

Evaluation of N-Losses and Nitrogen Use Efficiency in Maize, Fertilized with Resin Coated Urea

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by

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(2017)

CERTIFICATE –I

This is to certify that the thesis entitled “**Evaluation of N-Losses and Nitrogen Use Efficiency in Maize, Fertilized with Resin Coated Urea**” submitted in partial fulfillment of the requirement for the degree of **MASTER OF SCIENCE in AGRICULTURE (SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)** of Rajmata Vijayaraje Scindia Krishi Vishwa Vidhyalay, Gwalior is a record of the bona-fide research work carried out by **Priyanka Jadon** under my guidance and supervision. The subject of the thesis has been approved by the student’s Advisory Committee and the Director of Instruction.

No part of the thesis has been submitted for any other degree or diploma or has been published. All the assistance and help received during the course of this investigation has been acknowledged by the scholar.

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Abbreviations and Acronyms

Abbreviations/ Acronyms	Meaning
"	Seconds
%	Per cent
&	And
@	At the rate of
AE	Agronomic efficiency
Ag.	Agriculture
CD	Critical difference
Dist.	District
dSm ⁻¹	Deci Siemens per meter
EC	Electrical conductivity
<i>et al.</i>	And co-workers
Fig.	Figure
H I	Harvest index
Ha	Hectare
i.e.	In reference to; that is
K	Potassium
Kg	Kilogram

kg ha ⁻¹	Kilogram per hectare
M	Meter
Max.	Maximum
mg kg ⁻¹	Milli gram per kilogram
Min	Minimum
Mm	Milli meter
N	Nitrogen
No.	Number
°C	Degree centigrade
OC	Organic carbon
P	Phosphorus
PE	Physical use efficiency
PFP	Partial factor productivity
pH	Soil reaction
POR	Pine-oleoresin
Ppm	Parts per million
R.V.S.K.V.V.	RajmataVijayarajeScindiaKrishiVishwaVidhyalaya
RCU	Resin coated urea
RP	Rock phosphate
S	Sulphur

SCU	Sulphar coated urea
SE (m)	Standard error of mean
SSP	Single Super Phosphate
t ha ⁻¹	Tones per hectare
Temp.	Temperature
UE	Utility efficiency
Viz	Namely
Vs	Verses
Zn	Zinc
ZnO	Zinc oxide

Chapter-I

INTRODUCTION

All plants require nitrogen (N) to complete their life cycle. Nitrogen is vital to various biochemical processes, with the formation of chlorophyll molecules being one of the most important (Marshchner, 2012). Nitrogen is often the primary limiting factor for plant growth due to high demand to facilitate essential biochemical processes and the fact that soluble soil N is easily lost to the surrounding environment due to its mobile nature (Chatterjee, 2012). Without adequate concentrations of N, plants produce less chlorophyll and proteins, which results in decreased growth and increased susceptibility to pests and diseases (Marschner, 2012).

Nitrogen is one of the important primary nutrients for crop production. Indian soils are generally low in available N due to poor organic matter content and high temperature. Mineralization of organic matter in soil is considered as major sources of available pool of N. Due to low availability and easy loss/escape of N from soil due to various fates, external supply of N is vital for crop production and is being practiced from long back. Total consumption of N in Indian agriculture is about 16.94 million metric tonnes (MMT) during 2014-2015. Among the nitrogenous fertilizers, urea is the most commonly used fertilizer in India and about 30.6 MMT of urea is currently consumed which accounts 83% of total N fertilizer consumption in the country (IFA 2015).

Efficient use of nitrogen is absolutely essential for sustaining agriculture productivity as well as acting as a driving force for climate mitigation. Because of strong interrelationship among N uses, climate change and food security, there is an urgent need to search possibilities to increase N use efficiency in crop production. However, the N use efficiency of conventional chemical fertilizers is as low as 30 to 35 % (Galloway and Cowling, 2002, Lodha *et al.*, 2005). Therefore, a significant amount of fertilizer N-used in agriculture escapes in reactive forms which have cascading effect on human health and ecology. Therefore, improving N use efficiency of the fertilizers is/will be the major challenge.

In this connection, coating of urea is considered as one of the promising technologies and is act as efficient slow release fertilizer. Previously, a lot of research

work was done to test a number of coating material, containing urease inhibitors and nitrification inhibitor (Banerjee and Mosier, 1989; Pathak *et al.*, 2010), biodegradable polymers, palm stearin and selected micronutrient (Junejo *et al.*, 2011, 2012) and other polymers (Farmaha and Sims, 2012); but high cost and potent risks limit their field applications. However, currently only neem coated urea (NCU) is being manufactured and utilized in the country (Prasad, 2005) due to its low production cost. But still there is a scope for further improving the NUE of fertilizers. This calls for the search of new low cost indigenous coating material for developing more efficient N fertilizer (Prasad, 2012).

Keeping all the above in mind, the protocol has been developed to coat the urea with pine oleoresin (POR) (Kunduet *et al.*, 2013). POR is commercially extracted from pine tree (*Pinus roxburghii*) and is having empirical formula pimaric acid ($C_{20}H_{30}O_2$). The natural POR contains four resin acids, namely, levopimaric acid (22%), palustric acid (11%), labietic acid (10%) and neoabietic acid (15%). All these four acids comprise about 50-60% of the acidic portion of the POR. This group of conjugated-diene and acids are frequently referred to as abietic type acids (Baldwin *et al.*, 1958). Of the four conjugated diene resin acids, levopimaric acid possesses the most reactive system of double-bonds and is more resistant to oxidation (Lloyd and Hedrick, 1965). Coating urea with POR provides a physical barrier for slow release of N from urea may inhibit urease activity through antibacterial properties and may also reduce volatilization loss by acidifying alkaline micro-sites in soil (Kunduet *et al.*, 2013). All these process may contribute to the availability of N to the plants from POR coated urea; however, there is no any systemic data on N losses, uptake and use efficiency by plants under POR coated urea applications.

Further, POR coated fertilizers were developed and studied in the laboratory scale, the detailed mechanisms and scientific information is lacking in regards with the behaviour of the POR in soil, changes in soil properties, N losses through ammonia volatilization and leaching. Further field level evaluation of these materials is necessary to get a clear picture on its efficacy and also to calculate the economics. Therefore, the current investigation is aimed to study the effect of application of POR coated urea on losses of N from soil, and N uptake by maize with the following objectives:

Objectives

- ❖ To study nitrogen losses through volatilization and leaching from resin coated urea applied soil
- ❖ To study nitrogen use efficiency of maize crop fertilized with resin coated urea
- ❖ To study the effect of resin coated urea application on plant growth and soil properties.

Chapter-II

REVIEW OF LITERATURE

In this chapter, an attempt has been made to bring out review for the topic of interest **“Evaluation of N-Losses and Nitrogen Use Efficiency in Maize, Fertilized with Resin Coated Urea”**. A brief resume of the work done in the past by various workers is reviewed under appropriate heads.

2.1: Nature of N in plants

Nitrogen is an essential nutrient required for the growth of plants (Grundon 1987) and is a key element in amino acids, proteins including grain protein, chlorophyll and root development (Olson and Kurtz 1982). N acts as a key catalyst to support photosynthesis and other important biochemical reactions required for healthy plant growth. N is a significant component of nucleic acids such as DNA, the genetic material that allows plant cells to grow and reproduce. Adequate N availability is vital in order to maintain the plant's genetic integrity from one generation to the next which is dependent on sufficient plant N uptake. Grain protein and grain yield are reduced when N supply is inadequate (Grundon, 1987). Nitrogen is highly mobile in crop plants hence when N is deficient, older leaves become yellow as N is mobilized to younger plant parts including grain (Grundon, 1987). Other symptoms of N deficiency are stunting of the plant, a reduction in the number of tillers, grain with a mottled colouring and lower grain yield (Grundon, 1987; Wurst *et al.* 2010).

Most plants take up nitrogen continuously throughout their lives, and plant nitrogen uptake usually increases as plants increase in size. Plant available nitrogen exists in three general forms: organic nitrogen compounds, ammonium (NH_4^+) ions and nitrate (NO_3^-) ions. However, the biogeochemical dynamics that occur belowground greatly differ between different N forms. Soil microbes can be utilized to continually cycle and liberate inorganic nutrients back into plant available forms to significantly increase plant N uptake. Organic nitrogen is also not directly available to plants, and must be converted to plant available forms by microorganisms.

2.2: Production, consumption of N fertilizers in India

Fertilizer has been the key input in augmenting food production in India by enhancing the land productivity. Role of fertilizer in food grain production became more evident after the green revolution. Average N consumption in India has increased from 0.45 kg ha⁻¹ during 1950-51 to 90.01 kg ha⁻¹ during 2011-12. In the meantime food grain production has also increased from 50.82 Mt to 257.44 Mt. However, the fertilizer consumption in India is quite skewed. There are large variations in fertilizer use across the states. Among the major states, Punjab stands first in fertilizer consumption with 213 kg per hectare of gross cropped area followed by Andhra Pradesh with 208 kg/ha, 193 kg/ha in Tamil Nadu and Haryana with 187 kg/ha. The states like Kerala, Madhya Pradesh, Chhattisgarh, Maharashtra, Rajasthan, Goa, Uttarakhand, Himachal Pradesh, Jammu and Kashmir, Jharkhand, Orissa and north-eastern states have witnessed fertilizer use level below the national average of 119 kg/ha. The states which use more than the national average are Punjab, Andhra Pradesh, Tamil Nadu, Haryana, Karnataka, Gujarat, Uttar Pradesh, Bihar and West Bengal. Haryana ranks second in per hectare use of N and P, but the use of K in this state is very low. Tamil Nadu stands first in the use of K followed by West Bengal. It is interesting to note that per hectare application of K in southern states is higher than the use of K in other states except West Bengal. The lowest use of all three plant nutrients (N, P and K) is observed in the north east region. The information thus confirms that there are imbalances in the use of fertilizers in the country as well as across different states. As there is significant variation in the status of soil fertility in various parts of the country, the imbalances at the micro level can be better understood and addressed by developing location specific norms for balanced use of fertilizer (Chand and Pandey 2008). Moreover, the imbalances in fertilizer use are also attributed to prices and subsidies available to the farmers in addition to farm and household specific characteristics.

At present, India is the second largest producer and consumer of fertilizer nitrogen in the world. India produced a record 24.5 million tonnes of urea in 2015-16, the highest ever quantity of commonly used fertilizer. While country needs 30 million tonnes of urea production was stagnant at around 22 million. According to IFA (2015), total consumption of N in Indian agriculture is about 16.94 million metric tonnes (MMT)

during 2014-2015. Among the nitrogenous fertilizers, urea is the most commonly used fertilizer in India and about 30.6 MMT of urea is currently consumed which accounts 83% of total N fertilizer consumption in the country.

2.3: Responses of crops to applied N-fertilizer

Suryavamshi *et al.* (2008) have conducted a field experiment to study the response of maize to nitrogen and phosphorous application in Vertisols. They concluded that in Vertisols having low available nitrogen and medium available phosphorous, the yield potential of maize (67.50 q ha^{-1}) was obtained by application of 250 kg N ha^{-1} and $67.5 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$. They inferred that maize crop responded quadratically to both the inputs of nitrogen and phosphorous.

Singh *et al.* (2003) have reported that application of 50% higher recommended level of nitrogen and potassium (180 kg N and $60 \text{ kg K}_2\text{O ha}^{-1}$) recorded significantly higher growth and yield parameters. Grain yield (71.1 q ha^{-1}) and stover yield (114.3 q ha^{-1}) of maize were significantly greater than recommended levels of N and K (120 kg N and $40 \text{ kg K}_2\text{O ha}^{-1}$). The increase in N and K levels beyond 50 per cent did not show further improvement up to the level of statistical significance.

Singh *et al.* (2005) have estimated the fertilizer requirement for specific yield targets of maize in the alluvial soil of the Indo-Gangetic plains. The requirement of N, P and K for one tonne of grain yield was 26.6, 4.5 and 25.3 kg, respectively. Experimental results indicated that application of $200:65:65 \text{ kg N, P}_2\text{O}_5 \text{ and K}_2\text{O ha}^{-1}$, respectively recorded significantly higher grain yield (3.3 t ha^{-1}).

Verma *et al.* (2005) have conducted an experiment to ascertain the validity of soil test based fertilizer prescriptions for achieving specific yield targets for maize crop in wet temperate zone of Himachal Pradesh. They have revealed that fertilizer recommendations based on targeted yield concept is found more precise and dependable. They recorded higher grain yield of maize (5.2 t ha^{-1}) with higher application of $162:102:85 \text{ kg N P}_2\text{O}_5 \text{ and K}_2\text{O ha}^{-1}$ compared to 3.2 t ha^{-1} by state level recommendation ($120:60:40 \text{ kg N P}_2\text{O}_5 \text{ and K}_2\text{O ha}^{-1}$).

Harvest indices were significantly ($p \leq 0.01$) greater at 224 kg N ha^{-1} fertility level compared to 179 kg N ha^{-1} and 134 kg N ha^{-1} level. Neither effect on HI by different rates of K fertility used in the experiment nor any significant interaction for HI noted between

N and K fertility levels. Increased HI has been observed at the greater N fertility rates indicating N facilitates translocation of photosynthate to developing maize kernels (Arnold and Wayne 2006).

Onasanya *et al.* (2009) have conducted experiment in southern Nigeria with twelve different rates of nitrogen and phosphorus fertilizers on growth and yield of maize (*Zea mays* L.). They have reveal that application of 120 kg N and 40 kg P ha⁻¹ significantly increases the growth and yield (7.13 t ha⁻¹) of maize than other treatments.

Ashok Kumar (2008) has conducted an experiment during 2005 and 2006 at New Delhi on effect of varied nitrogen levels on productivity and economics of sweet corn and pop corn and reveal that higher net return of 41, 590 ha⁻¹ and 49,420 ha⁻¹ by pop corn and sweet corn is found at higher nitrogen level of 120 kg ha⁻¹ compared to lower levels. The higher net returns are directly contributed by higher grain yield of pop corn (3.48 t ha⁻¹) and green cobs of sweet corn (13.46 t ha⁻¹).

2.4: Major issues associated with N use

There is a fundamental flaw in how N fertilizer has been applied in India. Application of N has not been done as per the crop needs. In some cases, application of all N as basal dose before sowing resulted in loss of N. Nitrogen is subjected to environmental losses namely volatilization, denitrification, leaching, runoff, etc. that all lead to low use efficiency of applied fertilizers, contamination of surface water bodies and ground water.

Gupta (2014) has claimed that leaching is one of the most important physical processes responsible for migration of soil nutrients and pollutants. Over fertilized agricultural areas poses a threat to the ground water quality mainly because of leaching of salts through macro pores along with percolating water.

Freney and Black (1988) have recorded the loss of N from the cropping system in the form of gaseous ammonium (NH₃). Volatilisation occurs when fertiliser-N is converted to ammonium gas through hydrolysis and is located on or very close to the soil surface such that the gas can escape from the soil. The risk of volatilisation therefore depends on soil moisture, soil disturbance, and the method used to apply the N fertiliser to the soil.

Rose and Dalal (1988) and White (1988) have reported that less than 2% of soil N is typically lost through leaching and erosion and these losses can be significant in particular soils since N is a highly mobile nutrient. Leaching of N occurs in soils where water moves quickly down the soil profile and surface water movement occurs in cropped soils with poor water infiltration rates, high rainfall events or little ground cover.

Dinnes *et al.* (2002) have reported that loss of N from applied N fertilizer has several possible negative agricultural and environmental consequences including decreased crop production and profitability, water contamination and potential impacts on global climate change and ozone depletion. It is critical to the health of humans and ecosystems that this challenge be met. It is doubly critical because without action, future populations will be more stressed either due to nitrogen limitations or due to nitrogen excesses.

Poor nutrient utilization and nitrogen (N) losses from urea applications have been reported for many years (Khalil *et al.* 2009). The N losses from applied urea are estimated at 30 to 60% in tropical soil (Khalil *et al.* 2003; Zhang *et al.* 2010). The main reason of these losses is the immediate increase in pH and NH_4^+ concentration around the fertilizer micro site due to the activity of enzyme urease (Ahmed *et al.* 2008; Mohsina *et al.* 2004).

Dobermann (2005) and Cantarella (2007) have also reported nitrogen use efficiency is usually low. Used data from over 800 experiments across the globe to estimate that, on average, only 51% of the N applied was recovered by the aboveground parts of cereals. Similar results are also compiled by using N-15 data for maize in Brazil (cantarella, 2007). Fan *et al.* (2004) and Quaggio *et al.* (2005) have reported that the average N fertilizer recovery in cereals in China was 30–35%. Available data for perennial crops, such as citrus, show the same range of results; between 25% and 50% of the applied N was taken up by the plants.

2.5: Strategies to overcome the issues associated with N use

Nitrogen is a nutrient element necessary for crop production. However, excessive inputs of N will lead to inefficient use and large N losses to the environment, which can adversely affect air and water quality, biodiversity and human health. There are various strategies are adopted by many workers to overcome the N loss mainly controlled-

release fertilizers (CRF) (Nick 2004; Harikrishna *et al.* 2005; Zhao *et al.* 2006; Thind *et al.* 2010; Khan *et al.* 2011; Kundu *et al.* 2013, 2016), super urea granules (Mohanty *et al.* 1999), spilt application of fertilizers (Harikrishna *et al.* 2005), band placement (Riaz *et al.* (2004); synchronization of plant demand and supply, site specific nutrient management, integrated nutrient management (Negi *et al.* (2007), etc.

Among these controlled release fertilizers (CRF) particularly coated urea fertilizers are one of the major options to overcome the N losses and to improve use efficiency of applied N. Shaviv (2005) and Trenkel (1997) mentioned that the terms “slow-release” and “controlled-release” are used interchangeably, it has become acceptable recently to apply the term controlled-release to coated or encapsulated fertilizers for which the factors determining the rate, pattern, and duration of release are known and regulated during fabrication, and slow-release be used for microbial decomposed N products such as UF.

Slow release nitrogenous fertilizers such as sulfur, neem, calcium carbide, polymer, micronutrients coated and agrotain coated urea are studied across the global. The potential benefits claimed are increased plant use efficiency by prolonged soil retention and less fertilizer applications, thus saving fertilizers and application costs (Leong 2002). A reasonably good prediction of nutrient release is possible with controlled-release fertilizers coated with hydrophobic materials, particularly polymer-coated fertilizers because they are less sensitive to soil and climatic conditions (Shaviv 2005; Shoji 2005). In the following paragraphs it is briefly discussed on coated urea fertilizers and their type, further their impact on crop yield, uptake and use efficiency as well as soil properties.

2.6: What are coated fertilizers and their type?

A variety of coatings have been applied to fertilizer particles to control their solubility in soil. Controlling the rate of nutrient release can offer multiple environmental, economic, and yield benefits. Coatings are most commonly applied to granular or prilled nitrogen (N) fertilizer, but multi-nutrient fertilizers receive the coatings as well. Since urea contains the highest N of common soluble fertilizers, it's the base material for most coated fertilizers.

Trenkel (1997) has mentioned that there are two important groups of fertilizers classified as slow or controlled release fertilizers. One group is formed by condensation products of urea and urea aldehydes, of which the most significant types on the market are urea formaldehyde (UF), isobutylidene diurea (IBDU), and crotonylidene diurea (CDU). The second group is comprised of coated or encapsulated fertilizers, such as S-coated urea (SCU) or polymer-coated urea (PCU) that may avoid the rapid transformation of N into forms that are less stable in certain environments.

A wide range of materials have been used as coatings on soluble fertilizers such as elemental sulfur, pine oleoresin, polymers, neem cake and neem oil etc. Goertz, (1993) has developed sulfur coated urea one of the first CRF and nitrogen release is controlled by the thickness of the sulfur coating. Although still used in agriculture, sulfur coated urea is rarely used in forest, conservation, and native plant nurseries.

Nick (2004) has prepared polymer coated urea; also called plastic-coated urea, or PCU, fertilizers can permit a more precise rate of nitrogen release than sulfur-coated urea products. It's possible to produce polymer-coated products where the nitrogen release can be delayed for 10 months after application. The primary disadvantage of polymer-coated urea products is their relatively high cost compared to sulfur-coated urea.

Neem has proven nitrification inhibition properties. This way it slows down the process of nitrogen release from urea. It is the best nitrification inhibiting agent till date and better than sulfur. Neem is a key ingredient in the non-pesticidal management of different pests and provides a natural alternative to synthetic pesticides. Although neem oil has been shown to avert termite attack as an ecofriendly and economical agent hardly any systematic attempt has been made to study pesticidal properties associated with NCU or NOCU (Yash Roy and Gupta, 2000).

Kundu *et al.* (2013) have developed a protocol to coat urea with POR that provides a physical barrier for slow release of N from urea; inhibits urease activity through antibacterial properties and reduces volatilization loss by acidifying alkaline micro sites in soil.

2.7: Production mechanism of CUF

Gould *et al.* (1986) have developed SCU. Urea granules are coated with elemental S melted at about 156°C, followed by a wax layer that acts as a sealant to cover fissures or cracks in the S coating, and finally by a conditioner layer. The pattern of N release of SCU depends on the thickness and quality of the coating. Cracks in the coatings, excess manipulation, and flaws in the manufacturing process may jeopardize the slow-release properties of the fertilizer.

Lu *et al.* (2013) has come-up with a new type of controlled release fertilizer- poly coated urea. The granulated urea was firstly changed into a liquid urea by heating as the coating liquid. By spraying uniformly the urea was coated with the poly coated urea synthesized by the reaction of isocyanates with a liquid urea. The effects of different modifiers on N release characteristics of poly coated urea (PCU) are studied. The morphology and chemical structure of PCU coating materials is investigated by SEM and FTIR. Further they have studied the nitrogen release characteristics of the PCU applied in both water and soil, and the biodegradability of PCU coating after buried in soil. The results showed that PCU reduced nitrogen release rate and exhibited excellent controlled release property. The PCU coating materials can biodegrade in soil. This indicates that the low cost PCU products from urea are expected to use in agricultural and horticultural applications.

Kundu *et al.* (2013) have developed a protocol to coat urea with pine oleoresin to obtain slow-release urea fertilizer. Water and turpentine are removed from the crude oleoresin by oven-drying. The crude resin is dissolved in an organic solvent (alcohol) and to this urea and methyl red indicator are added. Then the whole content is transferred to a horizontal shaker and shaking operation was continued with maximum speed. Thereafter the whole material was kept in a hot-air oven for hardening and to obtain oleoresin-coated urea. It is found that coated urea contained 4% POR and 44.3% N. Based on the density of urea (1.32 g cm^{-3}) and POR (1.07 g cm^{-3}), the calculated thickness of the coating is 11 μm . Further to reduce the cost of production commercial petrol has been used to solubilize POR. They have prepared four POR coated urea with 1.25%, 2.50%, 3.75% and 5.0% POR and 45.43%, 44.87%, 44.33% and 43.80% N, respectively (Kundu *et al.* 2016). These materials are tested for its efficacy in pot culture

experiment raising maize. It is found that significant increase in biomass yield and NUE when urea is coated with POR at 3.75% or more.

2.8: Impact of CUF on crop growth and yield

Kundu *et al.* (2016) have conducted a pot culture study with maize in Vertisol, Inceptisol, Alfisol and Aridisol to evaluate the efficacy of the pine oleoresin coated urea fertilizers (coated with 1.25, 2.50, 3.75 and 5.00% pine oleoresin). Significant increase in biomass yield is observed in all the soils when urea is coated with pine oleoresin at 3.75% or more.

Khan *et al.* (2011) have reported that the viable approach to reduce the N losses from the surface applied urea is to coat it with sulfur, urease inhibitor and other biodegradable materials and conducted field experiments to investigate the impact of sulfur and urease inhibitor coated urea on growth, yield, yield components and N uptake in maize under calcareous soil conditions of Khyber Pakhtunkhwa (KPK).

Thind *et al.* (2010) have studied the performance of NOCU/ NCU against urea at three N levels and find increase in N uptake and yield of rice and wheat in coarse and fine textured soils.

Zhao *et al.* (2006) have conducted an investigation the effects of CRFs on yield, ammonia volatilization, N use efficiency (NUE) and photosynthetic rate after anthesis in summer maize hybrid cultivar *Zhengdan-958*. Treatments comprise of CCF(common compound fertilizer- applied at 1250 kg ha (the local average commercial fertilizer N application rate); CRF- resin-coated CRF- CRFI (50%), CRFII (75%), CRFIII, (100%); SCF- a sulphur-coated CRF, , SCFI (50%), SCFII, (75%), SCFIII, (100% CCF) and no fertilizer. It is found that treatments CRFIII, SCFIII, CRFII and SCFII produced grain yields that are 13.15%, 14.15%, 9.69% and 10.04% higher than CCF. There are no significant differences in grain yield among CRFI, SCFI and CCF. It is also found that the ammonia volatilization rates of CRF are significantly lower than those of CCF. The CRF treatments have reduced the emission of ammonia by 51.34% to 91.34% compared to CCF. In addition, after treatment with CRF, maize exhibits a higher net photosynthetic rate than CCF after anthesis. Agronomic NUE and apparent N recovery are higher in the CRF treatment than in the CCF treatment. The N uptake and physiological NUE of the four yield-enhanced CRF treatments are higher than those of

CCF. These results suggest that the increase in NUE in the CRF treatments is generally attributable to the higher photosynthetic rate and lower ammonia volatilization compared to CCF-treated maize.

Singh *et al.* (1995) from the field trials have reported that grain yield of lowland rice from a single application of PCU is equivalent to or better than 3–4 well-timed split urea application. Fertilizer recovery with PCU was 70–75% compared with 50% with prilled urea (PU). The higher recovery of N from two PCU products was related to N release and subsequent N uptake by rice during the post anthesis stage. A one-time application of PCU may have distinct advantages over prilled urea, not just in terms of labor saving, but also because PCU may provide a more stable and sustained N release in rainfed crop systems where well-timed split N applications may not be feasible due to variability in rainfall and soil moisture (Singh *et al.* 1995).

Fan *et al.* (2004) have demonstrated that coated urea performs better than regular fertilizers by promoting increased grain yield and N uptake in rice in Spain. Similarly Carreres *et al.* 2003 in winter wheat (China); Wen *et al.* 2001 in peanuts (Japan); Munoz *et al.* 2005 in potatoes (USA); and Shoji *et al.* 2001 in maize (Japan) have reported the coating of urea has improved grain yield and N uptake. On the other hand, some formulations of PCU are not efficient in increasing grain yield and N recovery by flooded rice in Spain, probably because of insufficient coating of the urea granule (Carreres *et al.* 2003).

2.9: Impact of CUF on NUE and uptake

Singh and Shivay (2003) has described that three terms are, in general, used in relation to nitrogen use-efficiency (NUE). These are: Agronomic Efficiency (AE), Recovery or Utilization Efficiency (RE) and Partial Factor Productivity of Fertilizers (PFPPF).

Kundu *et al.* (2016) have developed coat urea with POR (1.25, 2.5 and 3.75 5%) and have studied their efficacy. In All the pine oleoresin coated urea in Inceptisol and Aridisol, and 3.75% and 5% pine oleoresin coated urea in Vertisol and Alfisol significantly have increased nitrogen (N) uptake as compared to uncoated urea. Nitrogen use efficiency is also increased from 19.34% to 32.80% in Vertisol, 13.06% to 28.27% in Alfisol, 13.87% to 23.86% in Inceptisol and 10.68% to 20.23% in Aridisol, as

a result of coating urea with pine oleoresin (5%). This may be slow hydrolysis, the reduced N-loss and high amounts of NH_4^+ accumulation in the soil that available for plant uptake.

Ning *et al.* (2012) have noticed that when N is applied in the form of coated urea, the N release rate is slowed and the N uptake by maize is increased, which reduces the risk of N loss and increased the use efficiency of fertilizer-N. Polymer-coated urea (PCU) tends to have a more predictable release pattern, and it has resulted in yields similar to or greater than those with soluble N sources (Trenkel, 1997). Studies showed that CRF not only improved the N use efficiency of corn but also decrease NO_3 leaching (Zvomuya *et al.*, 2003; Wilson *et al.*, 2009). Use of sulphur coated urea (SCU) resulted in the positive interaction between N and S in increasing crop yield and also improves NUE in wheat by increasing N-uptake (Salvagiotti *et al.*, 2009). Application of neem cake coated urea has increased the percent nitrogen content and uptake of nitrogen (Jat and Pal 2002, Kumar and Prasad, 2004). Similarly Sannagoudra *et al.* (2012) have also reported that application of neem coated urea increased the N content and uptake in rice over normal urea.

2.10: Reduction of N losses due to CUF application

Fertilizers upon application to soil are subjected to numerous reactions, transformations and N loss mechanisms such as ammonia volatilization, nitrification and subsequent denitrification, leaching, chemical and microbial immobilization and surface runoff. Losses of soil N are expected in continuous cereal cropping systems or when there is a long term decline in grain yields or protein content. These circumstances indicate the next crop will be deficient in N without N fertilizer (Angus and Peoples, 2012, Holford *et al.* 1992).

Snyder *et al.* (2007) as early as the 1960s and 1970s, various chemical compounds were extensively tested for their nitrification retarding properties to inhibit oxidation of $\text{NH}_4\text{-N}$ to $\text{NO}_3\text{-N}$, and thus reduce $\text{NO}_3\text{-N}$ leaching/ denitrification N losses. Decreasing denitrification of $\text{NO}_3\text{-N}$ to N_2O and N_2 can also benefit the environment, as N_2O and N_2 are now considered a part of the green-house gases that are responsible for global warming.

Trenkel (1997) has mentioned that there are many compounds known as nitrification inhibitors but three products have come out on a commercial basis. These are (1) 2-chloro-6- (trichloromethyl) pyridine (Nitrapyrin) with the trade name “N Serve,” (2) dicyandiamide (DCD, $\text{H}_4\text{C}_2\text{N}_4$), which is available with several commercial names, and (3) 3,4-dimethylpyrazole phosphate (DMPP) with the trade name “ENTECH.” Domingues *et al.* (2008) have reported that eight phosphoroamide-derived compounds presented higher in vitro urease inhibitory activities than NBTPT, the commercial product used as a reference; two of the compounds tested (4-methyl-2-nitrophenyl phosphoric triamide and 2-nitrophenyl phosphoric triamide) showed marked differences from NBTPT in acidic soils, whereas the commercial inhibitor is reported to be less effective.

In flooded soils, urea has greater N losses through denitrification, and loss of ammonia-N in to the atmosphere (Fillery *et al.* 1986; IFA 1992). The rapid urea hydrolysis creates high ammonium-N concentrations in the floodwater, and potentially large volatilization losses appear when weather conditions facilitate the removal of ammonia from the water-air interface (Byrnes *et al.* 1989). These losses could be minimized through slow release urea coated fertilizers.

A different type of potent nitrification inhibitor, acetylene gas, was reported by Hynes and Knowles (1982) and Walter *et al.* (1979). Freney (1997) has demonstrated the addition of wax-coated calcium carbide (CaC_2), which reacted with water to produce acetylene gas to urea fertilized soil, reduced nitrification and increased yield, or recovery of N, in irrigated wheat, maize, and cotton, and flooded rice as summarized.

Kiss and Simihaian (2002) has reported the use of urease inhibitors to reduce NH_3 volatilization from urea hydrolysis has thus been considered one effective strategy to increase N efficiency of urea-based N products, and more than 14,000 compounds or mixtures of compounds with a wide range of characteristics have been tested and many patented as urease inhibitors.

Many organic compounds are capable of inhibiting urease activity. Up to the early 1970s, hydroquinone and some benzoquinones were shown to be urease inhibitors (Bremner and Douglas, 1971), but later studies showed that the compounds of the group of structural analogues of urea were more effective (Martens and Bremner, 1984; Radelet *et al.* 1988; Watson, 2000).

The toxicity, plant nutrient uptake improvement, nutrient loss, particularly leaching of nitrate-N and volatilization of ammonia could be reduced through many standard coated fertilizers. Controlled-release fertilizers make it possible to meet the full nutrient requirements of crops and multiple cropping by making a single or split fertilizer application which substantially decreases the risk of environmental pollution (Zhang *et al.* 2001; Shaviv, 2005; Shoji, 2005).

Slow-release or control-release fertilizers reduce N loss from agricultural land and raise N fertilizer efficiency has been recommended (Dai *et al.*, 2003). Wang *et al.* (2007) has found the cumulative NH₃ losses from the urea treatments were significantly higher than those of the coated urea treatments and control. Also coated urea fertilizer showed higher grain yield for rice-wheat rotations. It has been concluded that coated urea has more advantages than urea for both grain yield and environmental conservation.

2.12: Influence of CUF on soil properties

Moisture is essential to the dissolution and outward movement of N from CRF. While research has shown that a level of 50% field capacity or less will negatively affect release of N (Huett, 2000; Kochba *et al.*, 1990). The quick change in moisture at the soil surface caused by wetting and drying periods also affects the release rate of N from PCU. With fluctuating temperatures, there is a parallel in fluctuating water potential. This has been shown to increase N release from CRF as it promotes a mass flow of N out of the prill and into the soil solution (Adams *et al.*, 2013).

In a laboratory experiment with CRF placed in incubators that replicated diurnal fluctuating temperatures, the rates of nutrient release would mimic the fluctuating temperatures (Husby *et al.*, 2003). The increase in fluctuating temperatures resulted in a higher percent of N released. Blaize and Prasad (1997) have studied the dynamics of N release from different coated fertilizers and found that polymer coated urea and neem coated urea maintained higher exchangeable NH₄-N and lower nitrate in soil as compared to prilled urea. Similar results of lower nitrate nitrogen in neem coated fertilizers have been reported by Suganya *et al.* (2009).

Jiao *et al.* (2005) have studied that impact of urea coated fertilizers and N inhibitors on urease enzyme activity, soil available NH₄⁺-N, and soil microbial N and nematode communities under maize. They have demonstrated that the application of slow-release

urea fertilizers inhibits soil urease activity and increases the soil NH_4^+ -N content. Combined application of coated urea and nitrification inhibitors increased the soil active N pool and improved the population of predators/omnivores compared with the other treatments.

Field experiments has been conducted with combined application of PCU and normal urea in winter wheat and the treatments are Urea alone and PCU 10, 20, 30 and 40% with 90, 80, 70 and 60% urea respectively. The accumulation amount of NO_3^- -N in 0-100 cm soil layer in all treatments ranges in 39.70-49.93 kg hm^{-2} , and the lowest (39.70 kg $\times$ hm^{-2}) in treatment receiving 40% PCU. The N release pattern of 40% PCU plus 60% urea under field condition better fitted the N absorption characteristics of winter wheat (Yi *et al.* 2011b).

Chapter-III

MATERIALS AND METHODS

The present investigation “**Evaluation of N-Losses and Nitrogen Use Efficiency in Maize, Fertilized with Resin Coated Urea**” was carried out during *kharif* season of 2016-17 at the research farm, ICAR-IISS, Bhopal, Madhya Pradesh. The present chapter deals with a brief description of the methods followed and materials used during the investigation.

3.1: Laboratory experiments

3.1.1: *Estimation of volatilization loss*

An incubation laboratory experiment was conducted to estimate volatilization loss of $\text{NH}_4\text{-N}$ from soil fertilized with different N sources using a force draft technique at ICAR-Indian Institute of Soil Science, Bhopal during 10-25 August, 2016. About 1 kg capacity of sealed plastic container was filled with 500 g (2 mm) sieved Vertisol (refer field experiment section given below for soil sample collection and its initial properties). For this experiment soil was treated with 220 mg N per kg soil through various N sources namely normal urea alone and in combination with resin (1000 mg per kg), neem coated urea and resin coated urea; and also absolute control (soil without any fertilizers) to know the mission from natural soil. Immediately after N spiking the container was closed and sealed properly using sticking material (gum) and paraffin films to avoid any leakage from the system. The closed dynamic (aerobic), air-flow system contained an air-exchange chamber (500 ml plastic box) and a trapping flasks containing 20 mL 2% boric acid to absorb the volatilized ammonia. The stopper on each container was fitted with an inlet and outlet facility. The inlet was linked to an air pump and the outlet was connected by polyethylene tubing to the trapping flasks. Then periodic measurements were made after 24, 72, 96, 120, 144, 168, 192, 216 and 240 h by removing trapping flasks and the content in the flasks were titrated with standard acid. The loss of $\text{NH}_4\text{-N}$ after different periods from coated and uncoated urea was calculated. The total working system of volatilization loss experiments is displayed in the Plate 3.1.



Photo 3.1: Volatilization loss experimental incubation setup

3.1.2: Determination of nitrate leaching

Experiment on leaching loss of N from various N sources that applied to soil was conducted using undisturbed transparent plastic columns in a laboratory condition at ICAR-Indian Institute of Soil Science, Bhopal during 1- 20 March, 2017. The treatments were 1. control, 2. normal urea, 3. neem coated urea, 4. resin coated urea, 5. Rock-phosphate coated urea and 6. Nano ZnO coated urea. The nutrient content of all the fertilizers used in the current experiment has been listed in Table 3.1. The amount of N applied in each treatment except control was 220 mg N. The experimental soil was Vertisol that collected from the research farm, ICAR-IISS, Bhopal (refer field experiment section given below for soil sample collection and its initial properties).

Plastic transparent columns (size 60 cm height and 8 cm inner diameter) were used with assembly for leaching and collection of leachate (Plate 3.2). The columns were filled up to 15 cm with 2 mm sieved Vertisol (about 1.06 kg soil) and gently tapped to maintain the bulk density of 1.42 Mg m^{-3} . The soil in the column was saturated with addition of 300 ml water and kept 2 days to reach water to the bottom of the column. Then 220 mg N was applied on the top surface of soil in the column with different sources in respective treatments except control and about 200 mL distilled water was added immediately after fertilizer application, 4th, 7th, 10th and 13th days to all the columns/treatments. Three replications were maintained for each treatment. Leachates were collected in 250 mL conical flasks periodically from 3, 6, 9, 12 and 15 days.

Table 3.1: Nutrient content (%) of different fertilizers which are used

Material used	Nutrient content (%)				
	N	P	K	S	Zn
Urea	46.0	-	-	-	-
RCU	44.3	-	-	-	-
NCU	46.0	-	-	-	-

Nano ZnO coated urea	43.0	-	-	-	1.45
Nano Rock phosphate coated urea	32.9		-	-	-
SSP	-	7.2	-	12	-
MOP	-	-	50	-	-

About 20 mL of leachate was taken in 100 ml beaker and was kept on a water bath for evaporating water till dryness, then it was kept for cooling, 3 mL of phenol-disulphonic acid and 15 mL of distilled water were added and mixed well with using glass rod and the content was transferred to 100 mL volumetric flask and 1:1 diluted ammonia solution was added till appearance of yellow colour, then the volume was made upto 100 mL. Similar practice was done for by taking known standard solution of nitrates as well as blank using distilled water for colour development. Then measurements were made using spectrophotometer (model-CE 2031) at 420 nm to measure the concentration of nitrate.



Photo 3.2: Nitrate leaching column study

3.2: Field experiments

3.2.1: Location and climate

The field experiment was conducted during *khari* fseason of 2016-17 at the research farm, ICAR-IISS, Bhopal, Madhya Pradesh. The study area falls under semi-arid and sub-tropical zone characterized by hot summer and cold winter. Mean annual precipitation is about 650 mm, most of which is received during the monsoon period of July to September. The average maximum temperature during summer is 35°C, while the average minimum temperature during winter is 4°C. Climatic condition during plant growth period is depicted in Table 3.2.

3.2.2: Experimental field

Maize (Hybrid Nutan KH-101) crop was used and grown as test crop in the current investigation adopting Randomized block design with four blocks (as four replications) and six plots in a block (as six treatments). The size of plots was five-meterlength and four-meter breadth. According to fertility gradient of the experimental field, the blocks were formed and by using randomization number table the treatments were allotted in each block. The layout and design of the experimental field is depicted in Plate 3.4. The general view of experimental field was shown in Plate 3.3. Initial soil properties of experimental field were studied and presented in Table 3.3.

Table 3.2: Meteorological data during crop season (June to October, 2016)

Source, ICAR-IISS Bhopal, 2016

Month	Standard week No.	Date	Temperature (°C)		Relative humidity (%)	Rainfall (mm)	Number of rainy days
			Max.	Min.			
June	23	6-12	44.37	31.40	61.00	5.8	-
	24	13-19	40.71	29.94	64.00	-	-
	25	20-26	37.68	26.37	79.40	33.2	-
	26	27-3	34.85	26.27	84.42	55.6	5
July	27	4-10	29.38	24.57	88.57	323.8	7
	28	11-17	28.38	24.24	89.82	124.2	5
	29	18-24	30.34	25.10	87.14	98.6	2
	30	25-31	30.85	24.57	92.57	80.0	5
August	31	1-7	29.61	24.34	90.57	110.8	5
	32	8-14	28.65	24.14	89.14	90.8	4
	33	15-21	28.62	23.37	90.85	129.4	4
	34	22-28	27.27	23.68	91.14	69.2	3
	35	29-4	32.01	25.15	88.42	45.6	3
September	36	5-11	31.10	23.67	89.57	-	-
	37	12-18	32.42	25.18	88.28	20.6	1
	38	19-25	33.00	24.82	88.14	12.0	2
	39	26-2	32.91	24.61	87.57	14.0	0
October	40	3-9	32.42	24.51	89.57	45.8	2
	41	10-16	32.94	23.21	86.42	-	0
	42	17-23	33.57	21.54	68.42	-	0
	43	24-30	33.47	22.64	62.71	-	0
	44	31-6	30.90	14.71	73.75	-	0
					GT	831.17	48



Photo 3.3.: Experimental field overview

N ←

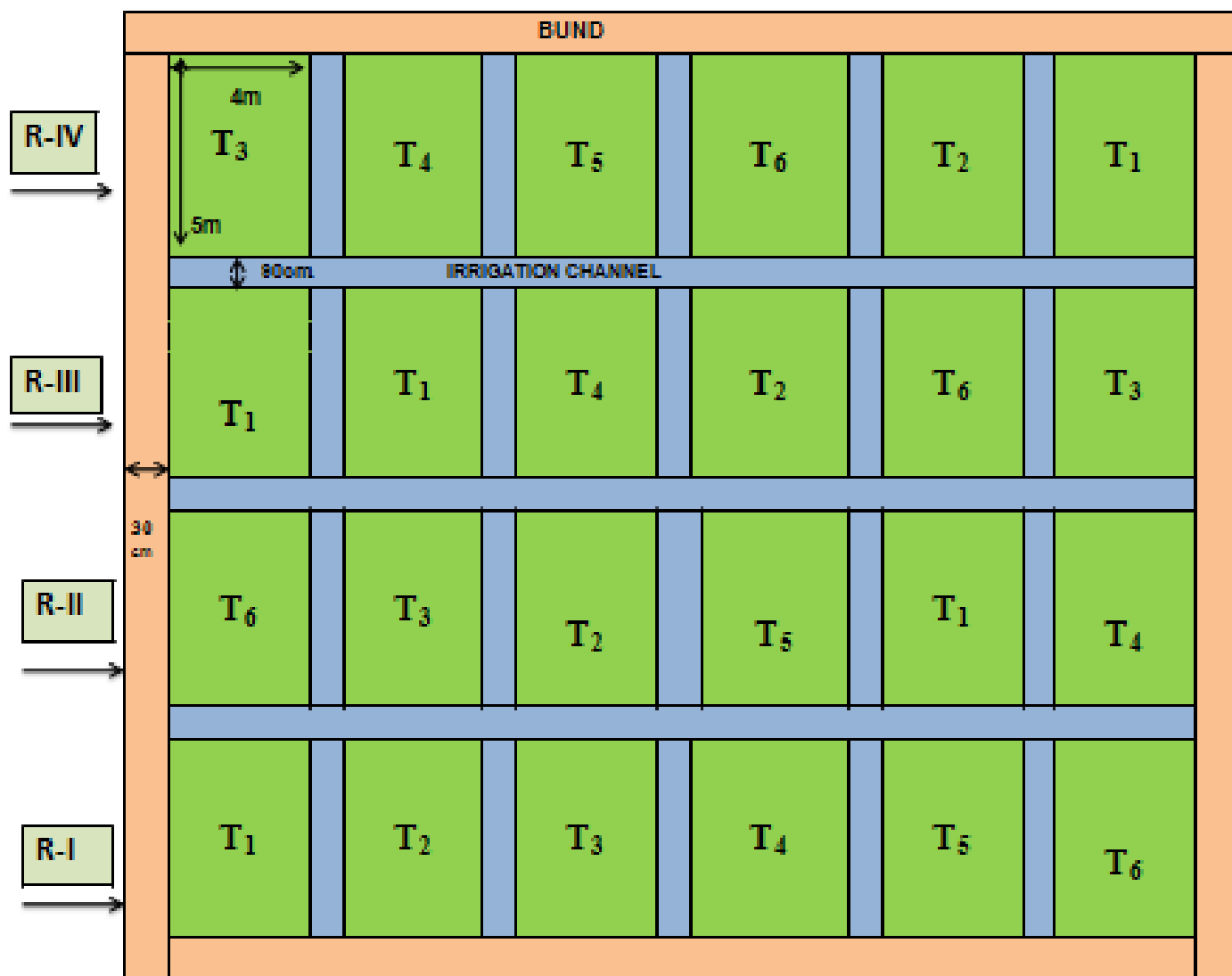


Plate 3.4: Layout plan of field experiment

3.2.3: *Experimental details*

The experiment was laid out in a randomized block design with four replications and details are presented in Table 3.4 and 3.5. Each replication accommodated six treatments. All the treatments were randomized separately in each replication.

3.2.4: *Land preparation*

The plots (5 m x 4 m) were tilled with tractor drawn disk plough to a depth of 15 cm twice and with cultivator to a depth of 12 cm once before sowing of Maize. In the well prepared field Hybrid Maize was sown manually at the rate of 20 kg ha⁻¹ with 60*20 cm² spacing on 29th June,

3.2.5: *Seed rate and Sowing*

The maize (hybrid Nutan KH-101) was sown @ 20 kg ha⁻¹ on 29 June, 2016 by manually about 3 cm deep in lined furrows keeping row to row distance 60 cm and plant to plant distance 20 cm. Chemical fertilizers were applied below the seed in furrows before sowing. Then seed were covered with soil to level the opened furrows. After germination and emergence, thinning and gap filling were done to maintain the desired plant population.

Table 3.3: Physiochemical characteristics of experimental soil

S. No.	Soil parameters	Mean±SD	Methods	Remarks
1.	pH (1:2.5 soil/water ratio)	8.03±0.03	Jackson, (1973)	Slightly Alkaline
2.	Electrical conductivity (dSm ⁻¹)	0.08±0.08	Jackson, (1973)	Normal
3.	Organic Carbon (%)	0.45±0.14	Walkley and Black, (1934)	Low
4.	Available Nitrogen (kg ha ⁻¹)	162±8.90	Subbiah and Asija, (1956)	Low
5.	Available Phosphorus (kg ha ⁻¹)	19.6±0.14	Olsen et al., (1954)	Low
6.	Available Potassium (kg ha ⁻¹)	1050±26.3	Hanway and Heidel, (1952)	High
7.	Available Sulphur (mg kg ⁻¹)	5.90±0.29	Chesnin and Yien, (1950)	Low
8.	DTPA extractable Micronutrients		Lindsay and Norwell, (1978)	
(i)	Copper(mg kg ⁻¹)	0.95±0.24		Sufficient
(ii)	Zinc (mg kg ⁻¹)	0.51±0.09		Sufficient
(iii)	Iron (mg kg ⁻¹)	10.5±0.10		Sufficient
(iv)	Manganese (mg kg ⁻¹)	8.80±0.85		Sufficient

Table 3.4: Details of experiment

1.	Design of experiment	:	Randomized Block Design
2.	No. of replication	:	4
3.	No. of Treatments	:	6
4.	No. of Total plots	:	24
6.	Gross plot size	:	5 m *4 m (20m ²)
7.	Row spacing&	:	60 cm
8.	Plant to plant	:	20 cm
9.	No. of rows per plot	:	9
10.	Crop	:	Maize
11.	Plant population per plot	:	225
12.	Variety	:	Hybrid Nutan KH-101
13.	Seed rate	:	20 kg ha ⁻¹
14.	Date of sowing	:	29 June 2016
15.	Date of harvesting	:	18 November 2016

Table 3.5: Treatment details

Symbol	Treatment	Description
T ₁	Control	No any fertilizers added
T ₂	Urea (100%)+P+K	100% recommended dose (RD) of N through normal Prilled urea
T ₃	RCU (75%)+P+K	75% RD of N through resin coated urea
T ₄	RCU (100%)+P+K	100% RD of N through resin coated urea
T ₅	NCU (75%)+P+K	75% RD of N through neem coated Urea
T ₆	NCU (100%)+P+K	100% RD of N through neem coated Urea

Note: P and K at 100% RDs were supplied through SSP and MOP, respectively

3.2.6: Application of fertilizers and crop management

The full recommended doses (60 kg P₂O₅ & 50 kg K₂O per hectare) of fertilizers were applied as basal in all the treatments except control through SSP and MOP, respectively. While recommended dose of N (150 kg ha⁻¹) was applied in T₂, T₄, T₆ and 75% of recommended dose of N (112.5 kg ha⁻¹) was applied in T₃ and T₅. In case of T₂ N was applied through normal urea, I T₃ and T₄ through resin coated urea and in T₅ and T₆ through neem coated urea. 50% of N is supplied as basal and the remaining N was top dressed in equal splits at 30 DAS and 60 DAS respectively. The maize crop was grown in rainfed condition and no any irrigation was given and one hand weeding was done at 30 DAS.

3.3: Plant growth parameters and chlorophyll content

Plant height, number of leaves, leaf area was measured by randomly selecting three plants in different treatments at 60 and 90 DAS and Leaf area index was calculated. Further SPAD meter reading and chlorophyll content of index leaf by DMSO method were also observed at 90 DAS (third leaf from the tassel)

Leaf chlorophyll content was measured as method described by Richardson et al. (2002). Leaf samples were collected at 90 DAS and washed with distilled water to remove the dusts. The leaf samples (0.2 g) were ground and 10 ml of DMSO was added and centrifuged. The supernatant was collected and the absorbance was measured at 645 and 663 nm. Chlorophyll a, b and total content were calculated using the following formulae.

$$\text{Chl a (mg g}^{-1}\text{)} = \frac{[12.7(A_{663}) - 2.69(A_{645})] \times V}{1000 \times W}$$

$$\text{Chl b (mg g}^{-1}\text{)} = \frac{[22.9(A_{645}) - 4.68(A_{663})] \times V}{1000 \times W}$$

$$\text{Chl total (mg g}^{-1}\text{)} = \text{Chl. a} + \text{Chl. b}$$

Where, V= volume of solvent (mL); W= fresh weight of tissue extracted (g)

3.4: Harvesting, threshing and winnowing

The crop was harvested at maturity stage, when the foliage was shaded off and the pods turned yellowish brown to brown colour. One border row from both sides and 30 cm from either ends of each plot were harvested in order to eliminate the border effect. The rest experimental plot was harvested by sickles, cobs were separated and the plant biomass of each plot was tied in bundles. Bundles were kept open in sun as such for drying for 3 – 4 days, and then weighed to record biomass yield per plot.

The yield attributes like number of cobs per plant, number of grains per cob, 100 grain weight and grain yield per cob were also recorded. Threshing was done manually and grains were separated from cob using wooden sticks by repeated hitting, followed by winnowing with the help of indigenous winnower *Supa*. After cleaning, the grain yield per plot was recorded and weight of biomass of cob after removing grains was also recorded. Further plant samples were oven dried at 70°C for overnight and plant dry matter and grain yields were recorded.

3.5: Collection and Preparation of Soil and Plant Samples

The representative soil (0-15 cm) samples from each plot were collected before sowing and after harvesting of crop with the help of tube auger. Each sample was air-dried and sieved through 2 mm sieve. The processed soil samples were used for laboratory analysis.

Plant samples of maize were collected at maturity from 4 m² area in the center of each plot. Plant samples were dried at 70°C in oven and ground up for further laboratory analysis.

3.6: Plant analysis

Plant samples (grain and straw) were collected and dried in oven at 70°C, then dried samples were ground in an electric grinder to 0.5 mm size. These samples were used for the analysis of NPK.

3.6.1: Determination of Nitrogen

Nitrogen in plant sample was determined by KEL PLUS nitrogen estimation system. Pelicans KEL PLUS System is designed to perform the Kjeldahl, (1883) method to estimate Nitrogen which consists of the following three processes namely 1. Digestion; 2. Distillation; 3. Titration

3.6.1.1: Digestion Process

In this process, 0.5 g oven dried ground plant sample was transferred to the digestion tube. 10 ml of concentrated sulphuric acid and 2 g of digestion activator (Salt mixture of K_2SO_4 + $CuSO_4$ in 20:1 ratio) to the sample were added. Digestion tubes were loaded in to the digester and the digestion block was heated. At the end of digestion process, the sample turned colorless or light green color.

3.6.1.2: Distillation process

During distillation, the ammonium radicals were converted to ammonia under excess alkali condition after neutralizing the acid in the digested sample with 40% alkali (NaOH) on heating. In Distillation unit (DISTYL-EM), the digested samples are heated by passing steam and the ammonia liberated due to the addition of 40% NaOH is dissolved in 4% boric acid. The ammonia in boric acid was taken for titration.

3.6.1.3: Titration Process

The solution of boric acid and mixed indicator containing the “distilled off” ammonia was titrated with the standardized H_2SO_4 . The titration value of a blank solution of boric acid and mixed indicator was also determined.

$$\text{Nitrogen\%} = \frac{(\text{Sample titer} - \text{Blank titer}) \times \text{Normality of } H_2SO_4 \times 14 \times 100}{\text{Sample weight (g)} \times 100}$$

3.6.2: Determination of phosphorus and potassium

About 1 g oven dried ground plant sample was taken in 100 ml conical flask and was digested using 10 ml of di-acid mixture consisting of AR grade concentrated HNO₃ and HClO₄ in the 9:4 ratio and the volume of digested material was made-up 100 mL volumetric flask and was filtered through Whatman No. 42 filter paper and filtrate was used for estimation of P, K.

3.6.2.1: Estimation of phosphorus

About 10 ml of aliquot from the colorless filtrate was taken into 25 mL volumetric flask for determination and then 5 mL of ammonium molybdate vanadate mixture was added to it and volume was made up to 25 mL after shaking well. It was kept for 30 minutes for development of yellow color and color intensity was measured in spectrometer (model CE 2031) at 470 nm after setting the instrument to zero with blank as described by Jackson (1973).

3.6.2.2: Estimation of potassium

About 10 mL aliquot of the filtrate was taken in 100 mL volumetric flask and it was diluted to mark with distilled water. The potassium content in extract was estimated by flame photometer (ELICO-model CL 378) (Black, 1965).

3.7: Nitrogen use efficiency

3.7.1: Nutrient uptake

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient content (\%)} \times \text{Yield (kg ha}^{-1}\text{)}}{100}$$

3.7.2: Nitrogen use efficiency (NUE)

NUE (agronomical and physiological) and nutrient recovery by plant were computed as per suggested by

$$\text{Agronomic use efficiency} = \frac{\text{Grain yield}_f(\text{kg ha}^{-1}) - \text{Grain yield}_c(\text{kg ha}^{-1})}{\text{Fertilizer N applied (kg ha}^{-1}\text{)}}$$

$$\text{Utilization efficiency (\%)} = \frac{\text{Nutrient uptake}_f (\text{kg ha}^{-1}) - \text{Nutrient uptake}_c (\text{kg ha}^{-1})}{\text{Fertilizer N applied (kg ha}^{-1})} \times 100$$

$$\text{Physiological use efficiency (\%)} = \frac{\text{Grain yield}_f (\text{kg ha}^{-1}) - \text{Grain yield}_c (\text{kg ha}^{-1})}{\text{Nutrient uptake}_f (\text{kg ha}^{-1}) - \text{Nutrient uptake}_c (\text{kg ha}^{-1})} \times 100$$

$$\text{Partial Factor Productivity} = \frac{\text{Grain yield (kg ha}^{-1})}{\text{Fertilizer applied (kg ha}^{-1})}$$

Where, f= fertilized crop; c = unfertilized (control)

3.8: Soil Analysis

All the individual soil samples were analyzed for the following chemical properties.

3.8.1: Soil pH

The pH of soil was determined by using pH meter with glass electrode (model, 420A) using 1:2.5 soil water suspensions (Jackson, 1973).

3.8.2: Electrical conductivity (dSm^{-1})

The supernatant liquid of the soil suspension formerly used for pH determination was used for the determination of electrical conductivity by conductivity meter (model- 105 Aplus) (Jackson, 1973).

3.8.3: Organic carbon

Organic carbon was estimated by the dichromate wet oxidation method of Walkley-Black (1934). In this method organic matter in the soil was oxidized with a mixture of potassium dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$) and concentrated H_2SO_4 utilizing the heat of dilution of H_2SO_4 . Unused $\text{K}_2\text{Cr}_2\text{O}_7$ was back titrated with ferrous ammonium sulphate.

$$\text{SOC \%} = \frac{10(B - S) \times 0.003 \times 100}{B \times W}$$

Where, B= blank reading; S= sample reading; W= weight of the soil sample

3.8.4: Available Nitrogen

Available nitrogen was estimated by alkaline KMnO_4 method where the organic matter in the soil was oxidized with hot alkaline KMnO_4 solution. The ammonia (NH_3) evolved during oxidation was distilled and trapped in boric acid and mixed indicator solution. The amount of NH_3 trapped was estimated by titrating with standard acid (Subbaiah and Asija, 1956).

$$N \text{ (kg ha}^{-1}\text{)} = \frac{(S - B) \times \text{Normality of H}_2\text{SO}_4 \times 14 \times 2.24 \times 10^6}{1000 \times W}$$

Where, B= blank reading; S= sample reading; W= weight of the soil sample

3.8.5. Available Phosphorus

The available phosphorus of soil was extracted with 0.5 M NaHCO_3 (pH 8.5) (Olsen *et al.*, 1954). The content of phosphorus in the extract was determined using ammonium molybdate and ascorbic acid reduction method by developing blue colour and intensity of blue colour was measured using spectrophotometer (model-CE2031) at 660 nm wave length (Jackson, 1973).

$$P \text{ (mg kg}^{-1}\text{)} = \frac{C \times \text{Final volume (mL)} \times \text{olsen reagent (mL)}}{\text{aliquot (mL)} \times W}$$

Where, C= concentration of P; W= weight of the soil sample

3.8.6: Available Potassium

The potassium in soil was extracted with neutral normal ammonium acetate and the content of potassium in the extract was estimated by flame photometer (model, CL 378)(Jackson, 1973).

$$K \text{ (mg kg}^{-1}\text{)} = \frac{R \times F \times \text{volume of ammonium acetate (mL)}}{\text{Weight of the soil}}$$

Where, R= reading; F= unit factor; W= weight of the soil sample

3.8.7: Available Sulphur

Available sulphur in soil was determined by turbidimetric method after extracting the soil with 0.15% CaCl₂ solution as described by Chesnin and Yien, (1951).

$$S \text{ (mg kg}^{-1}\text{)} = \frac{R \times F \times \text{Final volume (mL)} \times \text{volume of filtrate (mL)}}{\text{Volume for estimation (mL)} \times W}$$

R= reading; F= unit factor; W= weight of the soil sample

3.8.7: Available micronutrient by DTPA extractions

Micronutrients such as copper, iron, manganese and zinc were extracted from soil using diethylene-triamine-penta-acetic acid (DTPA) extractant through chelation. The extraction solution comprised of 0.005 M DTPA, 0.01 M calcium chloride di-hydrate (CaCl₂.2H₂O) and 0.1 M tri-ethanol amine (TEA). The pH was adjusted to 7.3 using diluted 4 NHCl and the volume made up to 1 L with distilled water. All calibration blanks and standards were prepared in the DTPA extraction (Lindsay and Norwell, 1978).

3.9: Economics

Recommendation and adoption of any practices by cultivator depends upon its economics. Therefore, it becomes essential to work out economics of the treatments for getting higher net profit/ha.

3.9.1: Cost of cultivation

For different treatments total cost was calculated on the basis of prevailing market rate of fertilizer, field preparation, sowing of seeds, labour charges, culture and intercultural operations etc.

3.9.2: Gross return

For different treatments gross returns was calculated on the basis of prevailing market rate of produce.

3.9.3: Net profit

It was calculated treatment wise. The total cost of cultivation per hectare was subtracted from the gross income for computing net returns from each treatment.

$$\text{Net profit (Rs ha}^{-1}\text{)} = \text{Gross return (Rs ha}^{-1}\text{)} - \text{Cost of cultivation (Rs ha}^{-1}\text{)}$$

3.9.4: Benefit Cost Ratio (BCR)

It was calculated treatment wise. The gross income per hectare of each treatment was divided by the cost of cultivation of respective treatment

$$\text{Benefit Cost Ratio (BCR)} = \frac{\text{Gross return}}{\text{Cost of cultivation}}$$

Chapter-IV

RESULTS

The results of the present investigation “**Evaluation of Nitrogen Losses and Nitrogen Use Efficiency in Maize, Fertilized with Resin Coated Urea**” related to application of coated urea fertilizers on ammonia volatilization and nitrate leaching losses; their impact on yield, uptake of nutrients and residual fertility status of experimental soil are displayed and explained in this chapter. The data of the final observations of the various parameters were subjected to statistical analysis and the results have, therefore, been presented through tables and suitable figures. All the findings of the experiments have been described in the following paragraphs under suitable heads:

4.1: Results of incubation experiments

The results of incubation experiments carried at room temperature for N losses through ammonia volatilization for 10 days and nitrate leaching for 15 days from a Vertisol treated with different N sources has been discussed below:

4.1.1: Volatilization loss of N

The amount of N volatilized from Vertisol treated with different N sources at different time intervals and the percentage of loss are summarized in Table 4.1. It was found that the rate of $\text{NH}_4\text{-N}$ volatilization loss for incubation period under control, normal urea, NCU, RCU and urea + POR applied soil varied from 0.30-1.45, 2.10-18.40, 2.65-11.80, 1.82-9.45 and 2.45-12.50 mg N per day per pot, respectively. Invariable to N sources, after third day there was significant increment in volatilization rate and attained maximum at 5th and 6th day and there after followed the declining trend. The rate of ammonia volatilization was highest for normal urea applied soils from day one to 7th day and 8-10th day NCU applied soils had the highest ammonia volatilization rate. In initial stages (upto 7 days) ammonia volatilization was higher in normal urea applied soil and thereafter coated urea fertilizers applied treatments had the higher volatilization. Further the cumulative ammonia volatilization loss at different time has been displayed in Figure

4.1. The total amount of $\text{NH}_4\text{-N}$ volatilized from normal urea, neem coated urea and resin coated urea after 240 h was 82.4, 62.5 and 52.6mgN pot⁻¹, respectively and were significantly differ from each other. The percent of $\text{NH}_4\text{-N}$ volatilized from applied N under these treatments were 32.9%, 23.9% and 19.4%, respectively (Table 4.1). Further application of POR as solution along with normal urea also showed $\text{NH}_4\text{-N}$ volatilization loss of 66.4mgN pot⁻¹(25.7% N loss from applied N). The observed reduction in volatilizationloss from NCU, RCU and urea+ POR applied soil over normal urea applied soil was 27.5%, 41.1%, and 22.0%, respectively.

4.1.2: Nitrate leaching

The amount of $\text{NO}_3\text{-N}$ leached from the soil treated with different N fertilizers at different time intervals has been revealed in Table 4.2. Invariable to N source, application of N (220 mg per column) tremendously increased the $\text{NO}_3\text{-N}$ leaching from soil. Further the nitrate leaching was high in the initial stages after of incubation period after application of N fertilizers. The highest nitrate leaching rate was observed in first three days, and then it followed the declining trend upto the end of incubation period. However, the rate and amount of nitrate leaching from different N fertilizers applied soils at different time varied. For first 6 days the rate of nitrate leaching loss was highest in normal urea applied soils. Then in the later stages nano ZnO coated urea had the highest nitrate leaching rates. The cumulative loss of N through leaching from soil treated with different N sources has been displayed in Figure 4.2. The total amount of $\text{NO}_3\text{-N}$ leached from the soil treated with urea, NCU, rock phosphate coated urea, RCU, nano ZnO coated urea and control were 130.0, 110.0, 99.9, 102.0, 92.3 and 23.0mg $\text{NO}_3\text{-N}$ per column, respectively.

Table 4.1: Volatilization loss of N from different N sources applied to a VertisolNote: Amount of N applied 220 mg N pot⁻¹

Treatment	NH ₃ -N volatilization rate (mg N pot ⁻¹)											Percent loss of applied N
	24 h	48 h	72 h	96h	120 h	144 h	168 h	192 h	216 h	240 h	Cumulative loss	
Control	1.45 ^e	0.92 ^e	1.05 ^e	0.70 ^e	1.71 ^d	1.62 ^e	1.01 ^e	0.73 ^c	0.59 ^c	0.32 ^e	9.9 ^e	-
Normal urea	3.25 ^a	3.45 ^a	3.95 ^a	8.41 ^a	16.0 ^a	18.4 ^a	12.3 ^a	8.09 ^a	6.40 ^b	2.11 ^d	82.4 ^a	32.9
NCU	2.65 ^b	2.81 ^b	2.70 ^b	4.72 ^c	11.9 ^b	8.12 ^c	8.51 ^c	8.28 ^a	7.18 ^a	5.74 ^a	62.5 ^c	23.9
RCU	1.80 ^d	2.01 ^d	1.75 ^d	4.11 ^d	9.46 ^c	4.35 ^d	8.69 ^d	8.19 ^a	7.30 ^a	4.89 ^b	52.6 ^d	19.4
Urea + POR	2.45 ^c	2.53 ^c	2.85 ^c	6.20 ^b	12.5 ^b	11.8 ^b	10.1 ^b	7.40 ^b	6.19 ^b	4.40 ^c	66.4 ^b	25.7
CD(P=0.05)	0.13	0.18	0.21	0.53	1.01	1.24	0.80	0.62	0.53	0.42	5.13	-

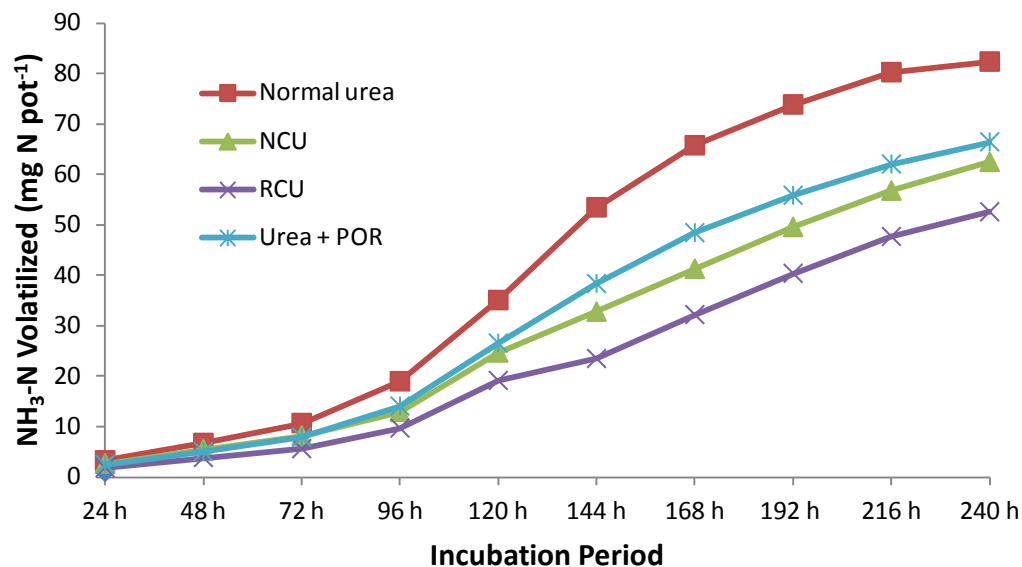


Figure 4.1: Cumulative volatilization loss of N from different N sources applied to a Vertisol

There was significant difference observed between coated fertilizers and normal urea applied soil in respect to total amount of $\text{NO}_3\text{-N}$ leached during the study period. Further, there was significant difference observed between RCU and NCU applied soil in total

amount of nitrate leaching. Among the different N sources applied, the nano ZnO coated urea fertilizer applied soil had the lowest total nitrate leaching and was significantly differ from other N sources applied treatments. The percent loss of applied N (220 mg) through nitrate leaching for urea, NCU, rock phosphate coated urea, RCU, nano ZnO coated urea were 48.5%, 39.7%, 34.9%, 36.0% and 31.5%, respectively (Table 4.2). The reduction in NO₃-N leaching due to neem, resin, rock phosphate and nano ZnO coatings were 18.3%, 28.0%, 25.7% and 35.1%, respectively.

Table 4.2: Leaching loss of N in the form of NO₃-N from different N sources applied to a Vertisol

Treatment	Nitrate-N leaching loss (mg N per column)						Percent loss of applied N
	3 day	6 day	9 day	12 day	15 day	Cumulative loss	
Control	14.0 ^e	6.31 ^e	1.81 ^f	0.59 ^e	0.31 ^{de}	23.0 ^e	-
Normal urea	86.0 ^a	38.8 ^a	3.24 ^e	1.23 ^{cd}	0.49 ^c	130 ^a	48.5
NCU	71.1 ^b	33.1 ^b	4.31 ^d	1.5 ^c	0.35 ^d	110 ^b	39.7
Rock phosphate coated urea	59.9 ^c	20.3 ^d	12.7 ^a	6.43 ^b	0.62 ^b	99.9 ^c	34.9
RCU	67.1 ^b	29.2 ^c	5.11 ^c	0.62 ^{de}	0.29 ^e	102 ^c	36.0
Nano ZnO coated urea	54.3 ^d	18.2 ^d	10.3 ^b	8.57 ^a	0.93 ^a	92.3 ^d	31.5
CD (P=0.05)	4.45	2.14	0.78	0.63	0.05	6.65	-

Note: Amount of N applied 220 mg N column⁻¹

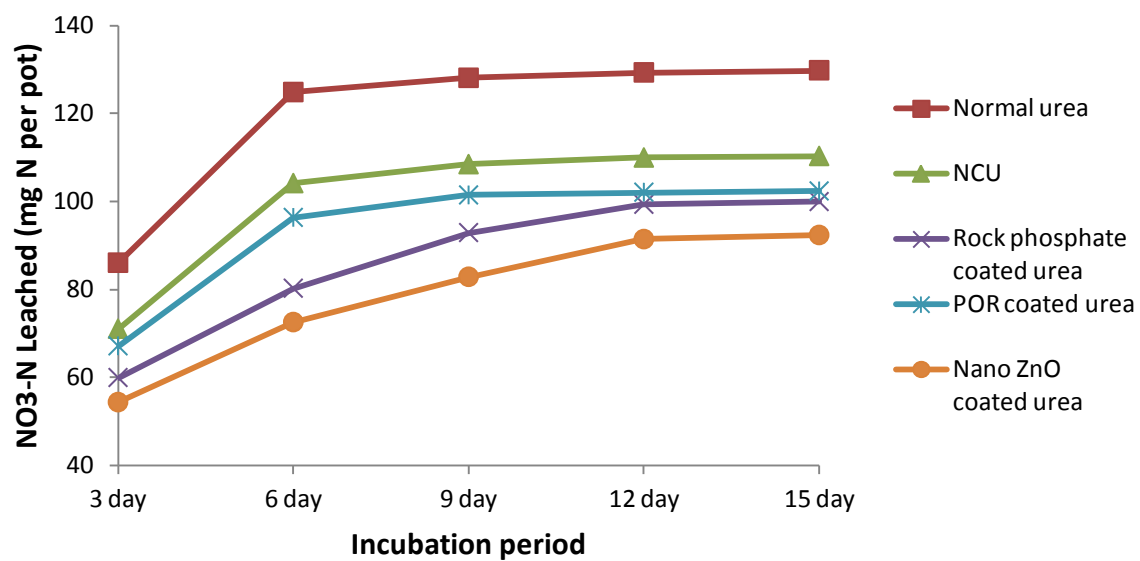


Figure 4.2: Cumulative leaching of NO₃-N from different N sources applied to a Vertisol

4.2: Results of field experiment

The results obtained through field experimentation with maize under different N sources and levels along with recommended doses of P and K and absolute unfertilized control has been briefly explained in the following paragraphs.

4.2.1: Plant growth parameters

The influence of different N fertilizer sources and doses on plant growth parameters like plant height, number of leaves, leaf area and leaf area index (LAI) has been depicted in Table 4.3.

4.2.1.1: Plant height

Application of N had significantly improved the plant growth (height) over control. However, there was no any significance difference among different N sources and levels with respect to plant height. The highest plant height was observed in resin coated urea (100% RD) applied treatment in both the stages i.e at 60 and 90 DAS with the average plant height of 131.7 cm and 143.3 cm followed by neem coated urea (100% RD). Never the less, plant height in both RCU (75% RD) and NCU (75% RD) applied treatments had slightly over edged the plant height of normal urea (100% RD) applied treatment (Table 4.3).

4.2.1.2: Number of leaves

The average number of leaves in plants treated with various N sources was significantly high over the unfertilized control treatments. Whereas the average number of leaves among different N sources and doses were statistically at par with each other. RCU (100% RD) treated plants recorded the highest number of leaves followed by RCU (75% RD), NCU (100% RD), NCU (75% RD) and normal urea (100% RD) in the sequence as 12.2, 11.9, 11.8, 11.7 and 11.6, respectively (Table 4.3).

Table 4.3: Influence of various N levels and sources on different plant growth parameters

Treatment	Plant height (cm)		Number of leaves		Leaf area (cm ²)		LAI	
	60 DAS	90 DAS	60 DAS	90 DAS	60 DAS	90 DAS	60 DAS	90 DAS
Control	84.7 ^b	94.6 ^b	9.40 ^c	10.0 ^b	1184 ^b	1240 ^b	0.99 ^b	1.03 ^b
Urea (100% RD)+P+K	116 ^{ab}	133 ^{ab}	11.4 ^{ab}	11.6 ^a	2369 ^a	2519 ^a	1.97 ^a	2.10 ^a
RCU (75% RD)+P+K	130 ^a	136 ^a	11.7 ^{ab}	11.9 ^a	2316 ^a	2613 ^a	1.93 ^a	2.18 ^a
RCU (100% RD)+P+K	132 ^a	143 ^a	12.1 ^a	12.2 ^a	2681 ^a	2936 ^a	2.23 ^a	2.45 ^a
NCU (75% RD)+P+K	126 ^a	138 ^a	11.2 ^b	11.7 ^a	2493 ^a	2713 ^a	2.08 ^a	2.26 ^a
NCU (100% RD)+P+K	127 ^a	140 ^a	11.8 ^{ab}	11.8 ^a	2660 ^a	2760 ^a	2.22 ^a	2.30 ^a
CD(P=0.05)	25.6	27.6	0.92	0.61	723	639	0.41	0.56

4.2.1.3: Leaf area and LAI

The average leaf area and LAI had been influenced by application of N at different dosage levels. The least leaf area and LAI at 60 DAS (1184 cm² and 0.99) and 90 DAS (1240 cm² and 1.03) was observed in unfertilized control treatment. But N applied at 75% and 100% RD, invariable to sources, had significantly improved the leaf area and LAI over the control. However, there was no significant difference found among different N sources and dosage levels with respect to leaf area and LAI. On the other hand, LAI

was highest in RCU (100% RD) and NCU (100% RD) applied treatments that were statistically at par with the LAI of normal urea (100% RD) treated plants. Further N supplied through RCU (75% RD) and NCU (75% RD) were also fetched equal LAI of normal urea (100% RD) applied treatments. The highest leaf area of 2936 cm² and LAI of 2.45 was observed at 90 DAS in RCU (100% RD) treated plants (Table 4.3).

4.3: Plant physiological parameters

The effect of application of N at various dosage levels and through different sources on leaf chlorophyll content and green seeker values at 90 DAS has been depicted in Table 4.4.

4.3.1: Leaf chlorophyll content

Chlorophyll-a concentration of maize leaves was significantly improved due to application of N to the soil, invariable to source and dose, when compared to unfertilized treatment (control). But there was no statistical difference found among the plants that supplied with different N sources. Whereas, chlorophyll-b concentration of maize leaves was significantly improved in coated urea applied fertilizers when compared to normal urea and control treatments. In case of total chlorophyll content, the highest value was observed in NCU (100% RD) with 1.88 mg g⁻¹, followed by RCU (100% RD), RCU (75% RD), NCU (75% RD), and normal urea (100% RD) in the descending order and statistically at par with each other. The least total chlorophyll content of 1.17 mg g⁻¹ was observed in unfertilized treatment (Table 4.4).

4.3.2: Greenness index

The greenness index obtained through SPAD meter reflects the total chlorophyll content of the leaves. Similar to the results obtained in total chlorophyll concentration of maize leaves, the greenness index value also found to be highest in NCU (100% RD) followed by RCU (100% RD), RCU (75% RD), NCU (75% RD), and normal urea (100% RD) in the descending order and were statistically at par with each other (Table 4.4). The corresponding least value was observed in unfertilized treatment which was significantly low from the other treatments.

Table 4.4: Effect of various N levels and sources on leaf chlorophyll content and greenness index

Treatment	Chloro- phyll-a (mg g⁻¹)	Chloro- phyll-b (mg g⁻¹)	Total chlorophyll (mg g⁻¹)	Greenness index
Control	0.95 ^b	0.22 ^b	1.17 ^b	27.9 ^b
Urea (100% RD)+P+K	1.49 ^a	0.24 ^b	1.73 ^a	34.7 ^a
RCU (75% RD)+P+K	1.45 ^a	0.39 ^a	1.84 ^a	35.6 ^a
RCU (100% RD)+P+K	1.42 ^a	0.43 ^a	1.86 ^a	36.4 ^a
NCU (75% RD)+P+K	1.36 ^a	0.41 ^a	1.77 ^a	32.4 ^{ab}
NCU (100% RD)+P+K	1.45 ^a	0.43 ^a	1.88 ^a	36.8 ^a
CD(P=0.05)	0.32	0.14	0.30	5.14

4.4: Yield attributes

The yield attributes such as number of cobs per plant, number of grains per cob, 100 grain weight or seed index and grain yield per plant or cob have been described in (Table 4.5).

4.4.1: Number of cobs per plant

There were no any significant changes in number of cob per plant due to application of fertilizer treatments in the current investigation (Table 4.5).

4.4.2: Number of grains per cob

The number of grains per cob varied from 140-236. The significant difference between coated urea fertilizer and normal urea applied treatments was observed with respect to number of grains per cob; however, there were no significant difference

among coated urea fertilizers invariable to N levels (Table 4.5). Further application of urea also significantly improved the number of grains per cob than the control.

4.4.3: Seed index

The seed index or 100 grain weight ranged from 19.0- 19.6 g. However, there were no any significant changes in 100 grain weight due to application of fertilizer treatments in the current investigation (Table 4.5).

4.4.4: Grain yield per cob

The significant changes in grain yield per cob or plant under various fertilizer treatments was observed. The unfertilized control treatment had 26.5 g grain per cob, which was significantly lower than the other treatments (Table 4.5). Moreover, plants applied with coated urea fertilizers had higher grain yield per cob than the normal urea applied plants and were statistically at par with each other.

Table 4.5: Information on various yield components under different fertilizer treatments

Treatment	Number of cobs per plant	Number of grains per cob	100 grain weight or seed index (g)	Grain yield per plant or cob (g)
Control	1.00	140 ^c	19.0	26.5 ^c
Urea (100% RD)+P+K	1.00	180 ^b	19.4	34.7 ^b
RCU (75% RD)+P+K	1.00	235 ^a	19.2	44.9 ^a
RCU (100% RD)+P+K	1.00	236 ^a	19.4	45.8 ^a
NCU (75% RD)+P+K	1.00	224 ^a	19.6	43.9 ^a
NCU (100% RD)+P+K	1.00	231 ^a	19.5	45.1 ^a
CD(P=0.05)	NS	32.3	NS	6.41

4.5: Crop yield

Maize shoot and grain yield and harvest index (HI) affected by application of N through coated fertilizers and normal urea have been presented in Table 4.6.

4.5.1: Shoot yield

The dry shoot yield of maize in control treatment (where no fertilizer applied) was recorded as 2995 kg ha⁻¹ that was significantly lower from other treatments in the study (Table 4.6). Among the N sources, the highest average dry shoot yield of 4588 kg ha⁻¹ was observed in RCU(100% RD) applied plots that was statistically at par with NCU (100% and 75% RD) and RCU (75% RD) and higher than normal urea (100% RD). It's worth mention here that even 75% RD of N supplied through coated fertilizers were at par with the normal urea (100% RD) applied treatment in respect shoot yield. The percent increase in shoot yield due to application of urea (100% RD), RCU (100% RD) and NUC (100% RD) along with P and K was 29.4%, 53.2% and 51.9%, respectively. Even in 75% RD of RCU and NCU along with full doses of P and K increased the shoot yield to 39.2% and 39.0% respectively over control (Figure 4.6).

4.5.2: Grain yield

Application of N to maize, invariable to source, had significantly increased maize grain yield. The grain yield of maize in the current investigation due to various fertilizer treatments varied from 2013 to 3373 kg ha⁻¹ (Table 4.6). When compared to unfertilized (control) and normal urea (100% RD) applied treatments, resin and neem coated urea fertilizer applied recorded the significantly higher yield both at 100% and 75% RD. But there was no significant difference observed among the coated urea fertilizer treatments with respect to grain yield. The percent increase in grain yield due to application of urea (100% RD), RCU (100% RD) and NUC (100% RD) along with P and K was 28.3%, 67.5% and 61.0%, respectively. Even in 75% RD of RCU and NCU along with full doses of P and K increased the shoot yield to 51.8% and 55.6% respectively over control (Figure 4.6).

Table 4.6: Maize shoot and grain yield and harvest index affected by various N treatments

Treatment	shoot yield (kg ha⁻¹)	Grain yield (kg ha⁻¹)	HI (%)
Control	2995 ^c	2013 ^d	40.4
Urea (100% RD)+P+K	3875 ^b	2583 ^c	40.2
RCU (75% RD)+P+K	4168 ^{ab}	3056 ^b	42.9
RCU (100% RD)+P+K	4588 ^a	3373 ^a	42.9
NCU (75% RD)+P+K	4163 ^{ab}	3132 ^{ab}	43.2
NCU (100% RD)+P+K	4550 ^a	3240 ^{ab}	42.2
CD(P=0.05)	433.7	327.8	NS

4.5.3: Harvest index

The harvest index of maize fertilized with various fertilizer treatments varied from 40.2-42.9%. However, there were no any significant changes in HI under various fertilizer treatments in the current investigation (Table 4.6).

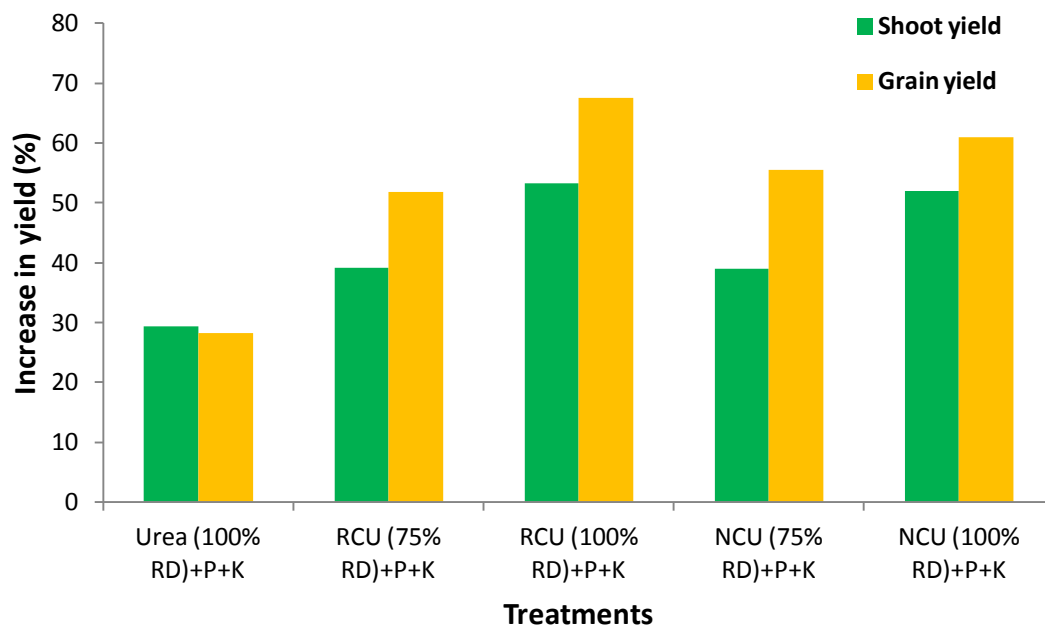


Figure 4.3: Percent increase in maize shoot and grain yield under various fertilizer treatments over control

4.6: Nutrient content

In Table 4.7, the concentration of mineral elements like N, P and K in maize leaf, stem and grain under different fertilizer treatments has been shown. There was significant difference in nutrient content of plant parts observed under different fertilizer sources and dosage levels.

4.6.1: N concentration

The significantly higher N content in maize leaves were observed in coated urea applied treatments (RCU and NCU at 100% RD) (1.53 and 1.55% N) than normal urea (1.11% N) and control (0.59% N) treatments (Table 4.7). Coated urea fertilizers applied at 100% RD had statistically high N in maize leaves than those applied at 75% RD. However, in case of N concentration in maize stem varied from 0.53-1.46% in the current investigation and followed similar trend as of maize leaves N concentration. RCU (100% RD) and NCU (100% RD) applied maize plants had significantly high N concentration in stem than that of control, normal urea RCU (75% RD) applied treatments, and were statistically at par with NCU (75% RD) treatment. Maize grain N concentration was the highest in NCU (100% RD) treatment (1.15% N) which was significantly higher than RCU (100% RD), RCU (75% RD), normal urea and control and statistically at par with NCU (75% RD). However, NCU (75% RD), RCU (100% RD) and RCU (75% RD) were statistically a par with each other.

4.6.2: P concentration

The P concentration of maize leaf, stem and grain in the current study ranged from 0.09-0.14%; 0.06-0.09% and 0.12-0.20%, respectively (Table 4.7). The coated urea fertilizers (100% RD) applied along with P+K treatments showed significantly higher P concentration in different plant parts than the normal urea applied and control treatments. Further there was significant difference observed between control and normal urea+P+K applied treatments with respect to P concentration. Among the coated urea fertilizers, there were no statistical differences found in P concentration in plant parts.

4.6.3: K concentration

Application of K at 100% RD along with different N sources and levels had significantly influenced K concentration of maize leaf, stem and grain than control. Application of RCU (100% RD) had significantly improved the K content of maize leaf, stem and grain from 1.49-1.83%, 1.02-1.57% and 0.48- 0.66%, respectively; however, they were statistically at par with NCU (100% RD), RCU (75% RD) and NCU (75% RD) treatments; and significantly higher from normal urea and control treatments.

Table 4.7: N, P, K concentration of leaf, stem and grain (in % by weight basis) under various fertilizer treatments

Treatment	Leaf			Stem			Grain		
	N	P	K	N	P	K	N	P	K
Control	0.59 ^d	0.09 ^c	1.49 ^b	0.53 ^d	0.06 ^c	1.02 ^c	0.49 ^d	0.12 ^c	0.48 ^d
Urea (100% RD)+P+K	1.11 ^c	0.11 ^b	1.64 ^b	0.98 ^c	0.07 ^{bc}	1.13 ^{bc}	0.84 ^c	0.17 ^b	0.56 ^c
RCU (75% RD)+P+K	1.16 ^c	0.14 ^a	1.76 ^a	1.17 ^b	0.08 ^{ab}	1.45 ^{ab}	0.97 ^{bc}	0.19 ^{ab}	0.61 ^{ab}
RCU (100% RD)+P+K	1.53 ^a	0.14 ^a	1.83 ^a	1.41 ^a	0.09 ^a	1.57 ^a	0.99 ^{bc}	0.20 ^a	0.66 ^a
NCU (75% RD)+P+K	1.40 ^b	0.11 ^{ab}	1.75 ^a	1.33 ^a	0.08 ^{ab}	1.45 ^{ab}	1.01 ^{ab}	0.19 ^{ab}	0.64 ^{ab}
NCU (100% RD)+P+K	1.55 ^a	0.13 ^a	1.81 ^a	1.46 ^a	0.08 ^a	1.52 ^a	1.15 ^a	0.19 ^{ab}	0.65 ^{ab}
CD (P=0.05)	0.10	0.01	0.10	0.15	0.01	0.34	0.16	0.02	0.04

4.7: Nutrient uptake

The results of N, P and K uptake by maize shoot and grain under different fertilizer treatments in the current investigation has been shown in Table 4.8. The total nutrient removal of maize aboveground biomass under various fertilizer treatments has been depicted in Figure 4.4.

4.7.1: N uptake

The N uptake of maize shoot and grain ranged from 16.72–67.49 kg ha⁻¹ and 9.92–37.2 kg ha⁻¹ respectively. All the treatments showed significantly higher N uptake in shoot and grain over the control. Further all the coated urea applied fertilizer treatments at equal N doses were statistically at par with each other and were superior over the normal urea applied treatment for N uptake was concern. The similar trend was observed in total N removal of maize above ground biomass (Figure 4.4). Between different N levels (75% RD and 100% RD), there was significant difference observed with respect to shoot N uptake and no difference found in case of grain N uptake (Table 4.8).

4.7.2: P uptake

All the treatments had significantly higher shoot and grain P uptake than that of control. The highest shoot P uptake were recorded in P applied with RCU (100% RD) and NCU (100% RD) and were statistically at par with the shoot and grain P uptake under application of P with NCU (75%), RCU (75% RD) and normal urea (100% RD) treatments (Table 4.8). The similar results were obtained in case of total P removal by the aboveground biomass of maize (Figure 4.4). Whereas, P applied with coated urea fertilizers showed significantly higher grain P uptake than P applied with normal urea applied treatment.

Table 4.8: N, P and K uptake (kg ha⁻¹) by maize shoot and grain after application of different fertilizer treatments.

Treatment	Shoot			Grain		
	N	P	K	N	P	K
Control	16.7 ^d	1.04 ^b	37.5 ^c	9.92 ^d	2.71 ^c	9.65 ^e
Urea (100% RD)+P+K	40.5 ^c	1.79 ^a	60.5 ^b	21.3 ^c	4.62 ^b	14.2 ^d
RCU (75% RD)+P+K	48.5 ^b	2.21 ^a	66.2 ^{ab}	29.6 ^b	5.64 ^a	18.6 ^c
RCU (100% RD)+P+K	67.4 ^a	2.34 ^a	74.7 ^a	32.9 ^{ab}	5.90 ^a	22.3 ^a
NCU (75% RD)+P+K	56.2 ^b	1.99 ^a	67.1 ^{ab}	31.9 ^{ab}	5.47 ^{ab}	19.7 ^{bc}
NCU (100% RD)+P+K	67.5 ^a	2.30 ^a	68.7 ^{ab}	37.2 ^a	5.83 ^a	21.0 ^{ab}
CD(P=0.05)	7.87	0.69	11.36	5.43	0.91	2.29

4.7.3: K uptake

The K uptake of maize shoot and grain ranged from 37.5–74.7 kg ha⁻¹ and 9.65–22.3 kg ha⁻¹ respectively (Table 4.8). The K uptake of maize shoot was not significantly improved due to application of K along with various N sources and doses. Whereas the K uptake by grain was significantly improved when K applied along with coated urea applied fertilizers than the normal urea. In case of total K removal also followed the similar trend as of grain K uptake and was ranged from 47.2- 96.9 kg ha⁻¹ (Figure 4.4). Further all the treatments significantly over edged the control treatment in respect with K uptake.

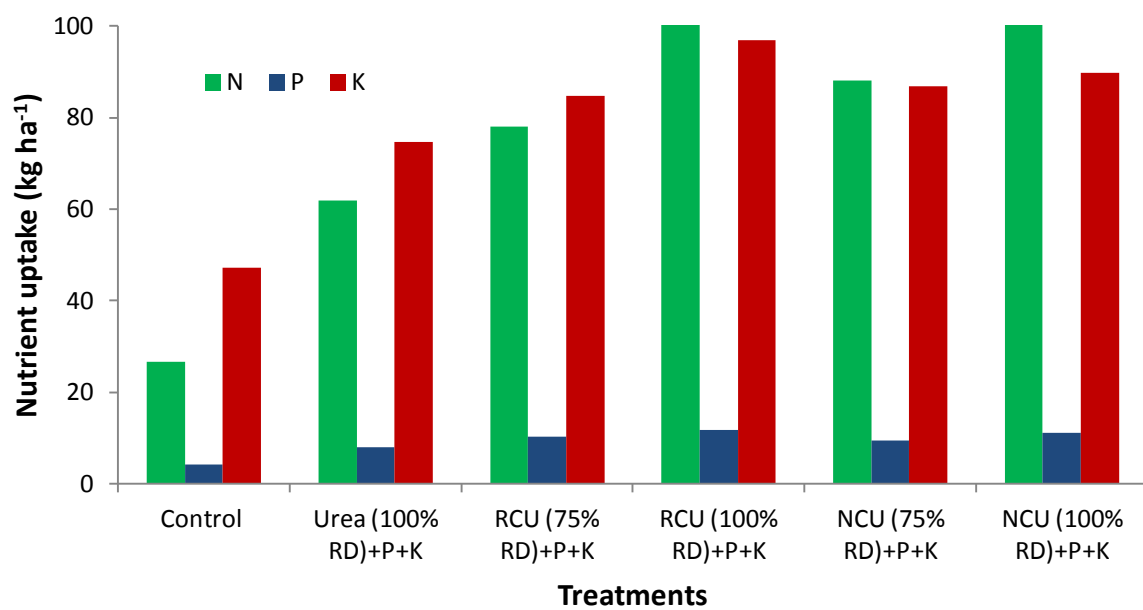


Figure 4.4: Total N, P and K uptake of maize (aboveground biomass) under various fertilizer treatments

4.8: Nutrient use efficiency

Agronomic efficiency (AE), physiological efficiency (PE), utilization efficiency (UE) and partial factor productivity (PFP) of N, P and K for maize under various fertilizer treatments has been revealed in Table 9.

4.8.1: N use efficiency

The use efficiency of N by maize, in terms of AE, PE and UE or apparent N recovery (ANR) and PFP under various fertilizer treatments varied from 3.59-9.94, 16.0-21.1%, 23.4%-54.3% and 17.0-27.8, respectively (Table 4.9). Among the treatments NCU applied at 75% RD along with full doses of P and K had high AE, UE and PFP of N and was significantly at par with other coated urea applied treatments. All the coated urea fertilizer, invariable to N dose, applied along with full doses of P and K significantly over edged the normal urea applied treatments in terms of AE, UE and PFP of N. In case of PE for there was no significant difference observed among the treatments.

4.8.2: P use efficiency

Application of RCU (100%)+P+K showed higher AE, UE and PFP of P by maize followed by NCU (100%)+P+K, and NCU (75% RD)+P+K treatment and were significantly at par with each other. Though 100% RD of coated fertilizers treatments were significantly higher AE, UE and PFP of P than RCU (75% RD)+P+K which was statistically at par with NCU (75% RD)+P+K treatment. Moreover, P applied with coated urea fertilizers has showed significantly higher AE, UE and PFP of P than that of normal urea. There was no significant difference observed among the treatments with respect to PE of P by maize (Table 4.9). The use efficiency of P by maize, in terms of AE, PE and UE and PFP under various fertilizer treatments varied from 20.7-52.3, 142-212%, 14.8-29.0% and 98.1-130, respectively.

4.8.3: K use efficiency

The use efficiency of K by maize, in terms of AE, PE and UE and PFP under various fertilizer treatments varied from 13.0-32.7, 23.6-32.7%, 66.3-124% and 61.5-81.3, respectively (Table 4.9). Application of RCU (100%)+P+K showed higher AE, UE and PFP of K by maize followed by NCU (100%)+P+K, and NCU (75% RD)+P+K treatment and were significantly at par with each other. Though 100% RD of coated fertilizers treatments were significantly higher AE, UE and PFP of K than RCU (75% RD)+P+K which was statistically at par with NCU (75% RD)+P+K treatment. Moreover, P applied with coated urea fertilizers has showed significantly higher AE, UE and PFP of P than that of normal urea. There was no significant difference observed among the treatments with respect to PE of K by maize.

Table 4.9: Nutrient use efficiencies and partial factor productivity of N, P and K for maize under various fertilizer treatments

Treatment	AE			PE (%)			UE (%)			PFP		
	N	P	K	N	P	K	N	P	K	N	P	K
Urea (100% RD)+P+K	3.59 ^b	20.7 ^c	13.0 ^c	16.3	142	23.6	23.4 ^c	14.8 ^d	66.3 ^c	17.0	98.1 ^c	61.5 ^c
RCU (75% RD)+P+K	9.26 ^a	40.1 ^b	25.1 ^b	21.1	176	23.6	45.5 ^b	23.0 ^c	90.7 ^b	27.2	118 ^b	73.6 ^b
RCU (100% RD)+P+K	9.06 ^a	52.3 ^a	32.7 ^a	18.7	181	30.6	49.1 ^{ab}	29.0 ^a	124 ^a	22.5	130 ^a	81.3 ^a
NCU (75% RD)+P+K	9.94 ^a	43.0 ^{ab}	26.9 ^{ab}	18.2	212	28.8	54.3 ^a	20.4 ^c	99.5 ^b	27.8	120 ^{ab}	75.5 ^{ab}
NCU (100% RD)+P+K	8.18 ^a	47.2 ^{ab}	29.6 ^{ab}	16.0	181	32.7	52.0 ^a	26.3 ^b	98.7 ^b	21.6	125 ^{ab}	78.1 ^{ab}
CD(P=0.05)	2.41	11.8	7.40	NS	NS	NS	6.72	2.78	22.4	2.48	11.8	7.40

4.9: Soil properties

Postharvest changes in various soil physico-chemical properties under various fertilizer treatments for maize crop has been described in Table 4.10.

4.9.1: Soil pH, EC and OC

Soil pH, EC and OC under current investigation varied from 8.18-8.26, 0.09-0.10 dS m⁻¹ and 0.35-0.49%, respectively (Table 4.10). There was no any significant change in soil pH and EC observed due to various fertilizers treatments in the study. However the significant difference between control and other treatments was recorded in case of SOC was concern.

4.9.2: Available N, P, K and S in soil

There were no significant changes observed in available P, K and S in soil due to various fertilizers treatments, whereas available N content of soil improved due to application of different N sources than the unfertilized treatment. The highest available N in soil was recorded under RCU (100% RD) followed by NCU (100% RD), RCU (75% RD), NCU (75%), and normal urea (100% RD) applied treatments and were statistically at par with each other (Table 4.10).

4.9.3: DTPA-extractable micronutrients in soil

The DTPA-extractable micronutrient (Zn, Cu, Fe and Mn) in postharvest soil varied from 0.39-0.59; 0.84-0.97; 9.63-10.7; and 7.71-10.7mg kg⁻¹, respectively (Table 4.10). There was no any significant change in DTPA-extractable micronutrients due to various fertilizer sources applied.

Table 4.10: Status of soil physico-chemical properties under various fertilizer treatments after harvest of maize

Treatment	pH	EC	SOC	Available nutrients							
				N	P	K	S	Zn	Cu	Fe	Mn
				(kg ha ⁻¹)			(mg kg ⁻¹)				
Control	8.18	0.10	0.35 ^b	134 ^b	23.6	993	3.67	0.39	0.97	11.3	10.5
Urea (100% RD)+P+K	8.22	0.09	0.42 ^{ab}	183 ^a	27.6	987	5.89	0.45	0.91	10.2	10.2
RCU (75% RD)+P+K	8.19	0.09	0.46 ^a	190 ^a	26.5	974	5.41	0.47	0.95	10.2	9.76
RCU (100% RD)+P+K	8.24	0.09	0.48 ^a	214 ^a	17.1	954	5.67	0.53	0.93	9.63	10.7
NCU (75% RD)+P+K	8.21	0.09	0.49 ^a	193 ^a	26.1	945	3.75	0.49	0.84	10.7	7.71
NCU (100% RD)+P+K	8.26	0.09	0.49 ^a	190 ^a	18.6	964	4.49	0.59	0.94	10.6	11.5
CD(P=0.05)	NS	NS	0.10	28.1	NS	NS	NS	NS	NS	NS	NS
<i>Initial</i>	8.03	0.08	0.45	162	19.60	1050	5.90	0.51	0.95	10.5	8.80

4.10: Economics

Adoption of recommended practices by cultivators depends upon its economics. Therefore, it becomes essential to work out economics of the treatments tested for judging the best treatments under study, for getting higher net profit per hectare. Economics of maize as affected by sources and doses of N has been given in Table 4.11. The highest total cost of cultivation ($\text{Rs}19137 \text{ ha}^{-1}$) was noticed with RCU (100% RD) followed by NUC (100% RD) ($\text{Rs}19062 \text{ ha}^{-1}$) treatments. The cost of cultivation for normal urea applied treatment was $\text{Rs}18897 \text{ ha}^{-1}$. This clear from results that coating of urea with resin (Pine oleoresin) and neem showed more cost of cultivation as compared to same dose of N applied through normal urea.

The maximum gross income of $\text{Rs}50595 \text{ ha}^{-1}$ of maize crop was recorded under RCU (100% RD) applied treatment followed by NUC (100% RD) applied treatment with gross return of $\text{Rs} 48600 \text{ ha}^{-1}$. The gross income for normal urea applied treatment was $\text{Rs} 38745 \text{ ha}^{-1}$. The minimum gross income ($\text{Rs}30195 \text{ ha}^{-1}$) was recorded under control treatment. The highest net return of $\text{Rs}31458 \text{ ha}^{-1}$ was obtained from RCU (100% RD) applied treatment followed by NUC (100% RD) applied treatment with net return of $\text{Rs} 29538 \text{ ha}^{-1}$. The lowest net return ($\text{Rs}17045 \text{ ha}^{-1}$) noted in control treatment. The highest B:C ratio (1.64) was recorded from RCU (100% RD) applied treatment which was followed by NUC (100% RD) applied treatment with 1.55 B:C ratio. The B:C ratio of normal urea applied treatment was 1.05 which was least and lesser than the control (1.30).

Table 4.11: Economics of different treatments under maize crop

Tr. No.	Treatments	Cost of cultivation exclusive treatment * (Rs. ha ⁻¹)	Treatment cost (Rs. ha ⁻¹)	Total cost of cultivation (Rs. ha ⁻¹)	Gross return** (Rs. ha ⁻¹)	Net return (Rs. ha ⁻¹)	B: C Ratio
T ₁	Control	13150	0	13150	30195	17045	1.30
T ₂	Urea (100% RD)+P+K	13150	5747	18897	38745	19848	1.05
T ₃	RCU (75% RD)+P+K	13150	5472	18622	45840	27218	1.46
T ₄	RCU (100% RD)+P+K	13150	5987	19137	50595	31458	1.64
T ₅	NCU (75% RD)+P+K	13150	5419	18569	46980	28411	1.53
T ₆	NCU (100% RD)+P+K	13150	5912	19062	48600	29538	1.55

* For details please refer Appendix- I, ** Price of maize grain Rs. 15 kg⁻¹

Chapter-V

DISCUSSION

The results obtained from the current investigation on “Evaluation of Nitrogen Losses and Nitrogen Use Efficiency in Maize, Fertilized with Resin Coated Urea” have been discussed in detail with the available scientific literatures. The study mainly emphasize the effect of the coated urea fertilizers on N losses through ammonia volatilization and nitrate leaching and maize yield, nutrient acquisition and its recovery.

5.1: Impact on ammonia volatilization

Ammonia volatilization in coated urea fertilizers applied treatments were significantly lower than that of normal urea applied treatments. The findings were in concurrence with results reported by many workers (Kundu et al 2013; Junejo et al., 2011 & 2012; Wang et al. 2007; Freney 1997). Among the coated fertilizer, RCU reduced significantly low $\text{NH}_3\text{-N}$ loss than the NCU. This might be due to slow release of N from coated urea fertilizers because it might have acted as physical barrier. Further, the antimicrobial properties and microsite pH changes due to POR caused the reduction in urea hydrolysis by inhibiting urease-producing microbes (Junejo et al., 2011& 2012; Kundu et al. 2013). Also it was demonstrated that time required for hydrolysis of 90% of the applied urea had markedly increased from 88.56 to 328.94 h in the presence of pine oleoresin. Moreover, presence of phenolic compounds and aromatic ketones in POR might have reduced the enzyme–substrate reaction rate by binding with the urease (Patra and Jain, 1993; Ghosh et al., 2002). In case of neem coated urea, alkaloid present in the neem oil might have inhibited the urease producing microbial activities resulted in low urea hydrolysis rate reduced the $\text{NH}_3\text{-N}$ loss (Prasad et al 2001,2007; Suri 2000; Majumdar, 2000, 2002, 2005). The percent reduction in volatilization loss from NCU, RCU and urea+ POR applied soil over normal urea applied soil was 24.2%, 36.2%, and 19.3%, respectively (Figure 5.1). The ammonia volatilization from applied fertilizers for initial two days was very low and then increase from third day to seventh day there after it was decreased. This might be due to conversion of urea to ammonia might have taken two days.

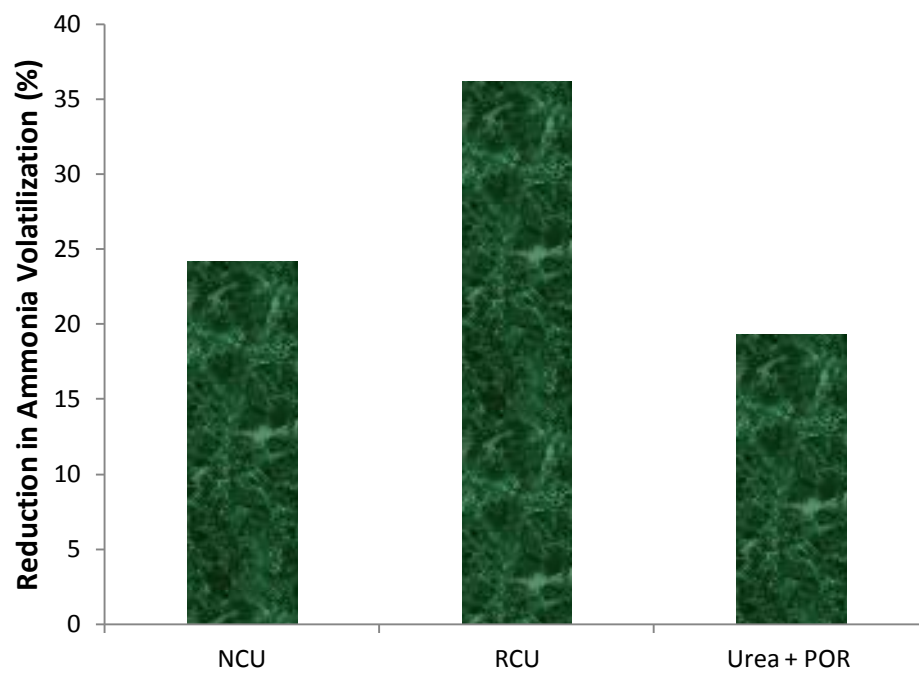


Figure 5.1: Percent reduction in ammonia volatilization loss from soil treated with coated urea fertilizers, urea plus pine oleoresin in comparison with urea

However in all the stages rate of $\text{NH}_3\text{-N}$ loss from coated urea fertilizers were lower than that of normal urea.

5.2: Reduction in nitrate leaching

Application of different coated fertilizers like RCU, NCU, and rock phosphate and nano ZnO coated urea in a Vertisol have significantly reduced the nitrate leaching losses than the normal urea. Due to the hydrophobic nature and the antimicrobial properties of POR (Kundu et al., 2013) and neem oil (Baboo 2014, Singh 2016), coated urea slowly dissolved and was gradually mineralized by microbes. The trend of nitrate leaching from different N sources applied to soil was observed as follow: nano ZnO coated urea < rock phosphate coated urea < RCU < NCU < normal urea. The percent reduction in nitrate leaching from different coated urea fertilizer when compared to normal urea depicted in Figure 5.2. The lowest leaching losses from nano ZnO coated urea might be antimicrobial properties of nano ZnO particles (Espitia et al., 2012; Singh and Nanda, 2013) that might have influenced the microbial activities that resulted in a reduction of the rates of urea hydrolysis and nitrification processes. All these processes might have led to a reduction of NO_3 production and leaching rate. Several researchers reported the antibacterial activities of nano-sized ZnO over a wide spectrum of bacterial species (Buzea et al., 2007; Nair et al., 2011; Raghupathi et al., 2011). Due to its smaller size and high surface reactivity might have ensured higher surface interaction and penetration of ZnO nanoparticles into the bacterial cells. The antimicrobial mechanisms of nano ZnO particles might be the destruction of bacterial cell integrity by direct contact of ZnO nanoparticles with cell walls (Zhang et al., 2007), liberation of antimicrobial ions mainly Zn^{2+} ions (Li et al., 2011), and reactive oxygen species formation (Lipovsky et al., 2011). Importance of particle size, morphology and concentration of ZnO nanoparticles in enhancing the antimicrobial properties had also been reported (Sirelkhatim et al., 2015). However, this was beyond the scope of the current investigation and might be studied further. Similarly low nitrate leaching from RP coated urea could be due to enlarged coating over POR that acted as a physical barrier that reduced the release and availability of N for microbes.

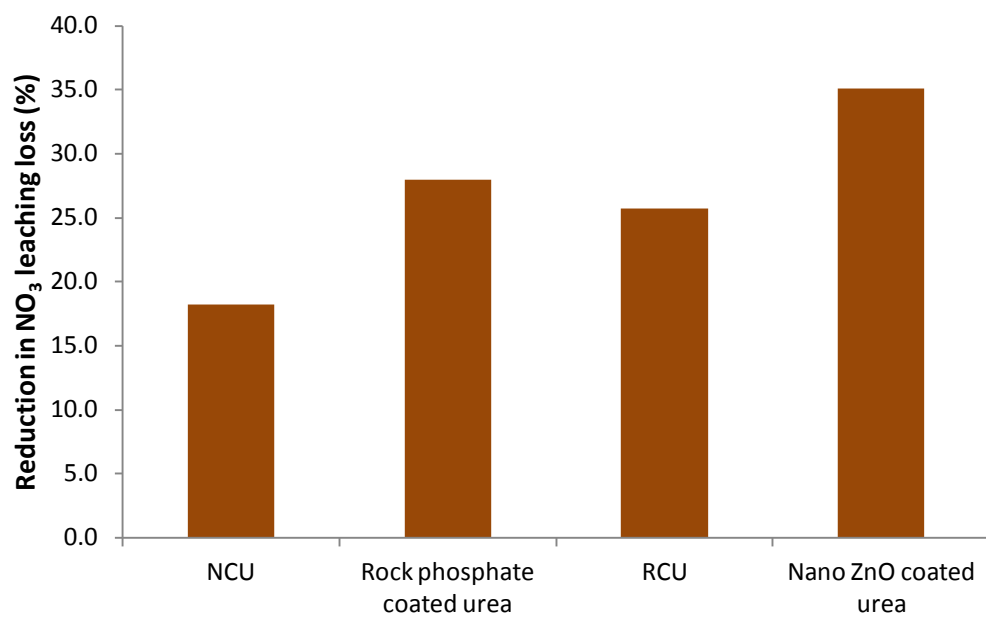


Figure 5.2: Percent reduction in nitrate-N leaching loss from soil treated with various coated urea fertilizers over urea

Also, the presence of high concentration of RP nanoparticles might have enhanced the interaction and reactivity of these particles with microbes preventing microbial activities and microbial-mediated nitrification process (Kundu et al. 2016).

5.3: Improvement in plant growth parameters

Plant growth, physiological parameters and yield attributes of different coated urea applied maize plants showed significant improvement in plant height number of leaves, leaf area, chlorophyll content, number of grains per cob, seed index when compared to control. However there was no difference among different N sources with respect to these parameters except number of grains per cob. Coated urea fertilizers applied maize plants had higher number of grains per cob than the normal urea applied maize. The availability of required quantity of nitrogen for longer time was probably responsible for higher values of yield components in treatment receiving coated urea fertilizers (Sannagaoudra et al. 2012). Further the low release of N from coated urea fertilizers facilitated the nutrient availability by reducing the losses of N that was also evidenced from the current investigation. Three neem coated urea products viz., 0.3% neem oil, 0.1% and 0.2% neem gold coated urea were prolonged urea release up to 10 days compared to prilled urea (Suganya et al. 2009). Further there was better relationship between plant height and leaf area (Figure 5.3), leaf chlorophyll content and N content (Figure 5.4) with r^2 values of 0.90 and 0.83, respectively.

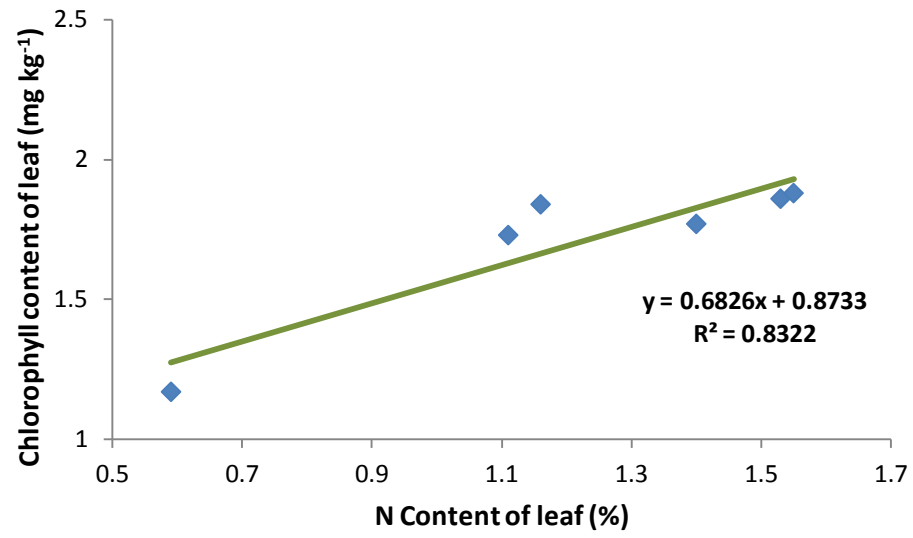


Figure 5.4: Interrelationship between leaf chlorophyll and N content under various fertilizers treatments

5.4: Augmentation of crop yield

In the current investigation, shoot and grain yields of maize under different coated urea fertilizers were significantly higher than that of normal urea applied treatments and control. It was reported that coated urea can produce higher yield due to the slow release of nitrogen (Zebarth et al., 2012; Kashiri et al., 2013; Farmaha et al., 2013). Kumar and Thakur (1993) also reported that higher grain yield and nitrogen uptake by rainfed rice in different slow release urea forms (coated urea) as compared to uncoated urea. The increase in biomass of the coated urea treatments might be due to sustained release and increased availability of N for the crop by slow release of N from coated urea, inhibition of urease activity through antibacterial properties and reduction of volatilization loss by acidifying alkaline micro-sites in soil (Kundu et al., 2013). The results obtained by Khan *et al.* (2011), Thind *et al.* (2010) and Zhao *et al.* (2006) were in agreement with the results of current investigation that application of coated urea fertilizers showed higher yield than normal urea fertilizers. Singh *et al.* (1995) from the field trials reported that grain yield of lowland rice from a single application of PCU is equivalent to or better than 3–4 well-timed split urea application. Fan *et al.* (2004) also demonstrated that coated urea performs better than regular fertilizers by promoting increased grain yield and N uptake in rice in Spain. Similarly Carreres *et al.* 2003 in winter wheat (China); Wen *et al.* 2001 in peanuts (Japan); Munoz *et al.* 2005 in potatoes (USA); and Shoji *et al.* 2001 in maize (Japan) had reported the coating of urea improved grain yield and N uptake. On the other hand, some formulations of PCU are not efficient in increasing grain yield and N recovery by flooded rice in Spain, probably because of insufficient coating of the urea granule (Carreres *et al.* 2003). Among the different coated urea fertilizers and doses, there was much significant difference found with respect to crop yield.

5.5: Enhancement in nutrient content, uptake and recovery

The nutrient content, uptake and use efficiency in terms of agronomic use efficiency, recovery or utilization efficiency and partial factor productivity of N by maize in different coated urea fertilizer application were higher than the normal urea applied treatments. Similar results were reported that coated urea increased the nitrogen use efficiency by

13.3% to 21.4% over normal urea (Yi et al., 2011a). Ning et al. (2012) also noticed that when nitrogen was applied in the form of coated urea, the nitrogen release rate was slow and the nitrogen uptake by crop was increased, which reduced the risk of nitrogen loss and increased the use efficiency of fertilizer nitrogen. Application of neem cake and neem oil coated urea increased the percent nitrogen content and uptake of nitrogen (Jat and Pal 2002, Kumar and Prasad, 2004; Bhatt 2012; Kumar et al. 2010, 2011). In case of physiological use efficiency there was no any difference observed among the fertilizer treatments. Further application of P and K along with coated urea fertilizers improved P and K content, uptake and use efficiency than P and K applied with normal urea. This might be due to improved plant growth and biomass yield mediated by the coated urea fertilizers enhanced the uptake of P and K. The concomitant results were reported by many workers (Ivonyi, 1997; Raja Rajan et al. 2005; Akram et al.2007).

5.6: Effect on soil properties

In this study it was observed that application of coated urea fertilizers along with P and K did not show any significant changes in soil pH, EC, available P, K, S and micronutrients. In case of organic carbon content and available N of soil improved due to application of fertilizer treatments over control. When compared to initial levels there was slight improvement in OC and available N content of soil in different sources of N in combination with P and K fertilizer applied treatments. The improvement in soil organic C and N due to NPK applied treatments were reported by many workers (Manna et al., 2005 and 2007; Ladha et al., 2011; Geiseller and Scow, 2014; Korschens et al. 2013). This might be due to enhanced plant growth particularly contribution from below ground root biomass and root exudation mediated built up of SOC by application of fertilizers. Further slow release and reduced loss of N from applied fertilizers could also contributed build up of available N in the soil. Moreover no use (control) or imbalance use (N and NP) and less usage of fertilizers (50% NPK) showed reduction in SOC and lower available N content in soil (AICRP-LTFE, 2013).

5.5: Economics

From the result it was observed that cost of cultivation of coated urea fertilizers viz. NCU and RCU just little higher than that of coated urea fertilizer applied treatments because of the price of neem oil and crude pine oleoresin (POR) and coating. For neem oil coated urea it only required 0.5 L neem oil and cost Rs.80-90 for coating 1000 kg urea (Baboo 2014). In case of POR for 4% coating, it required 40 kg crude and costs Rs. 400 for coating 1000 kg urea. However it can be further reduced if coated in bulk quantity with advanced technologies. On the other hand enhanced grain yield due to application of coated urea fertilizer showed higher net return than the normal urea applied treatments. Among the coated urea fertilizers though there was much difference in B:C ratio, the RCU urea applied treatment fetched higher net return and B:C ratio could be a good alternative to NCU and viable option than normal urea for enhancing crop yield and farmers income.

Chapter-VI

SUMMARY, CONCLUSION & SUGGESTION FOR FURTHER WORK

The chemical fertilizers are one of the costly inputs in agriculture and it is ironical that the nutrient use efficiencies of the conventional chemical fertilizers are very low. The rest of the applied fertilizers are lost causing pollution to soil, water and atmosphere continuum. Therefore, the development of nutrient efficient fertilizers is the need of the hour. In this direction the controlled release coated fertilizer might provide solution to the above issues. This might improve the mineral nutrition and yield of the crop. Keeping in view of the above, an attempt was made to study the nutrient losses specifically N from different coated urea fertilizers; and the effect of resin coated urea and neem coated urea on yield, nutrient content and uptake, nutrient use efficiency of maize (*Zea mays* L.) var. Nutan KH-101 grown on a Vertisol. The coated urea fertilizers were applied to maize crop at 100% and 75% recommended doses (RDs) along with 100% RDs of P and K. Apart from these treatments, conventional urea fertilizers along with P and K (100% RDs) and absolute control without any fertilizers was maintained for comparison. The salient findings of the current investigation are summarized as follow:

- Application of coated urea fertilizers such as neem coated urea (NCU) and pine oleoresin coated urea (RCU) in a Vertisol reduced the ammonia volatilization by 27.5% and 41.1%, respectively. Even application of pine oleoresin (POR) along with normal urea also reduced the ammonia volatilization by 22.0%.
- The percent loss of applied N (220 mg) through nitrate leaching for urea, NCU, nano rock phosphate coated urea, RCU, nano ZnO coated urea were 48.5%, 39.7%, 34.9%, 36.0% and 31.5%, respectively. The reduction in $\text{NO}_3\text{-N}$ leaching due to neem, resin, nano rock phosphate and nano ZnO coatings were 18.3%, 28.0%, 25.7% and 35.1%, respectively.
- Application of RCU and NCU along with P and K significantly improved the plant growth parameters like plant height, number of leaves per plant, leaf area and LAI when

compared to normal urea applied with P and K. But there was no significant difference observed among coated urea fertilizers with respect to above parameters.

- Application of coated urea fertilizers did not show any significant change in plant physiological parameters like chlorophyll content and greenness index when compared to normal urea applied fertilizers.
- In case of yield attributes, number of grains and grain yield per cob were significantly improved by application of coated urea fertilizers. On the other hand there was no difference in seed index.
- The percent increase in shoot yield due to application of urea (100% RD), RCU (100% RD) and NUC (100% RD) along with P and K was 29.4%, 53.2% and 51.9%, respectively.
- The percent increase in grain yield due to application of urea (100% RD), RCU (100% RD) and NUC (100% RD) along with P and K was 28.3%, 67.5% and 61.0%, respectively. Even in 75% RD of RCU and NCU along with full doses of P and K increased the shoot yield to 51.8% and 55.6% respectively over control
- N, P and K content of leaf, grain and stem was significantly higher in RCU (100% RD) and NUC (100% RD) applied treatments than urea (100% RD) applied treatment.
- The higher N uptake in shoot and grain was found in coated urea fertilizers applied treatments than normal urea applied treatment. In case of P and K uptake also coated urea fertilizers particularly RCU (100% RD) and NUC (100% RD) applied treatments showed significant improvement than normal urea.
- Nutrient use efficiency in terms of AE, UE and PFP for N, P and K were improved in coated urea fertilizers applied treatments than normal urea applied treatment.
- There was no much significant difference in soil physico-chemical properties among different fertilizer treatments.
- The gross income and the net return, and The B:C ratio were high in RCU (100% RD) applied treatments followed by NCU (100% RD).

Conclusions:

From the study it was obvious that application of coated urea fertilizers significantly reduced the N losses through ammonia volatilization and nitrate leaching. Further,

application of coated urea fertilizers along with P and K to maize in the Vertisol showed higher plant growth, yield and nutrients uptake than that of normal urea plus P and K application. Further it is worth to mention that application of coated urea at 75% RDs also over performed the normal urea for improving crop yield and NUE. Therefore, the reduction of N losses, higher crop yield and nutrient use efficiency imparted by coated urea fertilizers could be a viable N source for crops. Moreover both neem and pine oleoresin coated urea applied treatments were almost equal in their impact on maize yield and nutrient uptake, that indicates that resin coated urea could be a good alternative N source to neem coated urea that is largely in practice in India at present.

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APPENDIX- I

(A): Details of cost of cultivation:

S.No.	Particulars	Quantity	Rate (Rs./ha)	Amount (Rs./ha)
1	Ploughing	02	1200	2400
3	Cultivator	01	750	750
4	Cost of seed	20kg	100	2000
5	Cost of sowing charge	10 labour	200/- labour	2000
6	Cost of onehand weeding	10labour	200/- labour	2000
7	Cost of harvesting	10 labour	200/- labour	2000
8	Cost of Threshing	10 labour	200/- labour	2000
			TOTAL	13150

(B): Details of cost of treatment under different INM practices

Tr. No.	Cost of fertilizer under different treatments	Quantity (kg) (Urea + SSP+MOP)	Amount (Rs./ha)*
T ₁	Control	-	0
T ₂	N ₁₅₀ P ₆₀ K ₅₀ (Urea)	330+375+85	5747
T ₃	N _{112.5} P ₆₀ K ₅₀ (RCU)	254+375+85	5472
T ₄	N ₁₅₀ P ₆₀ K ₅₀ (RCU)	338+375+85	5987
T ₅	N _{112.5} P ₆₀ K ₅₀ (NCU)	248+375+85	5419
T ₆	N ₁₅₀ P ₆₀ K ₅₀ (NCU)	330+375+85	5912

Urea =Rs. 5.52/kg, SSP= Rs. 6.67/kg, MOP = Rs. 16.8/-kg, NCU= Rs. 6.02/kg; RCU=Rs. 6.10/kg

APPENDIX-II

Value of Mean Sum of Square for volatilization loss of N

Source of variation	D. F.	NH ₃ -N volatilization rate (mg N pot ⁻¹)				
		24 h	48 h	72 h	96 h	120 h
Replication	2	0.269	0.275	0.303	1.162	5.317
Treatments	4	1.514*	2.711*	3.692*	24.171*	85.916*
Errors	8	0.005	0.009	0.012	0.081	0.286
Total	14	-	-	-	-	-

Source of variation	D. F.	NH ₃ -N volatilization rate (mg N pot ⁻¹)					
		144 h	168 h	192 h	216 h	240 h	Cumulati-ve Loss
Replication	2	3.916	3.30	2.139	1.535	0.606	149.856
Treatment	4	129.960*	54.32*	32.349*	23.574*	14.856*	2228.441*
Errors	8	0.433	0.18	0.108	0.079	0.050	7.428
Total	14	-	-	-	-	-	-

Value of Mean Sum of Square for Nitrate-N leaching loss

Source of variation	D. F.	Nitrate-N leaching loss (mg N per column)					
		3 day	6 day	9 day	12 day	15 Day	Cumulati-ve loss
Replication	2	206.976	35.483	2.334	0.599	0.015	518.19
Treatment	5	1793.10*	413.129*	54.719*	35.679*	0.181*	4012.86*
Errors	10	5.977	1.377	0.182	0.119	0.001	13.38
Total	17	-	-	-	-	-	-

Value of Mean Sum of Square for Yield Parameters:

Source of variation	D. F.	Grain yield (kg/ha)	Shoot yield (kg/ha)
Replication	3	48809.390	211765.705
Treatments	5	1042860.777*	1306971.719*
Errors	15	47336.891	131493.830
Total	23	-	-

Value of Mean Sum of Square for Growth Parameters:

Source of variation	D. F.	Plant height (cm)		Number of leaves	
		60 DAS	90 DAS	60 DAS	90 DAS
Replication	3	54.038	10.735	0.883	0.805
Treatments	5	489.832*	506.139*	3.650*	2.334*
Errors	15	96.354	75.793	0.376	0.164
Total	23	-	-	-	-

Source of variation	D. F.	Leaf area (cm ²)		LAI	
		60 DAS	90 DAS	60 DAS	90 DAS
Replication	3	312981.088	364120.081	0.106	0.353
Treatments	5	937160.924*	1137485.300*	0.662*	0.670*
Errors	15	3123.870	3791.618	0.062	0.136
Total	23	-	-	-	-

Value of Mean Sum of Square for leaf chlorophyll content

Source of variation	D. F.	Chl-a (mg g ⁻¹)	Chl -b (mg g ⁻¹)	Total chlorophyll (mg g ⁻¹)
Replication	3	0.016	0.006	0.027
Treatments	5	0.161*	0.038*	0.290*
Errors	15	0.045	0.009	0.039
Total	23	-	-	-

Value of Mean Sum of Square for Major nutrient (N, P & K) content in leaf

Source of variation	D. F.	N (%)	P (%)	K (%)
Replication	3	0.002	0.0001	0.006
Treatments	5	0.521	0.001*	0.065*
Errors	15	0.004	0.0001	0.005
Total	23	-	-	

Value of Mean Sum of Square for Major nutrient (N, P & K) content in grain

Source of variation	D. F.	N (%)	P (%)	K (%)
Replication	3	0.004	0.000	0.005
Treatments	5	0.205*	0.004*	0.020*
Errors	15	0.011	0.000	0.001
Total	23	-	-	-

Value of Mean Sum of Square for Major nutrient (N, P & K) content in stem

Source of variation	D. F.	N (%)	P (%)	K (%)
Replication	3	0.032	0.00009	0.101
Treatments	5	0.48*	0.0001	0.364*
Errors	15	0.009	0.00007	0.051
Total	23	-	-	-

Value of Mean Sum of Square for Nutrients uptake

Source of variation	D. F.	N-Uptake (kg ha ⁻¹)	
		Grain	Shoot
Replication	3	12.429	532.896
Treatments	5	394.469*	1476.254*
Errors	15	12.981	27.218
Total	23	-	-

Source of variation	D. F.	P-Uptake (kg ha ⁻¹)	
		Grain	Shoot
Replication	3	0.760	4.333
Treatments	5	11.591*	4.410*
Errors	15	0.126	0.147
Total	23	-	-

Source of variation	D. F.	K-Uptake (kg ha ⁻¹)	
		Grain	Shoot
Replication	3	13.733	1488.12
Treatments	5	90.995*	942.25*
Errors	15	2.314	56.82
Total	23	-	-

Value of Mean Sum of Square for Nutrient use efficiencies and partial factor productivity of N, P and K

Source of variation	D. F.	AE%		
		N	P	K
Replication	3	1.75	57.936	22.74
Treatments	4	17.49*	581.967*	228.41*
Errors	12	1.77	58.833	23.09
Total	19	-	-	-

Source of variation	D. F.	PE%		
		N	P	K
Replication	3	45.620	1169.37	351.497
Treatments	4	16.523 ^{NS}	2468.04 ^{NS}	68.650 ^{NS}
Errors	12	14.786	1193.77	45.480
Total	19	-	-	-

Source of variation	D. F.	UE%		
		N	P	K
Replication	3	269.41	54.654	5728.35
Treatments	4	535.56*	120.535*	3156.02*
Errors	12	11.01	3.156	211.66
Total	19	-	-	-

Source of variation	D. F.	PFP%		
		N	P	K
Replication	3	5.596	186.21	73.094
Treatments	4	17.490 [*]	582.02 [*]	228.383 [*]
Errors	12	1.765	58.83	23.080
Total	19	-	-	-

Value of Mean Sum of Square for Physico-chemical properties of soil

Source of variation	D. F.	pH (1:2)	E C (dSm ⁻¹)	Organic carbon (%)
Replication	3	0.002	0.0001	0.001
Treatments	5	0.004 ^{NS}	0.0002 ^{NS}	0.012 [*]
Errors	15	0.004	0.001	0.004
Total	23	-	-	-

Source of variation	D. F.	Available - N (kg ha ⁻¹)	Available - P (kg ha ⁻¹)	Available - K (kg ha ⁻¹)	Available - S (kg ha ⁻¹)
Replication	3	10.967	59.091	9016.290	1.201
Treatments	5	2895.237 [*]	56.981 ^{NS}	7811.633 ^{NS}	5.897 ^{NS}
Errors	15	346.551	27.329	10111.871	1.378
Total	23	-	-	-	-

Source of variation	D. F.	Available - Zn (mg ha ⁻¹)	Available - Cu (mg ha ⁻¹)	Available - Fe (mg ha ⁻¹)	Available -Mn (mg ha ⁻¹)
Replication	3	0.000	0.003	0.042	0.009
Treatments	5	0.048 ^{NS}	0.003 ^{NS}	0.026 ^{NS}	0.036 ^{NS}
Errors	15	0.013	0.004	0.016	0.025
Total	23	-	-	-	-

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