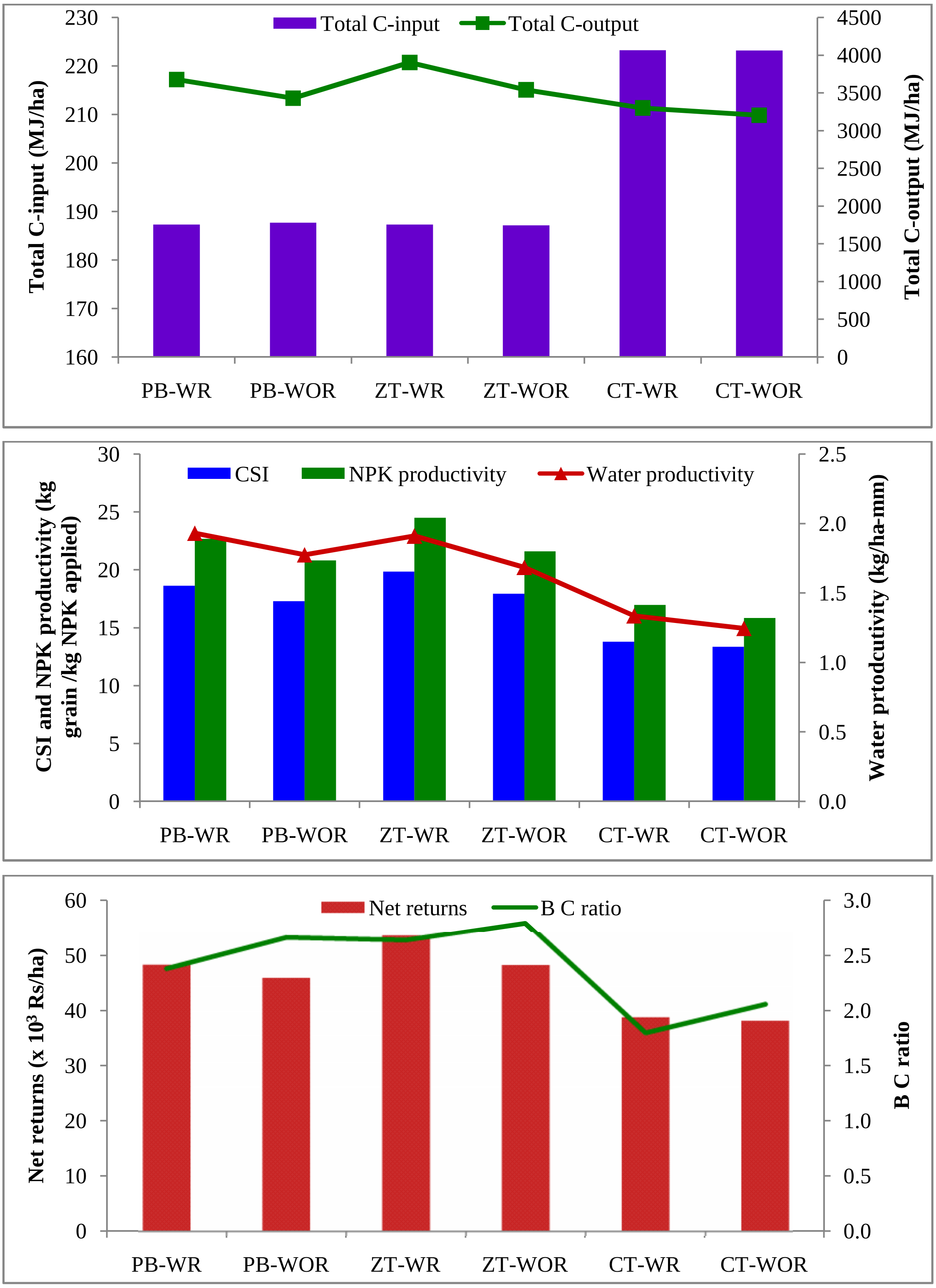


Fig.4.12. Effect of conservation tillage practices on carbon sustainability index (CSI), NPK and water productivity and economics in chickpea (mean of two years).

4.4 Maize-wheat/chickpea System

4.4.1 System productivity

Data on system productivity as influenced by conservation tillage practices and cropping systems are presented in Table 4.35 and Fig. 4.13. Conservation tillage practices exhibited significant improvement in system productivity during both the years. The highest system productivity was realized under ZT-WR (9.97 and 11.13 t/ha) followed by PB-WR (9.65 and 10.65 t/ha) during both the years. Application of residue improved system productivity in comparison to no residue irrespective to tillage treatment. Moreover, lowest system productivity was found under CT-WOR, which was at par with CT-WR.

4.4.2 Economics

Data pertaining to cost of cultivation, gross returns, net returns and B:C ratio of maize–wheat/chickpea cropping system are presented in Table 4.35 and Fig. 4.13 The cost of cultivation of maize–wheat/chickpea cropping system varied due to various conservation tillage practices from minimum under PB-WOR and ZT-WOR (40.91 x 10^3 and 43.35 x 10^3 ₹/ha) to maximum under CT-WR (48.38 x 10^3 and 51.34 x 10^3 ₹/ha) in 2012-13 and 2013-14, respectively. Moreover, cost of cultivation was higher under maize-wheat (46.30 x 10^3 and 48.98 x 10^3 ₹/ha) in comparison to maize-chickpea (41.94 x 10^3 and 44.64 x 10^3 ₹/ha) during both the years, respectively.

Gross returns as well as net returns were influenced significantly with various conservation tillage practices during both the years of study. However, cropping system did not influenced significantly during both the years except net returns in 2013-14. The maximum gross returns (132.39 x 10^3 and 165.14 x 10^3 ₹/ha) were recorded under ZT-WR practices in both the years, respectively. The maximum net returns were computed higher under ZT-WR (87.19 x 10^3 and 117.03 x 10^3 ₹ /ha) during 2012-13 and 2013-14, respectively, which remained at par with PB-WR. The gross and net returns were recorded minimum under CT-WOR during both the years.

The B:C ratio was influenced significantly due to different conservation tillage practices during both the years. The maximum B:C ratio was recorded under ZT-WOR (1.98 and 2.53). The Minimum B:C ratio was recorded under CT-WOR (1.51 and 1.82) during both the years, respectively. B:C ratio was also influenced significantly due to different cropping system. The maximum B:C ratio was recorded in maize-chickpea system during both the years.

Table: 4.35 Effect of conservation tillage practices and cropping systems on system productivity and economics

Treatments	System productivity (t/ha)		Gross Returns (x 10^3 Rs/ha)		Net Returns (x 10^3 Rs/ha)		Cost of Cultivation (x 10^3 Rs/ha)		B C Ratio (Net returns Rs /Re invested)	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
***Conservation tillage practices*:**										
PB-WR	9.65	10.65	130.36	159.51	85.15	111.40	45.21	48.11	1.89	2.32
PB-WOR	8.66	9.95	118.39	150.35	77.48	107.00	40.91	43.35	1.90	2.48
ZT-WR	9.97	11.13	132.39	165.14	87.19	117.03	45.21	48.11	1.93	2.44
ZT-WOR	9.02	10.19	121.51	152.27	80.60	108.92	40.91	43.35	1.98	2.53
CT-WR	9.08	9.72	122.42	145.89	74.04	94.55	48.38	51.34	1.53	1.85
CT-WOR	8.21	8.70	110.51	130.97	66.43	84.39	44.09	46.57	1.51	1.82
SEm±	0.134	0.158	1.524	2.131	2.155	3.013	-	-	0.042	0.064
LSD (P=0.05)	0.579	0.698	6.789	9.491	6. 789	9.491	-	-	0.141	0.202
Cropping systems:										
Maize-Wheat	9.08	9.89	123.08	148.70	76.78	9.97	46.30	48.98	1.66	2.05
Maize-Chickpea	9.11	10.23	122.12	152.68	80.19	108.04	41.94	44.64	1.92	2.43
SEm±	0.086	0.091	1.066	1.169	1.507	1.653	-	-	0.035	0.035
LSD (P=0.05)	NS	NS	NS	NS	NS	5.092	-	-	0.102	0.113

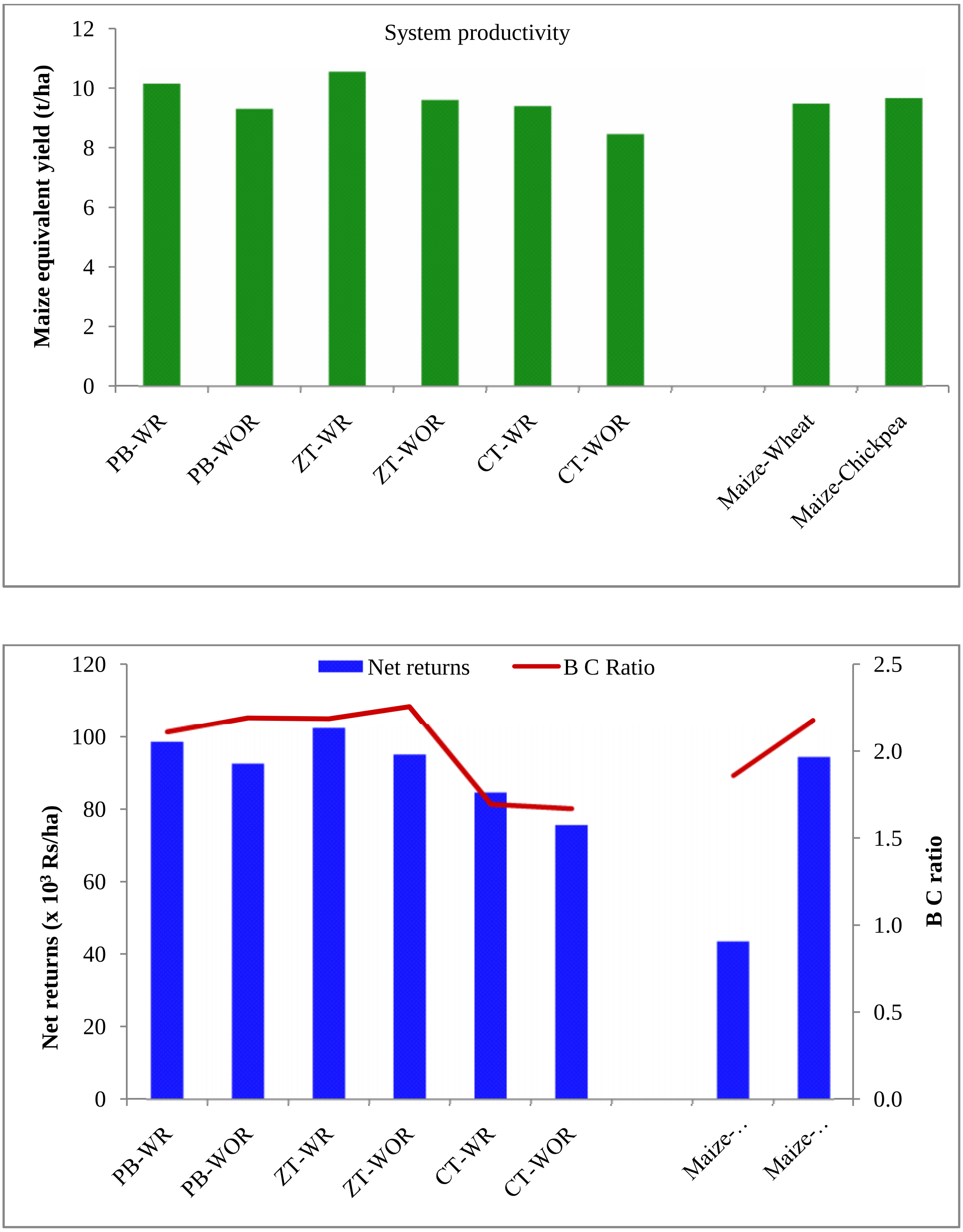


Fig.4.13. Effect of conservation tillage practices and cropping systems on system productivity and economics of maize-based cropping systems (mean of two years).

4.4.3 Nutrient uptake

Data on uptake of N, P and K of maize+wheat/chickpea cropping system are presented in Table 4.36 and Fig. 4.14. In general more nutrients (NPK) were uptake by maize crop in comparison to wheat and chickpea. Maximum NPK uptake by maize, wheat and chickpea were under ZT-WR and lowest under CT-WOR. The significantly higher system uptake of N was recorded under PB-WR (204.90 kg/ha) over all other treatments. The increase in N uptake was 17.9% higher over CT-WOR. However highest P uptake was in ZT-WR (46.52 kg/ha), which is at par with PB-WR. Similarly, significantly 45.4% higher K uptake was recorded in PB-WR (225.44 kg/ha) over CT-WOR. Lowest N, P and K uptake were found in CT-WOR. Application of residue under PB, ZT and CT increased nutrient uptake over no residue in respective tillage practices. Cropping system did not influenced significantly nutrient uptake. However, Higher N (195.62 kg/ha) and P (43.24 kg/ha) uptake by maize-wheat cropping system, whereas K (194.09 kg/ha) in maize-chickpea.

4.4.4 Water productivity

Water productivity of system was significantly influenced by different conservation tillage practices during both the years (Table 4.37 and Fig. 4.14). In general permanent bed planting gave significantly higher values of water productivity than CT and ZT, irrespective of residue during both the years. The highest water productivity was observed under PB-WR (10.60 kg/ha-mm) during 2012-13 and PB-WOR (6.57 kg/ha-mm) during 2013-14, which was significantly higher than ZT and CT planting systems, but it remained statistically similar with other bed planting treatment in both the years. Similarly, the lowest water productivity was recorded under CT-WR (9.42 and 5.66 kg/ha-mm; during 2012-13 and 2013-14, respectively). There was no significant difference among all the ZT and CT treatments in both the years. Different cropping system did not influenced water productivity during both the years of experimentation.

4.4.5 Carbon budgeting and C sustainability index

The total C input, output and CSI computed for maize-wheat/chickpea were significantly influenced by conservation tillage practices and cropping system (Table 4.37 and Fig. 4.14). The maximum C input was estimated under CT-WR with 677.04 and 685.29 MJ/ha during 2012-13 and 2013-14, respectively. Whereas, minimum C input was under PB-WOR. Similarly maximum C-output was recorded under ZT-WR (11959 and 13307 MJ/ha), whereas minimum under CT-WOR (9890.6 and 11326.6 MJ/ha). CSI was higher under ZT-WR (21.47 and 23.98) during 2012-13 and 2013-14, respectively.

Table: 4.36. Effect of conservation tillage practices on total nutrient uptake [(NPK kg/ha), mean of 2012-13 & 2013-14]

Treatments	Maize			Wheat			Chickpea			Total (maize + wheat/chickpea)			Total system nutrient added		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
Conservation tillage practices:															
PB-WR	111.37	28.22	115.22	97.69	18.54	120.97	95.43	16.62	76.19	204.90	46.44	225.44	202	107	68
PB-WOR	101.30	25.24	104.56	92.36	17.40	108.48	88.36	15.12	66.25	193.66	43.46	212.28	202	107	68
ZT-WR	114.86	29.30	117.17	98.55	18.69	116.88	100.07	17.53	79.05	199.07	46.52	217.75	202	107	68
ZT-WOR	102.62	26.00	106.26	89.16	17.25	107.57	89.54	15.85	69.47	193.02	42.11	172.98	202	107	68
CT-WR	105.50	25.74	107.38	91.06	18.13	110.16	83.50	14.88	67.06	198.81	42.68	177.14	225	110	80
CT-WOR	92.75	22.72	95.21	80.36	15.81	100.00	81.39	14.12	61.59	173.69	37.47	155.03	225	110	80
SEm±	1.400	0.403	1.775	1.595	0.230	2.830	2.033	0.365	1.992	2.044	0.573	2.369	-	-	-
LSD (P=0.05)	4.413	1.274	5.591	5.026	0.725	8.915	6.405	1.149	6.276	6.434	1.803	7.474	-	-	-
Cropping systems:															
Maize-Wheat	104.54	25.84	106.73	-	-	-	-	-	-	195.92	43.24	192.78	257	117	74
Maize-Chickpea	104.93	26.56	108.53	-	-	-	-	-	-	191.79	42.99	194.09	170	100	74
SEm±	1.442	0.494	1.923	-	-	-	-	-	-	2.224	0.537	2.706	-	-	-
LSD (P=0.05)	NS	NS	NS	-	-	-	-	-	-	NS	NS	NS	-	-	-

Table: 4.37. Effect of conservation tillage practices and cropping systems on system CSI, water and total NPK productivity

Treatments	Water productivity (kg/ha mm)		Total C-input (MJ/ha)		Total C-output (MJ/ha)		Carbon sustainability index (CSI)		Total NPK productivity (kg grain/kg NPK applied)	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
Conservation tillage practices:										
PB-WR	10.60	6.28	560.62	560.47	11764.50	12983.64	21.17	23.47	25.82	29.28
PB-WOR	10.43	6.57	544.80	544.68	10842.25	12668.59	20.15	23.62	23.29	27.32
ZT-WR	9.71	5.97	563.42	563.96	11959.20	13307.46	21.47	23.98	26.77	30.72
ZT-WOR	9.79	5.97	547.36	547.87	10871.78	12835.50	20.08	23.85	24.17	28.11
CT-WR	9.42	5.66	677.04	685.29	10823.31	12428.12	16.05	18.37	22.21	23.81
CT-WOR	9.57	5.99	632.43	640.66	9890.62	11326.60	15.89	17.96	20.14	21.39
SEm±	0.205	0.099	-	-	158.996	229.611	0.269	0.424	0.431	0.573
LSD (P=0.05)	0.642	0.304	-	-	500.931	723.405	0.851	1.337	1.371	1.802
Cropping systems:										
Maize-Wheat	10.02	6.19	661.22	671.36	11492.71	12952.29	17.53	19.48	20.58	22.73
Maize-Chickpea	9.82	5.95	514.00	509.62	10557.84	12231.01	20.75	24.27	26.88	30.82
SEm±	0.134	0.092	-	-	117.298	103.069	0.198	0.198	0.297	0.332
LSD (P=0.05)	NS	NS	-	-	361.391	317.545	0.621	0.606	0.911	1.024

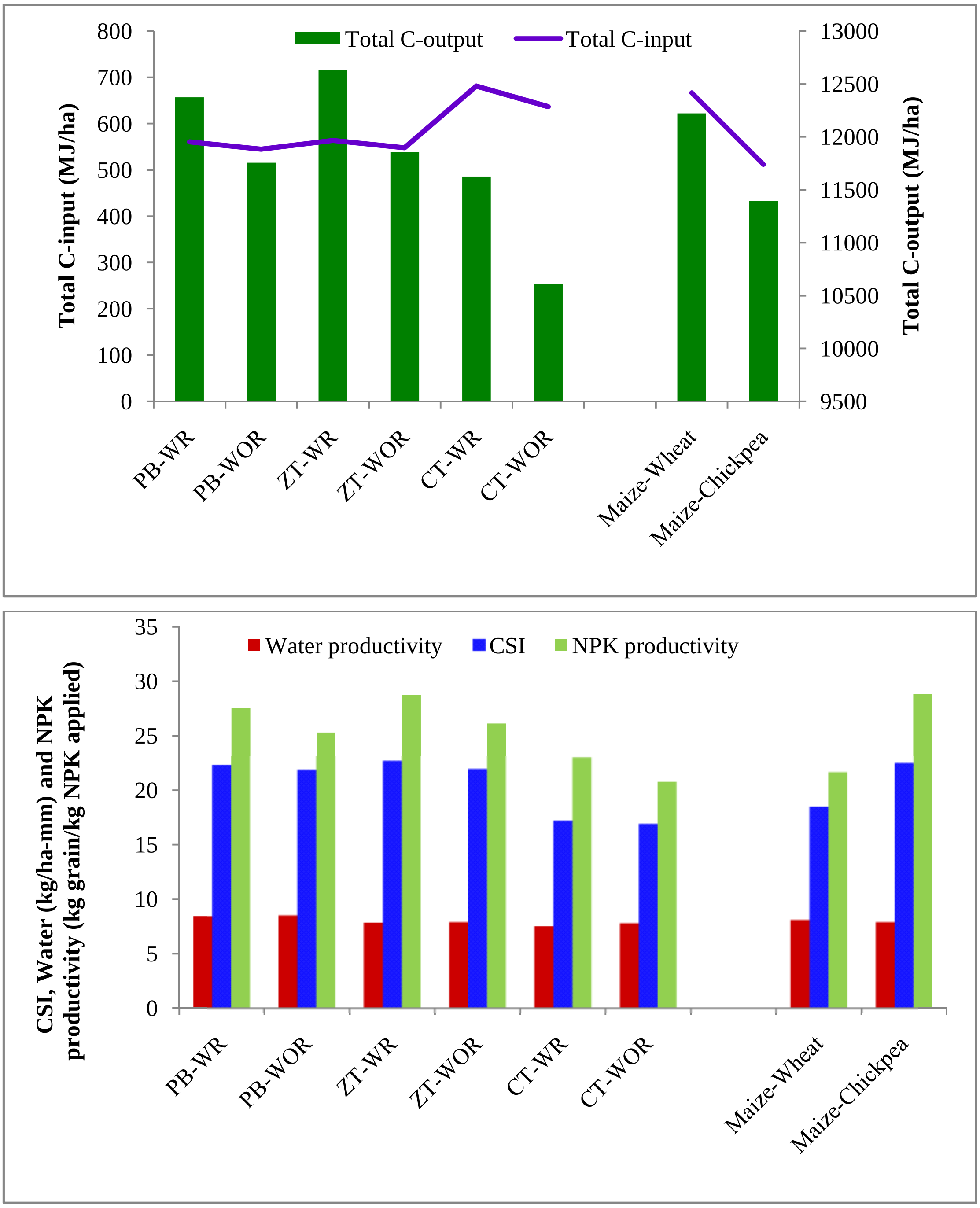


Fig.4.14. Effect of conservation tillage practices and cropping systems on carbon input and output, carbon sustainability index (CSI), NPK and water productivity of maize-based cropping systems (mean of two years).

4.4.6 Nutrient use efficiency

Nutrient use efficiency (NUE) of maize-wheat/chickpea system was significantly influenced with different conservation tillage practices and cropping system (Table 4.37 and Fig. 4.14). In general residue application gave significantly higher NUE in comparison to no residue irrespective of tillage practices during both the years. Significantly highest values of NUE was found under ZT-WR (26.77 and 30.72 kg grain/ kg NPK applied), which is being at par with PB-WR and significantly higher over all other treatments during both the years. Among cropping system, maize-chickpea (26.88 and 30.82 kg grain/ kg NPK applied during 2012-13 and 2013-14, respectively) recorded significantly higher NUE over maize-wheat.

4.5 Soil properties

4.5.1 Physical properties

Bulk density

The bulk density (BD) of soil was influenced significantly in upper layers of soil profile (0-15 cm) due to conservation tillage practices; however it remained statistically similar in lower layers (15-30 cm) of soil profile (Table 4.38). In general BD was increased with increased in the soil depth; moreover BD was recorded higher in lower layers of the soil profile than upper layers under all the treatments. Soil BD did not influence due to different cropping system in both the soil layers. The maximum BD was recorded under CT-WOR (1.62 and 1.71 g/cm^3) at 0–15 and 15–30 cm, respectively. While, lowest BD was recorded with PB-WR (1.49 g/cm^3) in 0–15 cm soil depth, which was significantly lower than CT-WR and CT-WOR treatments, but was remained statistically similar with rest of the treatments. Residue application resulted lower values of BD than no-residue application irrespective of conservation tillage; however difference was not reached to significant level.

Soil aggregation

Soil aggregation was analysed to determine the wet stability of soil aggregates, expressed in terms of mean weight diameter (MWD) grand mean diameter (GMD) are presented in Table 4.38. MWD and GMD were not influenced significantly with cropping system. At all three depths (0–10, 10–20 and 20–30 cm) of soil the MWD was found to maximum under PB-WR. Whereas, at all three depths the minimum MWD was recorded under CT-WOR treatment. In general application of residue was registered higher values of MWD over no residue in all the soil layers in respective conservation tillage practices. Irrespective of the conservation tillage practices top layer (0–10 cm) was recorded the maximum values of MWD than the lower layers of soil profile. Moreover, less difference was observed among the conservation tillage practices in term of MWD in lower soil layers (10–20 and 20–30 cm) than the top layer. Apparently the GMD with different continuous tillage and crop establishment techniques was also exhibited the more or less same trend as that of MWD throughout all the depths.

Table: 4.38. Effect of conservation tillage practices and cropping systems on soil physical properties, organic carbon (OC) content and available NPK status after completion of study

Treatments	Bulk density (g/cm^3)		Mean weight diameter (mm)			Grand mean diameter (GMD)			Hydraulic conductivity (cm/hr)		Organic carbon (%)	Available		
	0-15 cm	15-30 cm	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm	0-15 cm	15-30 cm		N (kg/ha)	P (kg/ha)	K (kg/ha)
Conservation tillage practices:														
PB-WR	1.49	1.59	0.735	0.348	0.267	0.424	0.408	0.373	1.95	1.59	0.427	153.48	15.86	231.63
PB-WOR	1.57	1.64	0.708	0.309	0.235	0.411	0.388	0.358	1.74	1.46	0.409	144.43	13.91	220.83
ZT-WR	1.50	1.60	0.752	0.334	0.260	0.424	0.407	0.366	1.85	1.60	0.431	155.68	16.79	235.55
ZT-WOR	1.53	1.59	0.703	0.315	0.251	0.407	0.383	0.340	1.65	1.38	0.399	148.20	14.93	221.85
CT-WR	1.61	1.68	0.523	0.305	0.224	0.392	0.353	0.326	1.61	1.18	0.372	149.62	14.24	229.37
CT-WOR	1.62	1.71	0.500	0.296	0.209	0.361	0.321	0.312	1.35	1.08	0.317	137.72	13.00	212.20
SEm±	0.028	0.042	0.0072	0.0071	0.0023	0.0072	0.0034	0.0031	0.021	0.021	0.0035	3.7554	0.7854	5.9971
LSD (P=0.05)	0.093	NS	0.0224	0.0131	0.0114	0.0114	0.0121	0.0012	0.071	0.082	0.0114	NS	NS	NS
Cropping systems:														
Maize-Wheat	1.57	1.64	0.648	0.315	0.241	0.404	0.377	0.347	1.70	1.40	0.395	145.721	15.432	227.591
Maize-Chickpea	1.55	1.64	0.659	0.320	0.241	0.402	0.376	0.345	1.68	1.36	0.390	150.651	14.141	222.892
SEm±	0.021	0.014	0.0074	0.0033	0.0032	0.0044	0.0032	0.0033	0.014	0.014	0.0044	3.204	0.431	5.085
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Initial status	1.58	-	-	-	-	-	-	-	1.12	-	0.380	147.41	12.61	208.42

Hydraulic conductivity

The average saturated hydraulic conductivity (HC) of soil was influenced significantly with conservation tillage practices in the surface (0–15 cm soil depth) as well as sub surface (15–30 cm soil depth) soil layers (Table 4.38). Moreover, hydraulic conductivity was lower at 15–30 cm soil depth compare to 0–15 cm soil depth. The maximum value of hydraulic conductivity was measured under PB-WR (1.95 and 1.59 cm/hr) in 0–15 and 15–30 cm soil depth, respectively; it was significantly greater than rest of the treatments. The minimum values of HC was recorded under CT-WOR (1.35 and 1.08 cm/hr) in both the soil layers, respectively, which were significantly lower than rest of the treatments. Residue application resulted significantly higher values of the HC than no residue in both the soil layers in respective conservation tillage practices. Similarly, ZT practices resulted significantly higher values of the HC over CT practices in both the soil layers in respective residue treatment. However, HC was not influenced significantly due to cropping system in both the layers.

4.5.2 Soil chemical properties

Organic carbon

Soil organic carbon (SOC) was affected significantly with conservation tillage practices (Table 4.38). The data revealed that crop residues application significantly increased the SOC under PB, ZT and CT by 4.4, 8.0 and 17.4 % over PB-WOR, ZT-WOR and CT-WOR, respectively. Different cropping system did not significantly influenced SOC.

Available nutrients in soil

Available N, P and K status in soil (after completion of 2 years research study in maize–wheat/chickpea cropping system) was not influenced significantly due to different conservation tillage and cropping system (Table 4.38). However, maximum available N was recorded under ZT-WR, while minimum was under CT-WOR. Moreover, residue application resulted higher available N in PB, ZT and CT than no residues by 6.3, 5.0 and 8.6%, respectively. The maximum soil available P (16.79 kg/ha) and K (235.55 kg/ha) was recorded in ZT-WR followed by PB-WR. Residue application also improved the available P and K in soil over no-residue application. High available N in soil was found in maize-chickpea, whereas P and K in maize-wheat cropping system.

4.6 GHG emission (CO_2 and N_2O)

The green house gases (CO_2 and N_2O-N) emission in maize, wheat and chickpea were significantly influenced by conservation tillage practices while cropping system did not influenced it (Table 4.39 & 4.40 and Fig 4.15). Maximum CO_2 emission (2.63 and 4.22 Mg/ha) in maize was recorded under CT-WR followed by PB-WR (2.36 and 3.84 Mg/ha) and lowest under ZT-WOR (1.96 and 2.27 Mg/ha) during 2012 and 2013, respectively. While, maximum N_2O-N emission was under CT-WOR (0.958 and 0.199 kg/ha) and lowest under PB-WR (0.474 and 0.130 kg/ha). Similarly, highest CO_2 emission in wheat was also recorded under CT-WR (9.74 and 9.61 Mg/ha) which is close to PB-WR (9.18 and 9.09 Mg/ha) and lowest under ZT-WOR (7.73 and 7.55 Mg/ha) during 2012-13 and 2013-14, respectively. Highest N_2O-N emission in wheat was recorded under CT-WOR (0.539 and 0.593 kg/ha) and minimum under ZT-WR (0.409 and 0.411 kg/ha) during 2012-13 and 2013-14, respectively. The maximum CO_2 emission in chickpea was estimated under CT-WR with 8.97 and 8.36 Mg/ha during 2012-13 and 2013-14, respectively. Whereas, minimum emission was under ZT-WOR. Similarly, maximum N_2O-N emission was recorded under CT-WOR (0.512 and 0.565 kg/ha), whereas minimum under ZT-WOR (0.364 and 0.385 kg/ha). Significantly highest total CO_2 emission in maize + wheat/chickpea cropping system was estimated under CT-WR (11.99 and 13.21 Mg/ha) followed by PB-WR (10.91 and 12.00 Mg/ha) and minimum under ZT-WOR (9.41 and 9.47 mg/ha) during 2012-13 and 2013-14, respectively. Whereas maximum N_2O-N emission was under CT-WOR (1.483 and 0.778 kg/ha) and minimum under PB-WR (0.888 and 0.542 kg/ha).

Table: 4.39. Effect of conservation tillage practices and cropping systems on GHG (CO_2 and N_2O) emission in maize, wheat and chickpea individually.

Treatments	Maize				Wheat				Chickpea			
	CO_2 (Mg/ha)		N_2O-N(kg/ha)		CO_2 (Mg/ha)		N_2O-N(kg/ha)		CO_2 (Mg/ha)		N_2O-N(kg/ha)	
	2012	2013	2012	2013	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Conservation tillage practices:												
PB-WR	2.36	3.84	0.474	0.130	9.18	9.09	0.417	0.421	7.92	7.22	0.411	0.402
PB-WOR	2.15	3.58	0.572	0.166	7.91	7.73	0.450	0.458	7.31	6.99	0.435	0.446
ZT-WR	2.32	3.18	0.516	0.115	9.02	8.91	0.409	0.411	7.91	7.14	0.364	0.385
ZT-WOR	1.96	2.27	0.630	0.147	7.73	7.55	0.439	0.437	7.16	6.85	0.416	0.423
CT-WR	2.63	4.22	0.760	0.169	9.74	9.61	0.503	0.504	8.97	8.36	0.462	0.487
CT-WOR	2.20	3.80	0.958	0.199	8.83	8.55	0.539	0.593	7.38	7.13	0.512	0.565
SEm±	0.115	0.349	0.0814	0.0163	0.398	0.414	0.0252	0.0334	0.339	0.291	0.0272	0.0354
LSD (P=0.05)	0.364	1.094	0.2422	0.0435	1.254	1.303	0.0813	0.1054	1.069	0.919	0.0843	0.1125
Cropping systems:												
Maize-Wheat	2.34	3.83	0.684	0.162	-	-	-	-	-	-	-	-
Maize-Chickpea	2.20	3.14	0.620	0.148	-	-	-	-	-	-	-	-
SEm±	0.052	0.234	0.0641	0.0084	-	-	-	-	-	-	-	-
LSD (P=0.05)	NS	NS	NS	NS	-	-	-	-	-	-	-	-

Table: 4.40. Effect of conservation tillage practices on GHG (CO_2 and N_2O) emission in maize based cropping systems.

Treatments	Total (maize + wheat/chickpea)			
	CO_2 (Mg/ha)		N_2O-N (kg/ha)	
	2012-13	2013-14	2012-13	2013-14
Conservation tillage practices:				
PB-WR	10.91	12.00	0.888	0.542
PB-WOR	9.77	10.94	1.015	0.618
ZT-WR	10.79	11.21	0.903	0.513
ZT-WOR	9.41	9.47	1.058	0.577
CT-WR	11.99	13.21	1.243	0.664
CT-WOR	10.31	11.64	1.483	0.778
SEm±	0.307	0.334	0.0794	0.0292
LSD (P=0.05)	0.954	1.043	0.2449	0.0966
Cropping systems:				
Maize-Wheat	11.08	11.71	1.143	0.632
Maize-Chickpea	9.98	11.11	1.053	0.599
SEm±	1.136	0.250	0.0714	0.0621
LSD (P=0.05)	NS	NS	NS	NS

CHAPTER-V

DISCUSSION

In the previous chapter, the experimental findings of the experiment entitled "*Studies on green house gas emissions and carbon sequestration under conservation agriculture in maize based cropping systems*" have been described. In this chapter, an earnest attempt has been made to analyse the results critically in the light of cause and effect relationship. The findings of earlier workers on the subject have also been taken into consideration while discussing the results of present investigation. An attempt has been made to explain these results as far as possible with the help of other research findings.

5.1 Weather and crop growth

Weather parameters play an important role in growth and development of crop plants. The productivity of maize and wheat/chickpea showed a slight variation in two years of experimentation. A cursory appraisal of weather data of two cropping years (Table 3.1 to 3.2 and Fig. 3.1 to 3.4) revealed that amount of precipitation and mean RH (%) were higher in 2013-14. A great variation was observed in the amount and distribution of rainfall between the two years. During *kharif* 2013, 1198 mm rainfall was received. On the contrary, only 481.8 mm rainfall was received in the corresponding period during 2012. Mean maximum and minimum temperature prevailed during the period was favourable hence no problem was encountered in germination of crop in both the years. During 2012, the crop experienced dry spell during initial stages due to meager and ill distribution of rainfall, high temperatures and evaporation. A close examination of weather data revealed that during *rabi* season in both the years rainfall is nearly same (176 mm in 2012-13 and 169.1 mm in 2013-14) but there was variation in distribution. During 2013-14, rainfall evenly distributed in crop period. It was observed that the crops were healthier during the second year of experiment than the first one.

5.2 Growth parameters

The different growth parameters, viz. plant height, dry matter accumulation, leaf area index, CGR and RGR of maize, wheat and chickpea were influenced significantly due to conservation tillage practices in both the year of study. The growth parameters of maize, wheat and chickpea 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 on beds avoids the adverse effect of short-term water logging during heavy rains and results in more efficient use of irrigation water and nutrients (Singh *et al*., 2007). Similarly, residue application significantly improved the all the growth parameters than no-residue under different tillage and bed planting, this might be due to residue application improve the physical environment in the soil; more available soil moisture and nutrients, moderate the soil temperature and reduce the evaporation losses from surface soil. Ram (2006) also reported the higher values of plant height, dry matter accumulation, LAI, CGR and RGR under permanent bed with residue than no-residue under both ZT and CT practices. The similar results were also reported by (Tolk *et al.,* 1999).

The growth parameters were marginally higher under ZT and residue management practices, this might be due to better soil health and micro-environment created by continuous adoption of these environment friendly and resource conserving practices. Wilhelm (1989) was also reported higher LAI and better growth of the wheat crop under no-till treatments. Yadav *et al.,* (2005) also reported marginally higher growth parameters under ZT than CT.

5.3 Yield attributes and yields

Cobs/m^2 and grains/cob were significantly influenced due to conservation tillage practices. However, cob length, cob girth, grains row/cob and 100-grain weight were statistically similar. The higher values of these characters under ZT-WR and remained at par with PB-WR. More LAI might helped in better photosynthesis and assimilation rate which resulted more dry matter and better growth indices, these ultimately gave good performance of crop. Behera and Sharma (2009) reported that under heavy rainfall with water logging situation during crop growing season results better performance in bed planting than flat planting. Maize performed better under ZT practice, while wheat under bed planting. These results are in the line with Singh *et al*. (2007). But, lower weed infestation during *rabi* than *kharif* season as well as more availability of post emergence herbicides and improved physical properties of soil might be contributed for better performance of wheat crop under ZT than CT practices. Yadav *et al.,* (2005) reported that ZT led to improvement in growth and yield attributes, viz. plant height, effective tillers, grains/ear and 1000- grain weight due to better establishment of plants as a result of less weed competition under ZT. Similar values of yield attributes under CT and ZT were reported by Singh (2000). However, application of residue under zero tillage treatments resulted higher values of yield attributes of both the crops than no residue, this might be due to maintain good and favourable soil moisture, moderated soil temperature, and improved soil fertility due to constant supply of nutrients through mineralization of these crop residues.

5.4 System productivity

The highest system productivity of maize–wheat/chickpea cropping system registered under ZT-WR (9.97 and 11.13 t/ha) followed by PB-WR (9.65 and 10.65 t/ha) was due to good crop growth, higher values of yield attributes and yields under these treatments. Maize and chickpea performed significantly better under ZT-WR, while wheat performed marginally better under PB-WR, thus contribution of all crops resulted higher productivity of the system under these treatments. Moreover, residue application improved the soil physico-chemical and biological environment in the soil through addition of nutrients and enhanced microbial activity (Singh *et al.,* 2009a). Jat *et al*., (2005) reported that productivity of maize–wheat system was maximum (10.84 t/ha) under FIRB system of planting followed by NT (no-till) and CT systems, respectively. Retaining residues to reduce runoff and enhance water infiltration is acutely important to both tillage/seeding systems but absolutely crucial for zero-till direct seeding. Based on wheat and maize yield performance after 10 years of testing, Sayre *et al*., (2005) reported yield improvements between 25–30% through adoption of zero-till seeding, appropriate rotations and residue retention as compared to the common practice of heavy tillage before seeding, mono-cropping and residue removal. Addition of large amount of residues over the years which added nutrient to the system resulting in higher levels of crop productivity (Behera *et al*., 2007).

5.5 Nutrient uptake

Conservation tillage practices brought significant differences in the nutrient uptake by the maize-wheat/chickpea. The higher mean total N, P and K uptake under PB-WR by the maize–wheat/chickpea cropping system might be due to better root growth, leading to more extraction of nutrient from soil, lower weed infestation and better performance of crops particularly by maize under water logging condition, thus all these factors might have contributed to higher uptakes of nutrients under PB-WR. Singh *et al.,* (2007) were reported that total N uptake by maize was highest (67.46 kg/ha) under bed planting than flat sowing of maize. Nema *et al.,* (1996) also reported higher uptake of N, P and K by maize under ridge and furrow system of planting. Lower uptake of nutrient under CT-WOR might be due to higher weed infestation, poor biomass production, poor root growth and water logging condition aroused due to higher bulk density and compaction of soil. However, the maximum N, P and K uptake were recorded under ZT–WR, this might be due to addition of nutrients through residue, improved physical environment favorable for better microbial activity that might helped in mineralization resulting better availability of nutrients (macro and micro) to crops and thus increased the uptake under these treatments (Behera *et al.,* 2007). Residue application suppress the growth of weeds, increased the moisture availability and moderate the soil temperature. Thus, it increased the biomass accumulation which ultimately increased the grain yield of crops. A similar result was also reported by Patra *et al.,* (2004).

5.6 Economics

Tillage practices contributed greatly to the labour cost in any crop production system resulting to lower economic returns (Labios *et al.,* 1997). The higher cost of production under CT practices due to more number of tillage operations have done and more labour cost involved in cultural operations like manual weeding. Fresh raised bed preparation also contributed to higher cost of productions in CT practices, but here the difference is only marginal because cost involved in irrigation water and its application was saved under bed planting system. The cost of production was higher in 2013-14 than year 2012-13. This was also due to increased in input and labour cost. Cost of PB and ZT were similar, this was due to initial costs in forming of raised beds was disappear because beds were retained permanently. Residue applied treatments exhibited higher cost of production due to higher prices of residue. Lower cost of production under ZT than CT practices due to no-tillage operations, except planting of crops, saving of money in weed control practices due to herbicide application, which were less costly than manual weeding and labour cost saving involved in various cultural operations. The use of ZT significantly reduces energy costs, mainly by reducing tractor costs associated with conventional methods (Erenstein and Farooq, 2009). Jat *et al.*, (2005) also 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. The higher gross and net returns under ZT+WR treatments due to greater yields performance of the crops, however lowest B:C ration were registered under residue treatment in all the tillage practices, due to high priced residue application. This was in agreement with the findings of Zentner *et al*., (2002). 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 system under NT was 30 and 322 US$ /ha more over FIRB and CT, respectively.

5.7 Water productivity

Water productivity is positively correlated with grain yield and negatively correlated with amount of irrigation water applied. The maximum water productivity was recorded under PB-WR during both the years of study, due to reduction in irrigation water requirement in bed planting. Similarly, a higher WUE was also reported in no-tillage (Chauhan *et al*., 2000) and bed planting (Kaur and Mahey, 2005; Ram *et al*., 2010). The better root growth (Aggarwal *et al.*, 2006) and lower infestation of weeds on the beds was might be other possible reasons of higher water productivity under PB-WR. Jat *et al.*, (2005) reported that irrigation water use (m^3/ha) in both maize and wheat was highest (3231 and 3700) under conventional till followed by zero-till (2723 and 2934) and the lowest being (2030 and 2619) under FIRB planting system, respectively. The increase in water productivity is the resultant of both increase in yield and saving in irrigation water.

5.8 Physical properties of soil

Soil bulk density (BD) was influenced significantly in the surface (0–15 cm) while it was non-significant in sub surface (15–30 cm) soil layer due to different tillage practices in maize–wheat/chickpea cropping system. The lowest value of soil BD under PB-WR in surface layer may be due to lower porosity, lower soil compaction due to looseness of the soil. Jat *et al*., (2005) also reported lower BD values under raised beds than flat system due to looseness and lower soil compaction. Similarly, crop residue decrease the soil BD under ZT practices may be by improving soil aggregation, organic matter content in soil that might helps in improving the porosity of soil. Ram *et al.,* (2010) reported lower values of soil BD under residue applied treatments than without residue ZT practices. Bautista *et al*., (1996) working in a semi-arid ecosystem found that zero-tillage plus mulch reduced bulk density (BD). The similar results were also reported by Obalum and Obi (2010).

Soil structure stability is the ability of aggregates to remain intact when exposed to different stresses. PB-WR and ZT-WR recorded higher mean weight diameter and grand mean diameter than the CT-WR/WOR. This might be due to non-disturbance of the soil with tillage and addition of residues might have contributed for increased MWD and GMD. Based on a study in Brazil, Madari *et al*., (2005) reported that NT with residue cover had higher aggregate stability, higher aggregate size values and total organic carbon in soil than CT. Govaerts, *et al.*, (2007) reported that soil from permanent raised beds with full residue retention had significantly higher mean weight diameter for wet and dry sieving compared to conventionally tilled raised beds. Permanent raised beds with full residue retention had significantly higher aggregate stability compared to those with residue removal. A lower aggregation resulted in a reduction of infiltration.

The hydraulic conductivity (HC) of the surface (0–15 cm) and sub-surface (15–30 cm) soil layer was significantly influenced due to conservation tillage practices. The HC was significantly higher under PB-WR and ZT-WR, than CT-WOR, The higher HC in ZT-WR practices was might be due to lower BD and compaction in surface as well as sub surface layers which restrict the water flow in the soil. Beds were having loose soil on the top as well as near the soil surface which permit the easy water flow in surface as well as sub surface layers of soil profile. The increase of HC in PB-WR was probably due to better root growth and continuous channels formed by decaying roots serve as routes linking the soil surface to deeper layers and this corroborates the findings of Williams and Weil (2004). Residue increased the HC due to addition of the organic matter in the soil which improve the soil macro-aggregates that might facilitate easy movement of water in the soil. The similar results were also reported by Das *et al*. (2001) and Rasool *et al*., (2007). The HC was non-significant with different cropping system.

5.9 Soil organic carbon (SOC)

Field studies have shown that zero tillage results in greater accumulation of soil organic matter in surface layers (0–20 cm) than does conventional tillage (Kern and Johnson, 1993; Govaerts, *et al.,* 2007). Similar results were obtained in this experiment also. ZT-WR and PB-WR recorded significantly higher soil organic carbon (SOC) than CT-WR and CT-WOR. This may be due to application of crop residues in these ZT treatments which decomposed and added the organic matter to the soil. Govaerts, *et al*., (2007) reported that permanent raised beds with full residue retention increased soil organic matter content 1.4 times in the 0-5 cm layer compared to conventionally tilled raised beds with straw incorporated and it increased significantly with increasing amounts of residue retained on the soil surface for permanent raised beds. It can be hypothesized that conventional tillage with all plant residues incorporated by disking, is actually a system that rapidly breaks down the organic C inputs, while C 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). Conservation agriculture, reduced/zero tillage, crop rotation and retention of a rational amount of residue is a practice that leads to soil organic C sequestration and C sequestration is a strategy to achieve food security through improvement of soil quality (Lal, 2004). Zero-tillage, on the other hand, combined with permanent soil cover, has been shown to result in a build-up of organic carbon in the surface layers (Lal, 2005). No-tillage minimizes SOM losses and is a promising strategy to maintain or even increase soil C and N stocks (Bayer *et al.*, 2000).

5.10 Available NPK

Interestingly in most of the cases the soil available NPK in tillage and residue management treatments were not varied much from the initial available NPK status (147.41, 12.61 and 208.42 NPK kg/ha). This might be due to the richness in application of uniform recommended dose of fertilizers (RFD) satisfied the requirement of the crop in terms uptake apart from the various forms of losses (volatilisation, runoff and leaching) resulted in fairly the same initial available status. This is in agreement with results of Verhulst *et al*., (2009) which indicated the soil was rich in those nutrients or adequate amounts of fertilizers were applied.

5.11 GHGs emission

The green house gases (CO_2 and N_2O-N) emission in maize, wheat and chickpea were significantly influenced by conservation tillage practices while cropping system did not influenced it. Higher CO_2 emission in maize-wheat/chickpea cropping system was under CT-WR. This may be due to rapid increase in microbial activities in decomposing the labile soil organic matter pool. However, Jackson *et al.*, (2003) and Roberts and Chan (1990) concluded that the increase in soil CO_2 emission immediately after tillage operation was not due to the increase in microbial activities, but it was rather due to the increase in soil aeration that was induced by tillage disturbance. Reicosky and Lindstrom (1993) also attributed greater CO_2 emission under CT from soil pores and solution. Meanwhile, tillage operations may physically facilitate gas emission from the soil pores due to soil disturbance (Ellert and Janzen, 1999).

Residue increased N_2O emission irrespective to tillage practices. This may be due to residue retention probably increased microbial activities, leading to reduced oxygen availability in the soil profile (Elmi *et al*., 2003), which favored N_2O production. Rochette (2008) evaluated 25 studies (approximately 45 site-years of data) with same site comparisons of no-till and tilled soil and concluded that no-till was not likely to increase N_2O emissions in medium- and well-aerated soils. Crop residues are generally considered as stimulants for N_2O emissions based on their N content (IPCC, 2006). The default IPCC conversion factor assumes that 1% of N in unburned crop residue is converted to N_2O (IPCC, 2006), which implies that agricultural systems which leave crop residues for decomposition in the field will always observe an increase in N_2O emissions. In agreement with Baggs *et al.*, (2000), Huang *et al.*, (2004), found residue retention increased N_2O emissions from CT plots by 35%.

CHAPTER-VI

SUMMARY AND CONCLUSION

The investigation entitled, "*Studies on green house gas emissions and carbon sequestration under conservation agriculture in maize based cropping systems*" was conducted during 2012-13 and 2013-14 at the Research Farm, Directorate of Maize Research Pusa New Delhi. The experiment was conducted in split plot design with three replications. The treatments consisted of combinations of six conservation tillage *viz.* PB-WR, PB-WOR, ZT-WR, ZT-WOR, CT-WR and CT-WOR and two cropping system *viz.* maize-wheat and maize-chickpea. The findings of the present experiment are summarized in this chapter.

6.1 Maize

6.1.1 The plant height, dry matter accumulation, leaf area and leaf area index (LAI) of maize were influenced significantly due to different conservation tillage practices at all the growth stages, except at 30 DAS during both the years of studies while cropping system did not influenced these parameters. There was no variation in days to 50% silking and maturity due to conservation tillage practices and cropping system.

6.1.2 CGR recorded 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-WR.

6.1.3 Cobs/m^2 and grains/cob were significantly influenced due to conservation tillage practices. However, cob length, cob girth, grains row/cob, and 100-grain weight were statistically similar. Maximum values of cobs/m^2 (7.33 and 8.17) and grains/cob (429.83 and 519.17) were recorded under ZT-WR.

6.1.4 ZT-WR registered 22.4, 20.0 and 18.5 %; 24.3, 12.8 and 14.4% increase in grain, stover and biological yields during 2012 and 2013, respectively. There was only a marginal non-significant difference in the harvest index of maize under different tillage practices in both the years.

6.1.5 The maximum nutrient uptake in grain and stover were recorded with ZT-WR. The percent increase in N uptake by grain and straw were 16.2 and 30.3 during 2012; 19.7 and 38.3 during 2013 over CT-WOR, respectively. Similar trend was found in P and K uptake by grain and straw during both the years of study.

6.1.6 The maximum C-input was estimated under CT-WR with 373.79 MJ/ha. Whereas, minimum C-input was recorded under PB-WOR. Similarly maximum C-output was recorded under ZT-WR (7899.76 and 8784.60 MJ/ha), whereas minimum under CT-WOR (6574.72 and 7567.74 MJ/ha). Both the cropping system were recorded same

C-input (316.64 and 314.34 MJ/ha) during 2012 and 2013, respectively. CSI was also higher under ZT-WR (24.87) during 2012 and ZT-WOR (29.02) during 2013.

6.1.7 Significantly higher values of NUE was found under ZT-WR (21.82 and 25.60 kg grain/ kg NPK applied during 2012-13 and 2013-14, respectively) over all other treatments except PB-WR. The highest water productivity was observed under PB-WR (4.85 and 5.57 kg/ha-mm; during 2012 and 2013, respectively), which was significantly higher than CT-WOR and ZT-WR, but it remained statistically similar with other treatments in both the years. Water productivity was not significantly influenced due to different cropping system in both the years.

6.1.8 The cost of cultivation of maize crop under different conservation tillage and cropping system varied from minimum with ZT-WOR and PB-WOR ($22.11 x 10^3$ and $23.32 x 10^3$ ₹/ha) to maximum under CT-WR ($25.09 x 10^3$ and $26.42 x 10^3$ ₹/ha) in year 2012 and 2013, respectively. The maximum net returns and B:C ratio were recorded under ZT-WR ($28.48 x 10^3$ ₹/ha and 1.21) during 2012 and ($34.80 x 10^3$ and 1.40). Slightly higher gross returns, net returns and B:C ratio were recorded under maize-chickpea cropping system in comparison to maize-wheat system.

6.2 Wheat

6.2.1 The tallest plants (84.00 and 88.57 cm) were recorded at harvest under PB-WR practice during both the years. At harvest the maximum dry matter accumulation (1038.82 and 1049.65 g/m^2) was recorded in PB-WR treatment during 2012-13 and 2013-14, respectively. At early growth stage (30 DAS) leaf area and LAI were low, but it was increased on later stages and reached maximum at 90 DAS. LAI values were found maximum (1.52 and 1.55) under PB-WR treatment during both the years, respectively.

6.2.2 The maximum CGR (17.90 and 18.46 g/m^2/day) were recorded at 60-90 DAS under PB-WR practice during both the years. Whereas, the RGR recorded a reverse trend in comparison to CGR, maximum value was found at 0-30 DAS. There was no variation in days to 50% anthesis and days to maturity due to conservation tillage practices during both the years.

6.2.3 The maximum value of effective tillers were observed under PB-WR (431.33 and 433.67/m^2) followed by ZT-WR (415.33 and 424.67 m^2) while lowest under CT-WOR (330.33 and 337.33/m^2) during 2012-13 and 2013-14, respectively. The maximum grain, straw and biological yield were recorded under PB-WR treatment, which were 22.3, 26.9 and 24.3 % higher during 2012-13 and 27.3, 20.6 and 23.4% higher during 2013-14 over CT-WOR, respectively.

6.2.4 Maximum N uptake in grain (64.84 and 68.38 kg/ha) and straw (31.73 and 35.81 kg/ha) was found under ZT-WR and PB-WR, respectively during both the years of study. Similar trend was found P uptake by grain and straw. Whereas, highest K uptake in grain (23.73 and 25.39 kg/ha) and straw (90.45 and 102.37 kg/ha) were found under PB-WR during both the years of study.

6.2.5 The maximum C-input was estimated under CT-WR and maximum C-output was under PB-WR (4595.22 and 5057.22 MJ/ha). CSI was higher under ZT-WR (18.13 and 21.56) during 2012-13 and 2013-14, respectively. Highest NUE was found under PB-WR (22.51 and 24.66 kg grain/ kg NPK applied) over CT-WR and CT-WOR and remained at par with all other treatments during 2012-13 and 2013-14, respectively. The highest water productivity was observed under PB-WR (2.94 and 2.35 kg/ha-mm; during 2012 and 2013, respectively).

6.2.6 The maximum cost of cultivation was recorded under CT-WR while, it recorded minimum under PB-WOR. The maximum gross (64.12 x 10^3 and 75.57 x 10^3 ₹/ha) and net returns (40.32 x 10^3 and 50.16 x 10^3 ₹/ha) were recorded under PB-WR during both the years, respectively. The maximum B:C ratio was recorded under PB-WOR (1.87 and 2.14).

6.3 Chickpea

6.3.1 The tallest plant of chickpea at harvest was recorded under PB-WR (62.13 and 67.53 cm). Branches/plant increased at later stages, after 120 days of sowing, there was marginally increased in number of branches. Significantly higher dry matter accumulated under ZT-WR at all the growth stages over CT-WOR except 40 DAS.

6.3.2 Highest numbers of pods/plant (72.67 and 77.33) were recorded under ZT-WR in 2012-13 and PB-WR during 2013-14. The maximum number of seeds/pod were observed under ZT-WR (1.73 and 1.93) followed by PB-WR (1.67 and 1.93) during 2012-13 and 2013-14, respectively.

6.3.3 The maximum seed yield (2.13 and 2.46 t/ha) was obtained under ZT-WR followed by PB-WR (2.01 and 2.24 t/ha), along with the minimum under CT-WOR (1.78 and 1.75 t/ha) during 2012-13 and 2013-14, respectively. Further, ZT-WR gave significantly higher seed yield by 19.6 and 40.5% over CT-WOR in 2012-13 and 2013-14, respectively. HI did not influenced due to treatments.

6.3.4 The maximum nutrient uptake in seed and stover were recorded with ZT-WR. The percent increase in N uptake by seed and straw were 20.9 and 14.4 during 2012; 26.9 and 26.7 during 2013 over CT-WOR, respectively. Similar trend was found in P and K uptake by seed and stover.

6.3.5 The maximum C-input was estimated under CT-WR with 223.12 and 223.33 MJ/ha during 2012-13 and 2013-14, respectively. Similarly maximum C-output was recorded under ZT-WR (3614.28 and 4190.17 MJ/ha). CSI was higher under ZT-WR

(18.13 and 21.56). The highest water productivity was observed under PB-WR (1.82 kg/ha-mm) during 2012 and ZT-WR (2.05 kg/ha-mm) during 2013.

6.3.6 The maximum cost of cultivation was recorded under CT-WR (20.90 x 10^3 and 22.53 x 10^3 ₹/ha). The maximum gross (65.85 x 10^3 and 81.94 x 10^3 ₹/ha) and net (62.30 x 10^3 and 44.56 x 10^3 ₹/ha) returns were recorded under ZT-WR during both the years, respectively. The maximum B:C ratio was recorded under ZT-WOR (3.33 and 2.25).

6.4 Maize-wheat/chickpea System

6.4.1 The highest system productivity was realized under ZT-WR (9.97 and 11.13 t/ha) followed by PB-WR (9.65 and 10.65 t/ha) during both the years.

6.4.2 The cost of cultivation of maize–wheat/chickpea cropping system was maximum under CT-WR (48.38 x 10^3 and 51.34 x 10^3 ₹/ha) in 2012-13 and 2013-14, respectively. Moreover, cost of cultivation was higher under maize-wheat (46.30 x 10^3 and 48.98 x 10^3 ₹/ha) in comparison to maize-chickpea (41.94 x 10^3 and 44.64 x 10^3 ₹/ha) during both the years, respectively. The maximum gross (132.39 x 10^3 and 165.14 x 10^3 ₹/ha) and net returns (87.19 x 10^3 and 117.03 x 10^3 ₹ /ha) were recorded under ZT-WR practice. The maximum B:C ratio was recorded under ZT-WOR (1.98 and 2.53).

6.4.3 Higher system uptake of N was recorded under PB-WR (204.90 kg/ha). However highest P uptake was in ZT-WR (46.52 kg/ha), While, significantly 45.4% higher K uptake was recorded in PB-WR (225.44 kg/ha) over CT-WOR. However, Higher N (195.62 kg/ha) and P (43.24 kg/ha) uptake by maize-wheat cropping system, whereas K (194.09 kg/ha) in maize-chickpea.

6.4.4 The highest water productivity was observed under PB-WR (10.60 kg/ha-mm) during 2012-13 and PB-WOR (6.57 kg/ha-mm). The maximum C input was estimated under CT-WR with 677.04 and 685.29 MJ/ha during 2012-13 and 2013-14, respectively. Maximum C-output was recorded under ZT-WR (11959 and 13307 MJ/ha), CSI was higher under ZT-WR (21.47 and 23.98) during 2012-13 and 2013-14, respectively. Significantly highest values of NUE was found under ZT-WR (26.77 and 30.72 kg grain/ kg NPK applied), which is being at par with PB-WR.

6.4.5 The maximum BD was recorded under CT-WOR (1.62 and 1.71 g/cm^3) at 0–15 and 15–30 cm, respectively. The maximum hydraulic conductivity was measured under PB-WR (1.95 and 1.59 cm/hr) in 0–15 and 15–30 cm soil depth, respectively.

6.4.6 Crop residues application significantly increased the SOC under PB, ZT and CT by 4.4, 8.0 and 17.4 % over PB-WOR, ZT-WOR and CT-WOR, respectively. Different cropping system did not significantly influenced SOC.

6.4.7 Maximum available N was recorded under ZT-WR, Moreover, residue application resulted higher available N in PB, ZT and CT than no residues. The maximum soil available P (16.79 kg/ha) and K (235.55 kg/ha) was recorded in ZT-WR followed by PB-WR.

6.4.8 Maximum CO_2 emission was recorded in wheat followed by chickpea and least in maize. Significantly highest total CO_2 emission in maize + wheat/chickpea cropping system was estimated under CT-WR (11.99 and 13.21 Mg/ha) followed by PB-WR (10.91 and 12.00 Mg/ha) and minimum under ZT-WOR (9.41 and 9.47 mg/ha) during 2012-13 and 2013-14, respectively. Whereas maximum N_2O-N emission was under CT-WOR (1.483 and 0.778 kg/ha) and minimum under PB-WR (0.888 and 0.542 kg/ha).

CONCLUSION

Based on two years experiment, it might be concluded that:

1. Zero tillage with residue showed better performance of maize-wheat/chickpea cropping system in terms of growth, yield attributes, yield and economics.
2. Zero tillage with residue improves physical and chemical properties of soil. It also reduces green house gases emission from soil.
3. Higher carbon sequestration and CSI was realized under zero tillage with residue.

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Appendix 1. Common cost of maize cultivation/ha and value of produce during 2012.

S. No.	Items	Rate (Rs.)	Amount (Rs.)	
A. Input			ZT & PB	CT
1. Sowing	Disking/harrowing/seed drilling	1000	400	2000
2. Seed	20 kg ha^{-1}	90 kg ha^{-1}	1800	1800
3. Thinning & gap filling	Labour (3 man days)	279 per man day	837	837
4. Fertilizer cost other than treatment	N: 150 kg ha^{-1} (130 kg N) remaining is adjusted by DAP	11.65 per kg	1515	1515
	P: 60 kg P_2O_5 ha^{-1} (109 kg DAP)	24.4 per kg DAP	2660	2660
	K: 40 K_2O kg ha^{-}1 (67 kg MOP)	16.80 per kg K_2O	672	672
	$ZnSO_4$. $2H_2O$: 10 kg	30 per kg	300	300
	Fertilizer application (3 man days)	279 per man day	837	837
5. Irrigation	Three irrigation	380 per irrigation	1140	1140
6. Residue cost*	5 t ha^{-1}	275 per tonn	1375	1375
7. Insecticides	Chlorpyrifos 20 EC @ 1.5 liter ha^{-1}	170 per litre	255	255
8. Manual weeding	Labour (4 man days)	279 per man day	1116	1116
9. Herbicides	Atrazine @ 1kg ha^{-1}	291 per kg	291	291
	Labour (1 man day)	279 per man day	279	279
10. Bird watching	15 man days	279 per man day	4185	4185
11. Harvesting	Labour (8 man days)	279 per man day	2232	2232
12. Shelling and cleaning	Labour (6 man days)	279 per man day	1674	1674
13. Bagging	Labour (3 man days)	279 per man day	837	837
14. Rental value of land	4 months	270 per month	1080	1080
Total			23485	25085
B. Output				
1. Main product	Grain	11750 per ton		
2. By-product	Stover	850 per ton		

* Residue cost included only in residue application treatments.

Appendix 2. Common cost of wheat cultivation/ha and value of produce during 2012-13.

S. No.	Items	Rate (Rs.)	Amount (Rs.)	
A. Input			ZT & PB	CT
1. Sowing	Disc harrow and cultivator	1200	450	2400
2. Seed	100 kg ha^{-1}	22 kg ha^{-1}	2200	2200
3. Thinning and gap filling	Labour (1 man day)	297 per man day	297	297
4. Fertilizer cost other than treatment	N: 120 kg ha^{-1} (100 kg N) remaining is adjusted by DAP	11.65 per kg	1165	1165
	P: 60 kg P_2O_5 ha-[1] (109 kg DAP)	24.4 per kg DAP	2660	2660
	K: 40 K_2O kg ha-[1] (67 kg MOP)	16.80 per kg K_2O	672	672
	Fertilizer application (2 man days)	297 per man day	594	594
5. Irrigation	Four irrigation	350 per irrigation	1400	1400
6. Residue cost*	5 t ha^{-1}	584	2919	2919
7. Manual weeding	Labour (2 man days)	297 per man day	594	594
8. Herbicides	Isoproturon @ 0.75 kg ha^{-1}	270 kg^{-1}	0	203
	2-4D @ 0.5 kg ha^{-1}	174 kg^{-1}	87	87
	Glyphosate @ 1.25 lit ha^{-1}	220 $litre^{-1}$	250	0
	Labour (1 man day)	297 per man day	297	297
9. Bird watching	Labour (15 man days)	297 per man day	4455	4455
10. Harvesting	Labour (10 man days)	297 per man day	2970	2970
11. Threshing and cleaning	Labour (4 man days)	297 per man day	1188	1188
12. Bagging	Labour (1 man days)	297 per man day	297	297
13. Rental value of land	5 months	260 per month	1300	1300
Total			23795	25698
B. Output				
1. Main product	Grain	12850 per ton		
2. By-product	Straw	1300 per ton		

* Residue cost included only in residue application treatments

Appendix 3. Common cost of chickpea cultivation/ha and value of produce during 2012-13.

S. No.	Items	Rate (Rs.)	Amount (Rs.)	
A. Input			ZT & PB	CT
1. Sowing	Disc harrow and cultivator	800	350	1600
2. Seed	80 kg ha^{-1}	34.5 Rs kg^{-1}	2760	2760
3. Fertilizer cost other than treatment	N: 20 kg ha^{-1} (06 kg N) remaining is adjusted by DAP	11.65 per kg	70	70
	P: 40 kg P_2O_5 ha^{-1} (87 kg DAP)	24.4 per kg DAP	2121	2121
	K: 20 K_2O kg ha^{-1} (33 kg MOP)	16.80 per kg K_2O	336	336
	Fertilizer application (2 man days)	279 per man day	558	558
4. Irrigation	Three irrigation	350 per irrigation	1050	1050
5. Herbicides	Fluchloralin		300	300
	Labour (1 man day)	279 per man day	279	279
6. Residue cost*	5 t ha^{-1}	584 per ton	2919	2919
7. Insecticides	Monocrotophos		350	350
8. Manual weeding	Labour (4 man days)	279 per man day	1116	1116
9. Bird watching	Labour (8 man days)	279 per man day	2232	2232
10. Harvesting	Labour (6 man days)	279 per man day	1674	1674
11. Threshing and cleaning	Labour (6 man days)	279 per man day	1674	1674
12. Bagging	Labour (2 man days)	279 per man day	558	558
13. Rental value of land	5 months	260 per month	1300	1300
Total			19647	20897
B. Output				
1. Main product	Seed	28000 per ton		
2. By-product	Stover	1150 per ton		

* Residue cost included only in residue application treatments

Appendix 4. Common cost of maize cultivation/ha and value of produce during 2013.

S. No.	Items	Rate (Rs.)	Amount (Rs.)	
A. Input			ZT & PB	CT
1. Sowing	Disking/harrowing/seed drilling	1050	450	2100
2. Seed	20 kg ha^{-1}	125 kg ha^{-1}	2500	2500
3. Thinning & gap filling	Labour (3 man days)	297 per man day	891	891
4. Fertilizer cost other than treatment	N: 150 kg ha^{-1} (130 kg N) remaining is adjusted by DAP	11.65 per kg	1515	1515
	P: 60 kg P_2O_5 ha^{-1} (109 kg DAP)	24.4 per kg DAP	2660	2660
	K: 40 K_2O kg ha^{-1} (67 kg MOP)	16.80 per kg K_2O	672	672
	$ZnSO_4$. $2H_2O$: 10 kg	30 per kg	300	300
	Fertilizer application (3 man days)	297 per man day	891	891
5. Irrigation	One irrigation	400 per irrigation	400	400
6. Residue cost*	5 t ha^{-1}	290 per ton	1450	1450
7. Insecticides	Chlorpyrifos 20 EC @ 1.5 liter ha^{-1}	170 per litre	255	255
8. Manual weeding	Labour (5 man days)	297 per man day	1485	1485
9. Herbicides	Atrazine @ 1kg ha^{-1}	296 per kg	296	296
	Labour (1 man day)	297 per man day	297	297
10. Bird watching	15 man days	297 per man day	4455	4455
11. Harvesting	Labour (8 man days)	297 per man day	2376	2376
12. Shelling and cleaning	Labour (6 man days)	297 per man day	1782	1782
13. Bagging	Labour (3 man days)	297 per man day	891	891
14. Rental value of land	4 months	300 per month	1200	1200
Total			24766	26416
B. Output				
3. Main product	Grain	13100 per ton		
4. By-product	Stover	850 per ton		

* Residue cost included only in residue application treatments

Appendix 5. Common cost of wheat cultivation/ha and value of produce during 2013-14.

S. No.	**Items**	**Rate (Rs.)**	**Amount (Rs.)**	
A. Input			ZT & PB	CT
1. Sowing	Disc harrow and cultivator	1200	450	2400
2. Seed	100 kg ha^{-1}	24 kg ha-1	2400	2400
3. Thinning and gap filling	Labour (1 man day)	311 per man day	311	311
4. Fertilizer cost other than treatment	N: 120 kg ha^{-1} (100 kg N) remaining is adjusted by DAP	11.65 per kg	1165	1165
	P: 60 kg P_2O_5 $ha\text{-}^1$ (109 kg DAP)	24.4 per kg DAP	2660	2660
	K: 40 K_2O kg $ha\text{-}^1$ (67 kg MOP)	16.80 per kg K_2O	672	672
	Fertilizer application (2 man days)	311 per man day	622	622
5. Irrigation	Four irrigation	350 per irrigation	1400	1400
6. Residue cost*	5 t ha^{-1}	663 per ton	3315	3315
7. Manual weeding	Labour (2 man days)	311 per man day	622	622
8. Herbicides	Isoproturon @ 0.75 kg ha^{-1}	270 kg^{-1}	0	203
	2-4D @ 0.5 kg ha^{-1}	180 kg^{-1}	90	90
	Glyphosate @ 1.25 lit ha^{-1}	220 $litre^{-1}$	250	0
	Labour (1 man day)	311 per man day	311	311
9. Bird watching	Labour (15 man days)	311 per man day	4665	4665
10. Harvesting	Labour (10 man days)	311 per man day	3110	3110
11. Threshing and cleaning	Labour (4 man days)	311 per man day	1244	1244
12. Bagging	Labour (2 man days)	311 per man day	622	622
13. Rental value of land	5 months	300 per month	1500	1500
Total			25409	27312
B. Output				
3. Main product	Grain	12850 per ton		
4. By-product	Straw	1300 per ton		

* Residue cost included only in residue application treatments

Appendix 6. Common cost of chickpea cultivation/ha and value of produce during 2013-14.

S. No.	Items	Rate (Rs.)	Amount (Rs.)	
A. Input			ZT & PB	CT
1. Sowing	Disc harrow and cultivator	800	350	1600
2. Seed	80 kg ha^{-1}	39.75 Rs kg^{-1}	3180	3180
3. Fertilizer cost other than treatment	N: 20 kg ha^{-1} (06 kg N) remaining is adjusted by DAP	11.65 per kg	70	70
	P: 40 kg P_2O_5 ha^{-1} (87 kg DAP)	24.4 per kg DAP	2125	2125
	K: 20 K_2O kg ha^{-1} (33 kg MOP)	16.80 per kg K_2O	336	336
	Fertilizer application (2 man days)	311 per man day	622	622
4. Irrigation	Three irrigation	350 per irrigation	1050	1050
5. Herbicides	Fluchloralin	300	300	300
	Labour (1 man day)	311	311	311
6. Residue cost*	5 t ha^{-1}	663 per ton	3315	3315
7. Insecticides	Monocrotophos		350	350
8. Manual weeding	Labour (4 man days)	311 per man day	1244	1244
9. Bird watching	Labour (8 man days)	311 per man day	2488	2488
10. Harvesting	Labour (6 man days)	311 per man day	1866	1866
11. Threshing and cleaning	Labour (5 man days)	311 per man day	1555	1555
12. Bagging	Labour (2 man days)	311 per man day	622	622
13. Rental value of land	5 months	300 per month	1500	1500
Total			21284	22534
B. Output				
15. Main product	Seed	30000 per ton		
16. By-product	Stover	1150 per ton		

* Residue cost included only in residue application treatments

ABSTRACT

Title of thesis	:	Studies on green house gas emissions and carbon sequestration under conservation agriculture in maize based cropping systems
Full name of degree holder	:	**Muli Devi Parihar**
Admission No.		**2005A28D**
Title of degree	:	Doctor of Philosophy in Agronomy
Name and address of Major Advisor	:	Dr. R.K. Nanwal Department of Agronomy CCS Haryana Agricultural University, Hisar- 125 004, Haryana (India)
Degree awarding University/Institute	:	CCS Haryana Agricultural University, Hisar-125 004, Haryana (India)
Year of award of degree	:	2014
Major subject	:	Agronomy
Total number of pages in the thesis	:	126 + xxi + VI
Number of words in the abstract	:	306

Key words: carbon sequestration, conservation tillage, GHGs, maize

The experiment was carried out at the Research Farm, Directorate of Maize Research Pusa New Delhi for two consecutive *kharif* seasons of 2012-13 and 2013-14. The field was laid out in a split plot design with three replications. Six conservation tillage practices *viz.* PB-WR, PB-WOR, ZT-WR, ZT-WOR, CT-WR and CT-WOR were taken in the main plots and two cropping system *viz.* maize-wheat and maize-chickpea in subplots.

All growth parameters viz. Plant height, dry matter accumulation, LAI, CGR, RGR and NAR were significantly affected by conservation tillage practices. The growth parameters of maize did not influenced due to cropping system. Yield attributes of maize such as cobs/m^2 and grains/cob were significantly influenced by conservation tillage practices. Similarly, yield attributes of wheat and chickpea were also significantly influenced. ZT-WR registered 22.4, 20.0 and 18.5 %; 24.3, 12.8 and 14.4% increase in grain, stover and biological yields during 2012 and 2013, respectively. The highest system productivity was realized under ZT-WR (9.97 and 11.13 t/ha) followed by PB-WR (9.65 and 10.65 t/ha) during 2012-13 and 2013-14, respectively. Cropping system did not have a significant effect on growth, yield and soil properties. The maximum gross (132.39 x 10^3 and 165.14 x 10^3 ₹/ha) and net returns (87.19 x 10^3 and 117.03 x 10^3 ₹/ha) were recorded under ZT-WR practice while, maximum B:C ratio was recorded under ZT-WOR (1.98 and 2.53) during both the years.

The maximum C input was estimated under CT-WR whereas maximum C-output and CSI were under ZT-WR. Physical properties like BD, hydraulic conductivity, soil aggregation and infiltration rate were optimum under ZT-WR. Minimum GHGs (CO_2 and N_2O) emission from soil was recorded in maize followed by chickpea and wheat. Significant highest total CO_2 emission in maize- wheat/chickpea cropping system was estimated under CT-WR and minimum under ZT-WOR. Whereas, maximum N_2O-N emission was under CT-WOR and minimum under PB-WR.

MAJOR ADVISOR

SIGNATURE OF STUDENT

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