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Enhancing plant growth, yield and nitrogen use efficiency of maize through application of coated urea fertilizers

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Abstract
Enhancing crop yield and fertilizer use efficiency is being a major challenge to meet the food and nutritional security of ever increasing population and also to conserve the natural resources from degradation. In this investigation, it is aimed to study application of oleoresin and neem coated urea on enhancement of yield and nitrogen use efficiency of maize. A field experiment was conducted by growing maize (*Zea mays* L.) *var.* Nutan KH-101on a Vertisol. The treatments were neem coated urea (NCU) and pine oleoresin coated urea (RCU) at 100% and 75% recommended doses (RDs), normal urea (100% RDs)and absolute control (without any fertilizers). In all the treatments P and K (100% RDs) were applied except in control. The percent grain yield increase in RCU and NCU over normal urea at 100% RDs was 30.1% and 25.4%, respectively. Agronomic efficiency, recovery efficiency and partial factor productivity were significantly higher in coated urea applied treatments than that of normal urea applied treatment. The N recovery efficiency of RCU, NCU and urea was 49%, 52% and 33%, respectively. Further application of coated urea at 75% RDs also over performed the normal urea for improving crop yield. Moreover both neem and pine oleoresin coated urea applied treatments were almost equal in their impact on maize yield and nutrient uptake, that indicates resin coated urea could be a good alternative N source to neem coated urea that is largely consumed in India at present.

Keywords: Coated urea, pine oleoresin, neem, maize yield, nutrient uptake

Introduction
Fertilizers are added to the soil to provide nutrients necessary for plant growth and development. Among the fertilizer nutrients, nitrogen (N) is the most vital nutrient for crop production. Indian soils are generally low in available N due to poor organic matter content and high temperature. 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. Among the nitrogenous fertilizers, urea is the most commonly used fertilizer in India and about 30.6 million metric tonnes (MMTs) of urea is currently consumed which accounts 83% of total N fertilizer consumption in the country [5]. However use efficiency of urea-N by different crops can be as low as 20% and it rarely exceeds 50% [8, 19]. The rest of N lost to the environment contributes to environmental pollution [4]. Therefore 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. Improving N use efficiency of the fertilizers is being/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 [33]. Previously, a lot of research work was done to test a number of coating material, containing urease inhibitors and nitrification inhibitor, biodegradable polymers, and other polymers [7]; 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 due to its low production cost [23]. Moreover neem coated urea increase NUE by only 5-6% over urea in cereals even under best management practices [28]. Therefore protocol has been developed to coat the urea with naturally available pine oleoresin (POR)

[17] as coating material. The 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%), Iabietic acid (10%) and neoabietic acid (15%). 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 [17]. All these process may contribute to the availability of N to the plants from POR coated urea; however, POR coated fertilizers were developed and studied only in the laboratory scale [18], the detailed mechanisms and scientific information is lacking. Further, there is no any systemic data on yield, N uptake and use efficiency of crops under POR coated urea applications in field conditions. Therefore, in the current investigation, the efficacy of POR coated urea in improving crop yield and N use efficiency has been studied in comparison with neem coated urea and normal prilledurea.

Materials and Methods

Experimental Site

A field experiment was conducted during *kharif* (rainy) season of 2016-17 at the research farm, ICAR-Indian Institute of Soil Science, Bhopal, Madhya Pradesh, India. The study area falls under semi-arid and sub-tropical zone characterized by hot summer and cold winter. Mean annual precipitation is about 850 mm, most of which is received during the monsoon period of July to September. The soil in the field was black cotton soil (Vertisol) with clay texture. The representative soil (0-15 cm) samples from each plot were collected before field preparation with the help of tube auger. Soil sample was air-dried and sieved through 2 mm sieve. The processed soil samples were used for laboratory analysis. The soil of experimental field had 8.03 pH, 0.08 dSm^{-1}, 0.45% organic carbon, 162 kg N, 19.6 kg P and 1050 kg K per ha and DTPA extractable Cu, Zn, Fe, and Mn contents were 0.95 mg, 0.71 mg, 10.5 mg and 8.80 mg per kg soil, respectively.

Experimental Details

The experimental field was 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. Maize (Hybrid Nutan KH-101) crop was grown as test crop adopting randomized block design (RBD) with four blocks (as replications) and six plots in a block (as treatments). The size of plots was five-meter length 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. In the well prepared field maize was sown manually at the rate of 20 kg ha^{-1} with 60 cm and 20 cm inter and intra row spacing, respectively. The treatments were neem coated urea (NCU) and pine oleoresin coated urea (RCU) at 100% and 75% recommended doses (RDs), normal urea (10% RDs) and absolute control without any fertilizers. In all the treatments except control, P and K (100% RDs) were applied through SSP and MOP, respectively as basal dose before sowing. In case of N, 50% as basal and remaining 50% was top-dressed as two equal splits at 30 and 60 days after sowing (DAS). Pre-emergence herbicide was applied at 3 DAS; the crop was raised totally under rain-fed condition.

Plant Parameters

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 [25] at 90 DAS (third leaf from the tassel). Chlorophyll a, b and total content were calculated using the following formulae.

$$\text{Chl a } (\text{mg g}^{-1}) = \frac{[12.7(\text{A663}) - 2.69(\text{A645})] \text{ X V}}{1000 \text{ X W}}$$

$$\text{Chl b } (\text{mg g}^{-1}) = \frac{[22.9(\text{A645}) - 4.68(\text{A663})] \text{ X V}}{1000 \text{ X W}}$$

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

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

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.

Plant Sampling and Analysis

At maturity plants were harvested and maize cobs were separated, grains were removed from the cob manually and sundried. Then these materials were oven dried at 65°C for overnight. The dry weights of grain and shoot biomass was recorded. Plant samples were collected and ground using electrical grinder and passed through 0.5 mm sieve. Ground plant samples (grain and stalks 0.5 mm) were analyzed for N content. Nitrogen in plant samples was determined by following Kjeldahl method [12] using Pelicans KEL PLUS System.

Nitrogen Uptake and Use Efficiency

Nitrogen uptake was calculated using the following equation.

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

Agronomic, physiological and recovery efficiencyas well as partial factor productivity of Nwere computed using following equations.

$$\text{Agronomic use efficiency} =$$

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

$$\frac{\text{Utilization}}{\text{recovery}} \text{efficiency } (\%) =$$

$$\frac{\text{N uptake}_f (\text{kg ha}^{-1}) - \text{N uptake}_c (\text{kg ha}^{-1})}{\text{Fertilizer N applied } (\text{kg ha}^{-1})} \text{X100}$$

$$\text{Physiological use efficiency } (\%)$$

$$= \frac{\text{Grain yield}_f (\text{kg ha}^{-1}) - \text{Grain yield}_c (\text{kg ha}^{-1})}{\text{N uptake}_f (\text{kg ha}^{-1}) - \text{N uptake}_c (\text{kg ha}^{-1})} \text{X100}$$

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

Where, f= fertilized crop; c = unfertilized control

Economics

Total cost of cultivation as well as gross return was calculated on the basis of prevailing market ratesfor different practices and produces. Net profitwas calculated treatment wise. The total cost of cultivation per hectare was subtracted from the gross income for computing net returns from each treatment.

$$\text{Net profit (Rs ha}^{-1}\text{)}$$

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

Benefit cost ratio (BCR) was calculated treatment wise as below.

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

Results and Discussion

Plant growth parameters

The influence of different N fertilizer sources on plant growth parameters like plant height, number of leaves, leaf area and leaf area index (LAI) has been depicted in Table 1. There was no any significance difference among various N sources with respect to these parameters. Application of N had significantly improved the plant growth (height) over control. 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). Nevertheless, 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 1). The average number of leaves in plants treated with various N sources was significantly high over the unfertilized control treatments. 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 1). 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 cm^2 and 0.99) and 90 DAS (1240 cm^2 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. The 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 cm^2 and LAI of 2.45 was observed at 90 DAS in RCU (100% RD) treated plants (Table 1).

Plant physiological parameters

The effect of application of different N sources on leaf chlorophyll content and green seeker values at 90 DAS has been depicted in Table 2. 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 2). 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 2). The corresponding least value was observed in unfertilized treatment which was significantly low from the other treatments.

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 3). There were no any significant changes in number of cob per plant and seed index due to application of fertilizer treatments in the current investigation (Table 3). The seed index or 100 grain weight ranged from 19.0- 19.6 g. 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 3). Further application of urea also significantly improved the number of grains per cob than the control.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 3). 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.

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 and grain yield 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 [26]. Further the slow 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 [30]. Further there was better relationship between plant height and leaf area (Figure 1), leaf chlorophyll content and N content (Figure 2) with r^2 values of 0.90 and 0.83, respectively.

Crop yield

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). 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 3).

Grain yield

Application of N to maize, invariable to source, had significantly increased maize grain yield. The grain yield of maize I n the current investigation due to various fertilizer treatments varied from 2013 to 3373 kg ha^{-1} (Table 4). 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 3).

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 [7, 10, 35]. Higher grain yield and nitrogen uptake by rainfed rice in different slow release urea forms (coated urea) as compared to uncoated urea [13]. 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 [17]. The results obtained in current investigation that application of coated urea fertilizers showed higher yield than normal urea fertilizerswere in agreement with others results [11, 31]. Grain yield of lowland rice from a single application of PCU is equivalent to or better than 3–4 well-timed split urea application had been reported from field trials [29]. Coated urea performed better than regular fertilizers by promoting increased grain yield and N uptake in rice in Spain [6]. Similarly the coating of urea improved crop yield and N uptake had been reported in winter wheat (China) [4]; in peanuts (Japan) [32]; in potatoes (USA) [21]; andin maize (Japan) [27]. 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 [4]. Among the different coated urea fertilizers and doses, there was much significant difference found with respect to crop yield.

N content and uptake

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 5). 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.

N uptake

The results of N uptake by maize shoot and grain under different fertilizer treatments in the current investigation has been shown in Table 6. The total nutrient removal of maize aboveground biomass under various fertilizer treatments has been depicted in Figure 4. The N uptake of maize shoot and grain ranged from 16.72–67.49 kg ha^{-1} and 9.92–37.2kg 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). 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 5).

Nitrogen use efficiency

Agronomic efficiency (AE), physiological efficiency (PE), utilization efficiency (UE) and partial factor productivity (PFP) of Nfor maize under various fertilizer treatments has been revealed in Table 6. The use efficiency of N by maize, in terms of AE, PE and UE or apparent N recovery (ANR) and PFPunder various fertilizer treatments varied from 3.59-9.94, 16.0-21.1%, 23.4%-54.3% and 17.0-27.8, respectively (Table 6). Among the treatments NCU applied at 75% RD along with full doses of P and K had high AE, UE and PFP of N andwas 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.

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 [34]. When nitrogen was applied in the form of coated urea, the nitrogen release rate was slow and the nitrogen uptake by crop had increased, in turn which reduced the risk of nitrogen loss and increased the use efficiency of fertilizer nitrogen [22]. Application of neem cake and neem oil coated urea increased the percent nitrogen content and uptake of nitrogen [3, 9, 14-16]. In case of physiological use efficiency there was no any difference observed among the fertilizer treatments. The concomitant results were reported by other workers [1, 24].

Benefit: Cost ratio

Economics of maize as affected by sources and doses of N has been given in Table 7. The highest total cost of cultivation (Rs19137 ha^{-1}) was noticed with RCU (100% RD) followed by NUC (100% RD) (Rs19062 ha^{-1}) treatments. The cost of cultivation for normal urea applied treatment was Rs.18897ha^{-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 Rs 50595 ha^{-1} of maize crop was recorded under RCU (100% RD) applied treatment followed by NUC (100% RD) applied treatment with gross return of Rs. 48600 ha^{-1}. The gross income for normal urea applied treatment was Rs. 38745ha^{-1}.The minimum gross income (Rs30195 ha^{-1}) was recorded under control treatment. The highest net return of Rs31458 ha^{-1} was obtained from RCU (100% RD) applied treatment followed by NUC (100% RD) applied treatment with net return of Rs. 29538 ha^{-1}. The lowest net return (Rs17045 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 treatmentwith 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).The cost of cultivation of coated urea fertilizers viz. NCU and RCU were just little higher than that of normal 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 [2]. 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.

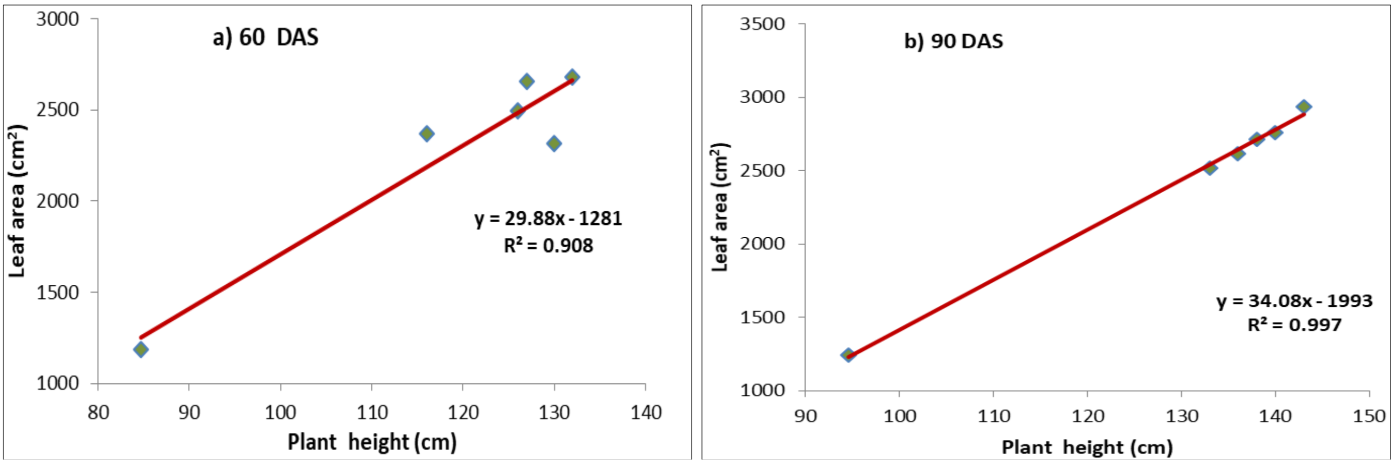

Fig 1: Interrelationship between plant height and leaf area under various fertilizers treatments

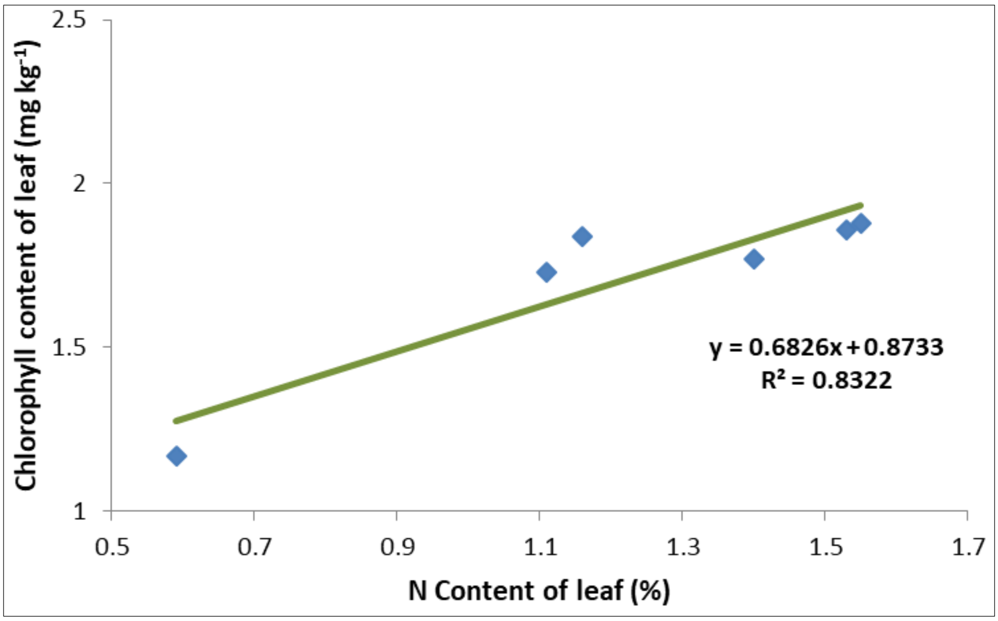

Fig 2: Interrelationship between leaf chlorophyll and N content under various fertilizers treatments

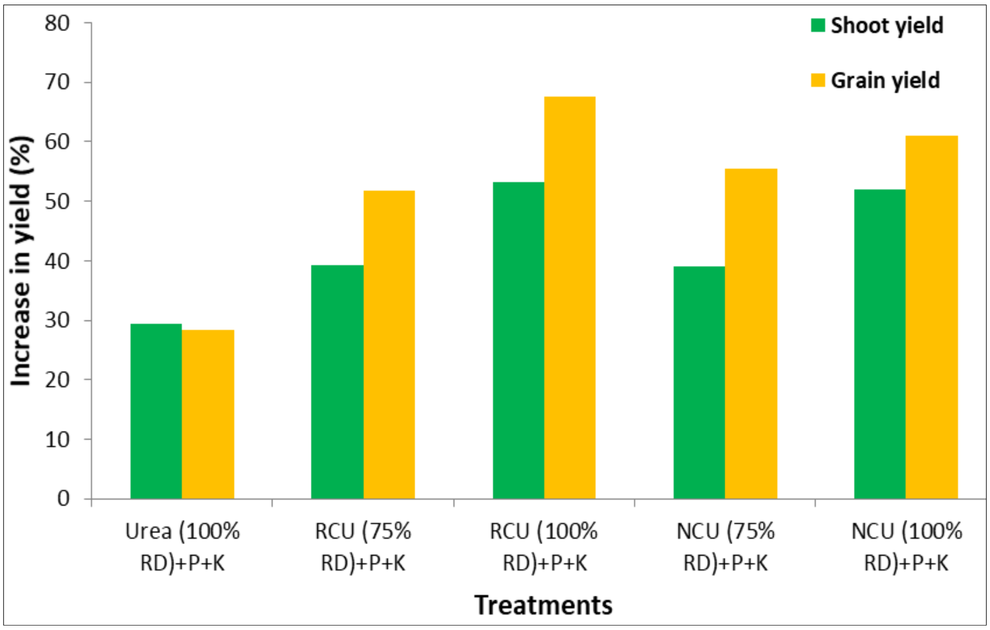

Fig 3: Percent increase in maize shoot and grain yield under various fertilizer treatments over control

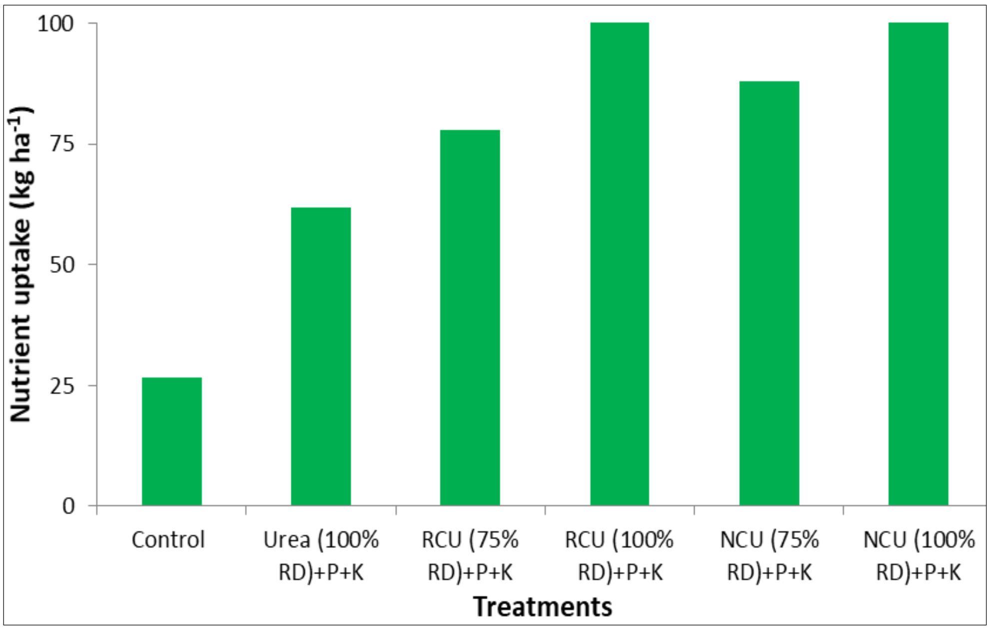

Fig 4: Total N uptake of maize (aboveground biomass) under various fertilizer treatments

Table 1: 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)	116^{ab}	133^{ab}	11.4^{ab}	11.6^a	2369^a	2519^a	1.97^a	2.10^a
RCU (75% RD)	130^a	136^a	11.7^{ab}	11.9^a	2316^a	2613^a	1.93^a	2.18^a
RCU (100% RD)	132^a	143^a	12.1^a	12.2^a	2681^a	2936^a	2.23^a	2.45^a
NCU (75% RD)	126^a	138^a	11.2^b	11.7^a	2493^a	2713^a	2.08^a	2.26^a
NCU (100% RD)	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*

Table 2: Effect of various N levels and sources on leaf chlorophyll content and greenness index

Treatment	Chlorophyll-a (mg g^{-1})	Chlorophyll-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)	1.49^a	0.24^b	1.73^a	34.7^a
RCU (75% RD)	1.45^a	0.39^a	1.84^a	35.6^a
RCU (100% RD)	1.42^a	0.43^a	1.86^a	36.4^a
NCU (75% RD)	1.36^a	0.41^a	1.77^a	32.4^{ab}
NCU (100% RD)	1.45^a	0.43^a	1.88^a	36.8^a
CD(P=0.05)	*0.32*	0.14	*0.30*	*5.14*

Table 3: 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)	1.00	180[b]	19.4	34.7[b]
RCU (75% RD)	1.00	235[a]	19.2	44.9[a]
RCU (100% RD)	1.00	236[a]	19.4	45.8[a]
NCU (75% RD)	1.00	224[a]	19.6	43.9[a]
NCU (100% RD)	1.00	231[a]	19.5	45.1[a]
CD(P=0.05)	*NS*	*32.3*	*NS*	*6.41*

Table 4: Maize shoot and grain yield and harvest index affected by various N treatments

Treatment	shoot yield (kg ha^{-1})	Grain yield (kg ha^{-1})
Control	2995[c]	2013[d]
Urea (100% RD)	3875[b]	2583[c]
RCU (75% RD)	4168[ab]	3056[b]
RCU (100% RD)	4588[a]	3373[a]
NCU (75% RD)	4163[ab]	3132[ab]
NCU (100% RD)	4550[a]	3240[ab]
CD(P=0.05)	433.7	274.2

Table 5: N concentration and uptake of leaf, stem (shoot) and grain (in % by weight basis) under various fertilizer treatments

Treatment	N content (%)			N uptake (kg ha^{-1})	
	Leaf	Stem	Grain	Shoot	Grain
Control	0.59[d]	0.53[d]	0.49[d]	16.7[d]	9.92[d]
Urea (100% RD)	1.11[c]	0.98[c]	0.84[c]	40.5[c]	23.3[c]
RCU (75% RD)	1.16[c]	1.17[b]	0.97[bc]	48.5[b]	29.6[b]
RCU (100% RD)	1.53[a]	1.41[a]	0.99[bc]	67.4[a]	32.9[ab]
NCU (75% RD)	1.40[b]	1.33[a]	1.01[ab]	56.2[b]	31.9[ab]
NCU (100% RD)	1.55[a]	1.46[a]	1.15[a]	67.5[a]	37.2[a]
CD (P=0.05)	0.10	0.15	0.16	7.87	5.43

Table 6: Nutrient use efficiencies and partial factor productivity of N for maize

Treatment	AE (kg/kg)	PE (%)	ANR (%)	PFP (kg/kg)
Urea (100% RD)	3.59[b]	16.3	33.4[c]	17.0
RCU (75% RD)	9.26 [a]	21.1	45.5[b]	27.2
RCU (100% RD)	9.06 [a]	18.7	49.1[ab]	22.5
NCU (75% RD)	9.94[a]	18.2	54.3[a]	27.8
NCU (100% RD)	8.18 [a]	16.0	52.0[a]	21.6
CD (P=0.05)	2.41	NS	6.72	2.48

Table 7: Cost of cultivation, gross and net return, and benefit: cost ratio of different treatments

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
Control	13150	0	13150	30195	17045	1.30
Urea (100% RD)	13150	5747	18897	38745	19848	1.05
RCU (75% RD)	13150	5472	18622	45840	27218	1.46
RCU (100% RD)	13150	5987	19137	50595	31458	1.64
NCU (75% RD)	13150	5419	18569	46980	28411	1.53
NCU (100% RD)	13150	5912	19062	48600	29538	1.55

Conclusions

Application of coated urea fertilizers to maize in the Vertisol showed higher plant growth, yield and nutrients uptake than that of normal urea. 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 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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