संरक्षण कृषि के अंतर्गत मक्का (*जीया मेज* एल.) में नत्रजन प्रबंधन

NITROGEN MANAGEMENT UNDER CONSERVATION AGRICULTURE IN MAIZE (*Zea mays* L.)

भरत राज मीना

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NITROGEN MANAGEMENT UNDER CONSERVATION AGRICULTURE IN MAIZE (*Zea mays* L.)

By

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CERTIFICATE

This is to certify that the thesis entitled **"Nitrogen Management under Conservation Agriculture in Maize (*Zea mays* L.)",** submitted to the Faculty of the Post-Graduate School, Indian Agricultural Research Institute, New Delhi, in partial fulfillment of the requirements for the award of the degree of **Master of Science** in **Agronomy**, embodies the results of bona fide research work carried out by **Mr. Bharat Raj Meena, (Roll No. 20526)** under my guidance and supervision, and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help availed during the course of investigation as well as source of information have been duly acknowledged by him.

Date: **(Shakar Lal Jat)**
Place: New Delhi Chairperson Advisory committee

Dedicated to

My Family

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Abbreviation

MMuMb/MMMb	Maize-mustard-mungbean cropping system
MWMb	Maize-wheat-mungbean cropping system
PB+R	Permanent bed with residue retention
PB-R	Permanent bed without residue retention
CRF	Controlled release fertilizer
PCU	Polymer coated urea
SCU	Sulphur coated urea
NCU	Neem coated urea
NT	No tillage
ZT	Zero tillage
PT	Plough tillage
e. g.	for example
i.e.	that is
viz.	namely/they are
@	at the rate of
SAS	Statistical analysis software
DAS	Days after sowing
WR	with residue
WoR	without residue
DMA	Dry matter accumulation
LA	Leaf area
LAI	Leaf area index
CGR	Crop growth rate
RGR	Relative growth rate
NAR	Net assimilation ratio
NDVI	Normalized differential vegetation index

SPAD	Soil plant analysis development
CTD	Canopy temperature depression
LSD	Least significant difference
Fig.	Figure
HI	Harvest index
MP	Main plot
SP	Sub plot
SSP	Sub-sub plot
NS	No significant
DM	Dry matter
PR	Penetration resistance
/	Per
ha	hectare/s
MBC	Microbial biomass carbon
p	probability
g	gram/grams
mg	milligram/milligrams
kg	kilogram/kilograms
t	tonne/tonnes
q	quintal/s
mt	million tonne/s
mha	million hectare/s
cm	centimetre/s
ANR	Apparent nitrogen recovery
PFP_N	Partial factor productivity of nitrogen
AE_N	Agronomic efficiency of nitrogen
PE_N	Physiological efficiency of nitrogen

Chapter 1

INTRODUCTION

Maize is the third most important cereal in the world and is grown in wide agro-ecologies in 155 nations. It is often referred to as "Queen of cereals, back bone of America and miracle crop. The ideal day time temperature for maize varies from 26^0C to 30^0C, but it can tolerate higher temperature if assured irrigation facilities are available. Night-time temperatures above 21^0C can result in wasteful respiration in maize (Keeffe, 2009). The optimum soil temperatures for germination and early seedling growth are 12 ^{0}C or greater while at tasselling 21 to 30 ^{0}C is ideal. It can grow and yield with as little as 300 mm rainfall, but prefers 500 to 1,200 mm as the optimal range. Depending on soil type and stored soil moisture, crop failure would be expected if less than 300 mm of rainfall were received. It is a tropical grass adapted to many climates and hence has wide-ranging maturity duration from 70 to 210 days (Belfield and Brown, 2008).

Worldwide maize occupies 185 m ha cultivated area with annual production of 1018 m t, with productivity of 5.5 tonnes/ha (Fertiliser Statistics, 2014-15). Nearly 34.7% of the maize grain is produced in United State of America followed by China (21.4%), Brazil (7.8%), Mexico (2.2%), India (2.2%) and Indonesia (1.8%). The highest productivity of maize is in the Israel i.e. 22.56 tonnes/ha which is more than 4.1 times of the global average (Fertiliser Statistics, 2014-15). Maize, an important crop for food, feed and nutritional security in India grown in diverse agro-environments and seasons on an area of 9.18 m ha with production of 24.17 m t and an average productivity of 2.63 t/ha during 2014-15 (GoI, 2016). India ranks 4^{th} in maize area in the world but has the productivity less than half of the worlds average. It's grain is used for industrial (13%), food (23%) and feed (63%) purposes in the country (Yadav *et al.,* 2014).. There is a tremendous need to increase the acreage and productivity of this crop in near future to meet rising feed, food and industrial demands, especially in view of the very fast growth in livestock and poultry sectors in India (Srinivasan *et al.,* 2004, Kar *et al.,* 2004 and 2005). Growth and yield of any crop under a particular environment are largely governed by soil moisture, nutrients, radiation interception and the efficiency of conversion of intercepted radiation and partitioning of dry matter to grain (Gallaghar and Biscoe, 1978; Kar *et al.,* 2005; Figuerola and Berliner, 2006; Kar *et al*., 2013).

One hundred gram of fresh grain contains 361 calories of energy, 9.4 g protein; 4.3 g fat, 74.4 g carbohydrate, 1.8 g fiber, 1.3 g ash, 10.6% water, 140 mg vitamins, 9 mg calcium, 290 mg phosphorus and 2.5 mg iron. It is a source of raw material for industry, where it is being extensively used for the preparation of corn starch, corn oil, dextrose, corn syrup, corn flakes, cosmetics, wax, alcohol and tanning material (Arain, 2013). Maize consumed as second-cycle produce converted in meat, eggs and dairy products in high income economies. In developing countries, it is consumed directly and serves as staple diet for around 200 million and it is regarded as a breakfast cereal. It is also found as fuel (ethanol) and starch in processed forms. Starch used to make products such as sorbitol, dextrine, sorbic and lactic acid by enzymatic reaction, and appears in household items (Plessis, 2003) like candies, thickening agents, crunchiness in bakery products, shoe polish, ice-cream, baby-food additives, syrup, beer, cosmetics and paint.

In pre-green revolution era, coarse cereals including maize were the principal crops of rainy season in northern India. But with the introduction of high yielding varieties and expansion of irrigation facilities, rice has become prominent rainy season while wheat as winter crop after green revolution. Hardly less than one tonne organic manure per ha is being added to the soil, which leads to fast decline in organic matter content of soils. The ground water depletion due to over exploitation for planting of rice, as it is done in north-western Indo-Gangetic plains (IGP) two months before onset of monsoon and that has dangerously lowered the water level. On an average ground water is depleting at the rate of 300 mm per year in Punjab and Haryana which resulted in increasing pumping costs, replacement of shallow tube wells with submersible pumps, adverse effects on water quality and overall ecology of the region. Water is expected to be the most scarce ecological factor and costly input in determining agricultural production. The scope for further water exploitation seems to be negligible as indicated by receding water table. Moreover, in command areas due to excessive and indiscriminate use of irrigation water, salinity is building up. The genetic homogeneity both at varietal and crop levels enhanced genetic vulnerability to biotic stresses *e.g.* frequent outbreak of stem borer, white backed plant hopper and leaf folder in rice. Beside some environment and economic problem such as development of hardpans, low input-use efficiency including water, more insectspests, environmental pollution through emission of gases and large scale burning of rice straw are the emerging threats for RWCS.

Economically, it is becoming less and less profitable because of increasing input costs; particularly conventional tillage practices. Therefore, identification of suitable crops and cropping systems and developing the technologies that can reverse the process leading to resource degradation urgently needed. Conservation agriculture (CA) has emerged as a major way forwards from the existing unsustainable mode of crop production (Sharma and Behera, 2007). The escalating prices of the agricultural inputs going to affect the crop production cost due to use of diesel in agriculture on one hand and higher fertilizer and agrochemical prices on other hand. Recently, CA practices for crop production comprising of minimum soil mechanical manipulation, permanent soil cover and profitable crop rotation found to be useful in reduction in cost of crop production in addition to giving ecological services for lower carbon consumption/emission and improvement in soil health. The area under CA is increasing due to shortage of labour and escalating input prices in South Asian region and practiced on 157 m ha area worldwide (FAO, 2015). However, in India CA is practiced only on 1.5 m ha during 2013 (FAO, 2016). So, adoption of CA in India is required to harness more environmental and social benefits along with productive soils and profitable sustainable farming.

A short-duration dual purpose grain legume (e.g. mungbean) provides another option in cereal-based cropping systems of IGP to improve soil health besides increasing profits in crop production (Yadvinder-Singh *et al.,* 2011, Jat *et al.*, 2014). The traditional intensive tillage based crop production technologies are less water efficient (Bhushan *et al.*, 2007), results in decreasing soil health (Jat *et al.,* 2013) and lesser cost-effective (Jat *et al.*, 2014) compared to CA. Earlier studies in IGP, showed that crop yields, water productivity, and economic sustenance in various cropping systems can be increased by CA practices (Das *et al.*, 2014 and Jat *et al.*, 2014). Tillage practices enhances the soil drying and heating/cooling processes as it disturbs the soil surface and thus increases the loss of N from the soil by volatilization and results in lower N-use efficiency (NUE). Application of N beyond 120 kg/ha gave a reduction in PFP_N, but yield was more at subsequent level under ZT treatment than CT which indicates that ZT is more responsive for increasing the N level and gave more PFP_N (Sharma *et al.,* 2005). As compared to no-till, the emission of N_2O can increase (Ussiri *et al.,* 2009), have no effect at all (Jantalia *et al.,* 2008) or decrease (Steinbach and Alvarez, 2006) by tilling the soil. Residue increases surface soil moisture and near the surface C source to microbes where high soil temperature favours denitrification which results in closer zone of denitrifying activity in ZT than other tillage practices. N loss in wheel track area was 1.6 times higher than the non-wheel track area due to anaerobic conditions after rainfall (Hilton *et al.*, 1994).

Even with the high N rate for @ 150 kg/ha applied may seem high considering that fertilizer N recovery by cereals is rarely greater that 50% (Malhi *et al.,* 2001, 2009; Chien *et al.,* 2009). Both surface residue retention and ZT potentially induce major changes in N dynamics and thus requires differential N management in comparison with straw removal and tillage (McConkey *et al.,* 2002; Arora *et al.,* 2010). While ZT may reduce N mineralization by decreasing decomposition of soil organic matter, particularly in the initial 3–4 years of its adoption, crop residues can influence N dynamics from immobilization and volatilization (Drinkwater *et al.,* 2000; Yadvinder-Singh *et al*., 2005). However, with surface residue retention, broadcasting N onto crop residues can be an inefficient method of application because of immobilization in association with the microbial break down of rice residues (Rice and Smith, 1984; Thuy *et al.,* 2008; Xu *et al.*, 2010) and because of greater ammonia volatilization (Janssen, 1996; Patra *et al.,* 2004; Bacon *et al.,* 1986) than when applied to bare soil. Grain yield of wheat with no fertilizer N increased by 17% in the second year and by 51% in the third year over the first year, whereas the corresponding increase in yield of the N fertilized treatments averaged 5.2% and 18.2%. The recover efficiency of N can also be influenced by weather variation, crop rotation and N levels (Lopez-Bellido and Lopez-Bellido, 2001).

Despite more favourable results of CA in research, farmers are not adopting it at their field because of several reasons and one of them is improper nutrient especially N management practices. The five-split application of N in maize with recommended dose of nitrogen in ratio of 10:30:30:20:10 as basal, 4-leaf emergence, 8-leaf emergence, tassel emergence and early grain filling stages, respectively enhances the grain yield as compared to three split application (Singh, 2010). But at the same time split application requires more labour as compared to one time application and already there is shortage of labour in Indian agriculture. Moreover, the residue retention on the soil surface under CA becomes hurdle of split-urea application and lowers the NUE as part of it either volatilized or immobilized due to fraction of applied fertilizer rest on the residue and consumed by the microbes. For enhancing profitability in maize system through CA there is need to enhance fertilize N-use efficiency through use of slow release fertilizer which will also act as problem solving for labour shortage in agriculture. Hence, proper management practices requires for enhancing NUE and reducing environmental foot print in CA system. So, the review suggests that there is need of proper N management practices for accelerating adoption of CA. Considering these the present experiment entitled "**Nitrogen management under conservation agriculture in maize (*Zea mays* L.)**" was proposed with the following objectives:

1. To study the effect of slow release nitrogen fertilizers on crop performance and economic benefit in maize under conservation agriculture
2. To work out the effect of slow release nitrogen fertilizers on input use-efficiency in maize under conservation agriculture
3. To find out changes in physico-chemical and biological properties of soils with slow release nitrogen fertilizers under conservation agriculture.

Chapter 2

REVIEW OF LITERATURE

In this chapter the main focus has been made to review the previous related work carried out on **"Nitrogen management under conservation agriculture in maize (*Zea mays* L.)"** in India and abroad. The work pertaining to various aspects of tillage and nutrient management in maize or other crop has been discussed under different heads:

2.1. Conservation agriculture

The Conservation agriculture (CA) practices are gaining importance in India (Bunderson *et al*., 2013). CA was introduced as a concept for resource-efficient agricultural crop production an integrated management of soil, water and biological resources combined with external inputs to achieve economically viable sustainable agriculture and subsequently aim to improved livelihoods security of the farmers. It is based on three principles of (1) minimum or no mechanical soil disturbance; (2) permanent organic soil cover (consisting of a growing crop or a dead mulch of crop residues); and (3) diversified crop rotations to enhance rhizospheric and above ground biological processes (Giller *et al*., 2009 and Kassam *et al.,* 2012). The CA is one of the so-called emerging agro sciences (Lichtfouse *et al*., 2010) and encompasses techniques that minimize or eliminate tillage and, thus, maintain a vegetative cover that protects soil from its degradation. The beneficial effects of CA on the environment have been widely studied and disseminated by the scientific community since decades. Particularly with regard to erosion (McGregor *et al.,* 1990; Baker *et al.,* 2002 and Espejo-Perez *et al.,* 2013); increased organic matter content (Ordóñez Fernández *et al.,* 2007; González-Sánchez *et al.,* 2012; Repullo-Ruiberriz de Torres *et al.,* 2012 and Parihar *et al*., 2016a); improved water infiltration (Thierfelder and Wall, 2009 and Parihar *et al*., 2016a); water usage (Blanco-Canqui and Lal, 2007); water quality (Jordan and Hutcheon, 1997); reduced water pollution (Fawcett,1995); biodiversity enhancements (Kladivko, 2001); reduced CO_2 emissions (Lal, 2005 and Carbonell-Bojollo *et al.,* 2011). Likewise, several studies demonstrate the technical viability of CA in terms of yields when compared to TT (Cantero-Martinez *et al.,* 2003 and Van Den Putte *et al.,* 2010) and also regarding the economical revenue for farmers (Uri *et al.,* 1999; García-Torres *et al.,* 2003 and Parihar *et al*., 2016).

Thierfelder *et al.* (2015) studied the impact of CA on yield response of maize and found that there was a greater yield response (80%) than on conventional tillage treatments across sites and seasons. Further, yield benefits of maize increased with increasing years of practicing CA, which highlights need to gain experience to master critical management steps such as timely planting, weeding, fertiliser application and crop residue management.

2.2. Coated fertilizer in India

The ICAR-Indian Agricultural Research Institute (ICAR-IARI), New Delhi, pioneered the discovery and development of neem products as fertiliser urea adjuvants for enhanced nitrogen use efficiency (NUE). Neem properties Nitrification inhibiting properties and its role in increasing nitrogen use efficiency (NUE) in rice was first time reported by Dr S.S. Bains and co-workers in year 1971 (Division of Agronomy, ICAR-IARI, New Delhi). They treated the urea with ethanol extract of neem seeds. Afterwards, several research studies by Dr Rajendra Prasad and his colleagues made at the ICAR-IARI, New Delhi, have indicated an increase in yields and NUE by using neem cake, neem-oil emulsion coated urea, pusa neem golden urea and other modified fertiliser N materials in rice and some other crops. Besides increased NUE of applied N and yields, it is found to reduce the emissions of greenhouse gases. In the beginning the use of neem cake was advocated for coating of urea but required 0.1-0.2 ton neem cake per ton urea, which involved lots of transport and application costs and hence could not be used by the Indian farmers eventually. As an alternative of neem cake, use of 0.3 -0.5 kg neem-oil per ton urea could serve the purpose and is being used successfully for coating of urea in India.

The Government of India (GOI) has promoted and encouraged the research and development of neem coated urea (NCU) as a value-added fertiliser. In this direction, an earlier GoI notification permitted to produce and sell NCU equivalent to the maximum of 35% of installed capacity of factories in urea. Later on the GOI made it mandatory for fertiliser manufactures to produce at least 75% NCU of total production in 2014. In addition to this, the suphur coated urea (SCU) also been found effective for enhancing crop yield and NUE as slow release fertilizer in many crops (Kumar, 2015).

The application of urea fertilizer has always been associated with heavy N losses therefore, improving its efficiency is critical to minimize economic and environmental losses associated with its application. One possible approach to decrease the N losses from the surface applied urea is to coat it with sulfur, urease inhibitor and other biodegradable materials (Zhao *et al.*, 2013). Nelson *et al.* (2014) conducted a study on how polymer-coated urea release and corn yield response clay soils and found that pre-plant applied, urea-based fertilizer management in high-residue, no-till (NT) corn is challenging because of potential N loss due to cool, wet conditions in the spring and dry conditions during the summer months. They also reported that urea release from PCU was <35 % from fall through winter (November–January) and <20 % for early preplant (February–March) applications until 1 April. Considering the above mentioned facts of CA benefits and coated fertilizer importance the work done in maize on these aspect in India and elsewhere was reviewed for crop performance, resource-use efficiency and soil health and presented in 2.3 to 2.8 heads.

2.3. Effects of residue and N management on crop growth parameters

Coulter and Nafziger (2008) found that partial removal of residue left 21 to 26% surface residue coverage with a chisel plow system, compared with 53 to 65% with no-till, which shows higher biomass production capacity in CA compared to CT. Awaad (2013) conducted an experiment on effect of slow-release nitrogen fertilizers on maize plants grown on new reclaimed soil and recorded that urea form 100 kg/fed had the most significant effect on ear length (21.42 cm), plant height (213 cm), 100 grain weight, grain yield (3.89 ton/fed.) and biological yield (9.62ton/fed) followed by urea + humic acid on sandy soil. Ita *et al*. (2014) reported that the ZT practices found to have significant effect on plant height i.e. 1.89 m while under conventional tillage under hand weeding the average plant height was 1.69 m in maize. The enhancement in the maize plant height, leaf area, SPAD, NDVI and dry matter production was found to increased with better nutrient management under conservation agriculture compared to conventional farmers fertilization practices in maize in sandy loam soils of north-west India (Ghosh, 2015). N fertilization leads to increased values of NDVI and SPAD values and directly correlated with the N in leaves (Mohanty *et al.*, 2015). Ram (2006) reported higher values of plant height, dry matter accumulation, LAI, CGR and RGR under permanent bed with legume residue than no-residue.

Zavaschi *et al.* (2014) conducted an experiment on a Geric Ferralsol, in Uberlandia, MG, Brazil and reported that volatilization rates, soil plant analysis development (SPAD) readings, nitrogen concentration in leaf and grain as well as grain yield were not affected by coated urea compared to conventional fertilization. Similar results also reported by Pereira *et al.* (2009). In contrast to this, Orioli (2008) tested N rates (0-150 kg/ha) applied prior to maize sowing and found that SPAD values increased linearly with increasing rates, ranging from 27 to 54.2. Argenta *et al.* (2002) determined a SPAD threshold of 58 for leaves at flowering as critical.

2.4. Effects of residue and N management on yield attributes in crop

Kalpana and Krishnarajan (2002) reported that application of 150 kg N/ha in 3 split doses resulted in the highest cobs per plant (3.63), cob length (18.33 cm) and cob width (3.16 cm). Muthukumar *et al*. (2005) also reported that the yield parameters *viz.,* cob length, diameter and weight of cob significantly influenced by split N application. Yield attributes of yellow sarson were significantly higher under residue retention in East India (Sarkar *et al.,* 2007). Choudhary *et al.* (2013) recorded significantly higher cob parameters under paddy straw mulch compared to no mulch. Ghaffari *et al*. (2011) found that significant variation in grain rows/cob of maize was found in different foliar application treatments of multi-nutrients.

Ma and Han (1995) found that yield attributes in non-irrigated conditions were higher under mulched treatment. The 25% higher yield in bed planting with one row per bed of maize at Ludhiana was due to increased number of cobs per plant and more grains per cob than flat sowing (Kaur and Mahay, 2005). Ahmad *et al*. (2010) noticed that CT gave superior yield attributes in term of grains/cob, grain weight and grain yield as compared to NT and split application significantly increased grains/cob, grain weight and grain yield as compared to single application of prilled urea.

Palled and Shenoy (2000) also reported that neem coated urea was found effective for increasing yield and yield attributes of hybrid maize in Peninsular India. Kalpana and Krishnarajan (2002) reported that application of 150 kg K/ha in 3 split doses resulted in the highest cobs per plant (3.63), cob length (18.33 cm), cob width (3.16 cm). Muthukumar *et al*. (2005) reported that the application of N in split doses had significant influence on the yield parameters *viz*., length, diameter and weight of cob and corn. Vishram *et al*. (2006) stated that enhancement in yield attributes such as cob length, cob girth, grain weight per cob, shelling % and test weight as well as grain and stover yield was recorded with 180 kg N/ha applied through 100% chemical fertilizer.

2.5. Effects of residue and N management on crop yields

Aggarwal *et al*. (2000) found significantly higher grain yield and water use efficiency of maize under raised bed planting due to higher moisture conserving capacities of raised bed. CA may increase crop yield through improving long term soil fertility by soil organic carbon sequestration and reducing soil and water erosion (Holland, 2004; Govaerts *et al*., 2007a). The realistic effects of CA on crop yield may depend largely on specific CA practices, regional climate characteristics and cropping systems (Hobss *et al*., 2008; Putte *et al*., 2010 and Farooq *et al*., 2011). CA practices provided continuously higher and more stable yields for maize compared to the farmers' tillage and residue removal practices, even though optimum inputs and management practices were used in all cases (Erenstein *et al*., 2012). In another long-term study on CA in Malawi, grain yields of various maize based cropping sequences increase significantly (24–40%) over time under NT + legume residues retention on the surface compared with the traditional ridge and furrow system over CT (Thierfelder *et al*., 2015). Thierfelder *et al.* (2015) observed that in the majority of cases (80%), yield responses from CA systems were greater than the conventional control plot in Southern Africa. In 20% of the cases there was a negative response to CA, due to lack of experience by farmers in the initial year, slow increase in soil fertility at the respective site and waterlogging in some years with too much rainfall.

Tolk *et al*. (1999) observed that grain yield was improved due to straw mulch in maize under no-tillage and permanent bed planting. Govaerts *et al*. (2005) found that residue retention was essential to maintain productivity of maize and realize the benefits of direct drilling. ZT with residue retention and crop rotation resulted in high stable yields due to soil with good physical and chemical qualities compared to CT and ZT without residue (Govaerts *et al.,* 2005, Govaerts *et al.,* 2006a, Govaerts *et al.,* 2006b and Govaerts *et al.,* 2007). Famba *et al*. (2011) showed that without crop residues no yield differences between traditional tillage and different seeding technologies were noticed in short term. He *et al*. (2011) reported that summer maize yields tended to be higher under no/reduced tillage (NT) than conventional tillage (CT) without crop straw retention, especially in dry years.

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 maize crop by 17% compared to the CT. Sharma and Behera (2009) found that through inclusion of various pulses resulted in significantly higher maize-equivalent yield range from 11 to 26% than without inclusion of pulses. Ojiem *et al.* (2014) also reported similar findings due to improved N availability in legume- maize based cropping systems. Schmer *et al.* (2014) conducted a 10 year experiment on effects of tillage and residue management in a irrigated, continuous corn and found that mean grain yields were 7.5 to 8.6% higher for NT when stover was removed compared with no stover removal. Parihar *et al.* (2016b) in a 6 year study in sandy loam soil of north-west India reported that in the initial two years, higher system productivity was recorded in PB (8.2–8.5 Mg/ha), while from third year onwards ZT registered maximum productivity (11.3–12.9 Mg/ha). They also reported significant effect of maize based cropping system on the productivity under CA based management practices.

Banded controlled released urea use on winter-wheat in southern Alberta found that yield was marginally higher (B5%) for CRU than NCU (non coated urea) while fertilizer source did not affect protein concentration (McKenzie *et al.*, 2010). Gagnon *et al.* (2012) conducted a 3 year study (2008-2010) on clay soil near Quebec City (Canada) to compare the effect of polymer-coated urea (PCU), nitrification inhibitor urea (NIU), dry urea and urea ammonium nitrate 32% (UAN). They found that PCU and NIU resulted in higher grain yield than urea in wet years (2008 and 2009), but the increase was greater for PCU (+0.8 to +1.6 Mg/ha) than for NIU (+0.3 to +0.6 Mg/ha). However, no significant difference was reported between urea, PCU and NIU in dry year (2010). Tanwar (2014) found that neem coated urea significantly increased nutrient availability and uptake by maize crop, which gave higher grain and stover yield. Almost similar findings were also reported by Sharma and Prasad (1996) and Upadhyay and Tripathi (2000). However, Sistani *et al.* (2014) reported that there was no significant difference in corn grain yield or dry matter among the N sources.

A 2-year study conducted by Nelson *et al.* (2009) showed no significant differences in effects of CRU and non coated urea (NCU) on corn yield and N utilization under various water regimes and N rates in Missouri. The lack of differences was attributed to the limited loss of N under the climatic and management conditions during the experimental years and therefore they concluded the agronomic benefits of CRU might not be expressed in all climatic and management conditions. On the other hand, CA may also have detrimental impacts on crop yield by altering soil physiochemical and biological conditions, such as decreasing soil temperatures in areas of high latitude and seasons with low temperature and aggravating weed and disease incidence (Boomsma *et al.*, 2010). Several studies have found that CRU provides a significant yield benefit as compared with urea and other fertilizer types (Beres *et al.,* 2010; Ziadi *et al.,* 2011; Yang *et al.,* 2011).

The above reviewed studies (section 2.3 to 2.5) suggest that residue management and nutrient application practices and cropping system have either no or positive and negative effect on growth parameters and yield attributes in different agro-climatic situations. Thus, residue and fertilization of maize in various agro-climatic situations needs to be worked out separately as no system works universally for achieving higher crop performance and yields. At the same time information is also meagre on residue, N management and cropping systems interactions effect on maize growth parameters, yield attributes and yields.

2.6. Effects of residue and N management on resource-use efficiency

2.6.1. Nutrient concentration and uptake

The highest N (210.8 kg/ha), P (65.4 kg/ha) and (K 205.8 kg/ha) uptake was recorded with compost + NOCU + PK fertilizers. Application of ureaform at high rate increased the values of nitrogen uptake by both shoot and grain of maize plant, while urea at high rate + humic acid induced the highest values of both phosphorus and potassium uptake (Awaad, 2013). Yadav *et al.* (2016) observed that the maximum total N, P and K uptake (134.7, 40.9 and 156.6 kg/ha) as well as the protein content (8.7%) in maize grain were recorded in ZT and minimum in CT in sandy soil of north-west India. However, among the cropping systems plots the *kharif* maize planted in maize-chickpea-sebania plots registered the highest N, P and K uptake in stover and grain and protein (8.96%) content in grain due to higher availability of these nutrients in soil after six crop cycles.

Graham *et al*. (2002) reported that with addition of crop residue increases total N content significantly. Nasima *et al*. (2010) conducted a pot experiment and found that application of coated urea increased dry matter yield from 60 to 20% per pot and enhanced N uptake up to 77% as compared to urea alone. Grant *et al.* (2012)

conducted research trials at five locations across four major eco-regions of North America to evaluate the effects of a single application of polymer-coated urea (CRU) or split applications of urea fertilizer as compared with non-coated urea. Some yield losses occurred from use of the CRU as compared with the non-coated urea and were attributed to delays in release of N from the granule that limited early season N availability and crop growth, especially in corn with a high N demand. Effects on grain N concentration and accumulation of N in the crop at harvest were mixed, with the CRU, blended applications of CRU and urea or split applications occasionally producing higher grain N concentration and N accumulation in the crop than the non-coated urea.

McKenzie *et al.* (2007) in southern Alberta evaluated options of applying CRU to winter wheat and found that yield gains due to nitrogen application were reduced by application of high rates of seed-placed urea and the average gains in grain yield due to application of CRU relative to side-banded urea (9 to 21% among sites) were not significant. Grain protein concentration and N uptake were also similar for CRU and seed-placed urea. Malhi *et al.* (2009) at Star City, Saskatchewan reported that fall-banded CRU or urea generally produced lower crop yield and N uptake than spring-banded CRU or urea. Split application of urea (half each at seeding and tillering) resulted in higher seed yield and N concentration in at least 3 of 7 site-years than did CRU and urea applied at a similar rate. Seed yield, N recovery and NUE were higher with spring-banded CRU. Khan *et al.* (2015) carried out a pot experiment using two different textured: silt loam and clay loam soil to assess the effect of sulfur and urease inhibitor (agrotain) at Zhejiang University, Hangzhou, China. Urea coated with sulfur and urease inhibitor (agrotain) was applied at 60 kg N/ha in 2 splits. The sulfur and urease inhibitor (agrotain) coated urea significantly increased the dry matter yield, N uptake and grain protein of rice cultivars over granular urea (GU) and control treatment applied split, particularly in silty loam soil than clay loam soil.

Farmaha *et al.* (2013) conducted field experiments in Minnesota and found that PCU decreased grain yield compared with urea, which could be related to a reduced N release early in the growing season but compared with urea, higher N and protein concentrations with PCU were observed due to increased N availability later stage of growing season. Sindelar *et al.* (2013) found linear response of grain and total above ground N uptake to fertilizer N across stover management and tillage treatments.

Stover removal increased recovery efficiency for strip tillage and NT at fertilizer N rates ≤134 kg N/ha, but did not enhance N recovery in plots fertilized at rates >134 kg N/ha. Residual soil nitrate-N to a depth of 1.2 m was 10 to 16 kg NO_3-N /ha greater with stover removal at fertilizer N rates of 134 to 224 kg N /ha.

Concentrations of both micronutrients (Fe and Zn) were higher in grains as compared to root in all the three crops and at the same the ZT had a significantly higher concentration of both nutrients over CT in maize-wheat-soybean cropping system (Lavado *et al*., 2001). Woźniak and Makarski (2012) demonstrated that the ZT system increased contents of total ash, Zn and Fe in maize and wheat over CT planting. Wozniak *et al*. (2014) found that the interaction of residue management practices and different tillage practices were significant in terms of micronutrient concentration in grain. However, López-Bellido *et al*. (2001) reported higher amount of Zn and Fe under CT compared to ZT planted maize in maize –wheat cropping system. Control released fertilizer (CRF) increase nutrients uptake by gradual release of the nutrients that may better coincide with the plant needs and consequently increase the grain yield (Carreres, 2003; Munoz, 2005 and Cong, 2010). As the nutrients are released at a slower rate throughout the season, the nutrients supply can be sustained for a prolonged time and consequently lower the labour cost by eliminating application (Cong, 2010; Jacobs, 2004). Another imperative advantage of using CRF is reducing the rate of nutrient removal from soil by rain or irrigation water (Cong, 2010).

So, the above discussed research results in section 2.6.1 reveals that residue, cropping system and coated fertilizer had differential effects on the concentration and uptake of N, P, K , Fe and Zn in maize and their uptake by crop. Hence, the site specific effect of these practices needs to be evaluated in different cropping systems in varied ecologies for production of nutrient dense nutritionally superior food.

2.6.2. Water-use efficiency

Maize production in semi-arid areas suffers from strong annual variations both in crop yield and profitability; two factors that directly depend on rainfall volume and distribution during the growing season. Conservation of water and improved crop water use efficiency can be achieved with conservation tillage (Lal, 1991, Carter, 1994 and Tebrügge, 2001). Maize in India predominantly grown as rainfed crop and enhancement of WUE is very critical for sustaining maize production. The enhanced

WUE in conservation tillage could be due to positive changes in soil physical properties, such as aggregation (Dalal, 1989 and Dalal and Bridge, 1996), aggregate stability (McQuaid and Olson, 1998 and Parihar *et al*, 2016a) and soil water content (Pelegrin *et al.*, 1990, Mahboubi *et al.*, 1993, Norwood, 1994 and Lampurlanés *et al.*, 2001).

Lampurlane´s *et al.* (2002) concluded that NT systems were potentially better for yield dry climates and higher yield could be related to better retention of water through the observed changes in pore-size distribution and not only to the lower evaporation rates due to mulching effect of crop residue in NT, as described by Hill (1990), Munawar *et al.* (1990) and Baumhardt and Jones (2002). The efficiency of conservation tillage to improve water storage is universally recognized. This is very important not only in arid and semi-arid zones (Lampurlanes and Cantero-Martinez, 2003) but also in heavy rainfall areas of north eastern hill region in India (Das *et al*., 2014), where management of crop residues is of prime importance to obtain sustainable crop productions and for conserving natural resources and enhancing water productivity. Shen *et al.* (2012) found that straw mulching significantly improved soil moisture content at a depth of 20–80 cm below the ground surface during the anthesis-silking stage.

In rice-wheat systems in IGP, ZT save irrigation water by 20-35% in the wheat crop compared to CT and reduces water usage by one million liter/ha approximately (Hobbs and Gupta, 2004). The savings arise because ZT wheat can be sown just after the rice harvest, making use of the residual moisture for wheat germination and saving of pre-sowing irrigation (Erenstein and Laxmi, 2008). Mrabet *et al.* (2002) reported that the pre-planting tillage was unnecessary in addition; high residue rates under NT were not converted into higher water use by wheat. The ZT combined with crop residue retention on the soil surface greatly reduces erosion and enhances water-use efficiency compared to CT (Johnston *et al.*, 2002).

In sandy loam soil of north-western India, significantly higher yield and water use efficiency of maize on raised beds was found over flat planting **(**Aggarwal *et al*., 2000 and Jat *et al*., 2005). Devkota *et al*. (2013) found that following crops after cotton i.e. wheat and maize, produced 12 and 42% higher grain yields, respectively, under PB than under CT in the irrigated arid lands of Uzbekistan, Central Asia. Under PB, water productivity was recorded higher in wheat by 27% while in maize by 84%

with 11% less water was applied during wheat and 23% during maize production compared to CT. Hence, the response to applied N was more pronounced with PB than with CT (Devkota *et al*., 2013). These studies show that maize gives higher response to ZT conditions compared to wheat for higher water-use efficiency and can be used as test crop for CA.

Tolk *et al.* (1999) reported that mulch increased the maize grain yield, above ground biomass and WUE by 17, 19 and 14%, respectively as compared with bare soil treatment. Ram *et al*. (2012) in a CA based study at PAU Ludhiana, reported that maize and wheat planted on raised beds recorded about 7.8% and 22.7% higher water-use efficiency than under flat layout, respectively whereas straw mulch showed no effect on water use and water-use efficiency in maize. Parihar *et al*. (2011) reported that maize-chickpea-*Sesbania* cropping sequence resulted in maximum water productivity in various maize based cropping systems.

Parihar *et al*. (2011) found that establishment of maize through ZT resulted in maximum water productivity over CT in diversified maize-based cropping systems in Indo-Gangetic plain (IGP). Sharma *et al*. (2010) found that under rainfed condition in maize-wheat sequence, maize field should be ploughed immediately after maize harvesting and covered with maize straw mulch @ 5 t/ha up to wheat sowing to reduce the evaporation losses and soil water storage for the succeeding wheat crop. This practice leads to increase soil moisture conservation efficiency about 3 times higher than control treatments (maize harvesting at 30 cm height and tillage at the time of wheat sowing). It has been estimated that an additional 23 kg/ha wheat grain yield can be achieve per mm of conserved moisture. Adoption of CA enhanced water-use efficiency (WUE) by 12% with maize-rapeseed sequence to as high as 228% under rice-pea sequence (Das *et al*., 2014). Wang *et al*. (2015) in semi- arid region of China reported that straw incorporation significantly increased water productivity of maize. The significant effect of ZT over CT and two legume inclusion on maize system water productivity was also reported by Parihar *et al*. (2016) in sandy loam soil of IGP.

So, the above discussed research results in section 2.6.2 affirms that residue have positive benefits in enhancing the yields and the cropping system also plays significant role in the WUE. Moreover, the better nutrition and the water have positive correlation for their help in mineralization and uptake by plant and hence all these practices needs to be studied in location specific manner for realizing dream of more crop per drop of water.

2.6.3. Nitrogen-use efficiency

One of the major concerns in crop production is low and declining nitrogen use efficiency (NUE) reported in India and abroad. Only a few are cited here to focus the attention on low NUE. Even with the N rate for @ 150 kg/ha applied may seem high considering that fertilizer N recovery by cereals is rarely greater that 50% (Malhi *et al.,* 2001, 2009 and Chien *et al.,* 2009). Globally the value of AREn (Apparent Recovery Efficiency) is 55%, while TREn (True Recovery Efficiency) is 44% (Ladha *et al*., 2005). CA resulted in improved fertilizer efficiency (10–15%) in the rice-wheat system, mainly as a result of better placement of fertilizer with the seed drill as opposed to broadcasting in the traditional system (Hobbs and Gupta, 2004).

While ZT may reduce N mineralization by decreasing decomposition of soil organic matter, particularly in the initial 3–4 years of its adoption, crop residues can influence N dynamics from immobilization and volatilization (Drinkwater *et al*., 2000 and Yadvinder-Singh *et al*., 2005). However, with surface residue retention, broadcasting N on to crop residues can be an inefficient method of application because of immobilization in association with the microbial break down of rice residues (Rice and Smith, 1984; Thuy *et al.*, 2008 and Xu *et al.*, 2010) and because of greater ammonia volatilization (Janssen, 1996; Patra *et al.*, 2004; Bacon *et al.*, 1986) than when applied to bare soil. Both surface residue retention and ZT potentially induce major changes in N dynamics and thus requires differential N management in comparison with straw removal and tillage (McConkey *et al.*, 2002 and Arora *et al.*, 2010).

In some reports, nitrogen fertilizer efficiency was found to be lower in CA as a result of micro-organisms tying up the nitrogen in the residue. However, in other longer-term experiments, release of nutrients increased with time because of more microbial activity and nutrient recycling (Carpenter-Boggs *et al.*, 2003 and Hobbs, 2007). Six *et al*. (2004) reported lower Apparent Nutrient Recovery (ANR) under no-till system due to higher penetration resistance resulting limited root growth. Lopez-Bellido *et al*. (2006) reported that Nutrient Harvest Index (NHI) was significantly affected by year and the highest value was recorded with lowest biomass and grain yield.

The REn can also be influenced by weather variation, crop rotation and N levels (Lopez-Bellido and Lopez-Bellido, 2001). Application of CRF increases yield due to higher photosynthesis after flowering, which gave higher N uptake, physiological efficiency, agronomic NUE and apparent N recovery in silt loam soil of Shandong Province, China (Zhao *et al.*, 2013). The highest agronomic efficiency and apparent N recovery were obtained due to application of 60 kg N/fed urea+humic acid, while ureaform at rate of 100 kg N/fed gave the highest value of physiological efficiency (Awaad, 2013). Fertilizer N use efficiency was reported to be greater for PCU (36%) than for urea (32%) under continuous corn (Halvorson and Bartolo, 2014). Sanjay kumar *et al.* (2015) conducted a field experiment in Shivamogga (India) to evaluate effect of compost enriched with NPK fertilizers and neem oil coated urea on productivity and NUE in maize. Highest yield and the highest nitrogen use efficiency (NUE) of 34.5 kg grain/kg N applied was recorded with Compost + NOCU + PK fertilizers than other treatments.

So, the above discussed research results in section 2.6.3 shows that residue and N fertilization had positive benefits in enhancing the N-use efficiency. However, fewer studies have been found on the exploring potential of the slow release fertilizers especially in tropical and sub-tropical climatic conditions under conservation agriculture. Hence, the testing and adoption of these practices together in CA might help in enhancing fertiliser N efficiency which will reduce environmental footprint primarily by lower green house gas emission and reduce N fertilizer consumption owing to enhanced efficiency.

2.7. Effects of cropping system, residue and N management on soil properties

2.7.1. Physical soil properties

Soil compaction is assessed through penetrability and soil bulk density measurements. Nowadays soil compaction is a major concern for agricultural systems and the compaction caused by different heavy implements or trafficking (cattle, tractor tires, harvesting and tillage equipment) is a great challenge (Lal and Shukla, 2004). Soil bulk density (BD) affects the root penetration as well as soil aeration which has important role in crop growth and development. Bulk density had significant effects on plant growth due to its effect on soil strength and soil porosity. Increasing bulk density, strength tends to increase and porosity tends to decrease, that limit root growth. Bulk density is depends on the soil texture, structure, mineralogy, particle size, organic matter and management practices including tillage, intercultural operations and residue retention (Reichert *et al*., 2009).

The decrease in bulk density and penetrometer resistance was found with ZT compared to CT after 7 years in sandy loam soil (Parihar *et al.,* 2016). They also reported that maize based cropping systems also had significant effect on PR. Dolan *et al*. (2006) reported that the upper layer (0-7 cm) had low bulk density by reducing compaction due to rearrangement of soil particles and aggregates by various processes mainly the residue and mulch but soil bulk density was remained unchanged in deeper soil layers. Similar result was observed by Horn (2004). Bescansa *et al.* (2006) observed that soil OM in the upper 0.15 m was significantly higher (13%) under NTSB (no till with stubble burning), NT (no tillage without stubble burning) and RT (reduced tillage) than under mouldboard tillage (MT). Soil BD in the upper 0.15 m under NT and NTSB was more than under RT and MT, but at a depth of 0.15–0.30 m it was greater under RT than under the other treatments. Verhulst *et al*. (2010) in their study reported that most of the physical soil parameters measured were significantly affected by tillage-straw system, only BD showed no effect.

Yoo *et al*. (2006) reported that only physical protection of SOC had been enhanced by the use of ZT, where soil BD is relatively high (Strong *et al*., 2004). Dhiman *et al*. (2001) reported the increased in the BD of the soil from 1.50 g/cc in CT to 1.58 g/cc in NT. Dolan *et al*. (2006) reported that BD of the top soil layer (0-30 cm) was lower in PT (plough tillage) soils than in continuous NT, reflecting the rapture effect of tillage near the surface. Kumar *et al*. (2002) noticed higher BD in no tillage plots might be due to an undisturbed soil surface as a result of direct crop seeding. Ram-Singh *et al*. (2012) reported that double no till plots (0-15 cm) without straw mulch recorded the maximum BD over the fresh tillage treatment plots. Fabrizzi *et al*. (2005) showed higher BD and penetration resistance in NT experiments in Argentina, but the values were below thresholds that could affect crop growth.

In general, incorporation and/or retention of crop residues into the soils reduced bulk density and compaction of soils (Bellakki *et al*., 1998). Blanco-Canqui *et al*. (2006) reported that maize residue retention in silty loam soil at 5 and 10 t/ha for a period of one year reduced BD in the 0-5 cm layer from 1.42 g/cm^3 to 1.26, in ZT systems. On the basis of 15-year field experiment on the Loess plateau of northern China, Li *et al*. (2007) compared the effects of NT with residue retention and CT without residue and they observed that in the first 6 years of the experiment, BD of up to 20 cm depth was significantly less in the CT compared to NT due to heavy machinery and lack of regular soil loosening but in next following 5 years, soil BD were similar and in the last 2 years it was higher in CT as compared to NT. It shows that in heavy textures soil BD change requires more years of ZT adoption. However, the penetrometer and soil moisture determinations showed that ZT with retaining all residues did not cause significant compaction in the soil as compared to the CT with residues at Transvolcanic Belt of Mexico after 14 years of continuous practice (Fuentes *et al*, 2009).

2.7.2. Chemical soil properties

2.7.2.1. Mineral Nitrogen

Reduced soil tillage often results in lower nitrate-N content in the rooting zone, compared with CT as tilled soils have significantly higher aerobic microorganisms and nitrifiers than non-tilled soils (Doran, 1980). It has been shown that N cycling is linked directly with the C (Schlesinger, 1997). Excessive level of nitrogen mineralization for cereals is caused by deep tillage resulted lodging of crops and reduced tillage is a means of avoiding this (Riley, 1998). As reduced tillage the thought is to increase net immobilization and lower net mineralization, it results in lower nitrate concentrations in the soil solution. N mineralization rate in ZT with residue were higher than CT with and without residue in first year of experimentation itself (Etchevers *et al.*, 2000) and at 2 years microbial biomass was found to have increased in ZT and CT with residue as compared to ZT and CT without residue (Vidal *et al.*, 1998 and Fischer *et al.*, 2002). Total SOC and N stocks changed mainly in surface soils (0–30 cm), with no detectable cumulative changes at 0 to 150 cm and SOC declined after 10 year under CT at 0 to 15 cm and was affected by residue management at 15 to 30 cm (Schmer *et al.*, 2014).

Results from a long-term study (25 years) from Saskatchewan, Canada showed that less fertilizer N was needed to maximize yield of spring wheat in a ZT with residue retention system and this was associated with 24% higher soil organic carbon as well as higher potentially mineralizable soil N (Lafond *et al.*, 2005). Borie *et al*. (2006) observed significantly higher total N under both zero tillage and permanent raised beds compared to conventional tillage in the highlands of Central Mexico.

Wang *et al*. (2008) reported that compared to initial year, total nitrogen in 0-30 cm surface soil layer was improved by 21.3% on NT with straw cover while it decreased by 11.9% on traditional tillage with straw removal after 15 years of experiment.

The total N content in the 0–5 cm layer of the ZT + residue (R) (1.6 g/kg dry soil) was significantly higher than in the ZT − R, CT – R or CT + R treatments where it was ≤1.3 g/kg dry soil. No clear effect of treatment was observed in the 5–20 cm depths (Fuentes *et al.*, 2009). Retention of maize stubble significantly increased soil total C, organic C and total N, but decreased NO_3-N. The only significant effect of application of N to soil (329 kg N/ha/year) was an increase in N as NO_3 (Wakelin *et al*., 2007). Straw retention increase the N-supplying power of soil and it can be improved by returning straw with the soil and eliminating tillage (Malhi *et al.*, 2011a).

The Pereira *et al.* (2009) compared volatilization rates from urea and coated urea and observed that the ammonia losses from both fertilizers were comparable, but disagree with Noellsch *et al.* (2009), who reported a greater effect of polymer-coated urea on maize yield. Since soil under NT is not disturbed, the organic N mineralisation is significantly reduced and so is the concentration of inorganic N forms also. In addition to this, the lower N– NO_3^- concentration could be due to less aerobic conditions in the NT soil, which result in higher losses of N through denitrification. Wakelin *et al.* (2007) observed that retention of maize stubble significantly increased soil total C, organic C and total N while whole application of N to soil (329 kg N /ha/year) increased soil NO_3^--N. NH_4^+ (31.2 mg/kg) and NO_3^- (43.4 mg/kg) were recorded highest in treatment with stubble removed and N applied and the least in stubble removed with no nitrogen applied.

Gordon (2014) concluded that if producers wish to broadcast urea containing N-fertilizer on the soil surface in high-residue production systems there are several N additive options available that limit N loses and maximize grain yield with lower environmental footprints. Cancellier *et al.* (2016) in their experiment on NT maize in Brazilian cerrado on dystrophic Red *Latosols* or *Hapludox* soils and found values for daily volatilization varied with the different sources of N that were applied to maize crop by side-dressing, where common urea reached its maximum volatilization peak (12% applied N) on the 2nd day after its application. While other N sources induced delays in the peaks that occurred between the 3rd and 4th days, with lower values than urea. They also found that polymer sulfur coated urea resulted in a 37% reduction in ammonia volatilization.

2.7.2.2. Organic carbon in soil

Soil organic matter considered as an important indicator of soil quality because it is a nutrient sink and source, enhances soil physical and chemical properties and promotes biological activity (Doran and Parkin, 1994 and Gregorich *et al.,* 1994). The primary indicator of soil quality is soil organic carbon (SOC) (Conteh *et al*., 1997; Reeves, 1997) especially the SOC concentration of surface soil (Franzluebbers, 2002). Most soil microorganisms depend on soil organic C for energy and cell synthesis (Fuhrmann, 2005). The soil organic C was reported as the most powerful soil attribute by Brejda *et al.* (2000) for central and southern high plains and for northern Mississippi loess hills and Palouse prairie in the USA. In Northern California, the total N and total organic C were found to be the most sensitive chemical soil quality indicators (Andrews *et al.,* 2002). Karlen *et al*. (2006) concluded that TOC was the most sensitive indicator for soil quality. Lopez-Bellido *et al*. (2010) reported that Minimum Tillage (MT) practices can increase soil organic carbon in surface soil layer.

Halvorson *et al*. (2002) reported that no-till helps increase soil organic matter; reducing chance of crop-fallow with annual cropping does more to increase SOM than reduced tillage. 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 soils are likely to influence SOC (Campbell *et al*., 2000). No till had 3.86-31% higher organic matter as compared to CT. (Machado and Silva, 2001). Balota *et al*.2004 reported that significantly higher SOM in 0-10 cm soil depth under NT, but it was lower in the 10-15 cm depth compared to CT. Different tillage practices influence the distribution of SOC in the profile, under ZT higher SOC found in surface layers than with CT, but a higher content of SOC in the deeper layers of tilled plots where residue is incorporated through tillage (Jantalia *et al*., 2007; Thomas *et al*. 2007;). Jat *et al*. (2012) also found that that SOM tends to decrease across soil depth.

The response of soil to residue removal is assumed to be site-dependent and a number of reports have estimated and modelled the effects of residue removal on SOC and other soil properties in different soils from temperate regions (Wilhelm *et al.,* 2004; Blanco-Canqui and Lal, 2009; Bonner *et al.,* 2014 and Johnson *et al.,* 2014). Soil tillage, residue retention, crop rotation and the interactions of these factors, as in the case of CA, has been widely reported to influence SOC concentration (Verhulst *et al.*, 2010; Higashi *et al*., 2014 and Xue *et al*., 2015). Response of soil total carbon stocks to residue removal depends on the tillage practice used and are limited to the surface soil layer reflecting the stratification associated with topsoil addition of residues and nutrients, especially under conservation tillage systems (Wilhelm *et al.,* 2004 and Dolan *et al.*, 2006).

Dolan *et al*. (2006) conducted a 23-year field experiment on a Waukegan silt loam at Rosemount and found that with NT the surface (0–20 cm) soils had > 30% more SOC and N than moldboard plow (MB) and chisel plow (CH) tillage treatments. The trend was reversed at 20–25 cm soil depths, where significantly more SOC and N were found in MB treatments possibly due to residues buried by inversion. Similar effects were also rported by Dikgwatlhe *et al.* (2014) on soil organic carbon and nitrogen under wheat –maize cropping systems in the North China Plain (NCP) at 0-10 cm depth. Sindelar *et al*. (2015) in fine-textured soils in the Upper Midwest found that stover removal decreased SOC in the surface depth by 15% compared to when it was retained and 11% when compared with the baseline level. Therefore, crop residues play an important role in soil organic carbon and nitrogen management and improvement of soil quality.

2.7.2.3. Soil pH

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

Hulugalle and Entwistle (1997) reported after nine years of zero tillage, the pH was lower than in conventional tillage to the depth of 60 cm. It has been also proposed that due to greater leaching under conservation tillage was responsible for the higher removal of bases, which resulted in lowering of pH (Blevins *et al*., 1977), but some experiments report a higher susceptibility for leaching when tillage increases (Christensen *et al*. 1994). Kettler *et al*. (2000) reported that the main effect of ploughing on soil pH was more significantly change for 0–7.5 cm soil depth in both no-till and sub-till treatments, which leave plant residues at or near soil surface, were of lower pH than mould board ploughing treatments at all depths. Roldan *et al*. (2007) found under zero tillage soil pH was reduced in the top 0-15 cm soil depths. From a rainfed experiment in the highlands of Mexico, Govaerts *et al*. (2007) reported that pH was significantly higher in the topsoil (0–5 cm) of the permanent raised beds (PB) with full residue retention compared to conventional raised beds with residue retention. The pH in soil cultivated with maize and wheat was significantly affected by treatment, but only in the first 5 cm layer (Fuentes *et al*., 2009).

However, from another study Grant and Bailey (1994) reported that the soil pH reduced in the 10 to 12.5 cm soil depth, corresponding to the zone of fertilizer application under sandy loam as well as silty clay loam. Utomo *et al*. (2013) in a long-term experiment on tillage and N fertilization reported that high N rate reduces the soil pH as much as 10% at (0-40 cm) depth of the soil throughout the all tillage practices. Tolessa *et al.* (2014) from Ethiopia under a long term experiment on tillage and fertilization observed that MTRR (minimum tillage with residue retention) resulted in lower soil pH with N fertilization of tillage system. Li *et al*. (2007) in a long term conservation tillage based study found that soil pH decreased about 0.5 units after 22 years of RNT (under combination ridge with no-tillage), and this difference may be responsible for the decrease of N mineralization and nitrification rates observed under RNT. On the silty clay soil, pH was higher under ZT than CT in the 10 to 15 cm depth and tended to be higher under ZT than CT at all depths below 15 cm.

2.7.2.3. Soil P and K variability

Ismail *et al*. (1994) found that after 20 years of ZT, extractable P was 42% greater at 0-5 cm, but 8-18% lower at 5-30 cm depth compared with CT in a silt loam soil. Urioste *et al*. (2006) reported that the topsoil accumulation of P in no-till straw retention was attributed owing to the limited downward movement of particle bound P in NT soils and the upward movement of nutrients from deeper layers through nutrient uptake by roots. Another vital reason for higher proportion of P in the surface soil under NT system due to increased microbial biomass (Franzluebbers *et al*., 1994) but Roldan *et al*. (2007) reported that available P was not affected by tillage system, soil depth or type of crop. Similar result was found by Betrol *et al*. (2007) that under

No-till treatments have higher P concentrations in the surface soil layer. Gosai *et al*. (2009) reported that available phosphorus of the soil varied remarkably along the crops growing duration, its depth and upon the tilling tool used for tillage. Malhi *et al*. (2011b) reported under long-term no-tillage (NT) management higher amounts of available P obtained in the surface thin layer (0-5 cm or less) than CT due to P application and from decomposition of crop residues retained on the soil surface under ZT.

Due to a lack of mechanical incorporation of fertilizers in no till or minimum till system, the relatively immobile nutrients P and K remains concentrated in the upper 5 cm soil layer of minimum tilled plots (Triplett and Van Doren, 1969; Fink and Wesley, 1974). Standley *et al*. (1990) observed that retention of sorghum stubble on the soil surface increased the amount of exchangeable K concentration in the top soil (0-2 cm) in comparison with no stubble treatment. The available P and K in surface 0-5 cm layer of minimum tillage were 3.5 times greater than those for the 5-15 cm layer (Robbins and Voss, 1991). Govaerts *et al*. (2007b) reported that the K concentration in both the 0-5 cm and 5-20 cm of soil layers increased significantly with increasing residue retention on permanent raised beds. They further, revealed 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.

Despite the higher accumulation of organic matter at the surface layer of no-tilled soil, available P did not increase due to low solubility of phosphorus in slightly alkaline pH (El-Baruni and Olsen, 1979). 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). A study by Govaerts *et al.* (2007) reported 1.65 and 1.43 times higher K in 0–5 cm and 5– 20 cm layers of the soil PB+R, respectively compared to CT. Lou *et al.* (2012) reported that no-till can enhance total nitrogen stock in 0–30 cm soil profile but there may be no increase when compared to plough tillage. Soil exchangeable K was also higher within the surface soil layer under no-till situations, a response also observed by Karlen *et al.* (2013) which also attributed to the stratification of soil properties commonly observed in CA systems. Mohanty and Mishra (2014) suggested that minimum tillage with addition of crop residues and preservation of organic matter in the soil significantly increases available soil nitrogen (14.3%) than the initial status of 266.6 kg/ha.

2.7.3. Biological soil properties

2.7.3.1. Microbial biomass carbon in soil

The soil Microbial Biomass Carbon (MBC) is a living part of the soil organic matter and it contributes significantly in nutrient transformation and also a source of C, N, P and S; improving the physico-chemical properties of soil (Angers *et al*., 1992). Roldan *et al*. (2003) showed that after 5 years of maize cultivation under NT in Mexico, SOC and MBC had increased over CT as had more soil enzymes. They concluded that NT is a sustainable technology. Pankhurst *et al*. (2002) found that under zero tillage retention of crop residue with direct seeding increased the build-up of organic C and soil microbial biomass in the surface soil. Reduction in soil disturbance can stimulate soil microbial biomass and improve its metabolic efficiency, resulting in better soil quality, which in turn, can increase crop productivity (Hungria *et al*., 2009).

Maintaining soil microbial biomass (SMB) and micro-flora activity and diversity is fundamental for sustainable agricultural management (Insam, 2001). Balota *et al.* (2004) recorded significantly higher TOC and MBC under no tillage (NT) with maize-wheat rotation as compared to conventional (CT) on an oxisol in Brazil and increased total C by 45%, microbial biomass by 83% at 0–50 mm depth over CT. However, mulching had a significant effect on the productivity of maize and rapeseed. Wakelin *et al*. (2007) showed that the management of both stubble and N have significant and long-term impacts on the size and structure of the soil microbial community. The major treatment factor affecting MBC was stubble retention, which led to a significant increase ($P<0.001$). Nitrogen application reduced MBC where stubble was retained ($P = 0.011$). Wakelin *et al.* (2007) found that nitrogen application reduced MBC where stubble was retained (161.1 mg C /kg) as compared to the no nitrogen applied while retaining stubbles (224.7 mg C/kg).

Lupwayi *et al*. (2010) recorded effect on microbial bio-carbon (MBC) due to different fertilizers in mg/ kg soil; urea (695)>control (677)>CRU (603) under zero tillage (ZT) and CRU (671)>urea (616)>control (559) under conventional tillage (CT). Das *et al.* (2014) in Meghalaya, India found marked increase in SOC concentration (8·4%), water stable aggregates (9·3%), mean weight diameter (42·6%)

and soil microbial biomass carbon (66·8%) under NT as compared to CT in maize-rapeseed cropping system, but grain yield was similar in both methods. Parihar *et al* (2016a) found significant increase in MBC of sandy loam soil after 6 years with ZT compared to CT. They also reported higher MBC in maize-chickpea-*Sesbania* compared to other cropping system.

2.7.3.2. Enzymatic activity in soil

Soil enzymes has significant role to catalyzing the reactions necessary for organic matter decomposition and nutrient cycling. They are involved in energy transfer, environmental quality and crop productivity (Dick, 1994). Generally, the activities of enzymes decrease with soil depth (Green *et al.*, 2007) and vary with seasons and soils (Niemi *et al.,* 2005). Zero tillage management practices increased the enzymatic activities in the soil profile, probably due to of similar vertical distribution of organic residues and microbial activity (Green *et al*., 2007). Acosta-Martinez *et al*.(2008) observed that soil moisture, soil temperature, soil aeration and constitution of soil flora and fauna which may have important implications for both greenhouse gas production and soil C storage. Soil enzymes play a crucial role in catalysing reactions associated with organic matter decomposition and nutrient cycling (Jin *et al.,* 2009).

They respond to management practices such as tillage, fertiliser application, crop rotation, residue management and pesticides and in this way they may alter the availability of plant nutrients (Verhulst *et al.,* 2010) and a valuable tool for assessing soil's ability to resilience (Jin *et al.,* 2009).

Favourable effects of ZT and residue retention on soil microbial populations are mainly due to increased soil aeration, cooler and wetter conditions, lower temperature and moisture fluctuations and higher carbon content in surface soil (Doran, 1980). Limon-Ortega *et al*. (2006) observed that the practice of retaining crop residue as stubble mulch in permanent bed system and straw incorporation in conventional sowing method increased the productivity and improve the soil quality by increasing the soil microbial carbon in maize-wheat cropping sequence in Mexico. Dong *et al*. (2009) reported that the mean annual MBC was highest in the NT with residue, while lowest in conventional tillage. NT soils with crop residue addition had more available substrates than CT and this promotes microbial growth and assimilation of nutrients, leading to an increase in soil microbial biomass and activity of such soils (Buyer *et al*., 2010).

The microbial and enzymatic activities were stimulated by addition crop residue, aeration and by small doses of N, while removal of residue; conventional tillage and large amount of N exert weaker or negative effect on these biological activities (Marinori *et al*., 2000; Chakrabarti *et al*., 2000). Single enzyme assay may not be a representative of overall microbial community activity and do not take into account seasonal changes and inherent differences in enzyme activity (Roldan *et al.,* 2005). β-glucosidase and acid phosphatase enzyme activity was significantly greater under NT. This NT management practice increase stratification of soil enzyme activities near the soil surface, perhaps due to the similar vertical distribution of SOM in NT (Green *et al.,* 2007). At below 5 cm depth, no difference has been found in enzyme activities between NT and PT (Alvear *et al.,* 2005; Roldan *et al.,* 2007).The differences in dehydrogenase activity decreased with soil depth, which is an oxido-reductase present in viable cells. This enzyme has been considered as a sensitive indicator of soil quality (Ladd, 1985 and Nannipieri, 1994) and a valid biomarker to indicate changes in total microbial activity due to changes in soil management (Ceccanti *et al.,* 1994). Dehydrogenase activity represents the intracellular flux of electrons to O_2 (Nannipieri *et al.*, 2003). The significant correlations between microbial biomass and enzyme activities with total organic C content on silt and soil at Pulawy, Poland was noticed by Gajda *et al.* (2013).

Mangalassery *et al*. (2015) reported that under ZT soil MBC, dehydrogenase and ß-glucosidase activity was increased 30%, 60% and 28% respectively compared to CT and it may be due to more continuous supply of organic materials to soil microorganisms in the absence of tillage, they also observed that all the enzymatic activity was significantly higher in surface soil than subsurface soil. The BG activity has proven to be sensitive to a variety of different management regimes in different climatic regions and important indicator of the ability to degrade plant material and provide simple sugars for the microbial population in soil (Stott *et al*., 2010).

Eivazi and Tabatabai (1990) and Caldwell *et al.* (1999) reported that β-glucosidase activities were significantly correlated with organic C content. Roldan *et al*. (2007) reported higher dehydrogenase and phosphatase activities in the 0-5 cm soil layer with zero tillage than with mould-board ploughing to 20 cm on a Vertisol, but below 5 cm there was no change of enzymatic activity. Hota *et al*. (2014) noticed that incorporation of organic residues along with lime showed greater FDA hydrolytic, dehydrogenase and acid phosphatase activities than the soils received in organics alone or no source of nutrients. Singh *et al*. (2009) also reported higher MBC and dehydrogenase activities under bed planting than the conventional tillage in maize-wheat cropping system. Makoi and Ndakidemi (2008) reported that the enzyme β-glucoside is particularly sensitive to changes in the soil system such as soil pH and different management practices. The enhanced soil enzymatic activities in ZT and maize-chickpea-*Sesbania* cropping system was also reported by Parihar *et al*. (2016a) in sandy loam soil of IGP after 6th year.

In nutshell, the above discussed research results of earlier studies on soil health under section 2.7 shows that residue, cropping system and N fertilization had positive, negative or neutral effects on these soil properties. It is also evident from the studies that the responses are location specific for beneficial soil properties. Hence, these studies warrants for study of the interaction of these parameters (cropping system, residue and N fertilization) in different ecologies for maximizing benefit in soil health. However, most of the studies have been done in temperate or sub-tropical environments only. So, study on this aspect in India will help in restoring soil health of IGP as well.

2.8. Effects of cropping system, residue and N management on crop economics

Economic outcomes of CA are likely to be specific to particular people, places and situations (Gowing and Palmer, 2008). This is due to heterogeneity between regions (Erenstein *et al*., 2012) and between farms in a region (Tittonell *et al*., 2005) and heterogeneity in institutional factors (Stonehouse, 1996), farm sizes, risk attitudes, interest rates, access to markets (for inputs and outputs), farming systems, resource endowments and farm management skills, driving differences in benefits and costs of CA. CA has been regarded as management of soil, water and agricultural resources to achieve economic, ecological and socially sustainable agricultural production (Jat *et al*., 2012). Mazvimavi *et al*. (2012) found that gross return was positively related to labour and seed in CA but negatively in conventional farming. Erenstein and Laxmi (2008) reviewed a several studies of the economics of zero tillage in the Indo-Gangetic Plains. They found that due to site specificity and methodological differences the profitability of the various studies are sometimes complicated. Nevertheless, the results consistently showed benefits-both cost savings and increased yields. On average, slightly more than half of the benefits were due to cost savings and slightly less than half were due to yield increases. Yadav *et al.* (2016) recorded ne returns and BC ratio under ZT and PB were higher by 18-29% and 26-38%, compared to CT plots, respectively.

Khakbazan *et al.* (2013) evaluated effect of controlled-release urea (CRU) in wheat, barley and canola in a multi-location study in a range of agro-environments across western Canada. Application of non-coated urea produced similar or higher net revenues than CRU. In some treatments of split applications, CRU or CRU in a blend with the non-coated urea increased crop yield; however, the increased yield was not sufficient to cover the extra costs of CRU or the split application. Halvorson and Bartolo (2014) found that polymer coated urea (PCU) produced significantly higher yield advantage over urea 2 (continuous corn) which resulted in greater economic returns with PCU (4–14%) on a silty clay soil. Parihar *et al*. (2016) also reported increase in net returns of maize systems under ZT compared to CT and in maize-mustard-mungbean cropping system over other systems in sandy loam soil of IGP in a six year study.

The discussed results of earlier studies showed that application of urea on residue leads to increased immobilization and volatilization of applied N and reduces efficiency of applied resources in crop production. However, residue had beneficial effect on the soil moisture and other soil properties reported globally. The effect of slow release fertilizer can help in these situations which also solve problem of labour requirement in agriculture for split fertilization and reduce dependence on moisture availability in soil and fertilizer in market at critical crop growth stages. Hence, the present study was undertaken to evaluate crop performance, profitability, resource-use efficiency and soil health with different coated fertilizer with residue management two important irrigated intensified maize systems.

Chapter 3

MATERIALS AND METHODS

A field experiment entitled "**Nitrogen management under conservation agriculture in maize (*Zea mays* L.)"** was conducted during *kharif* season of 2015. The details of the materials used, experimental procedure followed and techniques adopted during the course of the present investigation are described in this chapter.

2.1. Experimental site

The experiment was conducted during *Kharif* season 2015 in block '9B' of experimental farm of the ICAR-Indian Agricultural Research Institute, New Delhi. The field had an even topography and good drainage system.

2.2. Climate and weather

New Delhi is situated at 28^{o} 40'N latitude, 77^{o} 11'E longitude and at an altitude of about 228 m above mean sea level. It has a semi-arid and sub-tropical climate characterized by hot summers and severe cold winters. The mean maximum temperature in June, which is the hottest month of the year, ranges from 40^{o} to 45^{o}C. 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 remaining during the period between October and May. The mean daily U.S. Class 'A' open pan evaporation value reaches as high as 16.0 mm in the month of June and as low as 2.2 mm in the month of January. The mean annual pan evaporation is about 850 mm. The mean wind velocity varies from 3.5 km/hr during October to 6.4 km/hr during April. Mean relative humidity attains the maximum value (70 to 77% or even more) during the south-west monsoon and the minimum (30 to 45%) during the summer months.

The weather data for the experimental period recorded at the meteorological observatory of IARI, New Delhi are presented in table 3.1 and depicted graphically in Fig 1. The total rainfall was 823.9 mm in 2015, which was higher than mean annual rainfall (650 mm). However, the effective rainfall calculated by CROPWAT 8.0 software by using USDA method was only 467 mm during the cropping season of *kharif* 2015. Mean monthly relative humidity was 82.8% and 55.4% in morning and noon respectively, during the period of experimentation.

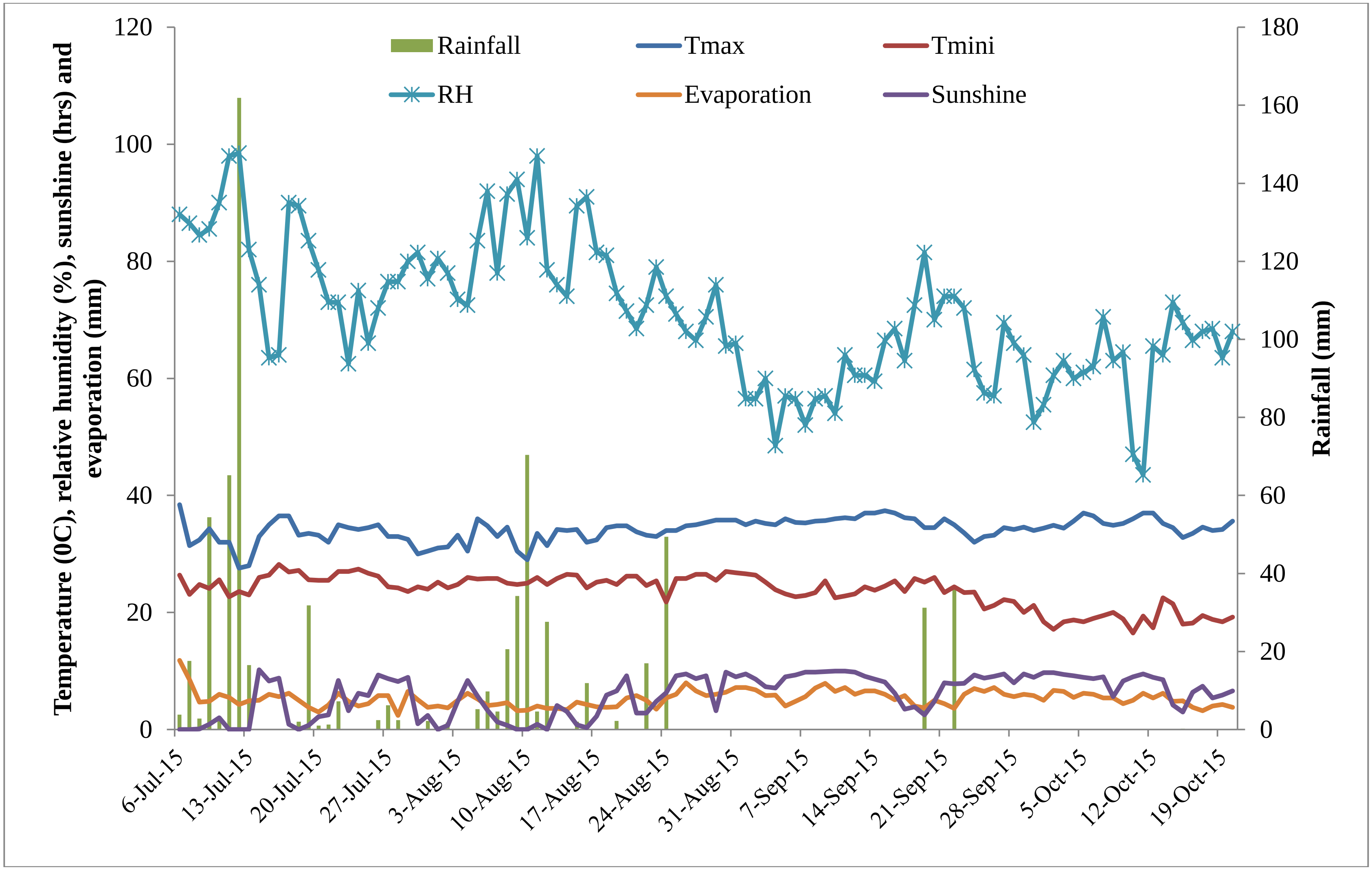


Fig. 3.1. Daily meteorological parameters during the growing season of *kharif* maize 2015 at IARI, Delhi

Table 3.1. Weekly weather parameters at IARI, Delhi during the cropping season of *kharif* 2015.

Standard week	Mean maximum temperature (0C)	Mean minimum temperature (0C)	Total rainfall (mm)	Mean wind speed (kmph)	Cloud cover (Okta) I	Cloud cover (Okta) II	Relative humidity (%) Morning	Relative humidity (%) noon	Bright sunshine (hours)	Total evaporati on (mm)
23.00	40.1	25.6	5.8	6.7	0.0	0.6	66.6	41.0	7.3	64.6
24.00	39.1	25.9	31.4	8.3	1.3	0.4	75.7	49.1	5.7	58.0
25.00	37.8	26.9	37.8	6.2	0.7	0.1	73.9	53.9	6.3	49.4
26.00	35.4	24.6	38.2	7.8	1.6	0.6	84.1	63.1	5.8	47.4
27.00	36.4	26.5	24.2	8.4	1.9	0.9	75.1	59.4	3.7	56.8
28.00	31.7	24.5	301.3	5.5	2.6	2.1	92.3	77.3	3.1	36.5
29.00	34.0	26.4	43.3	4.9	0.9	1.6	85.9	71.3	2.6	33.2
30.00	33.2	25.3	11.0	7.2	0.7	0.7	82.9	67.9	6.9	34.0
31.00	32.5	25.1	19.0	4.5	0.9	1.7	89.3	69.9	3.6	32.0
32.00	32.3	25.3	162.0	2.7	1.7	1.1	95.1	76.3	1.0	26.6
33.00	33.8	25.5	16.1	4.2	1.0	1.1	91.1	69.7	4.0	29.4
34.00	34.0	25.2	66.4	7.5	0.4	0.4	80.7	62.0	6.3	40.3
35.00	35.5	26.3	0.0	6.7	0.6	0.3	77.7	51.1	8.1	45.2
36.00	35.6	23.4	0.0	6.4	0.0	0.0	69.7	39.3	9.3	41.8
37.00	36.7	24.0	0.0	4.0	1.3	0.7	82.7	43.7	7.9	43.3
38.00	34.5	24.5	67.2	6.0	1.7	0.6	87.9	56.6	6.3	33.7
39.00	34.0	20.8	0.0	5.6	0.0	0.0	80.0	40.6	9.1	42.1
40.00	35.5	18.7	0.0	3.4	0.3	0.0	89.9	35.9	8.6	41.7
41.00	35.4	19.2	0.2	3.9	0.9	0.3	82.9	39.1	7.3	36.9
42.00	34.4	18.4	0.0	2.8	0.9	0.0	93.0	41.1	5.8	26.7
Seasonal	**35.1**	**24.1**	**823.9**	**5.6**	**1.0**	**0.7**	**82.8**	**55.4**	**5.9**	**819.6**

2.3. Soil characteristics

A composite representative soil sample was collected from the experimental field prior to the experimentation and analyzed. The soil was sandy loam in texture, poor in organic carbon, low in available N, medium in available P and available K concentration with the pH 7.6. The data are given in Table 2.

Table 3.2. Initial soil properties of the experimental field

A. Soil Physical properties						
Properties	Depth (cm)					
	0-10	10-20	20-30	30-40	40-50	50-60
BD (Mg m^{-3})	1.477	1.539	1.628	1.631	1.627	1.620
PR (kPa)	1150	1503	2012	2360	2309	2165

B. Carbon and aggregation					
Depth (cm)	SOC (g kg^{-1})	Water stable aggregate (%)	Mean weight diameter (mm)	Geometric mean diameter (mm)	Saturated Hydraulic conductivity (cm h^{-1})
0-15	5.40	54	0.820	0.593	0.913
15-30	5.21	50	0.710	0.530	0.870
30-45	4.70	47	0.530	0.520	0.610

C. Soil biological properties					
Depth (cm)	MBC (µg C/g soil)	FDA (µg Florescein/g/hr)	Dehydrogenase (µg TPF Rel/g/day)	ß Glucosidase (µg p-NP Rel/g/24 hr)	Alkaline Phosphatase (µg p-NP Rel/g/24 hr)
0-45 cm	330	0.425	18.38	20.56	3.70

D. Soil chemical properties								
Depth (cm)	pH	Mineral N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)	DTPA extractable nutrients (mg/kg soil)		
					Zn	Fe	Cu
0-15	7.1	96.5	17.4	240	3.52	11.12	1.95
15-30	6.8	90.5	15.2	210	3.25	8.52	1.82
30-45	6.7	89.5	14.5	190	3.01	7.56	1.75

2.4. Cropping history of the experimental field

The study was a part of the long-term trial started in *kharif* 2012 in maize-wheat-mungbean and maize-mustard-mungbean cropping system. Before this, field was under maize-wheat rotation since 2007.

2.5. Experimental details

The experiment was laid out in a split-split plot design and replicated thrice during *kharif* season of 2015 comprising combination of three nitrogen sources and residue management practices.

2.5.1. Experimental material

The experiment was conducted in split-split plot design with following treatments:

A. Main-plot (Cropping system)

S. No.	Treatment	Treatment notations
1.	Maize-wheat-mungbean	MWMb
2.	Maize-mustard-mungbean	MMuMb

B. Sub-plot (Residue Management)

S. No.	Treatment	Treatment notations
1.	Zero tillage without Residue	PB-R
2.	Zero tillage with Residue	PB+R

C. Sub-sub plot (Nitrogen application)

S. No.	Treatment	Treatment notations
1.	Absolute control	F0
2.	N through PU (Prilled urea)	F1
3.	N through SCU (S coated urea)	F2
4.	N through NCU (*Neem* coated urea)	F3

Note: RDN is recommended dose nitrogen @ 150 kg/ha for Delhi region in hybrid maize. In PU the nitrogen is applied in three equal splits at basal, knee high and tasseling stages while in NCU and SCU whole N will be placed as basal.

2.5.2. Experimental Layout

The experiment was laid out in a split-split plot design with sixteen treatments consisting of three nitrogen sources and residue management practices in two maize based cropping systems. The experimental layout is given in Fig.2 and other detail given below:

1	Experimental Design	Split-split
2	Total no. of treatment	4×2x2 =16

3	Replication	3
4	Net Plot size	5.36 m^2
5	Ultimate gross plot size	30.15m^2
6	Total number of plots	48
7	Spacing	67cm x 20 cm
8	Variety	DHM-117
9	Seed rate	20 kg/ha

Replication	PB-R (MMuMb)		PB+R (MMuMb)		PB - R (MWMb)		PB+R (MWMb)	
R1	F3	F1	F2	F1	F0	F3	F2	F0
	Irrigation channel							
	F0	F2	F3	F0	F2	F1	F1	F3
Replication border								
R2	F1	F3	F1	F3	F1	F0	F3	F1
	Irrigation channel							
	F2	F0	F2	F0	F3	F2	F0	F2
Replication border								
R3	F1	F3	F0	F1	F2	F0	F2	F0
	Irrigation channel							
	F0	F2	F3	F2	F1	F3	F1	F3

Fig. 3.2. Layout of the experiment

2.6. Crop management

2.6.1. Land preparation

The field was deep tilled (to 30 cm depth) using chisel plough to break the hard pan below the plough layer and then laser leveled before start of the experiment in July 2012. After this, no tillage operations were performed till the start of fourth maize season in intensified cropping system during *kharif* 2015. In experiment, different crops were direct drilled using

ZT planter with inverted 'T' types openers having press wheel behind the planter to ensure good seed germination. In *kharif* 2015, the maize crop was planted. 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. The schedule of various operations performed is given in Table 3.3.

Table 3.3. Schedule of field operations in the *Kharif* maize experimentation

S. No.	Field operation	Operation schedule
1.	Layout	04.07.2015
2.	Sowing	06.07.2015
3.	Thinning/gap filling	23.07.2015
4.	Fertilizer application	
	Basal dose	05.07.2015
	1st split application of N	10.08.2015
	2nd split application of N	02.09.2015
5.	Irrigation application	
	1st irrigation	01.09.2015
	2nd irrigation	12.09.2015
6.	Weed management	
	Herbicide application	
	Pre-emergence	07.07.2015
	Manual uprooting of hardy weeds	01.08.2015
7.	Plant protection measures	Nil
8.	Harvesting	20.10.2015

2.6.2. Residue management

The mungbean crop residue including stem comprises of air dried leaf and branches of previous crop after picking the pods was kept in with residue plots in both the cropping systems while in without residue plots the mungbean plants were stalk cut and removed from the field.

2.6.3. Nutrient management

The recommended dose of nitrogen @ 150 kg/ha along with 60 kg P_2O_5 and 40 kg K_2O for Delhi region in hybrid maize was applied in all the treatments except absolute control. In prilled urea treatments, 1/3rd dose of N and full dose of P_2O_5 and K_2O as basal were applied at the time of sowing by zero-till ferti-seed drill. In case of sulphur or neem coated urea full dose of N along with recommended phosphorus and potassium fertilizers was drilled using zero-till ferti-seed drill at the time of sowing. The sulphur coated urea used in the experiment had 2% commercial grade sulphur coating which was made in the laboratory which had 44.16% N content. However, the commercial grade neem coated urea having 46% N content was used in the experiment. Remaining amount of nitrogen in prilled urea treatments were applied in two equal splits at knee high/eight leaves stage (V8) and tasseling stages.

2.6.4. Seed and sowing

The single cross normal hybrid maize cv. DHM 117 seed were dibbled on the ridges spaced at 67 cm by using 20 kg seed/ha. The variety "DHM 117" was developed and released by CVRC in 1998 (CM137×CM138). It attains plant height of about 180-200 cm. It takes approximate 51 days for silking and 80-85 days for maturity. Ears of this variety are fully extended and tight, grains are orange flint and bold. It is resistant to major pests and diseases and tolerant to moisture stress. Its yield potential is 45 quintal grain per hectare.

2.6.5. Thinning and gap filling

The optimum plant population of maize was maintained by thinning at twelve days after sowing (DAS) keeping plant to plant distance of 20 cm. Three weeks after sowing extra plants from each row were thinned to maintain intra-row spacing (20 cm). The gap filling was accomplished immediately after the germination in order to maintain optimum and uniform plant population.

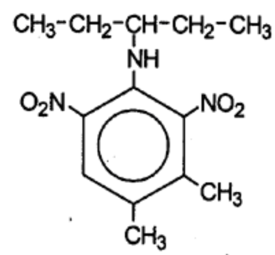
2.6.6. Weeding and inter-cultivation

The weeds were managed by the application of herbicides. Atrazine @ 0.75 kg a.i/ha + Pendimethalin @ 0.50 kg a.i./ha as pre-emergence in 600 litres of water was applied at one day after sowing of crop using flat nozzles sprayed to ensure better weed management. One manual weeding was also done after 25 days of crop planting for uprooting the hardy weeds. The details of the chemical used for weed management is as follows:

2.6.6.1. Pendimethalin

It is a highly selective pre-emergence herbicide and effective against a number of annual broad leaved weeds and grasses. Pendimethalin can also be used as pre-plant incorporation in soybean, maize, onion and potato. It is a germination inhibitor. The susceptible weeds are affected during germination or seedling emergence. It is formulated as both emulsifiable concentrate and granules. It belongs to the group of anilines. Chemical name of this herbicide is (N-1-ethyl propyl)-3, 4 dimethyl, 2-6-dinitrobenzenamine and it is marketed by its trade name 'Stomp 30 EC'.

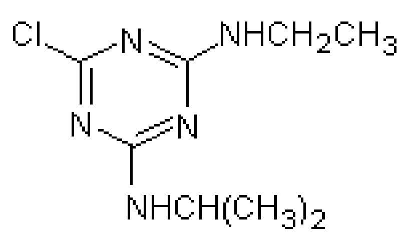
Structural formula:



2.6.6.2. Atrazine

Atrazine is a soil active herbicide, effective against a variety of annual weeds. In India it is used as a pre-emergence herbicide in maize, sugarcane and to some extent, in grain millets. Atrazine reported to enhance NO_3^- reductase enzyme activity in maize resulting in greener foliage and more proteinaceous grains**.** It belongs to the group Triazines. Its chemical name is [6-chloro–N-ethyl-N-(1-methylethyl) 1, 3, 5-triazine-2, 4-diamine] and trade name is 'Atrataf'. Empirical formula of this herbicide is $C_8H_{14}Cl\ N_5$.

Structural formula:



2.6.7. Irrigation

Irrigation was scheduled based on the crop water requirement and duration of dry spell or period without rainfall. To supplement the rainfall two irrigations were given during study period at 55 and 66 days after sowing of the maize crop.

2.6.8. Plant protection measures

There was no major insect and disease attack was observed in any of the experimental unit and hence no plant protection chemicals or any other measures were used for pest management.

2.6.9. Harvesting and shelling

The maize ears were harvested at brown husk stage from each of the net plot by excluding border area plants and rows in each experimental unit. The cobs were harvested manually by plucking method and grains were separated from cob by hand shelling.

2.7. Crop observation recorded

The various observations on plant growth, yield attributes and yields of crop and soil health properties were recorded using scientific methods in all the experimental unit to know the effect of various treatment on crop performance, soil health and economics of the maize crop. The various observations recorded were as follows:

2.7.1. Growth parameters

2.7.1.1. Plant stand (‘000/ha)

The total numbers of plants at 15 DAS was counted using a quadrate of one square meter from three random places in each experimental unit. The values were averaged to get the number of plant/m^2 and the calculated for one hectare and expressed as thousand plants/ha at 15 DAS. At harvest, the plants were counted from net plot area and expressed in thousands/ha.

2.7.1.2. Plant height (cm)

The plant height of five tagged plants was measured at 30 and 45 days after sowing (DAS) and at harvest from the ground level to up to the base of the fully opened leaf at pre-tasseling and up to the base of tassel at post-tasseling stage. The plant height of the five plants was averaged from each experimental unit and expressed in cm.

2.7.1.3. Dry matter accumulation (g/plant)

A total of 3 plants were cut from crown at different growth stages (30, 45 and 90 DAS) from each experimental unit and were chopped into pieces and after sun drying they were oven dried at 65^0 C for 48 hrs and weights were recorded by using electronic balance. The above-ground dry matter accumulation was averaged and expressed as g/plant.

2.7.1.4. Leaf area (cm²/plant)

The leaf area of three sampled plant was measured by leaf area meter (Model LICOR-3100) at 30, 60 and 90 DAS and expressed in cm^2/plant.

2.7.1.5. Leaf area index

Leaf area index expresses the ratio of total leaf area (one side only) to the total ground area in which the crop is grown. The leaf area measured by using the leaf area meter (Model LI-COR-3100) was used to calculate the leaf area index using the following formula:

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

2.7.1.6. Crop growth rate (g/plant/day)

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

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

Where,

W_1 : dry weight at first stage (g)

W_2 : dry weight at second stage (g)

T_1 : Days at first stage

T_2 : Days at second stage

The CGR was expressed g/plant/day.

2.7.1.7. Relative growth rate (mg/g/day)

The 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. The RGR value was calculated by using following equation:

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

2.7.2. Physiological studies

2.7.2.2. Days to tasseling

The number of days to 50% tasseling was determined by the number of days taken from sowing date to the 50% of the total number of plants per plot showed the tassel emergence.

2.7.2.3. Days to silking

The number of days to 50% silking was determined by the number of days taken from sowing date to the 50% of the total number of plants per plot showed the silk emergence.

2.7.2.4. Days to physiological 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 hilum region of the seed which generally observed at brown husk stage of the crop.

2.7.2.5. Reproductive period

The reproductive period of the maize crop in each experimental unit was calculated by subtracting the days to physiological maturity from days to tasseling.

2.7.2.6. SPAD

The reading of the SPAD values were measured using the KonicaMinolata chlorophyll meter at 30, 45 and 90 DAS in middle leaf of three plants of each experimental unit. At 90 DAS, the readings were taken from cob leaf. The values of three leaves were averaged to get SPAD value in each experimental unit.

2.7.2.7. NDVI

The reading of the normalized differential vegetation index (NDVI) values were measured using the Trimble make handheld green seeker by keeping 30 cm distance from plant at 30, 45 and 90 DAS in each experimental unit.

2.7.2.8. Canopy temperature depletion (^0C)

The canopy temperature depletion (CTD) was measured by using the sky spy integrated Everest make infrared thermometer which gives CTD by deducting the canopy temperature from ambient temperature given at the same time. The CTD thus obtained was expressed in ^{0}C.

2.7.3. Yield attributes

2.7.3.1. Cobs/plant

The cobs of maize from the net plot were plucked and counted. The plants/plot were divided by the cobs/plot to get number of cobs/plant.

2.7.3.2. Barrenness

The barrenness percentage in each experimental unit was calculated by using the following equation:

$$\text{Barrenness (\%)} = \frac{Plants/plot\ - Cobs/plot\ \ x\ 100}{Plants/plot}$$

2.7.3.3. Cob Length

The five cobs were selected randomly at the time of the harvest and after the removing of husk their length was measured from the base to the tip and averaged out of the samples.

2.7.3.4. Cob girth

The girths of five randomly selected cobs were measured at three places namely, near the butt, in the middle and at the top with the help of a measuring tape and the values thus obtained were averaged.

2.7.3.5. Grain rows/cob

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

2.7.3.6. Grains/row

The number of grains/row of the five randomly selected rows of cob were counted and averaged to get the grains/row in each experimental unit.

2.7.3.7. Grains weight/cob

The weight of grains from five randomly selected plants was weighed after shelling them separately. This weight of five cobs was averaged to get grains weight/cob.

2.7.3.8. 1000-grains weight

One thousand grains from sun-dried grain produce was taken from each experimental unit and weighed to get 1000-grains weight.

2.7.3.9. Shelling percentage

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

$$\text{Shelling (\%)} = \frac{Weight\ of\ grains\ (g)\ x\ 100}{Weight\ of\ whole\ cobs\ (g)}$$

2.7.4. Yields

2.7.4.1. Cob yield (kg/ha)

After separating from stover, all the cobs from each plot were dried in the sun and yield was calculated by weighing with electronic balance. The cob yield was expressed as kg/ha.

2.7.4.2. Grain yield (kg/ha)

After separating cob sheath, shelling was done using hand maize sheller. The moisture percentage in the grain was recorded at the same time of recording the grain yield. The grain yield was adjusted to 15% moisture content and expressed as kg/ha.

2.7.4.3. Stover yield (kg/ha)

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

2.7.4.4. Biological yield (kg/ha)

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

2.7.4.5. 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.

$$\text{Harvest index (\%)} = \frac{Econmic\ yield\ \ x\ 100}{Biological\ yield}$$

2.8. Plant nutrient analysis

Plant samples of stover and grain collected at harvest were dried in hot air oven at 60 °C for 12 hours. These oven-dried samples of plants and grains were grinded by Retch Mill and passed through 40 mesh sieve and used for chemical analysis.

2.8.1. Nitrogen estimation in plant and maize sample

Nitrogen concentration was estimated by following modified kjeldahl method (Prasad et al., 2006). A plant sample of 0.5 g was digested with concentrated H_2SO_4 (15 ml) in the presence of sodium sulphate (10 g) and copper sulphate (1 g). The digested and diluted sample (150 ml) was distilled in presence of 40% NaOH (120 ml) in a distillation unit. The ammonia gas evolved was collected in boric acid solution (25 ml). Titration was done against standard sulphuric acid (0.05 N). A blank titration was run simultaneously. The N concentration in plant sample was calculated as follows:

Amount of N in the sample (S) = (ml of acid used for sample – ml of acid used for blank) × Normality × 14 × 10 – 3

$$\text{N in sample (\%)} = \frac{\text{S}\times 100}{\text{Sample weight in g (0.5)}}$$

N uptake was calculated by using the following expression:

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

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

2.8.2. Phosphorus concentration

Phosphorus concentration in maize, straw and grain sample was determined by vanadomolybdophosphoric acid yellow color method. The intensity of yellow color developed was measured at 470 nm wave length using spectrophotometer (Jackson, 1973). Total P uptake (kg/ha) was calculated by following expression:

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

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

2.8.3. Potassium concentration

Potassium concentration in maize, straw and grain sample was determined using flame photometer as per method given by Jackson (1973).

Potassium uptake was calculated by multiplying K content with the dry matter yield

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

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

2.8.4. Determination of CU, Zn and Fe concentration

The copper (Cu), Iron (Fe) and zinc (Zn) contents in maize grain were determined by di-acid digestion as per the procedure described by Prasad *et al*. (2006) using supernatnetnt in Atomic Absorption Spectrophotometer (PerkinElmer) and expressed on mg/kg dry matter basis.

2.8.5. Crude protein content (%) in grain

Crude protein content in maize grain was obtained by multiplying N concentration with a coefficient factor 6.25 (AOAC, 1960). This factor is based on the nitrogen content (16.0%) of the maize protein.

2.9. Soil physical properties

Soils were sampled before imposing the experimental treatments (after harvest of uniformity trial mungbean crop) and at the harvest of the fourth maize crop on 26th June, 2012 and 21st October, 2015, respectively for analysis of various physical, chemical and biological properties of the soil.

2.9.1. Bulk density

The bulk density of soil at the end of the experimentation period was measured using core sampler method (Bodman, 1942). Before start of the experiment 10 random samples were collected from experimental site using a core of 6 cm height and 2.5 cm diameter. After harvest, soil samples were collected from six depths (0–10, 10-20, 20-30, 30-40, 40-50 and 50-60 cm) with a core of 6 cm height and 2.5 cm diameter from three places in each plot. The triplicate soil samples for respective depths were dried in the hot air over at 105^{0}C for 48 hours for estimation of dry weight. The bulk density was calculated as follows:

$$\text{Bulk density (g/cc)} = \frac{Mass\ of\ soil\ on\ oven\ dry\ weight\ basis\ (g)}{Core\ volume\ (cc)}$$

2.9.2. Soil strength

The strength of the soil was measured using Rimik (Australia) make digital cone penitrometer made to comply with ASAE standard and has a 30° core angle and base diameter of 12 mm. The measurement was made at 10 mm interval up to 750 mm depth from each experimental unit after harvest of the crop. The penetration resistance values thus obtained were averaged in respective experimental unit for 10 cm interval and expressed in kilopascal (kPa).

2.9.3. Soil moisture

The soil from three depths (0-15, 15-30 and 30-45 cm) were collected using a core sampler of 2.5 cm diameter at before sowing and after harvesting along with critical crop growth stages of 30, 45, 65 and 90 days after sowing. The soil samples were oven dried at 105°C for 48 hours for gravimetric soil water content determinations by using following equation:

$$\text{Moisture content (\%)} = \frac{(Weight\ of\ moist\ soil - Weight\ of\ oven\ dried\ soil) x\ 100}{Weight\ of\ oven\ dried\ soil\ (g)}$$

2.10. Soil chemical properties

The soil was sampled using core sampler of 2.5 cm diameter from three depths in all 48 experimental units. Thus, in each set, 144 composite soil samples (3 replicates, 16 treatments and 3 soil depths) were analyzed. Each soil sample was obtained by mixing together three random soil cores taken from individual plots. Samples from individual plots were thoroughly mixed, air-dried, and grinded to pass through a 250 μm sieve. Air-dried samples were placed in plastic bags and stored at room temperature for analysis of available N, P, K, Fe, Zn, Cu and pH of the soil.

2.10.1. Soil pH

Soil pH of the air dried soil sample was measured by dipping of pH meter in soil: water ratio of 1:2.5, respectively (Prasad et al., 2006).

2.10.2. Total carbon and organic carbon (%)

The soil samples (0-15, 15-30 and 30-45 cm depth) were collected in small size polythene bags from each plot of the experimental field at the start and at the end of experimentation period. For organic carbon estimation in soil, samples were dried, grinded and passed through 2 mm sieve. A sieved 300 to 330 mg sample was weighed and transferred into quartz crucible and treated with 2.5 ml of hydrochloric acid and kept for 4 hours before drying these in hot air oven for 16 hours at 60 to 70 ^{0}C. The dried samples were analyzed by automatic Eltra make automatic C-S analyzer by dry combustion method. The total carbon content in grinded soil samples were analyzed by direct inserting of 300 to 330 mg soil in Eltra make automatic C-S analyzer.

2.10.3. Available N, P and K (kg/ha)

The soil samples collected from three different depths (0-15, 15-30 and 30-45 cm soil profile) at the start and at the end of experimentation. The collected soil samples were air dried, ground and pass through 250 μm mesh sieve and were analysed for available N, P and K. The available N was estimated by using of alkaline $KMnO_4$ method suggested by Subbiah and Asija (1956) and expressed in kg/ha. The available P content in soil was estimated with Olsen's method (Olsen *et.al*., 1954). Normal ammonium acetate extraction (flame photometer) was used for estimation of available K (Jackson, 1973) and expressed in kg/ha.

2.10.4. Ammonical and nitrate nitrogen

The soil from three depths (0-15, 15-30 and 30-45 cm) were collected using a core sampler of 2.5 cm diameter at before sowing and after harvesting along with critical crop growth stages of 30, 45, 65 and 90 days after sowing. The moist soil was transferred to the laboratory and refrigerated till the analysis was over within 2-3 days. A total of 5 g moist soil was used for analysis of ammonical (NH_4^+) and nitrate (NO_3^-) nitrogen by extracting it with potassium chloride. The supernatant was analyzed by FOSS make Flow Injection Auto-analyzer for getting NH_4^+ and NO_3^- in soil which was adjusted for moisture content estimated by gravimetric method. Thus, the soil NH_4^+ and NO_3^- nitrogen was expressed in mg/kg of soil on dry weight basis.

2.10.5. Cu, Zn and Fe

The available Zn, Cu, and Fe were estimated through DTPA extraction method (Lindsay and Norvell, 1978) and the supernatant was analyzed through PerkinElmer make Atomic Absorption Spectrophotometer and the results were expressed as mg/kg of the soil.

2.11. Soil biological properties

The soil from 0-15, 15-30 and 30-45 cm depth were collected at flowering and after harvesting of the crop using tube auger of 2.5 cm diameter and soil was immediately taken to laboratory for analysis and refrigerated till the analysis was over for various soil biological properties within 3-4 days. The various biological properties studied in our experiment were as follows:

2.11.1. Microbial Biomass Carbon

Microbial biomass carbon (MBC) in soil was determined by fumigation-extraction method (Jenkinson and Powlson, 1976). For this purpose, 3.5 g of moist soil was fumigated with chloroform ($CHCl_3$) in vacuum desiccator and extracted with 0.5 *M* K_2SO_4 (soil: solution of 1:2.5). A duplicate soil sample as such (non-fumigated) was also extracted with 0.5 *M* K_2SO_4 in a similar fashion. Both the extracts of non-fumigated and fumigated soil were subjected to wet oxidation. About 10 mL of the extract was treated with 2 mL of 0.2 *N* $K_2Cr_2O_7$, 10 mL of conc. H_2SO_4 and 5 mL of H_3PO_4 and the mixture was digested at 100 °C for 30 min under refluxing condition. Samples were cooled and titrated with a solution of 0.005 *N* ferrous ammonium sulphate using diphenylamine as an indicator. The MBC was computed by subtracting the amount of organic carbon in fumigated soil from that of non-fumigated one and it was expressed on oven dry weight basis. The amount of the MBC in soil was calculated as follows:

Microbial biomass carbon = $(OC_F - OC_{UF}) / K_{EC}$

where, OC_F and OC_{UF} are the organic carbon extracted from fumigated and unfumigated soil, respectively (expressed on oven dry basis), and K_{EC} is the efficiency of extraction. A value of 0.25 is considered as a general K_{EC} value for microbial extraction efficiency and used for calculation.

2.11.2. Enzyme Activities in Soil

2.11.2.1. Dehydrogenase

Determination of dehydrogenase activity in soil was done by the method given by Klein *et al.* (1971). For this purpose, air-dried soil sample (1.0 g) was taken in an air-tight screw capped test tube of 15 mL capacity. The soil samples in the tubes were saturated with 0.2 mL of 3% triphenyl tetrazolium chloride (TTC) solution. Then, 0.5 mL of 1% glucose solution was added to each tube followed by gentle tapping of the bottom of the tube to drive out all trapped oxygen so that a water seal is formed above the soil. The tubes were incubated at 28±0.5 ^oC for 24 h. After incubation, 10 mL of methanol was added to the tubes, shaken vigorously and allowed to stand for 6 h. The clear pink coloured supernatant was withdrawn and their absorbance was recorded spectrophotometrically at a wavelength of 485 nm (blue filter). The amount of triphenyl formazon (TPF) formed in each sample was calculated from the standard curve drawn in the range of 10 mg to 90 mg TPF mL^{-1}. Dehydrogenase activity was expressed as µg TPF formed g^{-1} soil h^{-1}.

2.11.2.2. ß-Glucosidase

ß Glucosidase activity was assessed by measuring of the *p*-nitrophenyl released, after incubation of the samples with *p*-nitrophenyl *β* D glucoside (0.025M) for one hour at 37^0C; absorbance of the was measured at 490 nm (Eivazi and Tabatabai,1988).

2.12. Input use efficiencies

2.12.1. Water application, water use (ET) and water use efficiency (WUE) computations

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

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

$ET = (P+I+C) - (R+D+\Delta S)$……………… Eq (3.1)

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

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

Thus Eq. (3.1) simplifies to,

$ET = (P+I) - \Delta S$……………… Eq(3.2)

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

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

Where ,

Q = Flow rate in liter per second

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

Ha= water depth in converging section (cm)

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

Water applied (m^3*/ha)= {(Q-Qc) x T}*10/A*………………….Eq(3.4)

Where, *Qc* is correction factor for reduction in modular discharge due to submergence; *T* is time taken for irrigation of a plot (in seconds) and *A* is size of plot (m^2). Changes in soil moisture content (ΔS) were calculated by soil moisture sampling by gravimetric method.

Water Use Efficiency (WUE) was computed as

WUE= (Yield (kg/ha) / (ET (m^3))………………Eq(3.5)

Water-use efficiency was defined as follows (Zhou *et al*., 2011):

WUE = Y⁄ET

Where: Y – grain production (kg/ha).

2.12.2. Nitrogen-use efficiency

The estimated values of partial factor productivity (PFP), agronomic efficiency (AE), recovery efficiency (RE), physiological efficiency (PE) and N harvest index (NHI) of applied N were computed using the following expressions as suggested by Fageria and Baligar (2003) and Dobermann (2005):

$PFP = Y_N / N_a$

$AE = (Y_N – Y_{Ac})/ N_a$

$RE = [(U_N – U_{Ac})/ N_a] \times 100$

$PE = (Y_N – Y_{Ac}) / (U_N – U_{Ac})$

$NHI = GU_N/ U_N$

wherein, Y_N andU_N refer to the grain yield (kg/ha) and total N uptake (kg/ha), respectively, of rice in N applied plots; Y_{Ac} and U_{Ac} refer to the grain yield (kg/ha) and total N uptake (kg/ha), respectively, of rice in absolute control (no N and no Zn) applied plots; N_a refers to the N applied (kg ha$^/$); GU_N refers to N uptake (kg/ha) in grain.

2.13 Economics

The economics for the cost of cultivation, gross and net return and net return/rupee invested was worked out on the basis of prevailing market rates of the inputs and minimum wages of the labours announced as per the government of National Capital Territory, Delhi presented in Appendix V.

2.13.1. Cost of cultivation (₹/ha)

The prices of the inputs that were prevailing at the time of their use were utilized for determining the cost of cultivation which was given in rupees per hectare. Total cost included in the cost of input such as seeds, fertilizers, irrigation and various cultural operations like ploughing, sowing, weeding, harvesting, threshing, etc (Annexure-II). The rental value of land was also taken into consideration for cost of cultivation calculation.

2.13.2. Gross return (₹/ha)

The minimum support prices of maize and market price of stover after its harvest were used for the cultivation of gross return.

2.13.3. Net return (₹/ha)

The net returns were calculated by using the following formula:

Net return = Gross return – Cost of cultivation

2.13.4. Benefit cost ratio

$$\text{Benefit cost ratio} = \frac{\text{Net return (Rs/ha)}}{\text{Cost of cultivation (Rs/ha)}}$$

2.14. Statistical analysis

The data recorded for different parameters were analysed with the help of analysis of variance (ANOVA) technique (Gomez and Gomez, 1984) for Split-split-plot design using SAS 9.1 software (SAS Institute, Cary, NC). The least significant difference test was used to decipher the effect of treatments at 5% level of significance (P=0.05). Critical difference (CD) values for different pair-wise comparison among the treatment effect were computed. Correlation and regression analysis was performed using data analysis tool pack of Ms Excel 2007. The ANOVA of each parameter studied is given in Appendices II to XII.

RESULTS

The results of the field experiment entitled '**Nitrogen management under conservation agriculture in maize (*Zea mays* L.)'** conducted during *kharif* 2015 are being presented in this chapter. Data were analyzed statistically by using general linear model in SAS software 9.3 to see the test of significance of the results. Analysis of variance for these data has been furnished in appendices (II to XII) wherein significance levels at various level of probability have been indicated by asterisk.

A. Growth attributes

4.1. Plant population

Data on plant stand recorded at 15 DAS and at harvest of fourth zero-till *kharif* maize are presented in Table 4.1. There was no significant effect of cropping system, residue and nitrogen management practices on plant stand at 15 DAS but the application of nitrogen increased the plant population at harvest and highest plant population was recorded with NCU which was statistically non-significant with SCU and PU application. However, there was no significant interaction effects were observed for plant population at both the stages among system, residue and N management practices.

4.2. Plant height (cm)

Data on plant height recorded at various crop growth stages of fourth zero-till *kharif* maize are depicted in Table 4.1.The plant height of maize was significantly affected by cropping system at 45 DAS where MWMb system gave significantly tallest plant height. However, residue application significantly increased plant height at 30 DAS, 45 DAS and at harvest in zero-till maize compared to WoR. Similarly, the application of N improved plant height in maize significantly over control. It was significantly higher in NCU at all the growth stages which was on par with SCU and PU at 45 DAS and at harvest of maize. Similar to plant stand, there was no interaction effects observed for plant height of maize.

4.3 Dry matter accumulation (DMA)

The data on DMA (g/plant) in maize plant recorded at various stages of crop growth are depicted in Table 4.2. Significantly higher DMA at 30, 60 and 90 DAS (27.6, 73.4

and 218.1 g/plant) was recorded under MWMb compared to MMuMb (25.5, 64.7 and 183.9 g/plant) cropping system. Similarly, residue retention had significant effect on dry matter accumulation (27.8 g/plant) at 30 DAS only while it was non-significant at 60 and 90 DAS. Among N management practices, the highest DMA was recorded with the application of NCU at all stages of 30, 60 and 90 DAS. The MWMb cropping system and NCU application significantly increased the DMA in maize plant at all the three stages. Significant interaction of effect of nitrogen with residue and system was also found for DMA at 90 DAS where NCU or SCU resulted in higher DMA with residue and reverse was observed with PU.

Table 4.1. Effect of cropping system, residue and nitrogen management on plant population and plant height in fourth zero-till *kharif* maize

Treatments	**Plant population (10^3/ha)**		**Plant height (cm)**		
	15 DAS	**At harvest**	**30 DAS**	**45 DAS**	**At harvest**
Cropping system (System)					
Maize-mustard-mungbean (MMuMb)	76.2	73.0	63.6	132.4b	206.4
Maize-wheat-mungbean (MWMb)	76.3	73.0	61.3	158.0a	210.5
LSD (*p*=0.05)	NS	NS	NS	17.75	NS
Residue management (Residue)					
Permanent beds - residue (WoR)	76.1	72.9	59.6b	139.8b	205.4b
Permanent beds + residue (WR)	76.4	73.2	65.3a	150.6a	211.5a
LSD (*p*=0.05)	NS	NS	6.15	8.72	4.30
Nitrogen management (Nitrogen)					
Absolute control	76.1	68.5b	45.5c	117.9c	169.9b
N by prilled urea (PU)	76.0	73.8a	66.9b	149.7b	222.0a
N by sulphur coated urea (SCU)	76.1	74.6a	63.4b	154.2ab	219.9a
N by neem coated urea (NCU)	76.8	75.3a	74.0a	159.0a	221.9a
LSD (*p*=0.05)	NS	1.65	4.39	5.34	7.85
p values					
System	0.9607	0.9538	0.1422	<.0001	0.1338
Residue	0.6178	0.6539	0.0010	<.0001	0.0337
*System*Residue*	0.7945	0.8055	0.0143	0.2726	0.2228
*System*Nitrogen*	0.7940	0.8190	0.3279	0.9723	0.7800
*Residue*Nitrogen*	0.4035	0.4297	0.7779	0.0004	0.2798
Nitrogen	0.7516	<.0001	<.0001	<.0001	<.0001

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

4.4. Leaf area (cm^2 /plant)

The data on leaf area in maize plant recorded at various crop growth stages are presented in Table 4.3. The leaf area of the maize was significantly enhanced by MWMb at 30 DAS, 60 DAS and 90 DAS over MMuMb cropping system. Similarly, residue retention affected the leaf area significantly compared to residue removal. The highest leaf area in maize plants was recorded by application of NCU at 30 DAS, 60 DAS and 90 DAS and least under absolute control. The MWMb cropping system and NCU application together increased the leaf area significantly at all the three stages in maize plant. Similarly, significant interaction effect of residue and NCU was observed statistically significant. Significant interaction of effect of residue*nitrogen at all growth stages and system*residue at 30 and 90 DAS for leaf area where NCU or SCU resulted in higher DMA with residue while PU gave higher leaf area without residue application.

Table 4.2. Effect of cropping system, residue and nitrogen management on dry matter accumulation (DMA) and leaf area in fourth zero-till *kharif* maize

Treatments	DMA (g/plant)			Leaf area (cm^2/plant)		
	30 DAS	**60 DAS**	**90 DAS**	**30 DAS**	**60 DAS**	**90 DAS**
Cropping system (System)						
Maize-mustard-mungbean (MMuMb)	25.5b	64.7b	183.9b	1775b	5491b	4094b
Maize-wheat-mungbean (MWMb)	27.6a	73.4a	218.1a	2005a	6023a	4911a
LSD (*p*=0.05)	1.09	7.12	21.12	79.4	450.1	79.5
Residue management (Residue)						
Permanent beds - residue (WoR)	25.2b	67.2	200.6	1778b	5054b	4125b
Permanent beds + residue (WR)	27.8a	70.9	201.4	2002a	6460a	4880a
LSD (*p*=0.05)	1.08	NS	NS	105.7	477.2	72.8
Nitrogen management (Nitrogen)						
Absolute control	17.2d	45.0c	122.3c	1122d	3784c	2874c
N by prilled urea (PU)	26.3c	70.0b	222.6b	1881c	6446b	4749b
N by sulphur coated urea (SCU)	30.4b	78.7b	218.9b	2198b	6152b	4944b
N by neem coated urea (NCU)	32.3a	82.7a	240.3a	2359a	6647a	5443a
LSD (*p*=0.05)	1.83	5.91	8.40	104.2	451.9	273.6
p values						
System	0.0030	0.0003	<.0001	<.0001	0.0021	<.0001
Residue	0.0003	0.0794	0.7965	<.0001	<.0001	<.0001
*System*Residue*	0.2549	0.7721	0.2048	0.9466	0.0617	<.0671
*System*Nitrogen*	0.3731	0.0108	<.0001	0.0002	0.1991	0.0038
*Residue*Nitrogen*	0.0084	0.4416	<.0001	<.0001	0.0197	<.0001
Nitrogen	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

4.5. Leaf Area Index (LAI)

The data on leaf area index in maize plant recorded at various crop growth stages are presented in Table 4.3 and depicted in Fig. 4.1.

Table 4.3. Effect of cropping system, residue and nitrogen management on leaf area index of in fourth zero-till *kharif* maize at different growth stages

Treatments	Leaf Area Index (LAI)		
	30 DAS	**60 DAS**	**90 DAS**
Cropping system (System)			
Maize-mustard-mungbean (MMuMb)	1.50a	4.10	3.06b
Maize-wheat-mungbean (MWMb)	1.32b	4.49	3.66a
LSD (p=0.05)	0.0617	NS	0.0637
Residue management (Residue)			
Permanent beds - residue (WoR)	1.33b	3.77b	3.08b
Permanent beds + residue (WR)	1.49a	4.82a	3.64a
LSD (p=0.05)	0.0808	0.3544	0.053
Nitrogen management (Nitrogen)			
Absolute control	0.84d	2.82c	2.14c
N by prilled urea (PU)	1.40c	4.81ba	3.54b
N by sulphur coated urea (SCU)	1.64b	4.59b	3.69b
N by neem coated urea (NCU)	1.76a	4.96a	4.06a
LSD (p=0.05)	0.0778	0.3362	0.2037
p values			
System	<.0001	0.0021	<.0001
Residue	<.0001	<.0001	<.0001
*System*Residue*	0.9138	0.0016	<.0001
*System*Nitrogen*	0.0003	0.1966	0.0037
*Residue*Nitrogen*	<.0001	0.0191	<.0001
Nitrogen	<.0001	<.0001	<.0001

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

The leaf area of the maize was significantly affected by MMuMb and MWMb cropping system at 30 and 90 DAS, However, at 60 DAS both cropping system was found to be statistically non significant. Meanwhile, residue retention has the significant effect on LAI at various crop growth stages residue removal, respectively. The highest leaf area index in maize plants were observed by application of NCU at all the three stages, which was at par with the prilled urea application at 60 DAS followed by SCU application and least LAI was recorded in absolute control treatment. The interaction effect on the LAI of maize also found significant similar to the leaf area. However, irrespective of treatments highest LAI was recorded at 60 DAS and afterwards it showed decreasing trends.

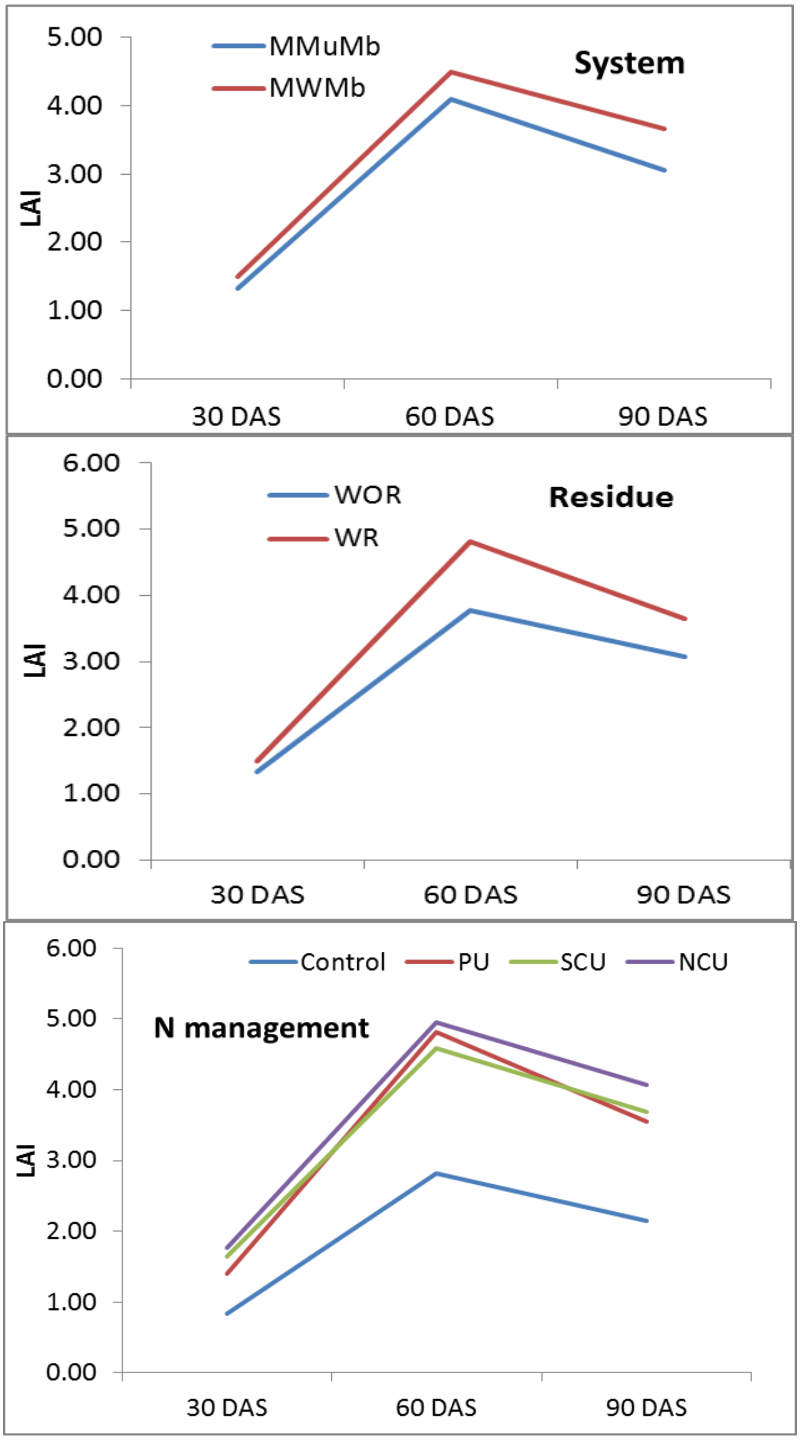


Fig. 4.1. Effect of cropping system, residue and nitrogen management practices on leaf area index of fourth zero-till maize at different growth stages

4.7. Physiological indices

4.7.1. Crop growth rate (CGR)

The data pertaining to CGR in maize plants at various crop growth stages are presented in Table 4.4. The data showed that MWMb had significant effect on CGR during 0-30 and 60-90 DAS compared to MMuMb cropping system but no significant effect was observed during 30-60 DAS. Residue retention also had significant effect on CGR only in first 30 days no significant effect was observed after that period. Among nitrogen management practices, the highest CGR was recorded with the application of NCU which was on par with the PU and SCU during 60-90 DAS and 30-60 DAS, respectively. The least CGR was recorded in the treatment with no nitrogen application. Significant interaction effect of system*nitrogen and residue*nitrogen was observed at different crop growth stages where coated urea found beneficial in WR while PU under WoR condition for enhancing CGR of maize.

Table 4.4. Effect of cropping system, residue and nitrogen management on crop growth rate and relative growth rate in fourth zero-till *kharif* maize

Treatments	**Crop Growth Rate (g/plant/day)**		
	0-30 DAS	**30-60DAS**	**60-90 DAS**
Cropping system (System)			
Maize-mustard-mungbean (MMuMb)	0.85b	1.31	3.97b
Maize-wheat-mungbean (MWMb)	0.92a	1.53	4.82a
LSD (*p*=0.05)	0.0346	NS	0.605
Residue management (Residue)			
Permanent beds - residue (WoR)	0.84b	1.40	4.45
Permanent beds + residue (WR)	0.93a	1.44	4.35
LSD (*p*=0.05)	0.0351	NS	NS
Nitrogen management (Nitrogen)			
Absolute control	0.57d	0.93c	2.58c
N by prilled urea (PU)	0.88c	1.46b	5.09a
N by sulphur coated urea (SCU)	1.01b	1.61ba	4.67b
N by neem coated urea (NCU)	1.08a	1.68a	5.25a
LSD (*p*=0.05)	0.0609	0.21	0.324
p values			
System	0.0030	0.0053	<.0001
Residue	0.0004	0.6109	0.3846
*System*Residue*	0.2826	0.5488	0.2039
*System*Nitrogen*	0.3681	0.0309	0.0030
*Residue*Nitrogen*	0.0069	0.2576	<.0001
Nitrogen	<.0001	<.0001	<.0001

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

4.7.2. Relative Growth Rate (RGR)

The data pertaining to RGR in maize plants at various crop growth stages are presented in Table 4.5. The data showed that RGR recorded maximum at younger stage (0-30 DAS) then decline gradually in all the treatments. Significantly higher RGR was recorded with MWMb cropping system and residue retention at 0-30 DAS only while NCU application at two growth stages where it was on par with SCU at 0-

30 DAS and PU at 60-90 DAS. Moreover, significant interaction effect of residue*nitrogen was also noticed on RGR during 60-90 DAS.

Table 4.5. Effect of cropping system, residue and nitrogen management on crop growth rate and relative growth rate in fourth zero-till *kharif* maize

Treatments	Relative Growth Rate (mg/g/day)		
	0-30 DAS	**30-60 DAS**	**60-90 DAS**
Cropping system (System)			
Maize-mustard-mungbean (MMuMb)	46.3b	13.7	15.1
Maize-wheat-mungbean (MWMb)	47.6a	14.0	15.7
LSD (*p*=0.05)	0.51	NS	NS
Residue management (Residue)			
Permanent beds - residue (WoR)	46.2b	14.2	15.7
Permanent beds + residue (WR)	47.7a	13.5	15.0
LSD (*p*=0.05)	0.62	NS	NS
Nitrogen management (Nitrogen)			
Absolute control	41.0c	14.1	14.5b
N by prilled urea (PU)	47.3b	14.1	16.7a
N by sulphur coated urea (SCU)	49.4a	13.8	14.8b
N by neem coated urea (NCU)	50.2a	13.5	15.5ba
LSD (*p*=0.05)	1.2	NS	1.4
p values			
System	0.0011	0.5494	0.2546
Residue	0.0002	0.2497	0.1726
*System*Residue*	0.0922	0.2443	0.5180
*System*Nitrogen*	0.1421	0.0884	0.3558
*Residue*Nitrogen*	0.0125	0.0972	0.0033
Nitrogen	<.0001	0.9048	0.0182

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

4.7.3. Net Assimilation Rate (NAR)

The data on NAR of maize at various growth stages showed that there was no significant effect of cropping systems on NAR while residue retention significantly enhanced the NAR at both the stages but the increase was more at 60 DAS (Table 4.6). Among the nitrogen treatments, significantly highest NAR was recorded with the application of PU which was at par with control treatment.

Table 4.6. Effect of cropping system, residue and nitrogen management on net assimilation ratio (NAR) in fourth zero-till *kharif* maize

Treatments	Net Assimilation Rate (g/cm^2 leaf area/day)	
	30-60 DAS	**60-90 DAS**
Cropping system (System)		
Maize-mustard-mungbean (MMuMb)	1.4014	0.0878
Maize-wheat-mungbean (MWMb)	1.8011	0.0333
LSD (p=0.05)	NS	NS
Residue management (Residue)		
Permanent beds - residue (WoR)	1.3098b	0.0322b
Permanent beds + residue (WR)	1.8927a	0.0888a
LSD (p=0.05)	0.4844	0.043
Nitrogen management (Nitrogen)		
Absolute control	1.8024a	0.0733a
N by prilled urea (PU)	2.0058a	0.1043a
N by sulphur coated urea (SCU)	1.2672b	0.0308b
N by neem coated urea (NCU)	1.3295b	0.0336b
LSD (p=0.05)	0.4036	0.0384
***p* values**		
System	0.0080	0.0004
Residue	0.0003	0.0002
*System*Residue*	0.0111	<.0001
*System*Nitrogen*	0.2298	0.0005
*Residue*Nitrogen*	0.0254	0.0254
Nitrogen	0.0018	0.0014

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

4.8. Physiological studies

4.8.1. Physiological stages

The data on commencement of various physiological stages of maize are depicted in Table 4.7. The data showed that cropping system and residue retention had no significant effect on days to tasseling, days to silking, days to maturity and reproductive period. However, days to 50% tasseling and silking was recorded significantly higher in control plots (61.5 and 70 days) compared to lowest PU (51.9 days and 59.9 days) which were statistically at par with SCU and NCU. Days to maturity were found to be non-significant with nitrogen management practices. Reproductive period recorded significantly higher with the application of NCU which was on par with the application of PU and SCU. No interaction effect was recorded among the cropping system, residue retention and nitrogen management practices for physiological stages in maize.

Table 4.7. Effect of cropping system, residue and nitrogen management on physiological stages in fourth zero-till *kharif* maize

Treatments	**Days to tasseling**	**Days to silking**	**Days to maturity**	**Reproductive period (days)**
Cropping system (System)				
Maize-mustard-mungbean (MMuMb)	55.3	62.8	101.1	45.9
Maize-wheat-mungbean (MWMb)	54.0	62.1	102.7	48.7
LSD (*p*=0.05)	NS	NS	NS	NS
Residue management (Residue)				
Permanent beds - residue (WoR)	54.3	62.2	101.7	47.4
Permanent beds + residue (WR)	54.9	62.8	102.1	47.2
LSD (*p*=0.05)	NS	NS	NS	NS
Nitrogen management (Nitrogen)				
Absolute control	61.5a	70.0a	102.3	40.8b
N by prilled urea (PU)	51.9b	59.6b	101.3	49.4a
N by sulphur coated urea (SCU)	52.4b	60.7b	101.8	49.3a
N by neem coated urea (NCU)	52.6b	59.6b	102.2	49.6a
LSD (*p*=0.05)	2.01	2.82	NS	2.40
p values				
System	0.0728	0.4448	0.0632	0.0021
Residue	0.4391	0.5513	0.3451	0.8413
*System*Residue*	0.5910	0.7978	0.5976	0.4856
*System*Nitrogen*	0.8204	0.6408	0.2379	0.5288
*Residue*Nitrogen*	0.8551	0.3701	0.3642	0.6779
Nitrogen	<.0001	<.0001	0.2896	<.0001
*System*Residue*Nitrogen*	0.5299	0.7752	0.4016	0.5774

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

4.8.2. NDVI values

Normalized differential vegetation index (NDVI) value shows direct correlation with plant growth and development and is one of the indicators for plant health. Cropping system and residue retention had no significant effect on NDVI value at any crop growth stage but significantly higher NDVI was recorded in NCU at 30 DAS, which was statistically at par with PU and SCU (Table 4.8). At 60 and 90 DAS, PU recorded significantly higher NDVI which was on par with the SCU and NCU but significantly superior over control. No interaction effect was observed among the cropping system, residue retention and nitrogen management practices for NDVI values in maize.

4.8.3. SPAD values

SPAD (Soil Plant Analysis Development)/chlorophyll meter value also show direct correlation with plant growth and development and indicate plant health. The highest

SPAD values were observed with the NCU at 30 and 90 DAS, which were at par with SCU at 30 DAS and PU and SCU at 90 DAS. However, PU recorded significantly higher value at 60 DAS and was at par with NCU but the least SPAD values were in the control. Similar to NDVI No interaction effect was observed for SPAD values in maize.

Table 4.8. Effect of cropping system, residue and nitrogen management on NDVI, SPAD and canopy temperature depression (CTD) in fourth zero-till *kharif* maize

Treatments	**NDVI**			**SPAD values**			**CTD (^{0}C)**
	30 DAS	**60 DAS**	**90 DAS**	**30 DAS**	**60 DAS**	**90 DAS**	**60 DAS**
Cropping system (System)							
Maize-mustard-mungbean (MMuMb)	0.509	0.608	0.485	45.4	36.3	43.9	-2.45
Maize-wheat-mungbean (MWMb)	0.525	0.612	0.479	45.7	38.3	44.0	-2.78
LSD (*p*=0.05)	NS	NS	NS	NS	NS	NS	NS
Residue management (Residue)							
Permanent beds - residue (WoR)	0.524	0.603	0.473	45.5	36.9	43.6	-1.84a
Permanent beds + residue (WR)	0.510	0.617	0.491	45.6	37.7	44.3	-3.39b
LSD (*p*=0.05)	NS	NS	NS	NS	NS	NS	1.041
Nitrogen management (Nitrogen)							
Absolute control	0.404b	0.505b	0.422b	30.2c	30.9c	34.4b	-2.59
N by prilled urea (PU)	0.552a	0.658a	0.512a	48.3b	41.8a	46.9a	-2.83
N by sulphur coated urea (SCU)	0.546a	0.639a	0.486a	50.9ab	37.5b	46.1a	-2.43
N by neem coated urea (NCU)	0.566a	0.637a	0.509a	52.9a	38.9ab	48.4a	-2.61
LSD (*p*=0.05)	0.051	0.0497	0.0365	3.2026	3.2811	4.0628	NS
p values							
System	0.9607	0.8088	0.5989	0.7610	0.1018	0.9528	0.3114
Residue	0.6178	0.4136	0.1745	0.9550	0.4461	0.6363	<.0001
*System*Residue*	0.7945	0.3143	0.1952	0.0632	0.5087	0.9057	0.7661
*System*Nitrogen*	0.7940	0.9918	0.1651	0.2316	0.2185	0.1298	0.1346
*Residue*Nitrogen*	0.4035	0.3960	0.0940	0.5619	0.5001	0.1419	0.4247
Nitrogen	0.7516	<.0001	<.0001	<.0001	<.0001	<.0001	0.8493

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

4.8.4. Canopy temperature depression (CTD)

Data on CTD were recorded at 60 DAS in maize after a dry spell of 12 days are presented in Table 4.8. There was no significant effect of cropping system and nitrogen management practice on CTD, but residue retention had the significant effect on CTD compared to residue removal. More reduction in canopy temperature was recorded WR (-3.39 ^{0}C) compared to WoR (-1.84 ^{0}C). Similar to NDVI No interaction effect was observed for CTD in maize.

4.9. Cob parameters

Data on cob parameters *viz.*, cobs/ha, barrenness, cobs/plant, length and girth of cob recorded about fourth zero-till *kharif* maize are presented in Table 4.9.

4.9.1. Cobs/ha

The cobs (10^3/ha) was not affected by cropping systems but residue retention significantly increased the cobs/ha (70,400) over residue removal (69,200). Among N management practices, NCU produced significantly higher cobs/ha, which was at par with the SCU.

4.9.2. Barrenness

MMuMb cropping system resulted significantly higher barrenness (4.77%) compared to MWMb (4.20%). Simlilarly, WoR recorded significantly higher barrenness (5.12%) compared to WR (3.88%). Among the N management practices, absolute control (7.5%) recorded significantly higher barrenness compared to the lowest barrenness recorded with NCU (3.3%). Further, the barrenness was found to be statistically at par by application of PU, SCU and NCU. Significant interactions were recorded for barrenness in maize for residue*system, system*nitrogen and nitrogen*residue (Table 4.8) where application of residue with NCU and SCU reduced barrenness more significantly compare to WoR and *vice-versa* for PU application.

4.9.3. Cobs /plant

The MWMb (0.958) cropping system showed significantly higher cobs/plant over MMuMb (0.952) cropping system while WR resulted in significantly higher cobs/plant (0.962) over residue removal (Table 4.8). Among N management practices, NCU gave significantly higher cobs/plant compared to the remaining N application and absolute control. Similar to other growth parameter residue*nitrogen interaction was significant for cobs/plant in zero-till maize.

Table 4.9. Effect of cropping system, residue and nitrogen management on cob parameters in fourth zero-till *kharif* maize

Treatments	Cobs (10^3/ha)	Barrenness (%)	Cobs/ plant	Cob Length (cm)	Cob Girth (cm)
Cropping system (System)					
Maize-mustard-mungbean (MMuMb)	69.5	4.77a	0.952b	18.2	14.7
Maize-wheat-mungbean (MWMb)	70.0	4.20b	0.958a	18.5	14.7
LSD (*p*=0.05)	NS	0.311	0.0047	NS	NS
Residue management (Residue)					
Permanent beds - residue (WoR)	69.2b	5.12a	0.948b	18.1b	14.6
Permanent beds + residue (WR)	70.4a	3.88b	0.962a	18.7a	14.8
LSD (*p*=0.05)	1.19	0.778	0.0133	0.25	NS
Nitrogen management (Nitrogen)					
Absolute control	63.4c	7.5a	0.929c	15.8b	14.0b
N by prilled urea (PU)	71.1b	3.7b	0.961b	19.7a	15.2a
N by sulphur coated urea (SCU)	71.9ab	3.5b	0.960b	19.1a	14.8a
N by neem coated urea (NCU)	72.8a	3.3b	0.970a	18.9a	14.8a
LSD (*p*=0.05)	1.42	0.82	0.0132	0.89	0.53
***p* values**					
System	0.3375	0.0539	0.02047	0.3421	0.8210
Residue	0.0269	0.0002	0.0065	0.0357	0.1827
*System*Residue*	0.4579	0.0248	0.1493	0.5809	0.9279
*System*Nitrogen*	0.1145	0.0047	0.1079	0.5579	0.9664
*Residue*Nitrogen*	0.4412	0.010	0.0418	0.0058	0.2739
Nitrogen	<.0001	<.0001	<.0001	<.0001	0.0012

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

4.9.4. Cob length and girth (cm)

No significant effect was observed in cob length by cropping systems while WR resulted in significantly higher cob length (18.7 cm) compared to WoR (18.1 cm). Among N management practices, significantly higher cob length (19.7 cm) was observed with PU application, however, SCU (19.1 cm) and NCU (18.9 cm) were found to be statistically at par. Similar to other growth parameter residue*nitrogen interaction was significant for cob length in zero-till maize. There was no significant effect was observed on cob girth with the cropping system and residue management practices (Table 4.8). However, significantly highest cob girth (15.2 cm) was recorded with PU application over absolute control (14 cm) but SCU and NCU remained statistically at par.

4.10. Yield attributes

Data on yield attributes *viz.*, grain rows/cobs, grains/row, grains/cob, grain weight/cob, shelling percentage and 1000-grain weight recorded in fourth zero-till *kharif* maize are presented in Table 4.10.

Table 4.10. Effect of cropping system, residue and nitrogen management on yield attributes in fourth zero-till *kharif* maize

Treatments	Grain rows/ cob	Grains/ row	Grains/ cob	Grain weight/ cob (g)	Shelling (%)	1000-grains weight (g)
Cropping system (System)						
Maize-mustard-mungbean (MMuMb)	13.2	31.9	422.1	97.6	76.6	239.9
Maize-wheat-mungbean (MWMb)	13.4	31.4	421.8	98.9	77.1	244.8
LSD (*p*=0.05)	NS	NS	NS	NS	NS	NS
Residue management (Residue)						
Permanent beds - residue (WoR)	13.3	31.3	417.7b	96.4b	77.2	239.4
Permanent beds + residue (WR)	13.3	32.1	426.2a	100.1a	76.5	245.3
LSD (*p*=0.05)	NS	NS	7.12	2.73	NS	NS
Nitrogen management (Nitrogen)						
Absolute control	12.7b	25.4b	320.7b	65.4b	74.1c	213.5b
N by prilled urea (PU)	13.6a	33.5a	454.4a	108.4a	76.8b	250.8a
N by sulphur coated urea (SCU)	13.3a	34.1a	453.4a	107.8a	76.5b	250.2a
N by neem coated urea (NCU)	13.7a	33.7a	459.4a	111.5a	80.0a	254.9a
LSD (*p*=0.05)	0.50	2.24	17.71	6.33	2.22	10.93
***p* values**						
System	0.3179	0.5436	0.9458	0.5385	0.0730	0.2059
Residue	0.7368	0.2794	0.0115	0.0524	0.3726	0.1235
*System*Residue*	0.6659	0.1282	0.1737	0.0958	0.1306	0.4602
*System*Nitrogen*	0.8219	0.3381	0.0608	0.0667	0.1105	0.3192
*Residue*Nitrogen*	0.4516	0.0947	0.0106	0.0122	0.9943	0.1819
Nitrogen	0.0020	<.0001	<.0001	<.0001	0.0002	<.0001
*System*Residue*Nitrogen*	0.5572	0.1465	0.081	0.0822	0.2186	0.1701

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

The cropping systems were found to be statistically non significant in affecting any of these yield attributes. However, in residue retention practice grains/cob (426.2) and grain weight/cob (100.1) were found significantly higher over WoR but found to be non significant in affecting most of the other yield attributes. Among N management practices, NCU application found to be most significant in enhancing the yield attributes viz., grain rows/cobs (13.7), grains/row (33.7), grains/cob (459.4), grain weight/cob (111.5g), shelling (80%) and 1000-grains weight (254.9 g). However, application of SCU and PU application were statistically at par with NCU except for shelling percentage but all these were significantly superior over control for all yield attributed under study. Interaction effect of residue*nitrogen application was found to be significant in enhancing grains/cob and grain weight/cob.

4.11. Yields (kg/ha)

Data on cob yield as influenced by cropping system, residue and nitrogen management practices have been presented in Table 4.11. The data revealed that there was no significant effect of cropping systems on cob yield but WR significantly increased the cob yield (7548 kg/ha) over WoR (6783 kg/ha). Among the N management practices, PU application resulted in significantly higher grain yield (8440 kg/ha), which was at par with the application of NCU (8328 kg/ha) followed by SCU (7889 kg/ha). However, significantly lowest cob yield (3953 kg/ha) was recorded in absolute control. The significant ($p<0.05$) residue*system and residue*nitrogen interactions were also observed for cob yield of maize.

4.12. Stover yield (kg/ha)

Data on effect of cropping system, residue and nitrogen management practices in stover yield are presented in Table 4.11. The MWMb significantly enhanced the stover yield (10589 kg/ha) over MMuMb (9751 kg /ha) cropping system. Similarly, WR resulted in significantly higher stover yield (10489 kg/ha) which was 7.5% higher over WoR (9851 kg/ha) in fourth zero-till maize. Among N management practices, significantly highest stover yield (11989 kg/ha) was recorded with the application of NCU followed PU (11119 kg/ha) and SCU (10004 kg/ha) and the lowest in absolute control where no fertilizer was applied. The significant ($p<0.05$) residue*nitrogen interactions were also observed for stover yield of maize where coated urea increased it under WR while PU under WoR conditions in fourth zero-till maize.

Table 4.11. Effect of cropping system, residue and nitrogen management on yields and harvest index in fourth zero-till *kharif* maize

Treatments	Cob Yield (kg/ha)	Stover yield (kg/ha)	Grain Yield (kg/ha)	Harvest index (%)
Cropping system (System)				
Maize-mustard-mungbean (MMuMb)	6975	9751b	5288b	31.0
Maize-wheat-mungbean (MWMb)	7356	10589a	5786a	31.6
LSD (*p*=0.05)	NS	779.9	377.5	NS
Residue management (Residue)				
Permanent beds - residue (WoR)	6783b	9851b	5270b	30.8
Permanent beds + residue (WR)	7548a	10489a	5804a	31.7
LSD (*p*=0.05)	629.8	514.5	361.8	NS
Nitrogen management (Nitrogen)				
Absolute control	3953c	7568d	2922c	25.3b
N by prilled urea (PU)	8440a	11119b	6495a	33.2a
N by sulphur coated urea (SCU)	7889b	10004c	6030b	33.7a
N by neem coated urea (NCU)	8382a	11989a	6701a	32.8a
LSD (*p*=0.05)	402.3	349.4	351.5	1.30
p values				
System	0.0108	<.0001	0.0004	0.1812
Residue	<.0001	<.0001	0.0002	0.0668
*System*Residue*	0.0168	0.2504	0.0900	0.8025
*System*Nitrogen*	0.7146	0.0608	0.4896	0.7897
*Residue*Nitrogen*	0.0001	0.0015	0.0006	0.0001
Nitrogen	<.0001	<.0001	<.0001	<.0001

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

4.13. Grain yield (kg/ha)

Data on effect of cropping system, residue and nitrogen management practices and their interaction on grain yield recorded in fourth zero-till *kharif* maize are presented in Table 4.11. MWMb cropping system recorded significantly higher grain yield by 9.42% over MMuMb (5288 kg/ha). The WR increased the grain yield (5804 kg/ha) significantly over WoR (5270 kg/ha and the difference was of 10.13%. The grain yield was significantly influenced by different forms of urea application and significantly higher grain yield recorded with the application of NCU (6701 kg/ha) which was 129.33% higher over the lowest yielding absolute control (2922 kg/ha). However, PU application (6495 kg/ha) was at par with application of NCU but both were significantly superior than SCU (6030 kg/ha). The PU and SCU gave 122.28 and 106.37 per cent higher grain yield than control, respectively. The significant interactions ($p<0.05$) effects were found in grain yield among cropping systems, residue and nitrogen management practices. The highest grain yield recorded with the interaction between MMuMb*WR*NCU followed by interaction among MMuMb*WoR*PU application (Fig. 4.2).

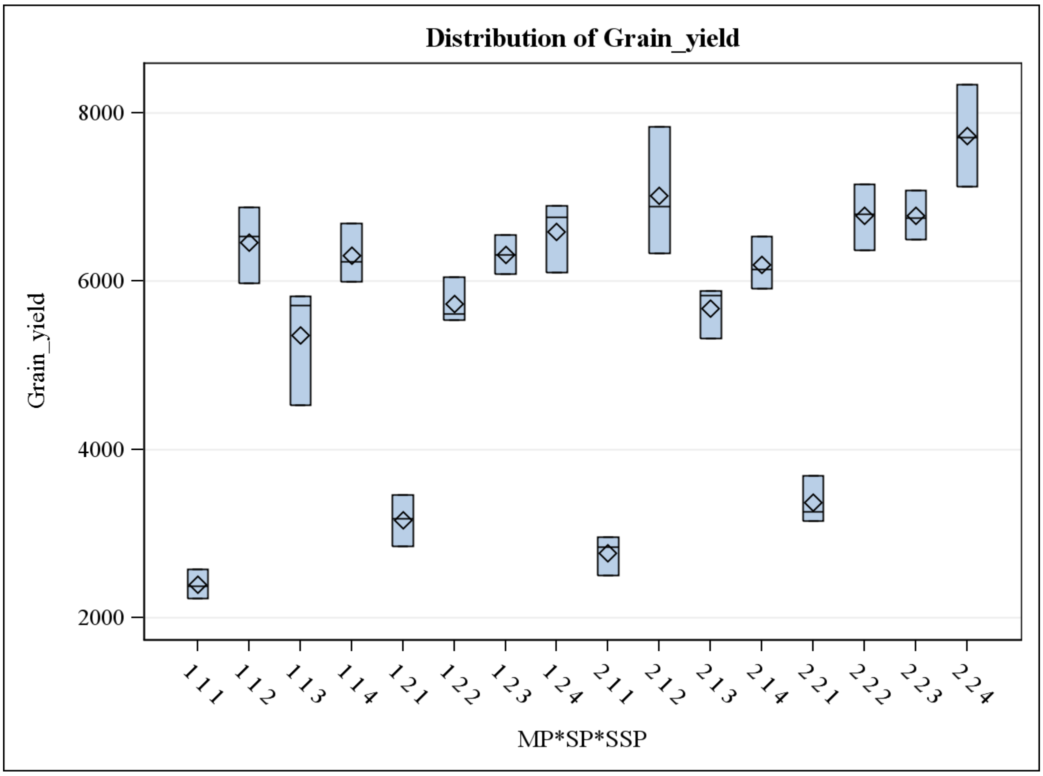


Fig. 4.2. Interaction effect of cropping system, residue and nitrogen management on grain yields in fourth zero-till *kharif* maize**.**

4.14. Harvest Index (HI)

Data on effect of cropping system, residue and nitrogen management practices on HI recorded in fourth zero-till *kharif* maize are presented in Table 4.11. In cropping systems and residue management practices no significant differences were observed but SCU resulted in significantly higher HI than control (33.7%) over control (25.3%), but it was statistically at par with PU and SCU application in our study. Significant residue*nitrogen interactions were also observed for maize HI in our study.

4.15. Economics

Data on effect of cropping system, residue and nitrogen management practices and their interaction on economics of fourth zero-till *kharif* maize are presented in Table 4.12. and depicted in Fig. 4.3. MWMb cropping system enhanced the gross returns, net returns and BC ratio to the tune of ₹7,442, ₹7,327 and 0.30 BC ratio, respectively over the MMuMb. The WR enhanced the gross returns to the tune of ₹7,712 over the permanent bed without residue retention but, there was no significant effect of residue management on net returns and BC ratio. The application of residue incurred ₹ 3,129 more cost of maize production than WoR.

Among the application of PU and coated ureas, highest gross returns (₹100,774), net returns (₹77,153) and benefit cost (BC) ratio (3.27) were obtained by the application of NCU but net returns fetched by NCU was at par with the application of PU. The significant ($p<0.05$) interaction effects were also found in net returns and B C ratio of ZT maize where highest net returns were obtained from the interaction between MWMb*NCU*WR (Fig. 4.3) while the highest BC ratio with MWMb*PU*WoR (Fig. 4.4). However, both of these combinations were found at par statistically for net returns and BC ratio of fourth ZT maize.

Table 4.12. Effect of cropping system, residue and nitrogen management on economics of fourth zero-till *kharif* maize

Treatments	Cost of cultivation (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	Benefit cost ratio
Cropping system (System)				
Maize-mustard-mungbean (MMuMb)	23485	79812b	56327b	2.37b
Maize-wheat-mungbean (MWMb)	23600	87254a	63654a	2.67a
LSD (*p*=0.05)	-	4833.4	4833.7	0.219
Residue management (Residue)				
Permanent beds - residue (WoR)	21978	79677b	57698	2.59
Permanent beds + residue (WR)	25107	87389a	62282	2.46
LSD (*p*=0.05)	-	5268.3	NS	NS
Nitrogen management (Nitrogen)				
Absolute control	22041	46287c	24246c	1.10d
N by prilled urea (PU)	24504	97173b	72669a	2.98b
N by sulphur coated urea (SCU)	24004	89897b	65893b	2.74c
N by neem coated urea (NCU)	23620	100774a	77153a	3.27a
LSD (*p*=0.05)	-	4685.9	4685.8	0.201
***p* values**				
System		0.0001	0.0001	0.0002
Residue		<.0001	0.0087	0.0754
*System*Residue*		0.0777	0.0893	0.1974
*System*Nitrogen*		0.4132	0.3711	0.4398
*Residue*Nitrogen*		0.0006	0.0011	0.0039
Nitrogen		<.0001	<.0001	<.0001

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

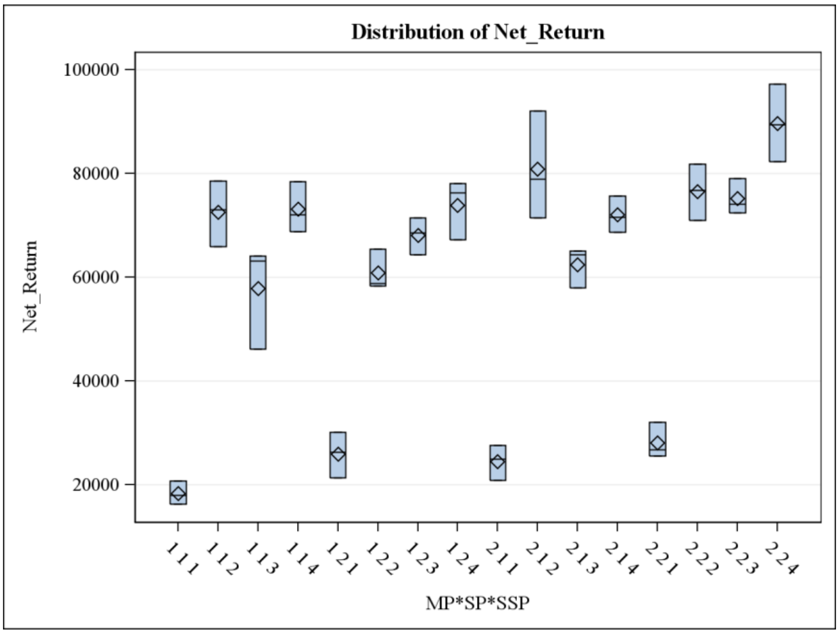


Fig. 4.3. Effect of cropping system, residue and nitrogen management on net returns of fourth zero-till *kharif* maize

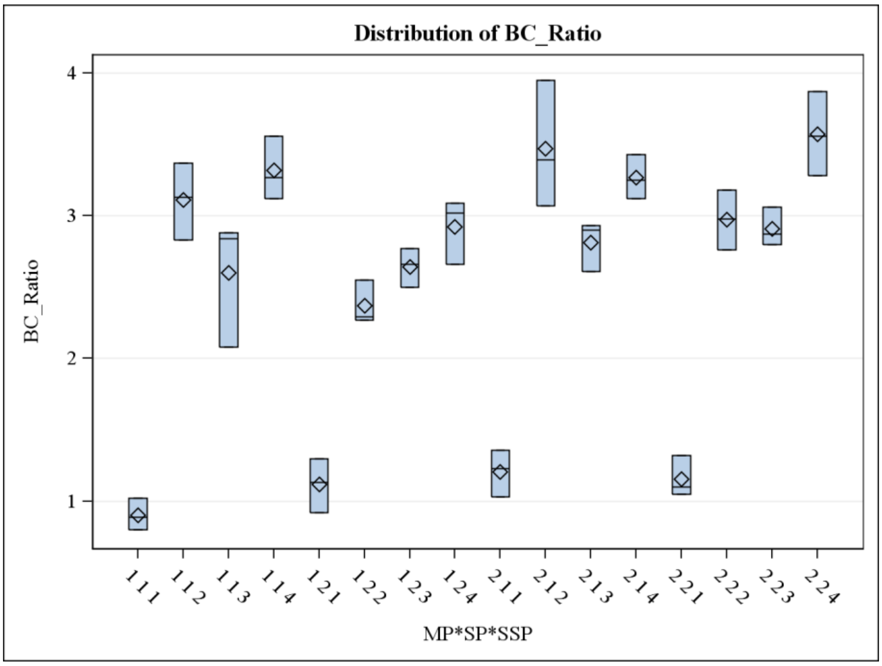


Fig. 4.4. Effect of cropping system, residue and nitrogen management on benefit cost ration of fourth zero-till *kharif* maize

4.16. Plant nutrient concentration and uptake

4.16.1. Concentration of N, P and K in grain and stover and protein content

Data on effect of cropping system, residue and nitrogen management practices and their interaction on concentration of N, P and K in grain and stover of fourth zero-till *kharif* maize are presented in Table 4.13. In MWMb cropping system, significantly higher P concentration in grain (0.28%) and K concentration in stover (1.11%) was recorded over MMuMb system. In WR, N concentration in grain (1.85%) and N (0.47%) and K (1.11%) concentration in stover and grain protein (11.58%) was significantly ($p<0.05$) higher over WoR.

Table 4.13. Effect of cropping system, residue and nitrogen management on concentration of N, P and K in grain and stover of fourth zero-till *kharif* maize

Treatments	Concentration in grain (%)			Concentration in stover (%)			Grain protein (%)
	N	P	K	N	P	K	
Cropping system (System)							
Maize-mustard-mungbean (MMuMb)	1.74	0.20b	0.45	0.46	0.27	1.03b	10.87
Maize-wheat-mungbean (MWMb)	1.79	0.28a	0.42	0.44	0.28	1.11a	11.20
LSD (*p*=0.05)	NS	0.035	NS	NS	NS	0.012	NS
Residue management (Residue)							
Permanent beds - residue (WoR)	1.68b	0.23	0.44	0.43b	0.28	1.04b	10.49b
Permanent beds + residue (WR)	1.85a	0.25	0.43	0.47a	0.27	1.11a	11.58a
LSD (*p*=0.05)	0.078	NS	NS	0.008	NS	0.049	0.485
Nitrogen management (Nitrogen)							
Absolute control	1.55c	0.21b	0.38b	0.37b	0.26b	1.08	9.70c
N by prilled urea (PU)	1.78b	0.25a	0.42a	0.46a	0.25b	1.09	11.15b
N by sulphur coated urea (SCU)	1.90a	0.24a	0.48a	0.46a	0.30a	1.08	11.86a
N by neem coated urea (NCU)	1.83ba	0.25a	0.47a	0.49a	0.30a	1.04	11.43ba
LSD (*p*=0.05)	0.087	0.031	0.079	0.063	0.033	NS	0.546
p values							
System	0.0846	<.0001	0.3321	0.4501	0.1476	0.0006	0.0843
Residue	<.0001	0.1286	0.5419	0.00878	0.8625	0.0035	<.0001
*System*Residue*	<.0001	<.0001	0.9268	0.3108	0.0030	0.0032	<.0001
*System*Nitrogen*	0.4356	0.0012	0.9687	0.3950	0.0010	0.4601	0.4341
*Residue*Nitrogen*	0.6006	0.0277	0.0052	0.3645	0.0013	0.4307	0.6003
Nitrogen	<.0001	0.0388	0.0521	0.0034	0.0037	0.4569	<.0001

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

The N application by SCU gave significantly higher concentration of N (1.90%) and protein (11.86%) in grain were significantly higher over PU and absolute control but at par with NCU. However, the P concentration in grain and stover was significantly higher with NCU which was at par with PU for grain and SCU for straw P concentration but all these were significantly superior over control. Significant first order interactions among system, residue and N management were also observed for grain and stover P concentration in ZT maize but for N concentration only system*residue interactions were significant. The SCU resulted in significantly high concentration of K (0.48%) in grain over absolute control (0.38%), however it was at par with PU and NCU and significant residue*nitrogen interactions were also found for grain K concentration.

Table 4.14. Effect of cropping system, residue and nitrogen management on uptake of N, P and K by grain and stover of fourth zero-till *kharif* maize

Treatments	Uptake by grain (kg/ha)			Uptake by stover (kg/ha)		
	N	P	K	N	P	K
Cropping system (System)						
Maize-mustard-mungbean (MMuMb)	93.6b	10.37b	23.98	45.33	26.67b	100.3
Maize-wheat-mungbean (MWMb)	106.5a	16.71a	24.69	47.14	29.74a	118.9
LSD (*p*=0.05)	10.25	2.0	NS	NS	2.41	NS
Residue management (Residue)						
Permanent beds - residue (WoR)	90.4b	12.13	23.79	42.9b	27.72	102b
Permanent beds + residue (WR)	109.6a	14.95	24.87	49.6a	28.69	116.6a
LSD (*p*=0.05)	6.61	NS	NS	2.09	NS	3.61
Nitrogen management (Nitrogen)						
Absolute control	45.7b	6.00b	11.15c	28.18c	19.84c	81.75c
N by prilled urea (PU)	116.1a	16.14a	26.87b	51.52b	27.13b	122a
N by sulphur coated urea (SCU)	115.0a	15.04a	28.10ba	45.92b	30.53b	108.1b
N by neem coated urea (NCU)	123.4a	16.97a	31.20a	59.33a	35.32a	125.4a
LSD (*p*=0.05)	8.61	2.13	4.04	6.89	3.70	8.83
***p* values**						
System	0.0002	<.0001	0.6131	0.4500	0.0238	<.0001
Residue	<.0001	0.0007	0.4464	0.0089	0.4523	<.0001
*System*Residue*	0.0001	<.0001	0.7598	0.1480	0.0201	0.0054
*System*Nitrogen*	0.2790	0.0009	0.9842	0.6734	0.0016	0.0997
*Residue*Nitrogen*	0.0044	0.0015	0.0251	0.8853	0.0008	0.2344
Nitrogen	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

4.16.2. Uptake of N, P and K by grain and stover

Data on effect of cropping system, residue and nitrogen management practices and their interaction on uptake of N, P and K by grain and stover of fourth zero-till *kharif* maize are presented in Table 4.14. In MWMb, uptake of 106.5 kg/ha N and 16.71 kg/ha P in grain was recorded which was significantly higher over MMuMb. In stover, the significantly higher P uptake (29.74 kg/ha) recorded in MWMb. The uptake of N and K in straw and K in grain were found to be statistically similar in both the cropping system. In WR, the uptakes of N in grain and stover and K in stover were significantly higher over WoR. However, N and K uptake in grain and P uptake in stover were not affected by residue management.

The uptake of NPK in grain and stover were significantly influenced by N management and application of NCU recorded significantly higher, which were 123.4 N kg/ha, 16.97 P kg/ha, 31.20 K kg/ha in grain and 59.33 N kg/ha, 35.32P kg/ha and 125.4 K kg/ha in stover. But the uptake of N and P in grain and straw was at par with PU and SCU however it was higher than control in all N application treatment. Similarly, K uptake in grain and straw was statistically similar in NCU and SCU and significantly higher over absolute control. Significant system*residue and residue*nitrogen interactions were found for uptake of NPK in grain and stover except N uptake by stover in our investigation.

4.16.3. Concentration of Cu, Fe and Zn in grain and stover

Data on effect of cropping system, residue and nitrogen management practices and their interaction on concentration of Cu, Fe and Zn in grain and stover of fourth zero-till *kharif* maize are presented in Table 4.15. Significantly higher Zn concentration in grain (30.77 Zn mg/kg DM) was recorded in MWMb compared to MMuMb. However, Cu and Fe concentration in grain and Cu, Fe and Zn concentration in stover were found statistically similar in both the cropping system. In WoR, Cu concentration in grain (22.96 Cu mg/kg DM) was observed significantly higher compared to WR (21.65 Cu mg/kg DM). However, Fe and Zn concentration in grain (38.19 and 33.48 mg/kg dry matter) were recorded significantly ($p<0.05$) higher with WR compared to WoR (35.52 Fe and 26 Zn mg/kg DM). In stover, the concentration of Cu, Fe and Zn were not affected by residue management practices significantly.

Table 4.15. Effect of cropping system, residue and nitrogen management on concentration of Cu, Fe and Zn in grain and stover in fourth zero-till *kharif* maize

Treatments	**Concentration in grain (mg/kg dry matter)**			**Concentration in stover (mg/kg dry matter)**		
	Cu	**Fe**	**Zn**	**Cu**	**Fe**	**Zn**
Cropping system (System)						
Maize-mustard-mungbean (MMuMb)	23.35	36.90	28.71b	14.93	365.2	14.23
Maize-wheat-mungbean (MWMb)	21.26	36.81	30.77a	14.30	363.4	14.27
LSD (*p*=0.05)	NS	NS	0.652	NS	NS	NS
Residue management (Residue)						
Permanent beds - residue (WoR)	22.96a	35.52b	26.00b	16.13	357.0	13.92
Permanent beds + residue (WR)	21.65b	38.19a	33.48a	13.10	371.5	14.58
LSD (*p*=0.05)	1.253	2.062	1.934	NS	NS	NS
Nitrogen management (Nitrogen)						
Absolute control	21.15b	35.37	27.25b	15.37	275.6b	16.24a
N by prilled urea (PU)	24.23a	37.90	28.03b	15.09	382.4a	13.54ab
N by sulphur coated urea (SCU)	21.26b	37.07	30.81a	13.66	405.3a	15.02a
N by neem coated urea (NCU)	22.60a	37.09	32.87a	14.35	393.9a	12.21b
LSD (*p*=0.05)	1.781	NS	2.473	NS	24.2	2.777
p values						
System	0.0021	0.9480	0.0229	0.5301	0.8308	0.9656
Residue	0.0414	0.0725	<.0001	0.0572	0.0923	0.4931
*System*Residue*	0.5915	0.9586	0.0925	0.0207	0.0003	0.0091
*System*Nitrogen*	0.0735	0.4442	0.1102	0.5221	0.0016	0.0223
*Residue*Nitrogen*	0.0003	0.8099	0.0075	0.0404	0.0073	0.0005
Nitrogen	0.0047	0.6454	0.0003	0.6135	<.0001	0.0341

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

Similar to coping system and residue effect, the N application methods also influenced the concentration of micronutrients in maize parts. Significantly higher Cu concentration in grain (24.23 Cu mg/kg DM) was recorded with PU over absolute control and SCU but it was statistically on par with NCU. Further, nitrogen management with NCU recorded significantly higher Zn (32.87 Zn mg/kg DM) over PU and absolute control but it was statistically at par to SCU. No significant differences were observed in Fe and Cu concentration in grain and straw in all the nitrogen management. However in stover, significantly higher Fe (405.3 Fe mg/kg DM) concentration was recorded with SCU while significantly higher Zn (16.24 Zn mg/kg DM) recorded in absolute control compared to NCU but it was at par to PU and SCU. Moreover, Fe concentration with PU and NCU were found at par with SCU. Significant interaction of residue*system was noticed for micronutrient concentration stover residue*nitrogen had interaction effects on grain and stover micronutrient concentration except Fe in grains.

4.16.4. Uptake of Cu, Fe and Zn by grain and stover

Data on effect of cropping system, residue and nitrogen management practices and their interaction on concentration of Cu, Fe and Zn by grain and stover of fourth zero-till *kharif* maize are presented in Table 4.16.

Table 4.16. Effect of cropping system, residue and nitrogen management on uptake of Cu, Fe and Zn by grain and stover in fourth zero-till *kharif* maize

Treatments	**Uptake by grain (g/ha)**			**Uptake by stover (g/ha)**		
	Cu	**Fe**	**Zn**	**Cu**	**Fe**	**Zn**
Cropping system (System)						
Maize-mustard-mungbean (MMuMb)	124.0	197.0	155.5b	145.4	3615b	135.9
Maize-wheat-mungbean (MWMb)	124.9	214.5	180.6a	149.4	3952a	149.6
LSD (*p*=0.05)	NS	NS	9.81	NS	282.9	NS
Residue management (Residue)						
Permanent beds - residue (WoR)	121.8	189.2b	136.6b	157.4	3561b	132b
Permanent beds + residue (WR)	127.0	222.2a	199.5a	137.5	4007a	153.5a
LSD (*p*=0.05)	NS	25.16	16.23	NS	406.2	9.5
Nitrogen management (Nitrogen)						
Absolute control	61.1c	104.0b	80.23c	116.4b	2087c	123.1
N by prilled urea (PU)	157.9a	246.7a	181.1b	167.3a	4278b	152.6
N by sulphur coated urea (SCU)	127.4b	223.8a	188.5b	134.9b	4049b	148.2
N by neem coated urea (NCU)	151.3a	248.3a	222.5a	171.1a	4721a	147.2
LSD (*p*=0.05)	13.92	28.9	16.5	31.28	266.2	NS
p values						
System	0.8607	0.0909	0.0002	0.7096	0.0011	0.1887
Residue	0.2943	0.0028	<.0001	0.0760	<.0001	0.0438
*System*Residue*	0.9745	0.5181	0.0072	0.0344	0.0334	0.0091
*System*Nitrogen*	0.0675	0.2916	0.7627	0.3282	0.0003	0.0066
*Residue*Nitrogen*	<.0001	0.2340	0.0001	0.1689	0.0006	0.0005
Nitrogen	<.0001	<.0001	<.0001	0.0033	<.0001	0.1869

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

No significant effect of cropping systems was observed on the uptake of Cu by grain and stover, uptake of Fe by the grains and Zn by the stover, but uptake of Zn and Fe by grain and stover was significantly increased in MWMb over MMuMb cropping system. There was no significant effect was observed of residue management practices on uptake of Cu by grain and stover but WR enhanced the uptake of Fe and Zn by grain and stover. The enhancement of Fe uptake by WR was to the tune of 33 g/ha and 446 g/ha by grain and stover, respectively while it was Zn uptake increased by 62.9 g/ha and 21.5 g/ha in grains and stover, respectively over WoR.

Table 4.17. Effect of cropping system, residue and nitrogen management on water use efficiency and water productivity in fourth zero-till *kharif* maize

Treatments	**Water input (m^3)**			**Water use efficiency (kg/m^3 of water)**		**Water productivity (net return ₹/ m^3 of water)**	
	Irri	**Irri + total RF**	**Irri + ER**	**IR + ER**	**IR + Total RF**	**IR + ER**	**IR**
Cropping system (System)							
Maize-mustard-mungbean (MMuMb)	1309	9548	5979	0.88b	0.55b	9.42b	5.90b
Maize-wheat-mungbean (MWMb)	1285	9525	5955	0.97a	0.61a	10.7a	6.68a
LSD (*p*=0.05)	NS	NS	NS	0.058	0.040	0.755	0.483
Residue management (Residue)							
Permanent beds - residue (WoR)	1330a	9569a	6000a	0.88b	0.55b	9.6	6.0
Permanent beds + residue (WR)	1264b	9503b	5934b	0.98a	0.61a	10.5	6.5
LSD (*p*=0.05)	0.702	0.702	0.702	0.060	0.038	NS	NS
Nitrogen management (Nitrogen)							
Absolute control	1297	9536	5967	0.49c	0.31c	4.07c	2.54c
N by prilled urea (PU)	1297	9536	5967	1.09a	0.68a	12.2a	7.62a
N by sulphur coated urea (SCU)	1297	9536	5967	1.01b	0.63b	11.05b	6.91b
N by neem coated urea (NCU)	1297	9536	5967	1.12a	0.70a	12.9a	8.09a
LSD (*p*=0.05)	NS	NS	NS	0.059	0.038	0.785	0.491
p values							
System	0.0792	0.0792	0.0792	0.0229	0.0289	0.0186	0.0199
Residue	<.0001	<.0001	<.0001	0.0103	0.0128	0.0504	0.0577
*System*Residue*	0.0822	0.0822	0.0822	0.1741	0.1664	0.2027	0.2054
*System*Nitrogen*				0.4728	0.5225	0.0012	0.3548
*Residue*Nitrogen*				0.0006	0.0009	<.0001	0.0012
Nitrogen				<.0001	<.0001	0.1593	<.0001

*Irri=Irrigation, total RF= total rainfall and ER=effective rainfall

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

Among N management practices, NCU significantly enhanced the uptake of Fe (144 g/ha) and Zn (142.27 g/ha) by grain and uptake of Cu (54.7 g/ha) and Fe (2634 g/ha) by stover but Fe uptake was at par with the SCU and PU by grain and Cu uptake was at par with PU by stover. However, Cu uptake in grain significantly increased by PU which was at par with the NCU. The lowest uptake of Cu, Fe and Zn was recorded in absolute control. Similar to concentrations of micronutrients, significant interaction of residue*system, residue*nitrogen and system*nitrogen was found for uptake of different micronutrients differently.

4.17. Input use efficiencies

4.17.1. Water-use efficiency and water productivity

Data on effect of cropping system, residue and nitrogen management practices and their interaction on water-use efficiency (WUE) and water productivity in fourth zero-till *kharif* maize are presented in Table 4.17. The total water input during the growing season was mostly contributed by rainfall (823.9 mm) but the effective rainfall (ER) was only 419 mm. The irrigation water input was higher in MMuMb and WoR plots compared to MWMb and WR plots, respectively. The significantly higher WUE for effective or total rainfall was found in MWMb system and under WR. However, the water productivity (WP) was significantly higher in MWMb system and residue had no significant effect on it. The N application by NCU gave significantly higher WUE and WP over control and SCU which was at par with PU. Significant ($p<0.05$) residue*nitrogen interactions were found in WUE and WP of fourth ZT maize where NCU outperformed under WR while PU under WoR conditions.

4.17.2. Nitrogen use efficiency

Data on effect of cropping system, residue and nitrogen management practices and their interaction on partial factor productivity (PFP_N), agronomic efficiency (AE_N), apparent recovery (ANR) and physiological efficiency (PE_N) by grain and stover of fourth zero-till *kharif* maize are presented in Table 4.18. The PFP_N (44.62 kg grain/kg N applied) was significantly enhanced by MWMb, which was 9.28% higher compared to MMuMb. The WR resulted in increased PFP_N (44.34 kg grain/kg N applied) to the tune of 7.86% over WoR (41.11 kg grain/kg N applied). The cropping system and residue management practices had no significant effect on AE_N, ANR and PE_N. Among N fertilizer sources, AE_N, ANR, PE_N and PFP_N were recorded significantly higher with the application of NCU, which was at par with PU in PFP_N and AE_N. Interaction between MWMb*NCU significantly enhanced AE_N, PFP_N and PE_N, but ANR was significantly enhanced by the interaction between MMuMb *SCU.

Similarly, interaction between WR*NCU enhanced the AE_N, PFP_N and PE_N, but ANR was significantly enhanced with the interaction between WoR*SCU.

Table 4.18. Effect of cropping system, residue and nitrogen management on partial factor productivity (PFP_N) agronomic efficiency (AE_N), apparent recovery (ANR) and physiological efficiency (PE_N) of nitrogen in fourth zero-till *kharif* maize

Treatments	PFP_N (kg grain/kg N applied)	AE_N (kg grain increase /kg N applied)	ANR (%)	PE_N (kg grain/kg N uptake)
Cropping system (System)				
Maize-mustard-mungbean (MMuMb)	40.83b	22.31	62.7	1431
Maize-wheat-mungbean (MWMb)	44.62a	24.17	68.9	1683
LSD (p=0.05)	2.44	NS	NS	NS
Residue management (Residue)				
Permanent beds - residue (WoR)	41.11b	23.90	67.3	1612
Permanent beds + residue (WR)	44.34a	22.58	64.2	1501
LSD (p=0.05)	2.71	NS	NS	NS
Nitrogen management (Nitrogen)				
N by prilled urea (PU)	43.30a	23.82a	62.4b	1530b
N by sulphur coated urea (SCU)	40.20b	20.72b	62.4b	1282b
N by neem coated urea (NCU)	44.67a	25.19a	72.5a	1858a
LSD (p=0.05)	2.83	2.83	4.1807	271.96
***p* values**				
System	0.0216	0.2374	0.1868	0.0541
Residue	0.0342	0.1655	0.5848	0.3922
*System*Residue*	0.1121	0.0282	0.0221	0.0064
*System*Nitrogen*	0.5923	0.5923	0.4038	0.9079
*Residue*Nitrogen*	0.0026	0.0026	0.0001	0.0025
Nitrogen	0.0121	0.0121	<.0001	0.0014

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

4.16. Physical properties

4.16.1. Bulk density (BD)

Data on effect of cropping system, residue and nitrogen management practices and their interaction on bulk density after harvesting of fourth zero-till *kharif* maize are presented in Table 4.19. In most of the cases, the BD was decreased in 0-10 cm soil depth compared to initial but it increased in control and WoR treatments over initial values at below 10 cm soil depths. There was no significant effect of cropping system on soil BD throughout all of layers. However, permanent bed with residue retention significantly decreased the soil BD over permanent bed without residue in all six layers of soil after harvest of fourth ZT maize. Among the N management practices, the application of different N fertilizers significantly decrease in the soil BD values at different depth was observed with application of NCU/SCU and in most of the cases PU also compared to absolute control. Significant interaction effects of residue*system and system*nitrogen in sub-soil layer while residue *nitrogen in almost all soil layers was observed for soil BD after harvest of fourth maize crop in sandy loam soil.

Table 4.19. Effect of cropping system, residue and nitrogen management on bulk density in different soil layers after harvesting of fourth zero-till *kharif* maize

Treatments	Bulk density (Mg/m^3)					
	0-10 cm	**10-20 cm**	**20-30 cm**	**30-40 cm**	**40-50 cm**	**50-60 cm**
Cropping system (System)						
Maize-mustard-mungbean (MMuMb)	1.35	1.46	1.43	1.47	1.47	1.53
Maize-wheat-mungbean (MWMb)	1.34	1.49	1.48	1.44	1.52	1.52
LSD (p=0.05)	NS	NS	NS	NS	NS	NS
Residue management (Residue)						
Permanent beds - residue (WoR)	1.38a	1.52a	1.49a	1.51a	1.54a	1.56a
Permanent beds + residue (WR)	1.31b	1.44b	1.43b	1.40b	1.45b	1.49b
LSD (p=0.05)	0.049	0.02	0.046	0.048	0.037	0.025
Nitrogen management (Nitrogen)						
Absolute control	1.38a	1.54a	1.52a	1.51a	1.51a	1.65a
N by prilled urea (PU)	1.36ba	1.45b	1.44cb	1.49a	1.51a	1.51b
N by sulphur coated urea (SCU)	1.33bc	1.45b	1.41c	1.44b	1.46b	1.47c
N by neem coated urea (NCU)	1.31c	1.47b	1.45b	1.39c	1.49ba	1.48c
LSD (p=0.05)	0.035	0.043	0.035	0.041	0.041	0.028
Initial	1.477	1.539	1.628	1.631	1.627	1.621
p values						
System	0.3143	0.0846	0.0005	0.0657	0.0020	0.5526
Residue	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
*System*Residue*	0.0103	0.1441	0.0187	0.0005	0.0003	0.0322
*System*Nitrogen*	0.4311	0.1134	0.2308	0.0356	0.0019	0.0007
*Residue*Nitrogen*	<.0001	0.0071	0.0001	0.1176	0.0012	<.0001
Nitrogen	0.0025	0.0010	<.0001	<.0001	0.0510	<.0001

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

4.16.2. Soil strength/Penetration resistance (PR)

Data on effect of cropping system, residue and nitrogen management practices and their interaction on soil strength/PR after harvesting of fourth zero-till *kharif* maize are presented in Table 4.20. The PR in soil profile was also measured at six depths and found no significant effect of cropping systems on PR. However, WR significantly decreased the PR over WoR in five out of six soil depths of the profile;

there was no significant decrement/decline in PR in the first layer (0-10 cm). The residue removal however increased PR compared to WR at below 20 cm depths. Among the N management practices, there was no significant effect of PU, SCU and NCU on PR in five out of six layers/depths of soil profile but application of NCU significantly decreased the PR in the first layer (0-10 cm) compared to application of SCU and PU and absolute control. No significant interaction effects were observed for PR at all six soil depths.

Table 4.20. Effect of cropping system, residue and nitrogen management on penetration resistance in different soil layers after harvesting of fourth zero-till *kharif* maize

Treatments	**Penetration resistance (*kPa*)**					
	0-10 cm	**10-20 cm**	**20-30 cm**	**30-40 cm**	**40-50 cm**	**50-60 cm**
Cropping system (System)						
Maize-mustard-mungbean (MMuMb)	1156	1451	2038	2377	2287	2057
Maize-wheat-mungbean (MWMb)	1044	1426	1929	2285	2316	2212
LSD (p=0.05)	NS	NS	NS	NS	NS	NS
Residue management (Residue)						
Permanent beds - residue (WoR)	1138	1539a	2150a	2670a	2608a	2329a
Permanent beds + residue (WR)	1062	1339b	1817b	1991b	1996b	1939b
LSD (p=0.05)	NS	71.9	281.6	350.9	315.2	305.6
Nitrogen management (Nitrogen)						
Absolute control	1189a	1452	1883	2408	2422	2135
N by prilled urea (PU)	1096ba	1474	2062	2461	2438	2405
N by sulphur coated urea (SCU)	1136ba	1507	1960	2214	2203	2005
N by neem coated urea (NCU)	977b	1319	2026	2239	2144	1991
LSD (p=0.05)	211.7	NS	NS	NS	NS	NS
Initial	1150	1503	2012	2360	2309	2165
p values						
System	0.3689	0.7723	0.4780	0.3321	0.8961	0.2404
Residue	0.3778	0.0331	0.0108	0.0141	0.0393	0.0290
*System*Residue*	0.6028	0.1488	0.0254	0.8951	0.5840	0.4493
*System*Nitrogen*	0.1897	0.0477	0.2983	0.5739	0.3071	0.1471
*Residue*Nitrogen*	0.3723	0.9670	0.4799	0.1585	0.2142	0.4340
Nitrogen	0.02257	0.2758	0.7802	0.5136	0.2744	0.2382

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

4.17. Soil pH

Data on soil pH at various soil depths (0-15cm, 15-30cm and 30-45cm) as influenced by the cropping system, residue and nitrogen management practices and their interaction after harvesting of fourth zero-till *kharif* maize are presented in Table 4.21. No significant difference was observed in soil pH at all soil depth for cropping systems. However, residue retention decreased the soil pH at 0-15 cm, 15-30 cm and 30-45 cm depths of soil. The N management practices had varied effect on soil pH and NCU and control in 0-15 cm depth while PU and SCU at 15-30 cm depth and NCU at 30-45 cm depth gave significantly higher pH values over others. Significant ($p<0.05$) system*nitrogen, residue*system and residue*nitrogen interaction s were found in sub-soil depths for soil pH values.

Table 4.21. Effect of cropping system, residue and nitrogen management on soil pH at various soil depths after harvesting in fourth zero-till *kharif* maize

Treatments	Soil pH		
	0-15 cm	**15-30 cm**	**30-45 cm**
Cropping system (System)			
Maize-mustard-mungbean (MMuMb)	6.96	6.85	6.78
Maize-wheat-mungbean (MWMb)	6.86	6.90	6.76
LSD (*p*=0.05)	NS	NS	NS
Residue management (Residue)			
Permanent beds - residue (WoR)	7.25a	6.93a	6.94a
Permanent beds + residue (WR)	6.57b	6.83b	6.59b
LSD (*p*=0.05)	0.101	0.091	0.090
Nitrogen management (Nitrogen)			
Absolute control	6.99ba	6.81b	6.77b
N by prilled urea (PU)	6.59c	7.03a	6.60c
N by sulphur coated urea (SCU)	6.94b	6.89ba	6.72cb
N by neem coated urea (NCU)	7.11a	6.78b	6.97a
LSD (*p*=0.05)	0.161	0.221	0.142
p values			
System	0.2997	0.4884	0.6952
Residue	<.0001	0.0285	0.0004
*System*Residue*	0.1252	0.0003	0.0009
*System*Nitrogen*	0.1302	0.0003	0.1462
*Residue*Nitrogen*	0.4394	0.0191	0.0826
Nitrogen	<.0001	0.1114	0.0001

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

4.17. Total organic carbon (TOC)

Data on on total organic carbon (%) at various soil depths after harvesting of fourth zero-till *kharif* maize as affected by the cropping system, residue and nitrogen management practices and their interaction are presented in Table 4.22. Significantly higher TOC (%) was recorded under MWMb at 0-15cm (0.69%) and 15-30 cm (0.58%) soil depth over MMuMb, but it had no significant effect on TOC at 30-45 cm soil depth. Similarly, WR significantly enhanced the TOC at 0-15 cm (0.69%) and 15-30 cm (0.59%) soil depth over WoR, but it had no significant effect on TOC at 30-45 cm soil depth. Among N management practices, significant effect on TOC was observed with the application of NCU in all the soil depths (0.73% at 0-15 cm, 0.61 % at 15-30 cm and 0.54% at 30-45 cm) compared to SCU and PU while signficnalty lowest TOC was registered in absolute control (0.48, 0.51 and 0.41% at 0-15,15-30 and 30-45 cm soil depth, respectively). In general, decrease in TOC at all depths was observed in absolute control compared to initial values after fourth maize crop while it decreased in WoR at 15-30 cm soil depth also. Significant residue*nitrogen and system*nitrogen effects were observed in TOC at top soil (0-30 cm depths).

Table 4.22. Effect of cropping system, residue and N management on total organic carbon status at various soil depths after harvest of fourth zero-till *kharif* maize

Treatments	**Total Organic Carbon (%)**		
	0-15 cm	**15-30 cm**	**30-45 cm**
Cropping system (System)			
Maize-mustard-mungbean (MMuMb)	0.55b	0.58a	0.50
Maize-wheat-mungbean (MWMb)	0.69a	0.51b	0.45
LSD (*p*=0.05)	0.06	0.009	NS
Residue management (Residue)			
Permanent beds - residue (WoR)	0.55b	0.50a	0.46
Permanent beds + residue (WR)	0.69a	0.59b	0.49
LSD (*p*=0.05)	0.037	0.019	NS
Nitrogen management (Nitrogen)			
Absolute control	0.48c	0.51b	0.41b
N by prilled urea (PU)	0.64b	0.51b	0.51a
N by sulphur coated urea (SCU)	0.63b	0.55b	0.44b
N by neem coated urea (NCU)	0.73a	0.61a	0.54a
LSD (*p*=0.05)	0.041	0.048	0.0505
Initial	0.543	0.524	0.471
p values			
System	<.0001	0.0007	0.0034
Residue	<.0001	<.0001	0.1146
*System*Residue*	0.1798	0.1888	0.5036
*System*Nitrogen*	<.0001	0.0739	0.1017
*Residue*Nitrogen*	0.0139	0.0001	0.9140
Nitrogen	<.0001	0.0008	<.0001

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

4.18. Mineral nitrogen

Data on mineral nitrogen (kg/ha) at various crop stages in three soil depth as affected by the cropping system, residue and nitrogen management practices and their interaction after harvesting of fourth zero-till *kharif* maize are presented in Table 4.23. There was no significant effect of cropping system on mineral N at all the stages except at 65 DAS (102.2 kg/ha) recorded significant and which is 12.06% higher under MMuMb over MWMb at 0-15 cm depth. WR significantly enhanced the mineral N by 32.99, 29.15, 13.94, 15.42 and 14.52% at 30, 45, 65 and 90 DAS and after harvest, respectively at 0-15 cm depth. However, no significant mineral N was found before sowing in both the residue management.

Among N fertilization practices, NCU application significantly increased the mineral N before sowing, at 30, 65 DAS and after harvest over PU, SCU and absolute control, which was at par with the PU and SCU application before sowing and at 30 DAS and at par with SCU application at 65 DAS and at after harvest. Fertilization with PU enhanced the mineral N at 45 (150.8 kg/ha) and 90 DAS (104.9 kg/ha) respectively, which was on par with the application of NCU (100.8 kg/ha) and SCU application at 90 DAS (101.5 kg/ha) only at 0-15 cm depth. Lowest mineral N was recorded in absolute control at all the stages of recording at all depths. In general, decrease in mineral nitrogen at sub-soil depth was observed compared to surface layers (0-15 cm depth) at all the stages of the observation except few cases. Almost similar trend in mineral N in sub soil (15-30 and 30-45 cm depth) was also observed at various stages of observation in our study. Significant interaction effects of the residue, nitrogen and cropping system for soil mineral N was observed at all depths and at most of the stages of the observation during the experimentation.

Table 4.23. Effect of cropping system, residue and nitrogen management on mineral nitrogen at various crop stages of fourth zero-till *kharif* maize

Treatments	0-15 cm (kg/ha)						15-30 cm (kg/ha)						30-45 cm (kg/ha)					
	Before sowing	**30 DAS**	**45 DAS**	**65 DAS**	**90 DAS**	**After harvest**	**Before sowing**	**30 DAS**	**45 DAS**	**65 DAS**	**90 DAS**	**After harvest**	**Before sowing**	**30 DAS**	**45 DAS**	**65 DAS**	**90 DAS**	**After harvest**
Cropping system																		
Maize-mustard-mungbean	96.6	113.5	109.5	102.2a	92.1	102.4	83.9	85.6	104.6	102.3a	80.2b	100.5	78.7	75.0	63.8	87.1a	84.3	87.1
Maize-wheat-mungbean	91.1	113.9	115.2	91.2b	95.1	95.6	82.7	88.1	103.2	88.4b	91.1a	100.0	86.5	71.0	72.4	77.3b	90.4	99.6
LSD(*p*=0.05)	NS	NS	NS	3.74	NS	NS	NS	NS	NS	10.7	1.86	NS	NS	NS	NS	5.63	NS	NS
Residue management																		
Permanent beds without residue	86.6	97.6b	98.1b	90.4b	86.9b	92.3b	85.3	81.4	90.9b	101.7a	85.6	108.2a	87.3a	69.2b	60.7b	83.3	69.9b	98.1a
Permanent beds with residue	101.1	129.8a	126.7a	103.0a	100.3a	105.7a	81.2	92.3	116.8a	89.1b	85.7	92.3b	77.9b	76.9a	75.5a	81.0	104.7a	88.6b
LSD (*p*=0.05)	NS	13.5	10.9	1.16	2.50	8.90	NS	NS	3.86	3.97	NS	5.05	3.05	7.73	7.7	NS	4.28	8.31
Nitrogen management																		
Absolute control	81.8b	76.2b	58.8d	48.3c	67.3b	66.2c	73.0b	62.2c	65.3c	67.4c	67.7c	48.2c	65.0c	59.8b	58.8b	56.2b	58.8c	43.8c
N by prilled urea (PU)	91.5ba	121.3a	150.8a	104.9b	104.9a	97.0b	85.8ba	84.8b	114.4b	97.5b	87.9b	123.2a	81.1b	76.0a	70.4a	88.2a	99.8a	95.2b
N by sulphur coated urea (SCU)	99.6a	127.7a	119.7b	115.1a	101.5a	114.8a	87.6a	93.2ba	124.1a	111.6a	95.1a	111.8b	93.7a	74.9a	73.4a	89.7a	88.8b	115.4a
N by neem coated urea (NCU)	102.6a	129.8a	120.2c	118.4a	100.8a	118.1a	86.8ba	107.3a	111.7b	105.1a	92.0ba	117.9b	90.7a	81.4a	69.7a	94.6a	101.9a	119.0a
LSD (*p*=0.05)	14.2	25.4	9.90	3.50	4.70	8.2	14.2	17.2	6.15	6.47	4.67	7.41	9.37	11.5	4.60	9.77	9.32	9.90
p values																		
System	0.2774	0.9621	0.1049	<.0001	0.0716	0.0239	0.7745	0.2489	0.4582	0.0311	0.0016	0.9159	0.1885	0.4888	0.0865	0.0177	0.1280	0.1289
Residue	0.0063	0.0011	<.0001	<.0001	<.0001	<.0001	0.3065	0.0663	<.0001	0.0009	0.8256	0.0009	0.0010	0.0497	0.0060	0.5263	<.0001	0.0335
System*Residue	0.7867	0.9168	0.0066	<.0001	<.0001	0.3077	0.4499	0.1405	<.0001	<.0001	<.0001	0.0092	0.0323	0.0109	0.8218	0.0015	0.0003	0.0020
System*Nitrogen	0.1861	0.0012	<.0001	<.0001	<.0001	0.0072	0.3487	0.1902	<.0001	<.0001	<.0001	<.0001	0.0176	0.0010	0.0002	<.0001	0.0031	0.0789
Residue*Nitrogen	0.0925	<.0001	<.0001	<.0001	<.0001	0.0451	0.0147	0.2284	<.0001	<.0001	<.0001	<.0001	0.0317	0.6853	0.0004	<.0001	<.0001	0.0145
Nitrogen	0.0267	0.0005	<.0001	<.0001	<.0001	<.0001	0.1371	0.0002	<.0001	<.0001	<.0001	<.0001	<.0001	0.0048	<.0001	<.0001	<.0001	<.0001

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

4.19. Soil potassium (K)

Data on available soil K status (kg/ha soil) at 0-15 cm soil depth after harvest as affected by the cropping system, residue and nitrogen management practices and their interaction after harvesting of fourth zero-till *kharif* maize are presented in Table 4.24. There was no significant effect was noticed for N management practices on K availability in 0-15 cm soil. However, WR enhanced the available K to the tune of 266.6 kg K/ha which is higher by 10.07% in value at 0-15 cm soil compared to PB-R after harvest. The MWMb had significantly higher available K at 0-15 cm depth compared to MMuMb system. No interaction effect was observed for the available K in 0-15 cm soil.

Table 4.24. Effect of cropping system, residue and nitrogen management on available nutrient status at 0-15 cm soil depth after harvest of fourth zero-till *kharif* maize

Treatments	**DTPA extractable nutrients (mg/kg soil)**			**Available K (kg/ha)**
	Cu	**Fe**	**Zn**	
Cropping system (System)				
Maize-mustard-mungbean (MMuMb)	1.93	13.29b	3.30b	241.4b
Maize-wheat-mungbean (MWMb)	1.79	13.99a	3.99a	267.4a
LSD (*p*=0.05)	NS	0.24	0.18	15.2
Residue management (Residue)				
Permanent beds - residue (WoR)	1.72b	13.39b	3.40b	242.2b
Permanent beds + residue (WR)	2.00a	13.89a	3.89a	266.6a
LSD (*p*=0.05)	0.128	0.212	0.254	11.2
Nitrogen management (Nitrogen)				
Absolute control	1.90	13.77	3.77	253.6
N by prilled urea (PU)	1.91	13.42	3.42	254.8
N by sulphur coated urea (SCU)	1.74	13.76	3.93	254.3
N by neem coated urea (NCU)	1.89	13.60	3.46	255.0
LSD (*p*=0.05)	NS	NS	NS	NS
p values				
System	0.2051	0.0001	0.0034	0.0034
Residue	0.0175	0.0037	0.0304	0.0055
*System*Residue*	0.4020	0.2876	0.3983	0.5434
*System*Nitrogen*	0.4221	0.9151	0.7393	0.9346
*Residue*Nitrogen*	0.9623	0.2819	0.6081	0.7708
Nitrogen	0.6655	0.3645	0.2883	0.9993

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

4.20. Soil micronutrients (Cu, Fe and Zn)

Data on DTPA extractable micronutrients status (mg/kg soil) at 0-15 cm soil depth after harvest as affected by the cropping system, residue and nitrogen management practices and their interaction after harvesting of fourth zero-till *kharif* maize are presented in Table 4.24. There was no significant effect of cropping systems and N management practices on available Cu while WR resulted in significantly higher Cu in soil by 16.28% compared to WoR. MWMb significantly increased the availability of Fe and Zn by 21.28 and 20.91%, respectively over MMuMb system. Similarly, WR gave 14.75 and 14.41% significantly higher Fe and Zn in soil compared to WoR. While N management practices had no significant effect on availability of Fe and Zn also. No interaction was observed in case of micronutrient (Cu, Fe and Zn) availability.

4.21. Biological parameters

4.21.1. Microbial Biomass Carbon (MBC)

Data on microbial biomass carbon (MBC) at flowering and after harvesting as affected by the cropping system, residue and nitrogen management practices and their interaction in fourth zero-till *kharif* maize are presented in Table 4.25 and 4.26. MWMb cropping system significantly enhanced the microbial biomass carbon (MBC) up to 507 µg C/g soil which was higher by 2.84% over MMuMb (493 µg C/g soil). However, there was no significant effect of cropping systems on MBC after harvesting. There was no significant effect of residue management practices on MBC at flowering, but WR significantly increased the MBC after harvesting up to 374 µg C/g soil over WoR (364 µg C/g soil). Among N management practices, significantly higher MBC was recorded with SCU application (571 µg C/g soil) over NCU and PU application at flowering stage and lowest MBC was found in absolute control. However, PU application recorded highest MBC (400 µg C/g soil) after harvesting of fourth ZT maize crop which was at par with the application of NCU (386 µg C/g soil) and SCU (384µg C/g soil). In general, across treatments lower MBC values were observed at harvesting compared to flowering stage. Significant interaction among the cropping system, residue and nitrogen management was observed during flowering stage for MBC content in the soil.

4.21.2. Enzymatic activity

Data on enzymatic activity in soil namely dehydrogenase, Floresein diacetate and ß glucosidase activity (mg/kg soil) at 0-15 cm soil depth at flowering and after harvest as affected by the cropping system, residue and nitrogen management practices and their interaction after harvesting of fourth zero-till *kharif* maize are presented in Table 4.25 and 4.26. In general, lower values of enzymatic activities were recorded at harvest compared to flowering stage of the crop across the treatments.

Table 4.25. Effect of cropping system, residue and nitrogen management on biological parameters of soil at flowering stage of fourth zero-till *kharif* maize

Treatments	**MBC (µg C/g soil)**	**Dehydrogenase (µg TPF Rel/g/day)**	**FDA (µg Florescein/ g/hr)**	**ß Glucosidase (µg p-NP Rel/g/24 hr)**
Cropping system (System)				
Maize-mustard-mungbean (MMuMb)	493b	29.2	0.634a	36.4a
Maize-wheat-mungbean (MWMb)	507a	27.1	0.492b	29.6b
LSD (*p*=0.05)	12.3	NS	0.0463	4.94
Residue management (Residue)				
Permanent beds - residue (WoR)	506	18.5a	0.446b	29.2b
Permanent beds + residue (WR)	494	37.8b	0.680a	36.9a
LSD (*p*=0.05)	NS	2.86	0.0172	3.59
Nitrogen management (Nitrogen)				
Absolute control	430c	19.0d	0.450c	16.1d
N by prilled urea (PU)	492b	28.4c	0.612b	40.2b
N by sulphur coated urea (SCU)	571a	30.4b	0.469c	32.7c
N by neem coated urea (NCU)	506b	34.8a	0.722a	43.1a
LSD (*p*=0.05)	33.6	1.62	0.0617	2.12
p values				
System	0.2493	0.0007	<.0001	<.0001
Residue	0.3241	<.0001	<.0001	<.0001
*System*Residue*	0.0019	<.0001	<.0001	<.0001
*System*Nitrogen*	0.0005	0.0001	0.0131	<.0001
*Residue*Nitrogen*	0.0014	<.0001	<.0001	<.0001
Nitrogen	<.0001	<.0001	<.0001	<.0001

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

4.21.2.1. Dehydrogenase (DHA)

Dehydrogenage activity was measured in terms of µg TPF (tri phynyl formazin) release/g soil/day and it was found to be non-significant at flowering stage in both of the cropping systems but WR significantly enhanced the its activity over WoR. Among the N management practices, DHA activity increased significantly with the application of NCU and lowest activity was found in absolute control. Significant interaction among the cropping system, residue and nitrogen management was observed during flowering and at harvest stage for dehydrogenase activity in soil.

Table 4.26. Effect of cropping system, residue and nitrogen management on biological parameters of soil after harvesting of fourth zero-till *kharif* maize

Treatments	**MBC (µg C/g soil)**	**Dehydrogenase (µg TPF Rel/g/day)**	**FDA (µg Florescein/ g/hr)**	**ß Glucosidase (µg p-NP Rel/g/24 hr)**
Cropping system (System)				
Maize-mustard-mungbean (MMuMb)	371	22.6	0.408	42.1a
Maize-wheat-mungbean (MWMb)	367	22.9	0.362	23.3b
LSD (*p*=0.05)	NS	NS	NS	1.90
Residue management (Residue)				
Permanent beds - residue (WoR)	364b	19.4b	0.397	26.2b
Permanent beds + residue (WR)	374a	26.1a	0.372	39.3a
LSD (*p*=0.05)	8.7	1.29	NS	2.66
Nitrogen management (Nitrogen)				
Absolute control	306b	16.4d	0.327b	9.70d
N by prilled urea (PU)	400a	21.9c	0.378ba	39.5b
N by sulphur coated urea (SCU)	384a	23.7b	0.426a	35.0c
N by neem coated urea (NCU)	386a	29.1a	0.407a	46.8a
LSD (*p*=0.05)	13.9	1.38	0.0597	2.72
Initial	330	18.38	0.425	20.56
p values				
System	0.4959	0.5597	0.0318	<.0001
Residue	0.0598	<.0001	0.2493	<.0001
*System*Residue*	0.3048	<.0001	0.0223	<.0001
*System*Nitrogen*	0.1746	<.0001	0.7236	<.0001
*Residue*Nitrogen*	<.0001	<.0001	<.0001	<.0001
Nitrogen	<.0001	<.0001	0.0148	<.0001

Note: Means followed by different letters in each column are statistically different at $LSD_{0.05}$.

4.21.2.2. Florescein diacetate (FDA)

Florescein diacetate enzyme activity was measured in terms of µg Florescein/g/hr and found that cropping systems and residue retention did not have any significant effect on FDA activity after harvest. But at flowering, significantly higher FDA activity was observed in MMuMb over MWMb and WR over WoR. Futher, among N fertilization practices, NCU application recorded highest activity at flowering followed by SCU and PU application. However, N fertilization by SCU significantly enhanced the FDA activity, which was at par with the fertilization by NCU. Simliar to MBC, significant interaction among the cropping system, residue and nitrogen management was observed during flowering stage for FDA activity in the soil.

4.21.2.3. ß Glucosidase

ß Glucosidase activity was measured in terms of µg p-NP (*para* nitro phenol) release /g/24 hr. At flowering stage, *ß* Glucosidase activity was found be higher in MMuMb cropping system over MWMb cropping system. Significantly higher *ß* Glucosidase activity was recorded under WR compared to WoR. In case of N management practices, NCU application was found to be superior for *ß* Glucosidase activity followed by PU and SCU. Interaction among cropping system, residue retention and NCU application contributed to enhanced *ß* Glucosidase activity at flowering and at harvest. Similarly, after harvesting of maize, almost similar results were observed, but *ß* Glucosidase activity was more in MMuMb cropping system compared to flowering stage. Decrease in *ß* Glucosidase activity at harvesting was observed under residue retention and N management practice by NCU application compared to flowering.

DISCUSSION

A field study entitled "**Nitrogen management under conservation agriculture in maize (*Zea mays* L.)"** was conducted during *kharif* season of 2015 in an ongoing experiment since 2012 at fixed site. The important findings of this study have been discussed under the following headings with possible scientific bases, providing a logical analysis of cause and effect relationship for the main and interaction effects of cropping system, residue and N management practices. The findings of earlier workers on the subject have also been taken into account while discussing the results of the present study.

5.1. Crop growth parameters in maize
5.2. Physiological indices in maize
5.3. Yield attributes in maize
5.4. Yields of maize
5.5. Economics of maize production
5.6. Resource use efficiencies
5.7. Soil properties

5.1. Crop growth parameters in maize

The crop growth parameters *viz.,* plant height, leaf area, dry matter accumulation, LAI and crop growth indices were studied in maize and found to be influenced by main and interaction effects of cropping system, residue management and N fertilization practices. The higher values of these parameters were observed in maize-wheat-mungbean (MWMb) compared to maize–mustard-mungbean (MMuMb) system. The lower mineral N availability reported in our study in 0-30 cm soil depth could be the important reasons for lower growth parameters under MMuMb system. Moreover, the enhancement in organic carbon and soil microbial activities recorded in this system might also have contributed for higher growth of maize in MWMb system. Some of the earlier studies also found cropping system effects on the crop growth parameters in maize (Thierfelder *et al*., 2015; Parihar *et al*., 2016a and Parihar *et al*., 2016b). Similarly, the residue retention (WR) enhanced these growth attributes at various crop growth stages as compared to residue removal (Ram, 2006).The residue retention helps in lowering down the drought stress effect in maize as evident from the very high (-3.39 ^{o}C) canopy temperature depletion recorded in our study might be the important reasons behind the enhancement of growth parameters of maize in WR compared to WoR. In addition to this, the residue retention over period of time resulted in positive changes in soil properties and hence improvement in crop growth was occurred. The residue retention lead enhancement in crop growth might be attributed to enhanced soil moisture (Erenstein and Laxmi, 2008 and Shen *et al.*, 2012), lower weed population and increase in soil health. The similar effects of residue retention benefit in crop growth were also reported by many workers in varied ecologies (Tolk *et al*., 1999 and Campbell *et al*., 2000). In contrast to this, in temperate regions negative effect of residue retention on crop growth was noticed probably due to high initial soil organic carbon and slow residue degradation and immobilization of applied nutrients (Rice and Smith, 1984; and Thuy *et al.,* 2008). However, such effects were less pronounced instead reversed in tropical and sub-tropical agro-ecologies (Etchevers *et al.,* 2000).

The application of N enhanced the growth parameters in maize significantly over control and these were significantly higher in neem or sulphur coated urea over prilled urea application. The slow and continuous supply of N with coated fertilizer (Carreres, 2003, Jacobs, 2004 and Cong, 2010) to the crop lead to better photosynthesis which increased the root and shoot growth in the crop (Zhao *et al.*, 2013). The higher concentration of mineral N observed in our study during most of the crop stages except 15 days after application of second split N i.e. at 45 DAS could be the important reason for enhanced crop growth in coated fertilizer application. Moreover, in conservation agriculture (CA) banding of fertilizer at same row year after year and non-inversion of these nutrients in sub-surface soil layer also helped in enhancing the crop growth in later years due to more residual nutrient content in soil. The enhanced root and shoot biomass in coated fertilizer over time increased more residue recycling compared to PU and control which might helped in improving beneficial soil properties in our study. The improvement in overall soil health could be the vital reasons for enhanced crop growth in our study. The similar effects of coated fertilizer on the crop growth of maize also reported by many workers (Tanwar, 2014, Sharma and Prasad, 1996, and Upadhyay and Tripathi, 2000). However, in some of the studies no response to coated fertilizer was observed on maize crop growth due to initial very slow release properties of polymer coated urea in temperate agro-ecologies (Nelson *et al.*, 2009).

The enhancement in leaf area lead to more photosynthesis which in turn increased the dry matter accumulation and crop growth rate and relative growth rate under neem coated urea (NCU) over control and other practices. The enhanced availability of N in soil lead to increased N uptake and hence the application of residue and NCU and other fertilization lead to increased values of NDVI and SPAD values as these values directly correlate with the N in leaves. The similar finding of better nutrition lead enhanced NDVI and SPAD values were also reported by Mohanty *et al*. (2015) in wheat and Ghosh (2015) in maize.

5.2. Physiological indices in maize

The application of residue and different N management strategies lead to significant ($p<0.05$) main and interaction effects on the various physiological parameters in intensified maize systems. The application of N by NCU or SCU lead to enhancement in CGR, and RGR at most of the crop growth stages but the NAR of maize at various crop growth stages was higher in control. The lower NAR in the control could be attributed to lower dry weight and leaf area of the plant at initial growth stages observed in our study which caused more net assimilation of photosynthates with per unit of leaf area in maize. Moreover, the application of N fertilization resulted in timely tasseling and silking in maize compared to control where it got delayed by 9 to 10 days. However, the maturity was arrived on same time which resulted in decreasing of reproductive period of crop by almost 9 days. This could be attributed to better growth parameters of leaf area of the crop with N fertilization compared to control which helped in achieving crop developmental stages on time.

Similarly, the MWMb system recorded higher CGR and RGR at initial crop growth stages (0-30 DAS) which could be attributed to enhanced leaf area and dry matter accumulation due to better soil nutrient supply observed in this system compared to MMuMb. Similar effects on CGR and RGR alongwith NAR of ZT maize was recorded by WR compared to WoR, which thereby boost crop health under residue retention over period of time and better crop nutrition compared to WOR. However, to significant effect of cropping system and residue management was observed on crop growth stages in maize which could be attributed to only at initial crop stages effects were significant of these practices CGR and RGR of maize.

5.3. Yield attributes in maize

5.3.1. Cob parameters

The yield attributes of maize including cob parameters and grain parameters were significantly ($p<0.05$) influenced with main and interaction effects of residue and nitrogen management practices in maize grown in intensified maize system. The WoR recorded significantly higher cob barrenness (5.12%) compared to WR (3.88%) which might help in better efficiency for growth environment in WR compared to WR in terms of enhanced nutrient and moisture availability which gave higher crop growth parameters and translated in producing more cobs. As the enrich moisture availability have significant positive interaction with nutrient mineralization, uptake and utilization by the crop. This subsequently enhanced cobs/plant and cobs/ha alongwith enhancement in cob length but no differences were observed for cob girth. This could be attributed to cob girth could be more genetically driven parameters of the crop which requires high management differences to get influenced significantly. Similarly, more cob/plant and less barrenness in fourth season ZT maize was recorded in MWMb system over MMuMb. The significantly higher leaf area was observed in MWMb system due to more nutrient supply lead to enhancement in these cob parameters. The increased cob parameters in ZT maize due to residue retention was also reported by Sarkar *et al.* (2007) and Choudhary *et al.* (2013).

The N management practices also significantly ($p<0.05$) influenced the cob parameters in ZT maize and significantly higher barrenness and lowest cobs/ha, cobs/plant, cob length and girth was observed in control compared to other practices. The enhancement in crop growth parameters could be attributed to increased leaf area, plant height and dry matter accumulation in ZT maize which gave significantly higher cob parameters due to enhanced photosynthetic areas for more resource utilization. The significant correlation among the growth parameters and cob parameters observed in this study supports our hypothesis of growth lead enhanced cob parameters. The barrenness in maize significantly reduced due to N fertilization as this is the main nutrient responsible for crop growth by way its direct involvement in photosynthesis as constituent of chlorophyll and its significant positive interactions with other nutrients utilization. Moreover, the hybrid maize responses to N fertilization also enhanced and under no fertilization the barrenness could be much higher and sometimes in low fertility soil it could not reproduce. The coated fertilizer increased these parameters more under residue retention conditions probably due to slow and continuous supply of N as per crop demand.

5.3.1. Other yield attributes

The yield attributes of fourth ZT maize was significantly influenced with maize and interaction effects of cropping system, residue management and N fertilization. The application of residue significantly increased grains/cob (426.2) and grain weight/cob (100.1) over WoR but other parameters were similar. There was no significant effect of cropping system on grain parameters of ZT maize. The increase of growth attributes and cob parameters in WR lead to better source-sink relationship which might enhance the grain/cob and grain weight/cob. The significant positive correlation of cob parameters and growth attributes with grain attributes found in our study supports our hypothesis of growth and cob parameters lead increased grain parameters in maize. Further, other parameters like 100-grains weight and grain rows/cob were found statistically similar amongst residue management practices probably these parameters are more genetically controlled and require more management difference to increase or decrease these significantly. The similar finding of enhanced yield attributes of maize under WR was also reported by Devkota *et al.*, 2013; Govaerts*et al.*, 2005; Govaerts *et al.*, 2006a; Govaerts *et al.*, 2006b; and Govaerts *et al.*, 2007.

However, the N management practices increased all these parameters significantly ($p<0.05$) compared to control and significantly higher grain rows/cob, grains/rows, grains/cob, grain weight/cob and 1000-grains weight were recorded with NCU which on par with SCU and PU but shelling (%) was significantly highest under NCU. The slow and continuous supply of N in coated fertilizer like NCU as evident from our study on mineral N at various crop growth stages lead to better crop growth and sink formation and culminated in better source-sink relationship. The advanced growth and sink lead increased grain parameters in maize hypothesis is further supported by significant positive correlation among these parameters in our experimentation (Table 5.1). The similar finding of enhancement in grain attributes in ZT maize was also reported in earlier studies (Noellsch *et al.*, 2009; Halvorson and Bartolo, 2014).

5.4. Yields of maize

The various yields (cob, stover, grain) in ZT maize was significantly influenced by main and interaction effect of residue, cropping system and N fertilization practices. The grain yield of maize increased significantly by 9.42% in MWMb system compared to MMuMb system beside increase in stover yield also. The progressive growth and yield attributes in maize lead to better source-sink relationship in maize which in turn gave higher grain and stover yields of maize due to enhanced mineral N at various crop growth stages found in this study. The yield attributes improve increased yield in particular treatment as supported by significant positive correlation in our study (Table 5.1). The residue application lead to increased grain yield of maize by 10.13% over WoR beside significant increase in cob and stover yields of maize. The better moisture regimes (Shen *et al.*, 2012) and better soil health parameters (Fuentes *et al*., 2009) could be the possible reasons for higher yields of maize in WR over WoR. Moreover, in this study application of residue found to decrease canopy temperatures which lead to lower water demand and thereby enrich mineral N content at various crop growth stages due to better soil moisture regime requires for mineralization.

Table 5.1. Correlation of yields with important growth and yield attributes of fourth zero-till maize.

Parameter#	LA	DMA	PH	CL	GRPC	GWPC	CY	SY
DMA	0.916**							
PH	0.935***	0.974***						
CL	0.931***	0.923**	0.980***					
GRPC	0.894**	0.962***	0.934***	0.897**				
GWPC	0.932***	0.966***	0.996***	0.967***	0.931***			
CY	0.960***	0.964***	0.994***	0.983***	0.945***	0.991***		
SY	0.928***	0.950***	0.916**	0.873**	0.986***	0.920**	0.938***	
GY	0.960***	0.979***	0.991***	0.967***	0.964***	0.989***	0.997***	0.960***

#LA: leaf area at 60 DAS, DMA: Dry matter accumulation at 90 DAS, PH: Plant height at 90 DAS, CL: cob length, GRPC: grain rows/cob, GWPC: grain weight/cob, CY: cob yield, SY: stover yield, GY: grain yield. The *,** or*** indicates significance at 5, 1 and 0.1% probability.

The N fertilization significantly increased ZT maize grain yields by 129.33% with NCU over control but this was at par with PU application and both were significantly superior over control and SCU. But the grain yield advancement in all N fertilization practices was more than 100%. However, the stover yield was significantly higher in NCU over all other practices which show that the biomass production capacity of maize enhanced due to NCU application but the culmination in grain yield was not much effective as of biomass. The application of N fertilizer lead to increased mineral N in soil at various crop growth stages in our study which lead to enhanced growth and yield attributes and finally better source-sink relationship gave higher yields of maize. Moreover, the yield is a function of the yield attributes and their efficiency in particular treatment resulting in increased yield naturally. The significant ($p<0.05$) interaction effects were found in all yields and the maximum grain yield was recorded in MMMb*WR*NCU followed by interaction among MMMb*WoR*PU application. In urea application over residue, more volatilization (Cancellier *et al.*, 2016) and immobilization of N (Rice and Smith, 1984; Thuy *et al.,* 2008 and Xu *et al.,* 2010) lead to lower mineral N availability of crop which caused decreased grain yield under residue condition by conventional urea application.

The similar effects reverse when urea is applied in no residue condition. However, the residue retention is key for success of ZT maize and is an integral part of conservation agriculture (CA). Thus, the other option of NCU under residue condition as one time basal application gives good opportunity for enhancing yield under CA. The coated fertilizer lead increased yield of ZT maize was also reported by (Gagnon *et al.*, 2012 and Sanjay-kumar *et al.*, 2015)**.** The enhanced enzymatic activities found in these treatments lead to increased yields which could be established by significant and positive correlation of the enzymatic activities found with yields of maize in our study (Table 5.2). However, in temperate environment conditions lower N mineralization rate caused decrease in grain yield maize with use of coated urea (Nelson *et al.,*2009, Grant *et al.*, 2012 and Farmaha *et al.*, 2013).

Table 5.2. Correlation of yields of fourth zero-till maize with soil enzymatic activities at flowering stage of the crop.

Parameter	Cob yield	Stover yield	Grain yield	DHA	FDA hydrolysis	MBC
Stover yield	0.938***					
Grain yield	0.997***	0.960***				
DHA	0.685**	0.675**	0.678**			
FDA hydrolysis	0.553	0.662**	0.559	0.816**		
MBC	0.710*	0.510	0.694*	0.392	0.412	
BG activity	0.919**	0.912**	0.916**	0.766*	0.810*	0.678**

The *,** or*** indicates significance at 5, 1 and 0.1% probability.

5.5. Economics of maize production

The economics in terms of cost of cultivation, returns and BC ration was significantly influenced by main and interaction effect of residue and N fertilization practices in fourth season ZT *kharif* maize grown in intensified cropping system. The MWMb cropping system enhanced ($p<0.05$) net returns and BC ratio to the tune of ₹7,327 and 0.30, respectively over the MMMb. Similarly, WR significantly boost gross returns to the tune of ₹7,712 over WoR but, there was no significant effect of residue management on net returns and BC ratio as the application of residue incurred ₹ 3,129 more cost of maize production than WoR. The economic profitability is the ultimate deciding factor for adoption of a technology by the framers. The advanced yield in MWMb and WR lead to increased gross returns but due to similar cultivation cost, net returns and BC ratio were higher in MWMb system which was not in the case of WR as the cost incurred for residue lead to similar net returns and BC ratio. The differential cropping system effect on the net returns was also reported in ZT maize by Parihar *et al.* (2016).

Among the N application practices, highest gross returns (₹100,774), net returns (₹77,153) and BC ratio (3.27) were obtained with NCU but net returns was at par with PU. The significant ($p<0.05$) interaction effects were also found in net returns and B C ratio of fourth ZT maize where highest net returns were obtained from the interaction between MWMb*NCU*WR (Fig. 4.3) while the highest BC ratio with MWMb*PU*WoR. However, both of these combinations were found at par statistically for net returns and BC ratio of fourth ZT maize. The enhanced grain and stover yield in NCU and PU resulted in increased net returns in these treatments. However, due to lower cost of cultivation in NCU significantly maximum BC ratio was recorded in this treatment. The lower cost of cultivation in NCU was due to the saving in labour charges on account of split application were more compared to enhanced costing for coating.

5.6. Resource-use efficiencies

5.6.1. Nutrient concentration and uptake

Significant ($p<0.05$) main and interaction effects of cropping system, residue and N management were found for grain and stover macro and micro-nutrient concentration. In MWMb cropping system, significantly higher Pconcentration in grain (0.28%) and

K concentration in stover (1.11%) was recorded over MMuMb. In WR, N concentration in grain (1.85%) and N (0.47%) and K (1.11%) concentration in stover and grain protein (11.58%) was significantly ($p<0.05$) higher over WoR. The N application by SCU gave significantly higher concentration of N (1.90%) and protein (11.86%) in grain and were significantly higher over PU and absolute control but at par with NCU. However, the P concentration in grain and stover was significantly higher with NCU which was at par with PU for grain and SCU for straw. The better soil supply of nutrients is key for higher nutrient density in grain and stover. The enhanced concentration of N and protein in SCU and NCU was due to better supply of N throughout growth period which in turn increased its uptake and culminated in higher protein subsequently. However, the other nutrients concentration also increased with MWMb and WR which might be due to enhanced soil availability and better biological and physical soil health observed in our study. The better soil moisture regimes in these treatments of WR also plays significant role in mineralization of native nutrients as well as applied nutrients which in turn increases density of nutrients in final products. Moreover, the N has significant positive interaction with P and K and hence increase of N increased their concentration maize grain and stover also. The similar findings of increased nutrient concentration by residue application (Etchevers *et al.*, 2000; and Fuentes *et al*., 2009), cropping system effect (Yadav *et al.*, 2016; and Dikgwatlhe *et al.*, 2014) and coated fertiliser effect (Awaad, 2013) was also reported in many earlier studies.

In MWMb, improved N and P uptake in grainsignificantly higher P uptake (29.74 kg/ha) recorded in MWMb. The NCU recorded significantly higher uptake in grain and stover but N and P in grain and straw was at par with PU and SCU however it was higher than control in all N application treatment. Similarly, K uptake in grain and straw was statistically similar in NCU and SCU and significantly higher over absolute control. The uptake is a function of concentration and the yields of the sink and thus increased concentration as well as yield lead to further enhancement in uptake of NPK in maize and stover in the respective treatments. Moreover, the well proven synergistic interaction among these macro-nutrients enhanced uptake of each other in final product.

Significantly higher Zn concentration in grain (30.77 Zn mg/kg DM) was recorded in MWMb but rest were found statistically similar. In WoR, Cu concentration in grain was observed significantly higher over WR but Fe and Zn concentration in grain (38.19 and 33.48 mg/kg dry matter) were significantly ($p<0.05$) higher with WR compared to WoR. Significantly higher Cu concentration in grain (24.23 Cumg/kg DM) was recorded with PU over absolute control and SCU but it was statistically on par with NCU. Further, NCU recorded significantly higher Zn (32.87 Zn mg/kg DM) over PU and absolute control but it was statistically at par to SCU. However in stover, significantly higher Fe (405.3 Fe mg/kg DM) concentration was recorded with SCU while significantly higher Zn (16.24 Zn mg/kg DM) recorded in absolute control compared to NCU but it was at par to PU and SCU. Moreover, Fe concentration with PU and NCU were found at par with SCU. The uptake of Zn and Fe by grain and stover significantly increased in MWMb over MMuMb cropping system and WR over WoR. The enhancement of Fe uptake by WR was to the tune of 33 g/ha and 446 g/ha by grain and stover, respectively while it was Zn uptakeincreased by 62.9 g/ha and 21.5g/ha in grains and stover, respectively over WoR. This could be due to more yield in these treatments (MWMb and WR) lead to enhanced uptake besides having at par nutrient concentrations. Among N management practices, NCU significantly enhanced the uptake of Fe (144 g/ha) and Zn (142.27 g/ha) by grain and uptake of Cu (54.7 g/ha) and Fe (2634 g/ha) by stover but Fe uptake was at par with the SCU and PU by grain and Cu uptake was at par with PU by stover. However, Cu uptake in grain significantly increased by PU which was at par with the NCU. However, the concentration was mixed but the higher yield level increased the uptake significantly.

These micronutrients had a mixed effect for their concentration and uptake as concentration of one nutrient enriched decreased others. However, the increased concentration of Fe and Zn in grain and their uptake with residue retention could be attributed to recycling of the sub-surface nutrients over surface through residue decomposition and which, thereby increase availability of nutrients in surface soil layers compared to WoR in our study. Moreover, in WOR these nutrients have trade-off due to removal of all stover containing these precious metals which causes nutrient mining. The enhanced in Fe and Zn concentration in grain due to residue application was also reported by Parihar *et al*. (2016b).This shows that this could be a potential strategy for fortification of these nutrients in maize grain and stover specially Fe and Zn and can be used for production of quality grains.

5.6.2. Nitrogen-use efficiency (NUE)

The PFP_N (44.62kg grain/kg N applied) was significantly enhanced by MWMb, which was 9.28% higher compared to MMuMb. The WR resulted in increased PFP_N (44.34 kg grain/kg N applied) to the tune of 7.86% over WoR. However, the cropping system and residue management had no significant effect on AE_N, ANR and PE_N. Among N fertilizer sources, AE_N, ANR, PE_N andPFP_N were recorded significantly higher with the application of NCU, which was at par with PU in PFP_N andAE_N. Interaction between MWMb*NCU significantly enhanced AE_N, PFP_N and $PE_{N,}$ but ANR was significantly enhanced by the interaction between MMMb *SCU. Similarly, interaction between WR*NCU enhanced the AE_N, PFP_N and $PE_{N,}$ but ANR was significantly improved with the interaction between WoR*SCU.

The more yield sunder MWMb and WR increased PFP_N but due to their non-involvement in direct N supply the other efficiencies were found non-significant. The application of NCU resulted better for enchaining all the N-use efficiencies primarily due to higher yield levels in this treatment. However, continuous supply of mineral N throughout cropping season with lesser losses due to volatilization and leaching (Jacobs, 2004; Carreres, 2003; and Cong, 2010) caused enhanced N-use efficiencies under residue conditions. However, more volatilization losses upon urea application on residue (Cancellier *et al.*, 2016) and lesser mineral N availability in PU in our study was responsible for lower N efficiencies in ZT maize. In addition to this, fertilizer placement in soil and broadcasting over soil surface always has good differences in terms for N availability in which former is always winner. The similar findings of enhanced N-use-efficiency in ZT maize was also reported by Hobbs and Gupta (2004).

5.6.3. Water-use efficiency (WUE)

The total water input during the growing season was mostly contributed by rainfall (823.9 mm) but the effective rainfall (ER) was only 419 mm. The irrigation water input was higher in MMuMb and WoR plots compared to MWMB and WR plots, respectively. The significantly higher WUE for effective or total rainfall was found in MWMb system and under WR.The enhancement in WUE could be attributed to better moisture regimes (Shen *et al.*, 2012; Erenstein and Laxmi, 2008) in residue retention and enhanced yield due to better soil health. The similar findings were also reported by Pelegrin *et al.*, 1990; Mahboubi *et al.*, 1993; Norwood, 1994 and Lampurlanés *et al.*, 2001. However, the water productivity (WP) in terms of net return ₹/m^3 of water was significantly higher in MWMb system and residue had no significant effect on it due to no significant effect of residue application on net returns of the maize. The N application by NCU gave significantly higher WUE and WP over control and SCU which was at par with NCU. Significant ($p<0.05$) residue*nitrogen interactions were found in WUE and WP of fourth ZT maize where NCU outperformed under WR while PU under WoR conditions. The increased yields under this treatment combination due to better soil moisture regimes might help in nutrient mineralization and uptake and thus resulted in enhancement in WP and WUE. The synergistic effect of water and nutrients, where in, efficiency of one factor increases with better management of another one and thus enhanced NUE lead to higher WUE. Results of our findings corroborate with the finding of (Devkota *et al.*, 2013; Tolk *et al.,* 1999).

5.7. Soil properties

5.7.1. Soil physical properties

It was observed that in most of the cases, the BD was decreased in 0-10 cm soil depth compared to initial but it increased in control and WoR treatments over initial values at below 10 cm soil depths due to field under CA from last three years of study. There was no significant effect of cropping system but WR significantly decreased the soil BD over WoR at all six depth of soil (0-60 cm) after harvest of fourth ZT maize. Among the N management practices, the application of different N fertilizers significantly decrease in the soil BD values at different depth was observed with application of NCU/SCU and in most of the cases PU also compared to absolute control.The enhancement in soil organic carbon due to residue application lead to decreased BD of soil. A significant positive negative correlation of BD with TOC (-0.589*) found in our study further confirms our assumptions of lower BD with increased TOC. Similar findings were also reported by Parihar *et al*. (2016a) in similar agro-ecologies.

Similar to soil BD, the penetration resistance (PR) at six depths measured where WR significantly decreased the PR over WoR in five out of six soil depths of the profile; there was no significant decrement/decline in PR in the first layer (0-10 cm). The residue removal however increased PR compared to WR at below 20 cm depths. Among the N management practices, there was no significant effect of PU, SCU and NCU on PR in five out of six layers/depths of soil profile but application of NCU significantly decreased the PR in the first layer (0-10 cm) compared to application of SCU and PU and absolute control.The increase in TOC leads to decrease in BD of soil which resulted in lower PR at various soil depths (Parihar *et al.*, 2016a). A significant positive correlation with BD and negative correlation of PR (-0.835**) with TOC at 0-15 cm depth found in our study further confirms our assumptions.

5.7.2. Soil nutrient status

Significant reduction in soil pH was found at various depths due residue application while WR improved the available mineral N and other nutrients in the soil compared to WoR. The residue application over period of time recycled nutrients from sub-soils to the surface and thus enhanced their availability in soil due to enhanced soil biological activities. The acid secretion from residue decomposition might decrease the Ph in soil compared to WoR. Similar finding of improved soil nutrient status due to residue application was also reported by (Etchevers *et al.,* 2000 and Lafond *et al.,* 2005) for mineral N, (Woźniak and Makarski, 2012 and Wozniak *et al*., 2014) for micronutrients by Lou *et al.* (2012) and Govaerts *et al.* (2007) for available K. Moreover, the residue application enhanced the TOC at all soil depths in our study. The application of residue lead to enhanced shoot growth which in turn enhanced the root biomass of the crop and its subsequent decomposing might increased the TOC in sub-soils also beside more residue recycling lead to increased TOC at surface soil depths. The infiltration of water might also helps in the TOC movement from surface to sub-surface layer which in turn also enhanced the TOC in sub-surface layers. As organic acts as source and sink for nutrients and its enrichment in WR help to increase nutrient status in soil. These results corroborated with findings of by Balota *et al.* (2004); Wakelin *et al*. (2007); Doran and Parkin, (1994); and Gregorich *et al.* (1994).

At the same time, mixed effect of cropping system was observed for TOC where MWMb increased in surface (0-15 cm) while MMuMb in sub-soil (15-30 cm) which could be attributed to differential rooting behaviour of mustard and wheat where mustard root biomass is more in sub-surface and for wheat it is higher in surface soil. The effect of cropping system on soil TOC was also observed by Parihar *et al*. (2016a) in similar agro-ecologies. This lead to mixed effect on mineral N in soil at different growth stages while increased micro-nutrient and K was observed in MWMB system probably due to higher biomass production lead to higher residue recycling.

The application of coated fertilizer NCU led to increased TOC at 0-30 cm depth significantly ($p<0.05$). The higher stover yield observed in this treatment was also observed in earlier crops and thus recycled more shoot and root biomass in this treatment and thus increase in TOC was found. However, all fertilizer treatments increase it significantly over control due to more root and shoot biomass recycling in CA. These enhancements in TOC lead to increased availability of mineral N as carbon acts as source and sink for the N in soil. Further, this also lead to increased K content and other micro-nutrient in soil due to more residue recycling in surface soil (0-15 cm). Moreover, the more residue recycling boost biological activities which might advance the mineralization of nutrients in the soil and in turn increased their availability in soil. The finding of Etchevers *et al.* (2000) corroborates with our results.

5.7.3. Soil biological properties

5.7.3.1. Microbial biomass carbon

The significant ($P<0.05$) interaction and main effects of cropping system, residue and management and crop rotations were observed on soil microbial biomass carbon (MBC) at 0-15 cm soil depth at flowering and harvest of 4^{th} year ZT kharif maize crop at fixed site. MWMb cropping system significantly increased the microbial biomass carbon (MBC) up to 507 µg C/g soil which was higher by 2.84% over MMMb at flowering stage and WR significantly increased the MBC after harvesting up to 374 µg C/g soil over WoR. Similarly, N fertilization increased MBC over control at both the stages. In general higher MBC values recorded at flowering compared to harvest stage which shows that higher microbial activities found when there is maximum root biomass present in the soil. The enhanced residue recycling might help in increased TOC, which thereby improves MBC in soil. In our study, the SOC content and MBC had significant positive correlation with each other (r=0.874**). Thus, the higher MBC was due to higher SOC content (Singh *et al*. 2009 and Parihar *et al*. 2016a).

5.7.3.2 Soil enzymatic activities

The significant ($P<0.05$) interaction and main effects of cropping system, residue and management and crop rotations were observed on soil enzymatic activities at 0-15 cm soil depth at flowering and harvest of 4th ZT kharif maize crop at fixed site. WR significantly enhanced the activity of dehydrogenase (DHA) over WoR. Among the N management practices, DHA activity increased significantly with the application of NCU and lowest activity was found in absolute control at flowering, significantly higher FDA activity was observed in MMuMb over MWMb and WR over WoR. Further, among N fertilization practices, NCU application recorded highest activity at flowering followed by SCU and PU application. However, N fertilization by SCU significantly improves the FDA activity, which was at par with the fertilization by NCU. Significantly higher *ß* Glucosidase activity was recorded under WR compared to WoR. In case of N management, NCU application was found to be superior for *ß* Glucosidase activity followed by PU and SCU. All these enzyme activities were significantly ($p<0.05$) and positively correlated with the TOC and MBC of the soil at 0-15 cm depth (Table 5.3).

Table 5.3. Correlation of total organic carbon at different soil depths with enzymatic activities at harvest.

Parameter	**TOC at harvest (0-15 cm)**	**TOC at harvest (15-30 cm)**	**TOC at harvest (30-45 cm)**	**DHA at harvest**	**FDA activity at harvest**
TOC at harvest (15-30 cm)	0.509*				
TOC at harvest (30-45 cm)	0.577*	0.675*			
DHA at harvest	0.883**	0.838**	0.756*		
FDA activity at harvest	0.270	0.452	0.491	0.509*	
BG at harvest	0.614*	0.755*	0.915**	0.827**	0.707*

The *,** or*** indicates significance at 5, 1 and 0.1% probability.

The similar higher soil microbial enzymatic activities due to conservation tillage or legumes were also reported by Gajda *et al.* (2013). On the basis of large number of published data across cropping systems and tillage practices, Stott *et al*. (2010) concluded that BG activity directly correlates with SOC which explains 94% variation in its activities and can be used as a sensitive indicator of soil quality.

SUMMARY AND CONCLUSIONS

A field experiment entitled '**Nitrogen management under conservation agriculture in maize (*Zea mays* L.)'** was carried out on sandy loam soil during *kharif* 2015 in block '9B' of experimental farm of the ICAR-Indian Agricultural Research Institute, New Delhi. The objectives of the experiment were to investigate the effect of slow release nitrogen fertilizers on crop performance and economic benefit, input use-efficiency and changes in physico-chemical and biological properties of soils in maize under conservation agriculture. The experiment was laid out in a split-split plot design and replicated thrice comprising combination of two cropping systems in main plots *viz.,* Maize-mustard-mungbean (MMMb) and maize-wheat-mungbean (MWMb), residue management practices in sub-plots *viz*., permanent bed with residue removal (WoR) and permanent bed with residue retention (WR) and N management practices in sub-sub-plots *viz.*, absolute control, recommended dose of N (RDN) through prilled urea (PU), sulphur coated urea (SCU) and neem coated urea (NCU).

The soil of the experimental field was low in nitrogen, medium in available phosphorus and available potassium with slightly alkaline in reaction. The climatic condition during experimental period was although congenial, the quantum of rainfall was optimum but its distribution was not uniform resulting in dry spell during crop growing period needed two irrigations. The crop stand of maize *cv*. DHM 117 was excellent without any severe problem of either insect pests or diseases due to its resistance to major pests and diseases and tolerance to moisture stress. All the observations on crop were recorded at regular intervals and chemical analysis was carried out as per the standard procedures. The salient findings of the investigation are summarized in this chapter under following paragraph:

1. Maximum plant population (75,000 plants/ha) at harvest was recorded with NCU application. Cropping system and residue management did not affect the plant population. Significant and maximum plant height was observed at 30, 45 DAS and at harvest (74, 159 and 222 cm) with the NCU application and SCU and PU at 45 DAS and at harvest of maize. Similarly in residue retention was observed (65.3, 150.6 and 211.5 cm) respectively, and at 45 DAS (158 cm) under MWMb cropping system.

2. Significantly superior in dry matter accumulation (DMA), leaf area and leaf area index (LAI) were recorded with application of NCU at 30, 60 and 90 DAS and leaf area index (LAI) under MWMb cropping. Higher LAI was found in MWMb cropping system, residue retention and NCU application.
3. Crop growth rate and relative growth rate were found significant and higher under NCU treatment during 0-30 DAS, 30-60 DAS and 60-90 DAS. Further, SCU and PU were found at par with NCU and at 30 DAS in residue management. Further, at 60 and 90 DAS residue management was recorded significantly in net assimilation ratio (NAR) with PU application and residue retention at 60 DAS and 90 DAS.
4. Days to take 50% tasseling and silking were recorded highest in control plots (61.5 and 70 days) compared to lowest PU (51.9 days and 59.9 days), Further, application of SCU (52.4 and 60.7 days) and NCU (52.6 and 59.6 days) were statistically at par. Days to 50% maturity were found to be non significant with nitrogen management practices. Reproductive period recorded highest (49.6 days) with the application of NCU which was on par with the application of PU and SCU.
5. Significantly higher NDVI at 30 DAS (0.566) and SPAD value at 30 and 90 DAS (52.9 and 48.4) were recorded with application of NCU. However, PU (0.552, and 50.9) and SCU (38.9 and 48.4) were at par with NCU, at 60 (0.638, 0.486) and 90 DAS (0.637 and 0.509) were at par with PU in NDVI and SPAD respectively, while at 60 DAS (41.8) PU recorded significant and NCU (38.9) was at par with PU. Canopy temperature depression (CTD) significantly influenced by residue management practice at 60 DAS.
6. In cob parameters, significantly superior in no. of cobs/ha (70.4), cobs/plant (0.962 cobs/plant) and cob length (18.7 cm) recorded with residue retention, however lower barrenness were recorded under MWMb and cobs/plant cropping system and residue retention. Residue retention enhanced the all of cob parameters and decreased the barrenness of cobs compared to residue removal. Significant in cob length and cob girth recorded in PU, however application of SCU and NCU were on par. Further, cobs/ha and cobs/plant resulted significant in NCU and SCU was at par.
7. Residue retention recorded higher grains/cob (426.2) and grain weight/cob (100.1) over residue removal (417.7 and 96.4), respectively. Among N management

practices, NCU application improved the all of yield attributes significantly *viz.*, grain rows/cobs (13.7), grains/row (33.7), grains/cob (459.4), grain weight/cob (111.5g), shelling (80%) and test weight (254.9 g). However, application of PU and SCU were at par with NCU in all the yield attributes.

8. Significantly superior yield *viz.*, stover (10589 kg/ha) and grain yield (5786 kg/ha) under MWMb cropping system, cob (7548 kg/ha), stover (10489 kg/ha) and grain yield (5804 kg/ha) in residue management was recorded. Application of NCU *viz.*, cobs (8382 kg/ha), stover (11989 kg/ha) and grain (6701 kg/ha) were superior over SCU, PU and control. However, SCU resulted in significantly higher HI than control (33.7%) over control (25.3%), but it was statistically at par with PU and SCU application in our study.
9. Data on economics revealed that MWMb cropping system enhanced the gross returns (₹87254), net returns (₹63654) and BC (2.67) ratio to the tune of 9.32%, 13% and 12.66%, respectively over the MMMb cropping system. Permanent bed with residue retention enhanced the gross returns to the tune of 9.68% over the permanent bed without residue retention. Among the application of PU and coated ureas, highest gross returns (₹100774), net returns (₹77153) and BC ratio (3.27) obtained by the application of NCU, net returns fetched by NCU was at par with the application of PU. Highest net returns and BC ratio were obtained by the interaction between MWMb*NCU*WR while the highest BC ratio with MWMb*PU*WoR. However, both of these combinations were found at par statistically for net returns and BC ratio of fourth ZT maize.
10. P concentration in grain and K concentration in stover was significantly higher in MMuMb cropping system. No significant effect was observed in case N and K concentration in grain, N and K concentration in stover and in grain protein content between cropping systems. Residue retention increased the N concentration in grain and N and K concentration in stover. Among N management practices, highest protein content (11.86%) obtained with application of SCU. Variable effects on concentration of N, P and K in grain and stover were observed.
11. Significantly, higher uptake of N (106 kg/ha) and P (16.71 kg/ha) by grain and uptake of P by stover (29.74 kg/ha) was recorded under MWMb cropping system over MMuMb cropping system. Residue retention also increased the uptake of N by grain (19.2 kg/ha) and N (6.7 kg/ha) and K (14.6 kg/ha) by stover compared

residue removal. Highest N, P and K uptake by grain and stover was recorded with the application of NCU application.

12. There was no significant effect between cropping systems on the uptake of Cu by grain and stover, uptake of Fe by the grains and Zn by the stover while uptake of Zn (180.6 kg/ha) and Fe (3952 g/ha) by grain and stover was significantly increased in MWMb over MMuMb cropping system. Residue retention increased the concentration Fe (2.62 mg/kg grain increase) and Zn (7.48 mg/kg grain increase) in grain. However, Cu concentration recorded significantly higher under residue removal (22.96 mg/kg grain) compared to residue retention (21.65 mg/kg grain). Significant interaction of residue*system, residue*nitrogen and system*nitrogen was found for uptake of different micronutrients differently.
13. The irrigation water input was higher in MMuMb and WoR plots compared to MWMb and WR plots, respectively. The significantly higher WUE for effective or total rainfall was found in MWMb system and under WR. However, the water productivity (WP) was significantly higher in MWMb system and residue had no significant effect on it. The N application by NCU gave significantly higher WUE and WP over control and SCU which was at par with PU. Significant ($p<0.05$) residue*nitrogen interactions were found in WUE and WP of fourth ZT maize where NCU outperformed under WR while PU under WoR conditions.
14. The PFP_N (44.62 and 44.34 kg grain/kg N applied) was significantly enhanced by MWMb and WR, respectively. Among N fertilizer sources, AE_N, ANR, PE_N and PFP_N were recorded significantly higher with the application of NCU, which was at par with PU in PFP_N and AE_N. Interaction between MWMb*NCU and WR*NCU significantly enhanced AE_N, PFP_N and $PE_{N,}$ but ANR was significantly enhanced by the interaction between MMuMb *SCU and WoR*NCU.
15. Significantly decreased in the soil BD was observed in WR retention over WoR in all six layers of soil after harvest of fourth ZT maize. Among the N management practices, the application of different N fertilizers significantly decrease in the soil BD values at different depth was observed with application of NCU/SCU and in most of the cases PU also compared to absolute control. Significant interaction effects of residue*system and system*nitrogen in sub-soil layer while residue *nitrogen in almost all soil layers was observed for soil BD after harvest of fourth maize crop in sandy loam soil.

16. WR significantly decreased the PR over WoR in five out of six soil depths of the profile. The residue removal however increased PR compared to WR at below 20 cm depths. Further, among the N management practices application of NCU significantly decreased the PR in the first layer (0-10 cm) compared to application of SCU and PU and absolute control.
17. No significant difference was observed in soil pH at 0-15 cm, 15-30 cm and 30-45 cm depth of soil between cropping systems. However, residue retention decreased the soil pH at 0-15 cm, 15-30 cm and 30-45 cm depths of soil. The N management practices had varied effect on soil pH and NCU and control in 0-15 cm depth while PU and SCU at 15-30 cm depth and NCU at 30-45 cm depth gave significantly higher pH values over others. Significant ($p<0.05$) system*nitrogen, residue*system and residue*nitrogen interaction s were found in sub-soil depths for soil pH values.
18. Cropping system and residue retention significantly enhanced the total organic carbon (TOC) at 0-15 cm and 15-30 cm depth, however no significant effect was observed at 30-45 cm depth. NCU application enhanced the TOC at soil depth of 0-15 cm, 15-30 cm and 30-45 cm. Significant residue*nitrogen and system*nitrogen effects were observed in TOC at top soil (0-30 cm depths).
19. No significant effect of cropping system on mineral N content at all the stages except at 65 DAS when MMMb cropping system recorded significantly higher mineral N (11kg/ha) over MWMb cropping system. PB+R significantly improved the mineral N content (kg/ha) by 32.2, 28.6, 12.6, 13.4 and 13.4 kg/ha at 30 DAS, 45 DAS, 90 DAS and after harvest, respectively except at before sowing when PB+R was found to be non significant. NCU application significantly increased the mineral N content at before sowing, 30 DAS, 65 DAS and after harvest at 0-15 cm depth over PU, SCU and absolute control.
20. PB+R significantly enhanced available K to the tune of 266.6 kg K/ha which is higher by 10.07% in value at 0-15 cm soil compared to PB-R after harvest. The MWMb had significantly higher available K at 0-15 cm depth compared to MMuMb system.
21. Significant increase in availability of Fe (21.28%) and Zn (20.91%) was recorded under MWMb cropping system by over MMMb cropping system. PB+R increased the Cu content by 0.70 mg/kg of soil compared to WoR. While N

management practices had no significant effect on availability of Fe and Zn also. No interaction was observed in case of micronutrient (Cu, Fe and Zn) availability.

22. An increase in microbial biomass carbon (MBC) 14 µg C/g soil was recorded under MWMb cropping system compared to MMMb cropping system. Residue retention increased the MBC by 10 µg C/g soil over residue removal after harvesting. Highest MBC was recorded with SCU application (571 µg C/g soil) at flowering and with PU application (400 µg C/g soil) after harvesting.
23. Highest activity of dehydrogenase (34.8 µg TPF Rel/g/day), Floresein diacetate (0.722 µg Florescein/g/hr) and ß Glucosidase (43.1 µg p-NP Rel/g/24 hr) recorded with NCU application at 0-15 cm soil depth on flowering stage. MWMb cropping system and residue retention also had positive impact on improving enzymatic activity at flowering. After harvesting, significantly improved ß Glucosidase activity (42.1 µg p-NP Rel/g/24 hr) was observed under MMuMb cropping system compared to MWMb cropping sytem. Residue retention significantly increased the dehydrogenase (6.7 µg TPF Rel/g/day increase) and ß Glucosidase (13.1 µg p-NP Rel/g/24 hr increase) over residue removal. Highest activity of dehydrogenase (29.1 µg TPF Rel/g/day) and ß Glucosidase (46.8 µg p-NP Rel/g/24 hr) recorded with NCU application at 0-15 cm soil depth after harvesting. However, highest floresein diacetate enzyme activity (0.426 µg Florescein/g/hr) was recorded with SCU application.

CONCLUSIONS

1. The application of neem coated urea (NCU) @ 150 kg N/ha as basal significantly enhanced growth parameters, yield attributes and that resulted in increased zero-till maize yield and significantly highest BC ratio (3.27) over conventional prilled urea application. However, under no residue condition prilled urea gave the highest net returns and BC ratio.
2. The application of slow release N fertilizers especially NCU and SCU improved nitrogen and water use efficiencies in zero-till maize.
3. Application of residue and nitrogen fertilization improved physico-chemical and biological properties of the soil.

EPILOGUE

The research may be undertaken for quantification of the N losses with application of either coated or non-coated urea or other modified fertilizers under residue retention in different cropping system in varied agro-ecologies. Hence, the interaction among cropping system with residue and N application was observed which warrants that these practices must be generated for each cropping system independently to harness maximum benefit of coated fertilizers.

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ABSTRACT

The application of nitrogen in conventional way under residue retention in conservation agriculture attracts losses due to volatilization and immobilization that leads to lower crop yields and resource-use efficiency that gives more environmental footprints and decreases farm profitability. A field study was conducted on **'Nitrogen management under conservation agriculture in maize (*Zea mays* L.)'** during *kharif* 2015 in an ongoing long-term experiment since 2012 at New Delhi. The soil of the experimental site was sandy loam in texture with neutral pH having low N, medium P and high K availability. The treatments consisted of two cropping systems: maize-mustard-mungbean (MMuMb) and maize-wheat-mungbean (MWMb); two residue management practices of with (WR) and without residue (WoR) and four N management practices of control, prilled urea (PU), sulphur coated urea (SCU) and neem coated urea (NCU) arranged in split-split plot design and replicated thrice. The growth parameters and yield attributes of maize were enhanced by the application of WR, MWMb and NCU. After water stress significant decrease in canopy temperature was recorded with WR (-3.39 ^{0}C) compared to WOR (-1.84 ^{0}C). Significantly superior yields *viz.*, stover (10589 kg/ha) and grain yield (5786 kg/ha) under MWMb, cob (7548 kg/ha), stover (10489 kg/ha) and grain yield (5804 kg/ha) in residue management while, cobs (8382 kg/ha), stover (11989 kg/ha) and grain (6701 kg/ha) by application of NCU were recorded. However, SCU resulted in significantly higher HI (33.7%) than control (25.3%), but it was statistically at par with PU (33.2%) and NCU (32.8%) application in our study. The significant effect on the N, P, K, Fe, Zn and Cu concentration and uptake of maize grain and stover was recorded with residue, cropping system and N fertilization practices. The treatments of WR, MWMb and NCU recorded higher PFP, AE, ANR and PE of applied N along with enhancement in water productivity and its efficiency. These treatments recorded lower bulk density and penetration resistance in soil with enhancement of organic carbon at different depths. The increase in mineral N at various crop growth stages and other nutrients availability at harvest (Fe, Zn, Cu and K) was also found in WR, MWMb and NCU treatments. However, at 45 DAS significantly highest mineral N was recorded in PU where split application was done at 30 DAS. The microbial biomass carbon and enzymatic activities (dehydrogenase, floresein diacetate and ß Glucosidase) were also recorded significantly higher by WR at flowering and at harvest stage of the crop. Similarly, MWMb cropping system enhanced the net returns and BC ratio to the tune of 13.0 and 12.7 per cent, respectively over the MMMb but no significant effect or residue was found on these parameters. Among the N application, significantly highest net returns (₹77153) and BC ratio (3.27) were obtained by the application of NCU, net returns fetched by NCU was at par with the application of PU. However, the highest net return was obtained by the interaction between MWMb*NCU*WR while the highest BC ratio was recorded with MWMb*PU*WoR which was at par with MWMb*NCU*WR in fourth ZT maize. It was concluded that the basal application of NCU and residue retention in MWMb system found significantly superior for enhancing yield, profitability, resource-use efficiency and soil health in maize under conservation agriculture.

सारांश

संरक्षण कृषि में मृदा सतह पर फसल अवशेष होने की परिस्थिति में नत्रजन उर्वरक का प्रयोग परम्परागत तरीके से करना वाष्पीकरण एवं स्थिरीकरण से होने वाले नुकसानों को आकर्षित करता हैं जो कि फसल उपज एवं संसाधन प्रयोग दक्षता में कमी को बढ़ावा देता हैं, जिससे पर्यावरण प्रदूषित होने के साथ साथ कृषि की लाभप्रदता कम होती हैं। नई दिल्ली में 2012 से चल रहे दीर्घकालीन परीक्षण में, खरीफ 2015 के दौरान, एक अध्ययन **'संरक्षण कृषि के अंतर्गत मक्का (*जीया मेज* एल.) में नत्रजन प्रबंधन'** पर किया गया। अनुसंधान स्थल की मृदा उदासीन पी एच वाली एवं रेतीली दोमट प्रकार की थी, जिसमें नत्रजन की उपलब्धता कम, फॉस्फोरस की मध्यम एवं पोटैशियम की उपलब्धता अधिक थी। अध्ययन परीक्षण में दो फसल प्रणालियाँ: मक्का-सरसों-मूंग एवं मक्का-गेहूं–मूंग; दो अवशेष प्रबंधन क्रियाएं: बिना अवशेष एवं अवशेष सहित और चार नत्रजन प्रबंधन क्रियाएं: नियंत्रित (पोषक तत्व रहित), साधारण यूरिया, सल्फर लेपित यूरिया एवं नीम लेपित यूरिया को द्विखंडित भूखंड रचना में तीन बार दोहराते हुए व्यवस्थित किया गया। मक्के के वृद्धि मानकों एवं उपज कारकों में अवशेष सहित, मक्का-गेहूं–मूंग फसल प्रणाली और नीम लेपित यूरिया के अनुप्रयोग से वृद्धि दर्ज की गई। मृदा जल तनाव के बाद अवशेष रहित (-1.84 डिग्री सेल्सियस) की तुलना में, पादप आच्छादन तापक्रम में अवशेष धारण के साथ (-3.39 डिग्री सेल्सियस) उल्लेखनीय गिरावट दर्ज की गयी। उल्लेखनीय रूप से बेहतर पैदावार मक्का-गेहूं–मूंग फसल प्रणाली से कडवी (10589 किग्रा/है.) व दाने की उपज (5786 किग्रा/है.); अवशेष अवधारण से कडवी (10489 किग्रा/है.), भुट्टे (7548 किग्रा/है.) व दाने की उपज (5804 किग्रा/है.); नीम लेपित यूरिया से कडवी (11989 किग्रा/है.), भुट्टे (8382 किग्रा/है.) एवं दाने की उपज (6701 किग्रा/है.) दर्ज/प्राप्त की गई। हमारे अध्ययन में, हालांकि, सल्फर लेपित यूरिया (33.7 प्रतिशत) के प्रयोग से फसल कटाई सूचकांक में नियंत्रित(25.3 प्रतिशत) की अपेक्षा उल्लेखनीय वृद्धि दर्ज की गई, लेकिन यह साधारण यूरिया (33.2 प्रतिशत) एवं नीम लेपित यूरिया (32.8 प्रतिशत) के साथ सांख्यिकीय रूप से समान था। मक्का के दानों एवं कडवी में नत्रजन, फॉस्फोरस, पोटैशियम, तांबा, लोहा और जस्ता की मात्रा व अंतर्ग्रहण पर फसल प्रणाली, अवशेष प्रबंधन एवं नत्रजन प्रयोग का उल्लेखनीय प्रभाव दर्ज किया गया। मक्का-गेहूं–मूंग फसल प्रणाली, अवशेष अवधारण और नीम लेपित यूरिया की पारस्परिक क्रिया ने सर्वाधिक प्रयुक्त नत्रजन की आंशिक कारक उत्पादकता, शस्य दक्षता, प्रत्यक्ष नत्रजन पुनर्प्राप्ति एवं पादप कार्यिकीय दक्षता के साथ-साथ जलोत्पदकता एवं जल दक्षता में भी वृद्धि की। इसी पारस्परिक क्रिया से मृदा के आभासी घनत्व एवं भेदन प्रतिरोधकता में कमी के साथ-साथ, मृदा की विभिन्न गहराइयों पर कार्बनिक कार्बन में वृद्धि दर्ज की गई। विभिन्न फसल वृद्धि अवस्थाओं पर खनिज नत्रजन में वृद्धि और फसल कटाई के समय अन्य पोषक तत्वों (पोटैशियम, तांबा, लोहा और जस्ता) की उपलब्धता में वृद्धि भी मक्का-गेहूं–मूंग फसल प्रणाली, अवशेष अवधारण और नीम लेपित यूरिया की पारस्परिक क्रिया के साथ पायी गई। यद्यपि, सर्वाधिक खनिज नत्रजन बुवाई के 45 दिन बाद वहाँ दर्ज किया गया, जहाँ बुवाई के 30 दिनों बाद साधारण यूरिया से नत्रजन प्रयुक्त की गई। पुष्पन एवं कटाई की अवस्था पर, सर्वाधिक सूक्ष्मजीव जैविक कार्बन एवं एंजाइम सक्रियता (डिहाइड्रोजिनेज, फलोरीसीन डाइएसीटेट एवं बीटा ग्लुकोसिडेज) भी अवशेष अवधारण के साथ दर्ज की गई। मक्का-गेहूं–मूंग फसल प्रणाली ने मक्का-सरसों-मूंग की तुलना में शुद्ध आय और लाभ लागत अनुपात में क्रमशः 13 एवं 12.7 प्रतिशत की वृद्धि दर्ज की गई, परन्तु इन मापदंडों पर अवशेष प्रबंधन का कोई उल्लेखनीय प्रभाव नहीं देखा गया। नत्रजन प्रबंधन में, सर्वाधिक शुद्ध आय (₹ 77153) एवं लाभ लागत अनुपात (3.27) नीम लेपित यूरिया के प्रयोग से हुई, नीम लेपित यूरिया के द्वारा प्राप्त शुद्ध आय सांख्यकीय रूप से, साधारण यूरिया के समान थी। यद्यपि, मक्का-गेहूं–मूंग फसल प्रणाली, अवशेष अवधारण और नीम लेपित यूरिया की पारस्परिक क्रिया द्वारा सर्वाधिक शुद्ध आय प्राप्त हुई, जबकि सर्वाधिक लाभ लागत अनुपात मक्का-गेहूं–मूंग फसल प्रणाली, अवशेष रहित और साधारण यूरिया की पारस्परिक क्रिया के साथ दर्ज किया गया, जो कि मक्का-गेहूं–मूंग फसल प्रणाली, अवशेष अवधारण और नीम लेपित यूरिया की पारस्परिक क्रिया के लगभग समान था। यह निष्कर्ष निकाला गया कि संरक्षण कृषि के अंतर्गत मक्का की उपज, लाभप्रदता, संसाधन उपयोग दक्षता एवं मृदा स्वास्थ्य को बढ़ावा देने हेतु मक्का-गेहूं–मूंग फसल प्रणाली, फसल अवशेष अवधारण और नीम लेपित यूरिया का प्रयोग सर्वोत्तम हैं।

APPENDICES

Appendix I: Cost of cultivation of fourth zero-till maize in kharif 2015.

A. Common cost in all treatments

S. No.	Particulars	Unit	Rate (₹/ unit)	Cost (₹/ha)
1	Seed (kg)	20	120	2400
2	Seed Sowing and basal fertilization (operation)	2	400	800
3	Thinning & gap filling (man-days)	3	329	987
4	Manual weeding (man-days)	3	329	987
5	Herbicide (Pendimetalin 0.5 kg ai./ha)	1.65	470	776
6	Herbicides (Atrazine 0.75 kg ai./ha)	1.5	290	435
7	Herbicides application (man-days)	1	329	329
8	Irrigation (number)	2	400	800
9	Watch and ward, harvesting threshing, shelling, cleaning and bagging (man-days)	15	329	4935
10	Rental value of land (months)	4	1000	4000
	Total (A)			**16449**
	B. Common cost in all fertilizer treatments			
1.	Fertilizer application			
	(i) P_2O_5 (by DAP)	**60**	**47.7**	2864
	(ii) K_2O (by MOP)	**40**	**16.8**	672
	Total (B)			**3536**

C. Special cost (treatment-wise) and **Treatment cost**

Treatments*		Residue cost (₹/ha)	Nitrogen fertilization: Unit	Rate (₹/ unit)	Man-days	Cost (₹/ ha)	Total (C)	Total (A+B+ C, ₹/ ha)	Interest @ 11% p.a. (4 months (₹/ ha)	Total cost (₹/ha)
MMuMb WoR	**AC**	0	0	0	0	0	0	19985	350	20335
	PU	0	137	11.7	4	2921	2921	22906	401	23307
	SCU	0	137	13.5	0	1852	1852	21837	382	22219
	NCU	0	137	12.3	0	1688	1688	21672	379	22052
MMuMb WR	**AC**	2843	0	0.0	0	0	2843	22828	399	23228
	PU	2347	137	11.7	4	2921	5268	25253	442	25695
	SCU	3475	137	13.5	0	1852	5327	25312	443	25755
	NCU	3180	137	12.3	0	1688	4868	24852	435	25287
MWMb WoR	**AC**	0	0	0.0	0	0	0	19985	350	20335
	PU	0	137	11.7	4	2921	2921	22906	401	23307
	SCU	0	137	13.5	0	1852	1852	21837	382	22219
	NCU	0	137	12.3	0	1688	1688	21672	379	22052
MWMb WR	**AC**	3867	0	0.0	0	0	3867	23852	417	24269
	PU	2360	137	11.7	4	2921	5281	25266	442	25708
	SCU	3542	137	13.5	0	1852	5394	25379	444	25823
	NCU	2987	137	12.3	0	1688	4674	24659	432	25091

MMuMb: Maize-mustard-mugbean, MWMb: Maize-wheat-mungbean, WoR: without residue, WR: with residue; AC: absolute control, PU: Prilled urea, SCU: sulphur coated urea, NCU: neem coated urea.* ***Maize produce selling price:* *₹13.25/kg for grain and ₹1/kg for stover*

Appendix II: Analysis of variance (MSS) for plant population, plant height (cm), NDVI, SPAD and CTD value in fourth zero-till *kharif* maize

Source	d.f.	Plant population (10^3/ha)		Plant height (cm)		
		15 DAS	At harvest	30 DAS	45 DAS	At harvest
Replication	2	1.64	1.61	159.58	246.29	722.94
System	1	0.01	0.01	385.33*	7851.52**	440.44
Error (a)	2	0.09	0.07	24.60	204.17	349.30
Residue	1	1.05	0.80	62.56	1396.44**	209.17
System *x* Residue	1	0.29	0.24	189.61**	50.64	136.01
Error (b)	4	3.77	3.39	10.57	118.37	48.52
System *x* Nitrogen	3	1.41	1.20	32.85	3.05	31.56
Residue *x* nitrogen	3	4.17	1.61	9.95	353.46	117.81
Nitrogen	3	1.66	0.01	1761.25***	4133.65***	7933.63***
System *x* Residue *x* Nitrogen	3	1.46	0.07	10.52	500.26***	124.21

Source	d.f.	SPAD			NDVI			CTD (^{0}C)
		30 DAS	45 DAS	90 DAS	30 DAS	45 DAS	90 DAS	
Replication	2	2.32	38.34	18.27	0.0109	0.0015	0.0002	0.15
System	1	1.37	43.89	0.08	0.0029	0.0002	0.0005	1.29
Error (a)	2	0.51	14.73	9.52	0.0020	0.0001	0.0012	0.70
Residue	1	0.05	9.10	5.33	0.0023	0.0024	0.0037	29.15**
System *x* Residue	1	54.83	6.83	0.33	0.0013	0.0037	0.0033	0.11
Error (b)	4	18.17	21.42	16.27	0.0093	0.0007	0.0016	0.94
System *x* Nitrogen	3	22.15	24.07	48.31	0.0031	0.0001	0.0035	2.47
Residue *x* nitrogen	3	10.10	12.30	46.33	0.0018	0.0036	0.0045	1.17
Nitrogen	3	1297.37***	253.74***	496.75***	0.0686***	0.0594***	0.0211***	0.32
System *x* Residue *x* Nitrogen	3	19.40	5.17	20.44	0.0003***	0.0010	0.0024	0.69

***, ** and * indicates 5, 1 and 0.1 per cent level of significance, respectively.

Appendix III: Analysis of variance (MSS) for cob parameters and yield attributes in fourth zero-till *kharif* maize

Source	d.f.	Cob placement height (cm)	Cobs ('000/ha)	Barrenness (%)	Cobs/plant	Cob Length (cm)	Cob Girth (cm)
Replication	2	1184.41***	0.26	0.037	0.00019	2.76	1.56
System	1	1029.53***	2.73**	3.916**	0.00041**	1.05	0.02
Error (a)	2	101.78	0.40	0.063	0.00001	1.30	0.22
Residue	1	24.80	15.82**	18.838**	0.00213*	5.54	0.75
System *x* Residue	1	56.55	1.62	5.461	0.00053	0.35	0.00
Error (b)	4	24.07	3.65	0.942	0.00029	0.09	0.39
System *x* Nitrogen	3	211.46	6.26	5.320	0.00054	0.79	0.03
Residue *x* nitrogen	3	20.29	2.65	0.570	0.00006	5.97	0.55
Nitrogen	3	1392.82***	223.82***	47.163***	0.00443***	36.98***	2.93
System *x* Residue *x* Nitrogen	3	78.61	7.85	7.163	0.00077	0.59	0.18

Source	d.f.	Grain rows/cob	Grains/ row	Grains/cob	Grain weight/cob (g)	Shelling (%)	1000-sgrain weight (g)
Replication	2	0.0027	8.22	1107.25	707.03	1.88	2559.73***
System	1	0.3675	2.66	2.08	22.01	75.50	284.46
Error (a)	2	0.1206	24.66	335.08	91.13	49.37	218.35
Residue	1	0.0408	8.59	867.00	169.88**	5.74	428.71
System *x* Residue	1	0.0675	17.40	3300.08	235.41**	17.04	94.78
Error (b)	4	0.5942	6.56	102.67	11.63	7.43	90.27
System *x* Nitrogen	3	0.1075	8.27	1241.19	153.81	15.52	207.64
Residue *x* nitrogen	3	0.3208	16.68	2051.22	254.28	0.18	295.94
Nitrogen	3	2.3431**	211.70***	54850.89***	5800.08***	70.65**	4488.10***
System *x* Residue *x* Nitrogen	3	0.2497	13.75	2188.31	203.09	11.03	306.57

***, ** and * indicates 5, 1 and 0.1 per cent level of significance, respectively.

Appendix IV: Analysis of variance (MSS) for yields and physiological stages of fourth zero-till *kharif* maize

Source	d.f.	Cob Yield (kg/ha)	Stover yield (kg/ha)	Grain Yield (kg/ha)	Harvest index (%)
Replication	2	426958.1	424447.5	212119.6	3.1564583
System	1	1738885.3*	8442018.8***	2980531.7**	4.501875
Error (a)	2	95463.6	394258.9	92353.2	5.008125
Residue	1	7013523**	4888356.8**	3420270.2**	8.7552083*
System *x* Residue	1	1503792	238572	543363.5	0.151875
Error (b)	4	616680.5	412155.1	203809.2	1.2735417
System *x* Nitrogen	3	104224.3	483930.8	144782.3	0.8302083
Residue *x* nitrogen	3	2414852.4	1199547	1445061.7	24.8813194
Nitrogen	3	55781766.8***	44038873.9***	37405742.7***	192.0035417***
System *x* Residue *x* Nitrogen	3	299837.3	370492.2	277700.1	3.986875

Source	d.f.	Days to tasseling	Days to silking	Days to maturity	Reproductive period (days)
Replication	2	33.40	39.15	3.65	24.33
System	1	20.02	6.75	28.52**	96.33*
Error (a)	2	5.40	2.44	0.40	5.33
Residue	1	3.52	4.08	1.69	0.33
System *x* Residue	1	1.69	0.75	0.52	4.08
Error (b)	4	3.48	12.29	5.23	10.83
System *x* Nitrogen	3	1.74	6.36	2.74	6.17
Residue *x* nitrogen	3	1.47	12.25	2.02	4.17
Nitrogen	3	254.58***	306.47***	2.41	222.58***
System *x* Residue *x* Nitrogen	3	4.30	4.14	1.85	5.47

***, ** and * indicates 5, 1 and 0.1 per cent level of significance, respectively.

Appendix V: Analysis of variance (MSS) for growth indices and protein content of zero-till *kharif* maize

Source	d.f.	Leaf area (cm^2/plant)			LAI			Dry matter accumulation (g/plant)		
		30 DAS	**60DAS**	**30 DAS**	**60DAS**	**90 DAS**	**90 DAS**	**30 DAS**	**60DAS**	**90 DAS**
Replication	2	17120.31	92872.58	5.36	137.61	4	0.0200	5.36	137.61	4
System	1	630666.75**	3400013.02	51.04**	905.53**	14076.75**	4.44***	51.04**	905.53**	14076.75**
Error (a)	2	4087.69	585225.08	0.77	32.82	289	0.0026	0.77	32.82	289
Residue	1	598980.08**	23723438.02***	81.38**	165.29	6.75	3.80***	81.38**	165.29	6.75
System *x* Residue	1	70.08	3611872.69**	6.38	4.23	168.75***	1.96***	6.38	4.23	168.75***
Error (b)	4	17404.83	354553.92	1.80	40.97	2.125	0.0044	1.80	40.97	2.125
System *x* Nitrogen	3	146948.47**	481567.41	5.10	1830.49***	1480.62***	4.38***	5.10	1830.49***	1480.62***
Residue *x* nitrogen	3	182777.69***	1143414.63*	23.07**	45.79	2108.62***	0.92***	23.07**	45.79	2108.62***
Nitrogen	3	3620768.92***	21261705.85***	540.85***	.	34117.12***	.	540.85***	.	34117.12***
System *x* Residue *x* Nitrogen	3	61662.58	364181.52	4.10	92.14	131.875	0.43**	4.10	92.14	131.875

Source	d.f.	CGR (g/plant/day)			RGR (mg/g/day)			NAR (g/cm^2/day)		Protein (%)
		30 DAS	**60DAS**	**90 DAS**	**0-30 DAS**	**30-60DAS**	**60-90 DAS**	**60 DAS**	**90DAS**	
Replication	2	0.006	0.099	0.12	0.000002	0.00000062	0.0000051	0.242	0.0064	0.61
System	1	0.056***	0.583***	8.68***	0.000020**	0.00000158	0.0000039	1.91**	0.035***	1.36
Error (a)	2	0.001**	0.044	0.24**	0.000000	0.00000132	0.0000007	0.312	0.0050	0.22
Residue	1	0.089**	0.017	0.12	0.000027**	0.00000595	0.0000057	4.077**	0.038**	14.02**
System x Residue	1	0.006	0.023	0.25	0.000005**	0.00000609	0.0000012	1.73	0.071**	9.98**
Error (b)	4	0.002	0.038	0.04	0.000001	0.00000186	0.0000021	0.365	0.0029	0.37
System x Nitrogen	3	0.006	0.21**	0.90**	0.000003	0.00001046	0.0000033	0.353	0.017***	0.40
Residue x nitrogen	3	0.026**	0.089	2.90***	0.000006**	0.00001007	0.000017**	0.85*	0.0077*	0.27
Nitrogen	3	0.59***	1.388***	18.38***	0.00020***	0.00000080	0.000011**	1.55***	0.014***	10.50***
System x Residue x Nitrogen	3	0.005	0.096	0.39	0.000002	0.00000441	0.0000044	0.529	0.012**	0.58

***, ** and * indicates 5, 1 and 0.1 per cent level of significance, respectively.

Appendix VI: Analysis of variance (MSS) for biological parameters and economics of soil of fourth zero-till *kharif* maize

Source	d.f.	At flowering				After harvesting			
		DHA(µg TPF Rel/g/day)	FDA(µg Florescein/g/hr)	BG (µg p-NP Rel/g/24 hr)	MBC (µg C/g soil)	DHA(µg TPF Rel/g/day)	FDA(µg Florescein/g/hr)	BG(µg p-NP Rel/g/24 hr)	MBC (µg C/g soil)
Replication	2	18.25	0.00063	7.95	26.3	5.48	0.001	0.43	0.001
System	1	56.33	0.23**	548.4**	2214.1**	0.94	0.026**	4232.77***	0.026
Error (a)	2	4.08	0.00139	15.8	97.5	1.37	0.012	2.33	0.012
Residue	1	4408.33***	0.65***	706.0***	1610.1	532.53***	0.007**	2067.06***	0.007
System *x* Residue	1	784.08***	0.53***	541.4***	19360.3**	188.73***	0.03**	1103.46***	0.03
Error (b)	4	12.70**	0.00046	0.54	2392.0	2.58	0.002	11.03	0.002
System *x* Nitrogen	3	39.05***	0.023**	608.7***	13490.8***	99.26***	0.002	966.00***	0.002
Residue *x* nitrogen	3	458.72***	0.11***	245.7***	11234.9***	50.18***	0.05***	700.75***	0.05***
Nitrogen	3	531.91***	0.19***	1749.1***	40179.1***	324.92***	0.02**	3110.85***1	0.02**
System *x* Residue *x* Nitrogen	3	48.47***	0.041***	205.1***	23406.9***	24.16***	0.006	308.06***	0.006

Source	d.f.	Cost of Cultivation (₹/ha)	Gross returns (₹/ha)	Net Returns (₹/ha)	BC Ratio
Replication	2	0	34693200	34693200	0.05851875
System	1	160776.7***	664645021**	644145880**	1.06505208**
Error (a)	2	0	15142771	15144926	0.03115208
Residue	1	117468918.7***	713853576**	252156672	0.19635208
System *x* Residue	1	160776.8***	105050419	96980416	0.09991875
Error (b)	4	0	43206158	43207175	0.07536042
System *x* Nitrogen	3	228130.2***	30690672	33808736	0.05305764
Residue *x* nitrogen	3	814975.3***	254251508***	228217341**	0.33047986**
Nitrogen	3	13585119.3***	7644276541***	7071394941***	11.40396319***
System *x* Residue *x* Nitrogen	3	228130.3***	51986076	57963721	0.12087986

***, ** and * indicates 5, 1 and 0.1 per cent level of significance, respectively.

Appendix VII: Analysis of variance (MSS) for mineral N status at various growth stages in soil and N use efficiency of fourth zero-till *kharif* maize

Source	0-15 cm (kg/ha)							
	d.f.	Before sowing	30 DAS	45 DAS	65 DAS	90 DAS	After harvest	Before sowing
Replication	2	271.90	1675.15	25.77083	22.58	294.43***	56.52	707.58
System	1	352.08	12480.75**	9747**	1474.08**	111.02	546.75	18.75
Error (a)	2	301.90	118.69	76.6875	9.08	63.15	145.31	175.00
Residue	1	2552.08*	2.08	385.33333	1850.08***	2146.68***	2160.08**	200.08
System *x* Residue	1	21.33	10.08	1200**	3040.08***	22925.02***	102.08	102.08
Error (b)	4	370.40	197.83	81.97917	2.08	9.29	122.08	145.83
System *x* Nitrogen	3	495.14	6582.52***	2878.38***	5119.47***	6311.40***	478.36***	323.92
Residue *x* nitrogen	3	684.81	11416.97***	2658.05***	4434.13***	1690.07***	292.47**	1206.47**
Nitrogen	3	1040.5**	7739.63***	18608.61***	12871.13***	3756.02***	6788.47***	569.92
System *x* Residue *x* Nitrogen	3	556.50	6861.41***	449.055**	2486.69***	3546.85***	1279.91***	96.03

Source	d.f.	**PFP_N**	**AE_N**	**ANR**	**PE_N**
Replication	2	5.72	6.81	27.16	77615.26
System	1	129.02**	30.97	464.31***	698820.28
Error (a)	2	2.89	11.15	131.13	52519.00
Residue	1	93.79**	15.80	162.61	120845.65
System x Residue	1	38.76	62.24**	3976.82**	3902257.53****
Error (b)	4	9.39	5.50	304.35***	127601.96
System x Nitrogen	3	5.79	5.79	43.51	8197.01
Residue x nitrogen	3	94.38**	94.38**	484.44***	880832.92**
Nitrogen	3	63.01**	63.01**	1498.77***	331182.24
System x Residue x Nitrogen	3	10.73	10.73	34.59	90804.46

***, ** and * indicates 5, 1 and 0.1 per cent level of significance, respectively. *Partial factor productivity (PFP_N) agronomic efficiency (AE_N), apparent recovery (ANR) and physiological efficiency (PE_N) of nitrogen.*

Appendix VIII: Analysis of variance (MSS) for concentration of N, P, K, Cu, Fe and Zn in grain and stover of fourth zero-till *kharif* maize

Source	d.f.	Concentration in grain (%)			Concentration in stover (%)			Concentration in grain (mg/kg dry matter)			Concentration in stover (mg/kg dry matter)		
		N	P	K	N	P	K	Cu	Fe	Zn	Cu	Fe	Zn
Replication	2	0.016	0.00000303	0.02*	0.002	0.000023	0.007	5.91	11.65	15.85	13.91	3921.94	0.90
System	1	0.035	0.071**	0.009	0.003	0.00346**	0.083	52.61	0.10	50.55**	4.73	38.52	0.02
Error (a)	2	0.006	0.00077	0.021	0.002	0.000090	0.020	8.43	29.10	0.27	3.07	1.90	4.23
Residue	1	0.358**	0.00342813	0.003	0.017***	0.000047	0.054**	20.65**	85.17**	670.35***	109.99	2537.52**	5.26
System x Residue	1	0.256**	0.031**	0.000	0.0059***	0.016**	0.055**	1.32	0.07	26.28	71.39	15016.68**	87.58***
Error (b)	4	0.009	0.00308808	0.001	0.000	0.000727	0.004	2.44	6.64	5.79	24.13	881.67	0.85
System x Nitrogen	3	0.010	0.010***	0.001	0.006	0.011***	0.005	11.69	22.30	19.13	8.96	5756.96***	41.75
Residue x nitrogen	3	0.007	0.00500253	0.04**	0.006	0.011***	0.005	42.40***	7.75	43.24**	37.54**	4184.07**	94.06***
Nitrogen	3	0.268***	0.0045**	0.02*	0.033**	0.009**	0.005	24.85**	13.56	80.13***	7.13	43031.35***	36.91**
System x Residue x Nitrogen	3	0.015	0.00161733	0.001	0.003	0.002808	0.004	12.33	12.93	5.81	10.05	13598.79***	0.68

***, ** and * indicates 5, 1 and 0.1 per cent level of significance, respectively.

Appendix IX: Analysis of variance (MSS) for uptake of N, P, K, Cu, Fe and Zn in grain and stover of fourth zero-till *kharif* maize

Source	d.f.	Uptake by grain (kg/ha)			Uptake by stover (kg/ha)			Uptake by grain (g/ha)			Uptake by stover (g/ha)		
		N	P	K	N	P	K	Cu	Fe	Zn	Cu	Fe	Zn
Replication	2	47.33	1.75	121.27	98.54	1.78	292.03	281.66083	1509.28	98.07	2273.10	185912	311.44
System	1	2013.17**	482.16**	6.04	39.49	112.95**	3917.25	8.58521	3657.19	7570.64**	195.62	1363675**	2256.25
Error (a)	2	68.08	2.59	34.27	41.45	3.72	267.61	165.04333	897	62.45	244.53	51865.14	1003.97
Residue	1	4402***	95***	13.79	543***	11.31**	2542***	313.65187	13084**	47491.***	4738.20	2386459**	5584.74**
System x Residue	1	2175.63**	180.12**	2.20	149.63**	120.20	1028.009**	0.28521	507.01	3303**	6933.62	508428	9915.03***
Error (b)	4	68.06	14.83	5.17	6.85	14.90	20.26	201.19667	986.13	409.89	3859.85**	256849	140.29
System x Nitrogen	3	142.05	49.06***	1.19	34.73	134.99***	256.06	739.5091	1553.15	148.59	1664.58	937388***	6398.12**
Residue x nitrogen	3	593.32**	44.61***	85.54**	14.37	152.27***	167.22	4043.58***	1794.95	4033***	2520.03	820835***	10633.78***
Nitrogen	3	15887***	310.86***	966.24***	2102.20***	508.45***	4739.89***	23431.14***	56643.67***	45082***	8298.54**	16290366***	2136.64
System x Residue x Nitrogen	3	321.41**	19.98**	0.82	50.43	30.60	195.76	135.18354	97.70	708.61	961.68	1162349***	419.57

***, ** and * indicates 5, 1 and 0.1 per cent level of significance, respectively.

Appendix X: Analysis of variance (MSS) for penetration resistance in fourth zero-till *kharif* maize

Source	d.f.	Penetration resistance (kPa)											
		Before sowing						After harvesting					
		0-10 cm	10-20cm	20-30cm	30-40cm	40-50cm	50-60cm	0-10 cm	10-20cm	20-30cm	30-40cm	40-50cm	50-60cm
Replication	2	4365	56240	12159	1167029	119877	41660	4365	88823	15305	142456	119877	41660
System	1	68629**	79463	265073	9804	10121	288300	149745	7376	142790	100833	10121	288300
Error (a)	2	4506	130537	225980	336898	463800	105706	113131	67436	190639	62588	463800	105706
Residue	1	149745	523963	240409	81345	4487798**	1825200**	68630	479800**	133066**	5532492**	448779**	1825200**
System x Residue	1	22231	253316	324559	359148	174605	115248	22231	149969	794130**	6302	174605	115248
Error (b)	4	124188	77633	186187	250283	493555	164228	69876	47067	65695	319605	493555	164228
System x Nitrogen	3	108549	51412	58252	568561	315296	127314	68811	5144	173376	430798	315296	127314
Residue x nitrogen	3	68811	125114	29505	660336	249343	263650	108549	182832**	264311	154710	249343	263650
Nitrogen	3	98279	147987	133159	214314	269902	441412**	98279	81957	74013	179234	269902	441412.5**
System x Residue x Nitrogen	3	10592	3798	118099	81524	167287	10075	10592	182146.24**	40857	108904	167287	10075

***, ** and * indicates 5, 1 and 0.1 per cent level of significance, respectively.

Appendix XI: Analysis of variance (MSS) for bulk density, potassium and micronutrients after harvesting in fourth zero-till *kharif* maize

Source	d.f.	Bulk density Mg/m^3 (after harvesting)						DTPA extractable nutrients at harvest (mg/kg soil)			K (kg/ha)
		0-10 cm	10-20cm	20-30cm	30-40cm	40-50cm	50-60cm	Cu	Fe	Zn	0-15 cm
Replication	2	0.019	0.006	0.015***	0.008	0.004	0.0002	0.210	0.09	0.079	1879.02
System	1	0.059**	0.009	0.028	0.013**	0.026	0.0004	0.256	5.88**	5.672**	8110.88
Error (a)	2	0.002	0.003	0.004	0.000	0.007	0.0026	1.485	0.04	0.022	2474.19
Residue	1	0.002	0.075***	0.039**	0.147**	0.087**	0.058***	0.984	2.99*	2.845	7174.53**
System x Residue	1	0.013	0.006**	0.011	0.043**	0.039**	0.0055**	0.110	0.34	0.397	292.53
Error (b)	4	0.006	0.001	0.003	0.003	0.002	0.0010	0.202	0.42	0.435	197.67
System x Nitrogen	3	0.020***	0.014**	0.003	0.008**	0.014***	0.0087***	0.147	0.05	0.226	108.30
Residue x nitrogen	3	0.002	0.006	0.019***	0.006	0.016***	0.0126***	0.014	0.39	0.334	289.76
Nitrogen	3	0.01**	0.021***	0.025***	0.032**	0.006*	0.0828***	0.080	0.32	0.714	5.03
System x Residue x Nitrogen	3	0.008**	0.011**	0.011**	0.006	0.009**	0.0342***	0.053	0.06	0.149	249.05

***, ** and * indicates 5, 1 and 0.1 per cent level of significance, respectively

Appendix XII: Analysis of variance (MSS) for total organic carbon and pH after harvesting in fourth zero-till *kharif* maize

Source	**d.f.**	**TOC (%)**			**pH**		
		0-15 cm	15-30	30-45	**0-15 cm**	**15-30cm**	**30-45cm**
Replication	2	0.046	0.0064	0.0144**	0.0047	0.1073	0.0002
System	1	0.25433**	0.0480***	0.0379	0.1339	0.0230	0.0039
Error (a)	2	0.002	0.0001	0.0107	0.0696	0.0324	0.0193
Residue	1	0.2428***	0.0870***	0.0096	5.4169***	0.1140**	1.49636***
System x Residue	1	0.005	0.0058	0.0017	0.0620	1.3567***	0.98756***
Error (b)	4	0.002	0.0006	0.0028	0.0166	0.0102	0.0127
System x Nitrogen	3	0.0486***	0.0083	0.0083	0.0723	0.6499	0.0539
Residue x nitrogen	3	0.0103**	0.0343***	0.0006	0.0325	0.2831	0.0689
Nitrogen	3	0.133***	0.02497***	0.04360***	0.60069***	0.1572	0.29761***
System x Residue x Nitrogen	3	0.01022**	0.01669**	0.0185**	0.0177	0.7317***	0.0039

***, ** and * indicates 5, 1 and 0.1 per cent level of significance, respectively