

Enhancing Crop Productivity and Nitrogen Use Efficiency by Application of Pine Oleoresin Coated Urea in Maize-Wheat Cropping Sequence in Vertisols

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Low nutrient use efficiency (NUE) of conventional chemical fertilizers has resulted in the loss of costly nutrients and related environmental implications. Consequently, enhancing crop productivity and nutrient use efficiency are major challenges. In this backdrop, a field experiment was conducted to study the impact of pine oleoresin (POR) and neem oil (NO) coated urea (CU) fertilizers on crop productivity and nutrient recovery efficiency in maize-wheat cropping system grown on Vertisols of central India. The treatment combinations were POR-CU and NO-CU at 100% and 75% of recommended doses of fertilizers (RDF); normal urea (100% RDF); and an unfertilized control. Two years results indicated that the increment in grain yields due to POR-CU and NO-CU applications were 18.8% and 11.7% for maize and 11.6% and 3.49% for wheat, respectively, over normal urea. The apparent recovery efficiency of N (RE_N) for POR-CU, NO-CU, and normal urea at 100% RDF were 65.8%, 64.2%, and 51.4% in maize and 43.2%, 37.0%, and 34.6% in wheat, respectively. There was no significant difference noticed between POR-CU and NO-CU with respect to grain yield and N recovery efficiency. Hence, the study suggested that POR-CU could be a possible alternative option to NO-CU for improving crop yield and NUE. However, further research is needed to determine how effective POR-CU is in diverse agricultural systems and climatic conditions.

DOI: 10.15376/biores.19.4.7898-7910

Keywords: Crop productivity; Maize; Nitrogen use efficiency; Pine oleoresin; Wheat

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INTRODUCTION

Nitrogen (N) is one of the main fundamental nutrients essential for plant growth and development. The importance of N fertilization in crop production has been demonstrated by many researchers (Kumar 2008; Meena *et al.* 2021; Kumar *et al.* 2022). Furthermore, over the past few decades, a positive correlation has been shown between global N fertilizer use and food grain production. Urea is the most used nitrogenous fertilizer across the globe, and it is a popular choice among the farmers due to its high N content (46%), low cost, convenient storage, and accessibility. However, lower nutrient use efficiency (NUE) of N fertilizers (only 30% to 50%) and loss of N through volatilization, denitrification, leaching, and run-off are major concerns because of many environmental implications (Ladha *et al.* 2005). As a result, a significant amount of the

applied nitrogen is lost through various means, leading to a low NUE. Therefore, improving NUE and reducing the losses of costly fertilizer nutrients are major challenges and need to be addressed.

In recent years, several efforts have been made to improve fertilizer use efficiency by applying urease and nitrification inhibitors (Pathak *et al.* 2010), and by coating urea with polymers (Farmaha and Sims 2013). When compared with normal urea, coated urea (CU) can increase crop yield and NUE, and it can reduce the pollution to the field, water, and environment (Kumar *et al.* 2010). However, their field applications are limited by their high cost, scarcity, phototoxicity, and potent risks (Purkayastha 2009). This calls for the search of a new low-cost indigenous coating material for developing more efficient N fertilizer in order to increase the crop productivity and NUE (Prasad 2012). Currently only neem oil coated urea (NO-CU) is being manufactured and utilized in India (Prasad 2005) due to its low production cost. There is still a scope for producing cost-effective CU fertilizers for improving the NUE and crop productivity. In this context, pine oleoresin, a natural resin from pine tree (*Pinus roxburghii*), is composed of levopimaric acid (22%), palustric acid (11%), l-abietic acid (10%), and neoabietic acid (15%) (Lloyd and Hedrick 1965), which have antifungal and antibacterial properties (Trapp and Croteau 2001). This can be a potential option to coat the N fertilizers. To harness these properties, a protocol was developed to coat the urea with pine oleoresin (POR) @ 40 g POR kg⁻¹ urea (Kundu *et al.* 2013, 2016) to increase the efficiency of normal urea. Coating urea with POR provides a physical barrier for slow release of N from CU, inhibits urease activity through antibacterial properties, and reduces the volatilization loss by acidifying alkaline microsites surrounding urea (Kundu *et al.* 2013).

Prior research examined the efficacy of POR-coated urea fertilizer in the laboratory conditions and found impressive results in terms of N release for crop usage (Kundu *et al.* 2013, 2016; Kishore *et al.* 2024). Therefore, this article describes a field study to evaluate the efficacy and feasibility of POR-CU in enhancing NUE and crop yield in a maize-wheat cropping system. The hypothesis of the current investigation is that coating the urea granules with POR can enhance crop yield and NUE in maize-wheat system on Vertisols.

MATERIALS AND METHODS

Experimental Site

A field experiment was conducted during rainy and winter seasons for 2 consecutive years (2017-2018 and 2018-2019) on a maize-wheat cropping system at the research farm of ICAR-Indian Institute of Soil Science located at Bhopal, Madhya Pradesh, India (23.3075°N, 77.4064°E, and 485 m above sea level) on a clayey soil (*Typic Haplusterts*). The climate of the experimental site is semi-arid and a sub-tropical zone characterized by hot summers and cold winters. The mean annual rainfall of the experimental station is 1120 mm and more than 80% of it generally occurs during the south-west monsoon period of July to September. Maximum and minimum temperatures remained almost constant during study period. The average maximum temperature during summer is 34 °C, while the average minimum temperature during winter is 20°C. The experimental soil was clayey in texture (52% clay, 24.5% sand, and 23.5% silt) with pH 7.95, organic carbon content 5.4 g kg⁻¹, and available N, available P, and available K content was 79.5, 8.23, and 447 mg kg⁻¹, respectively.

Preparation of POR-CU and Its Composition

The protocol for preparation of POR coated urea involves dissolution 200 g POR in 1 L commercial petrol. The requisite amount of urea (1 kg) was mixed with the above solvents (200 mL) in the ratio of 5:1 in a wide mouth glass bottle and shaken for 5 min. After that, 5 mL of ethyl alcohol containing a synthetic dye (Tartrazine at 1.72 g in 100 mL ethyl alcohol) was added so as to get a uniform light green color of the coated urea. This dye was used for physical verification by naked eye about the uniform coating of POR. Immediately after mixing the dye, the whole content was transferred to a plastic tray fitted snugly on a horizontal shaker. The shaking operation was continued with maximum speed for an hour with intermittent scrubbing with a hard brush. After the complete evaporation of solvent (petrol), the resulting coated urea becomes loose and friable, and thereafter was kept in an oven (50 °C) for an hour for hardening. The size of the urea granules varied from 2.5 to 3.0 mm. The thickness of POR coating was found to be in the range of 0.1 to 0.2 μm . The N content of the POR-CU was 44.3%. Neem oil coated urea (NO-CU) and normal urea (granular) were procured from the supplier Gujarat State Fertilizer and Chemicals Limited (GSFC Ltd., Bhopal), India. The N content of NO-CU was 46.0%.

Treatment and Experiment Details

The experimental design was a randomized complete block with six treatments and four replications with 5 m x 4 m plot size. The treatment details include absolute control, normal urea (100% recommended dose -RDF), POR-CU (75% RDF), POR-CU (100% RDF), NO-CU (75% RDF), and NO-CU (100% RDF). Different coated fertilizers were imposed in the field as per treatment details, and absolute control plots were also maintained during the whole study. The recommended doses of N fertilizers were 150 and 120 kg N for maize and wheat crop, respectively. Nitrogen was applied in split doses, half doses as basal as per the treatment details and the remaining half doses of N was top dressed in equal splits at 45 and 90 days after sowing (DAS), in both the crops. All the plots except control received a basal application rate of 60 kg ha⁻¹ P₂O₅ and 50 kg ha⁻¹ K₂O through single super phosphate (SSP) and muriate of potash (MOP) fertilizers, respectively, for maize and wheat crop.

The experimental field was tilled with a tractor drawn disc plough to a depth of 15 cm twice and with tine cultivator to a depth of 12 cm once and levelled before sowing both maize and wheat crop. The maize (Hybrid Nutan KH-101) was sown manually about 3 cm deep in lined furrows with row-to-row distance of 60 cm and plant-to-plant distance of 20 cm at the seed rate of 20 kg ha⁻¹. Similarly, the wheat (Malwa Shakti) was sown manually about 2 cm deep in lined furrows with row-to-row distance of 20 cm at the seed rate of 100 kg ha⁻¹. Basal dose of fertilizers was placed below the seed in furrows before sowing and then the seeds 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. The maize crop was grown under rainfed condition without any additional source of irrigation. For wheat crop, 5 irrigations using bore-well water were given at critical growth stages. Other agronomic protocols were used for plant growth and yield attributing parameters of both crops for all the years.

Plant Sampling and Analysis

At the time of maturity, crops were harvested under each treatment plot and the stover/straw and grain yields were recorded on a dry weight basis. Plant samples such as

straw/stover and grain were separated, collected, and dried in an oven at 70 °C until a constant weight was reached. Then, oven-dried samples were ground in a mill to pass through 0.5 mm size sieve and sub samples were analysed for N content. The total N concentration of plant was determined by following the Kjeldahl (1883) digestion and distillation method. Nitrogen uptake in plant parts was calculated from the sum of the dry matter and N concentration of the different plant parts.

Calculation of N Uptake and N Use Efficiencies

Nitrogen uptake, recovery efficiency (RE_N), and agronomic efficiency (AE_N) were calculated by the following formulae (Devkota *et al.* 2013),

$$NU = \frac{CY}{100} \quad (1)$$

where NU is nutrient uptake (kg ha^{-1}), C is nutrient content (%), and Y is yield (kg ha^{-1}). The N agronomic efficiency (%) is given by Eq. 2,

$$AE_N = \frac{Y_F - Y_C}{Q_N} \times 100 \quad (2)$$

where Y_F is grain yield in the fertilized plot (kg ha^{-1}), Y_C is grain yield in control plot (kg ha^{-1}), and Q_N is quantity of N applied (kg ha^{-1}). The N recovery efficiency (%) is given by,

$$RE_N = \frac{NU_F - NU_C}{Q_N} \times 100 \quad (3)$$

where NU_F is N uptake in fertilized plot (kg ha^{-1}), NU_C is nutrient uptake in control plot (kg ha^{-1}), and Q_N is quantity of N applied (kg ha^{-1}).

Statistical Analysis

The data obtained from four replicates for crop yield, nutrient content and uptake, RE_N , and AE_N were utilized for statistical analysis adopting randomised block design (RBD). One-way analysis of variance (ANOVA) was performed using SPSS (version 10.0) software. The means of treatments were considered for comparison with critical difference at 0.05% confidence level.

RESULTS AND DISCUSSION

Crop Yield

The influence of different fertilizer treatments on maize and wheat yield is reported in Table 1. Application of POR-CU (100% RDF) achieved the highest grain and stover yield of maize in both years, which was significantly higher than normal urea and control as well as 75% RDF of CU fertilizer applied treatments and statistically at par with NO-CU (100% RDF) applied treatments ($P < 0.05$). Similar results were obtained for wheat grain and straw yield (Table 1). The increment in grain yields due to POR-CU and NO-CU applications were 27.3% and 24.6% for maize and 24.8% and 23.6% for wheat in the first year and 11.6% and 14.6% for maize and 20.0% and 19.6% for wheat in the second year, respectively, over normal urea (Fig. 1). Nevertheless 75% RDF supplied through POR-CU and NO-CU were not significantly different from normal urea (100% RDF) applied treatment with respect to crop yields. Further normal urea applied treatments showed significantly higher crop yields than the control treatment (Table 1). Stover/straw and grain yields of maize and wheat under POR-CU and NO-CU fertilizers applied at 100% RDF

were significantly higher than that of normal urea (100% RDF) applied treatments ($P < 0.05$). Moreover, the results indicated that application of POR-CU (100% RDF) achieved the highest system productivity in terms of maize equivalent yield of wheat in both the years, which was significantly higher than normal urea and control as well as 75% RDF coated urea fertilizers applied treatments and statistically at par with NO-CU (100% RDF) applied treatments (Table 1). These results were in agreement with the results obtained by Thind *et al.* (2010). Furthermore, it was noted that CU produced higher grain yields and system productivity. This may be due to CU's gradual nitrogen release, which better synchronizes nitrogen supply with the crop peak demand, thereby supporting improved plant growth and development.

Table 1. Impact of Different Nitrogen Fertilizer-Based Products on Crop Yields and System Productivity under Maize-Wheat Cropping Sequence in Vertisols

Treatment	Maize Yield (kg ha ⁻¹)		Wheat Yield (kg/ha)		Maize Equivalent Yield (kg/ha)	System Productivity (kg/ha)
	Grain	Stover	Grain	Stover		
2017-2018						
Control	2700 ^c	3908 ^c	2511 ^c	3528 ^d	2720 ^c	5420 ^c
Urea (100% RDF)	4399 ^b	5946 ^b	3326 ^b	4113 ^c	3602 ^b	8001 ^b
POR-CU (75% RDF)	4480 ^b	5813 ^b	3577 ^b	4256 ^{bc}	3874 ^b	8354 ^b
POR-CU (100% RDF)	5600 ^a	7190 ^a	4150 ^a	4881 ^a	4495 ^a	10095 ^a
NO-CU (75% RDF)	4510 ^b	6089 ^b	3610 ^b	4235 ^c	3910 ^b	8420 ^b
NO-CU (100% RDF)	5480 ^a	7023 ^a	4111 ^a	4670 ^{ab}	4453 ^a	9933 ^a
2018-2019						
Control	2688 ^c	4000 ^c	2378 ^c	3242 ^c	2576 ^c	5264 ^c
Urea (100% RDF)	4889 ^b	6023 ^b	3420 ^b	4205 ^b	3704 ^b	8593 ^b
POR-CU (75% RDF)	4950 ^b	5971 ^b	3457 ^b	4115 ^b	3744 ^b	8694 ^b
POR-CU (100% RDF)	5456 ^a	6929 ^a	4106 ^a	5119 ^a	4447 ^a	9903 ^a
NO-CU (75% RDF)	4969 ^b	5875 ^b	3461 ^b	4151 ^b	3749 ^b	8718 ^b
NO-CU (100% RDF)	5604 ^a	7079 ^a	4089 ^a	5124 ^a	4429 ^a	10033 ^a

Numerous researchers (Kumar and Thakur 1993; Farmaha and Sims 2013; Kashiri *et al.* 2013) also reported that higher grain yield in rainfed rice by using of different slow-release urea forms (coated urea) as compared to normal urea. The slow release and assured amount of nitrogen supply over an extended period led to overall improvement in crop growth. This improved source-sink relationship subsequently enhanced the crop yield in treatment receiving CU fertilizers (Sannagoudra *et al.* 2012). The increase in crop biomass under the POR-CU treatments might be due to sustained release and increased availability of N from CU. This is due to the slow nitrogen release, inhibition of urease activity through antibacterial properties and reduction of volatilization loss by acidifying alkaline micro-sites (Kundu *et al.* 2016). Fan *et al.* (2004) also demonstrated that CU performs better than regular fertilizers by promoting increased grain yield in rice in Spain. Similarly, Wen *et al.* (2001), Munoz *et al.* (2005), and Shoji *et al.* (2001) also reported the coating of urea improved grain yield in peanuts (Japan), in potatoes (USA), and in maize (Japan), respectively. Moreover, application of 75% RDF of CU fertilizers performed almost equal to that of 100% RDF normal urea applied treatment with respect to crop yield and nutrient uptake. Coating urea with natural materials is an effective method of reducing urea

hydrolysis. Slow hydrolysis allows urea to remain in fertilized pots for long period of time due to the reduced loss of ammonia through volatilization and caused by high amounts of ammonium accumulation on fertilizer micro-sites (Junejo *et al.* 2011). Similarly in a pot culture experiment on four different soils, application of POR-CU improved the crop yield and NUE of maize crop due to the slow release of nitrogen (Kundu *et al.* 2016). Upon application of POR coated urea in soil, part of the resin acid gets neutralized by the basic ions such as ammonium (NH_4), calcium (Ca), sodium (Na) and K and forms a stable emulsion in soil-water system. This neutralization process continues slowly and thereby regulates the solubility of urea in soil (Kundu *et al.* 2016).

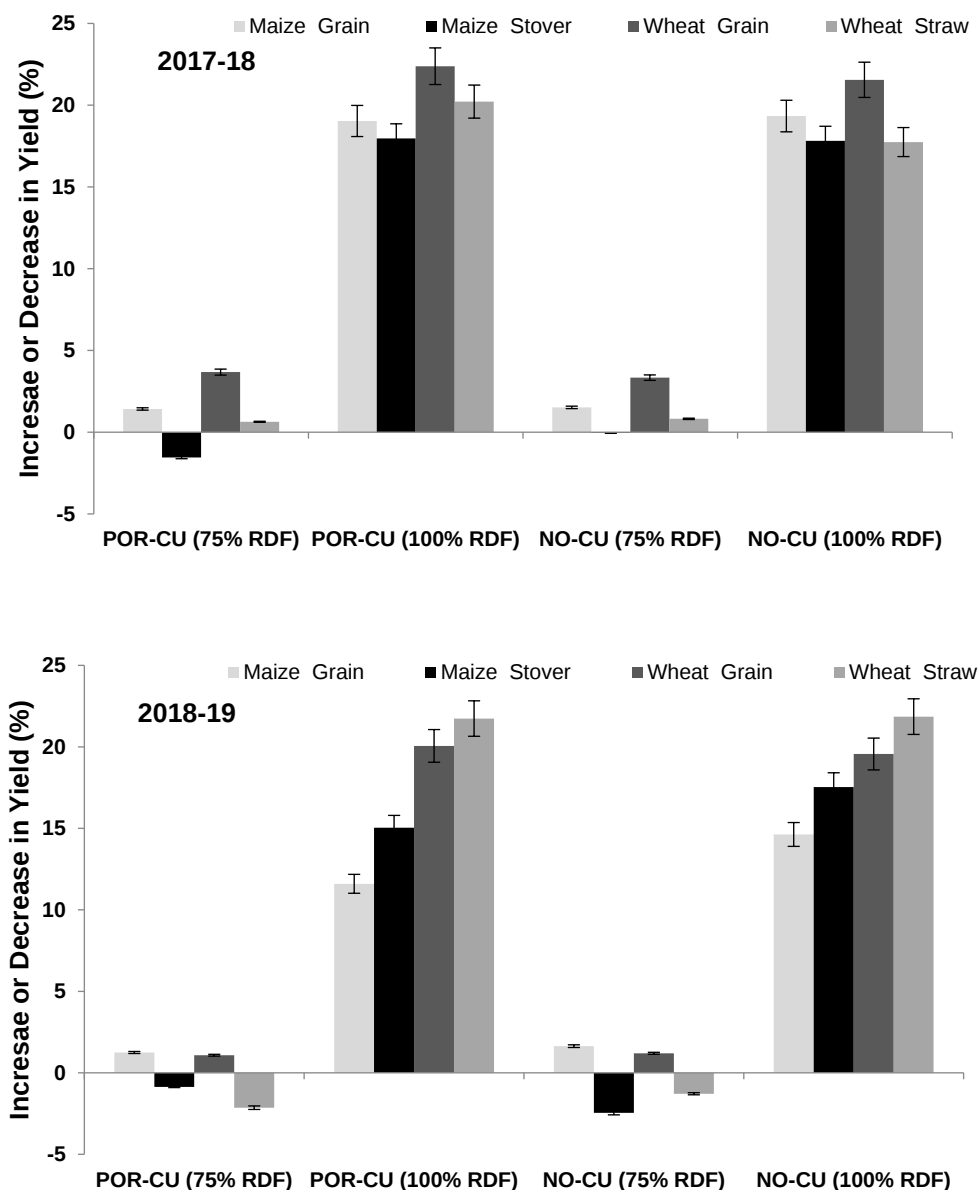


Fig. 1. Percent increase or decrease in crop yield under different coated urea fertilizers than normal urea

Nitrogen Content and Uptake

The experimental results showed that all the fertilizer treatments had significantly higher N concentration in grain and stover/straw than the unfertilized control (Table 2). Furthermore, normal urea and CU treatments were statistically at par with each other with respect to grain N content as well as stover/straw N content of maize in first year and wheat in both years, respectively. In the second year, maize grain N content (Table 2) was significantly higher in CU fertilizers applied treatments than the normal urea (100% RDF). N uptake by grain and stover/straw under various fertilizer treatments varied from 23.5 to 52.6 kg ha⁻¹ and 23.4 to 55.5 kg ha⁻¹ for maize grain; 31.3 to 63.9 kg ha⁻¹ and 32.4 to 63.7 kg ha⁻¹ for maize stover; 19.6 to 44.0 kg ha⁻¹ and 19.3 to 43.3 kg ha⁻¹ for wheat grain; and 25.5 to 46.4 kg ha⁻¹ and 25.0 to 50.7 kg ha⁻¹ for wheat straw in first and second year, respectively. Total N uptake of maize and wheat varied from 54.8 to 116.0 kg ha⁻¹ and 44.6 to 90.4 kg ha⁻¹; and 55.8 to 119.2 kg ha⁻¹ and 44.2 to 94.1 kg ha⁻¹ for the first and the second years, respectively (Table 2). There was no difference between POR-CU (100% RDF) and NO-CU (100% RDF) with respect to total N uptake, similarly among normal urea and CU treatments (75% RDF). The highest uptake was found in POR-CU (100% RDF) applied treatment followed by NO-CU (100% RDF), NO-CU (75% RDF), POR-CU (100% RDF), normal urea (100% RDF), and control treatment in the descending sequence. The higher N uptake in maize and wheat crop under CU fertilizer treatments might be due to enhanced crop yield under coated fertilizers as compared to normal urea during both years. Kumar and Thakur (1993) also reported higher grain yield and nitrogen uptake by rainfed rice in different coated urea as compared to uncoated urea. Further, the slow release of N from CU fertilizers facilitated the nutrient availability by reducing the losses of N. Suganya *et al.* (2009) demonstrated that three NO-CU products viz., 0.3% neem oil, 0.1% and 0.2% neem gold coated urea prolonged the urea release up to 10 days compared to prilled urea. 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.

On the other hand, Carreres *et al.* (2003) found that certain polymer CU formulations were ineffective in boosting grain production and nitrogen recovery in flooded rice most likely due to insufficient coating of the urea granule. Proper coating of urea is crucial for ensuring the slow release of nitrogen, which prolongs its availability and reduces nitrogen losses to the environment. In the current investigation, coating urea with POR might have acted as a physical barrier for slow release of N, inhibition of urease activity through antibacterial properties, and reduction of volatilization loss *via* acidifying alkaline micro-sites by POR, reducing the losses of N and prolonging the availability led to higher uptake of N in POR-CU applied treatments (Kundu *et al.* 2013, 2016). In the same way, neem oil coating of urea had also worked with a similar mechanism of antimicrobial properties to enhance the N uptake (Prasad 2005). The antimicrobial properties and microsite pH changes due to POR caused the reduction in urea hydrolysis by inhibiting urease-producing microbes (Junejo *et al.* 2012; Kundu *et al.* 2013). Also, it was demonstrated that time required for hydrolysis of 90% of the applied urea had markedly increased from 88.6 to 329 h in the presence of pine oleoresin (Kundu *et al.*, 2013). 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). Jadon *et al.* (2018) studied leaching and volatilization loss of N from NO-CU and POR-CU in a Vertisol. Application of coated urea fertilizers such as NO-CU and POR-CU reduced the ammonia volatilization by 27.5% and 41.1%, and NO₃-N leaching by 18.3% and 28.0%, respectively. In the same way, in comparison with normal

urea, application of POR (5%) coated urea to soil reduced the N₂O emission to the extent of 20.3% (Kundu *et al.* 2016). In neem coated urea, alkaloid present in the neem oil might have inhibited the urease producing microbial activities, leading to a lower urea hydrolysis rate and a consequent reduction in NH₃-N loss (Prasad *et al.* 2007; Suri *et al.* 2000; Prasad *et al.* 2001).

Table 2. Impact of Different Nitrogen Fertilizer-based Products on N Content and Uptake by Maize and Wheat Crops under Vertisols

Treatment	N Content (%)				N Uptake (kg ha ⁻¹)					
	Maize		Wheat		Maize			Wheat		Total
	Grain	Stover	Grain	Stover	Grain	Stover	Total	Grain	Stover	
2017-2018										
Control	0.87 ^d	0.80 ^d	0.78 ^b	0.71 ^b	23.5 ^c	31.3 ^c	54.8	19.6 ^c	25.1 ^c	44.6
Urea (100% RDF)	0.98 ^a	0.88 ^{ab}	1.06 ^a	0.96 ^a	43.1 ^{ab}	52.3 ^b	95.4	35.3 ^b	39.5 ^b	74.7
POR-CU (75% RDF)	0.92 ^c	0.86 ^{bc}	1.03 ^a	0.92 ^a	41.2 ^b	50.0 ^b	91.2	36.8 ^b	39.2 ^b	76.0
POR-CU (100% RDF)	0.94 ^{bc}	0.88 ^{ab}	1.06 ^a	0.95 ^a	52.6 ^a	63.3 ^a	116.0	44.0 ^a	46.4 ^a	90.4
NO-CU (75% RDF)	0.93 ^{bc}	0.84 ^c	1.01 ^a	0.94 ^a	41.9 ^b	51.2 ^b	93.1	36.5 ^b	39.8 ^b	76.3
NO-CU (100% RDF)	0.95 ^b	0.91 ^a	1.02 ^a	0.96 ^a	52.1 ^a	63.9 ^a	116.0	41.9 ^a	44.8 ^a	86.8
2018-2019										
Control	0.87 ^c	0.81 ^c	0.81 ^b	0.77 ^b	23.4 ^c	32.4 ^c	55.8	19.3 ^c	25.0 ^c	44.2
Urea (100% RDF)	0.94 ^b	0.87 ^{ab}	1.03 ^a	0.97 ^a	46.0 ^b	52.4 ^b	98.4	35.2 ^b	40.8 ^b	76.0
POR-CU (75% RDF)	0.91 ^b	0.86 ^b	1.02 ^a	0.95 ^a	45.0 ^b	51.4 ^b	96.4	35.3 ^b	39.1 ^b	74.4
POR-CU (100% RDF)	0.98 ^a	0.91 ^a	1.05 ^a	0.97 ^a	53.5 ^a	63.0 ^a	116.5	43.1 ^a	49.6 ^a	92.8
NO-CU (75% RDF)	0.92 ^b	0.86 ^b	1.01 ^a	0.96 ^a	45.7 ^b	50.5 ^b	96.2	35.0 ^b	39.9 ^b	74.8
NO-CU (100% RDF)	0.99 ^a	0.9 ^{ab}	1.06 ^a	0.99 ^a	55.5 ^a	63.7 ^a	119.2	43.3 ^a	50.7 ^a	94.1

Nitrogen Use Efficiencies

The fertilizer N use efficiency was significantly influenced with application of different coated fertilizers in maize and wheat crop during both years of experimentation under field condition. Results of NUE in terms of recovery efficiency (RE_N) and agronomic efficiency (AE_N) of maize and wheat applied with different fertilizer treatments are shown in Figs. 2 and 3, respectively. Application of POR-CU and NO-CU resulted in significantly

higher RE_N of 40.8% and 40.8% in maize and 38.1% and 34.1% in wheat during first year, respectively, and 40.5% and 42.3% in maize and 40.4% and 41.5% in wheat during second year. In contrast, normal urea fertilizers showed RE_N of 27.1% in maize and 25.1% in wheat during first year, and 28.4% in maize and 26.5% in wheat during second year, respectively. Similarly, application of POR-CU and NO-CU had significantly higher agronomic use efficiency (AE_N) than that of normal urea in both the crops (Fig. 3), and it varied from 11.3% to 20.3% in maize and 6.79% to 14.3% in wheat. Further, it is evident that 75% RDF of CU fertilizer application had significantly higher RE_N and AE_N than normal urea fertilizers (Fig. 2). This is in agreement with the findings of reduced application of fertilizers improved the agronomic efficiency of crops (Kumar *et al.* 2010; Kundu *et al.* 2016). The improvement in recovery efficiency (RE_N) and agronomic use efficiency (AE_N) under coated fertilizers might be due to better synchronization of N availability to crop peak demand of N (Prasad 2005; Liu *et al.* 2023). Similar results of increased N use efficiency of 13.3% to 21.4% over normal urea due to CU fertilizers have been reported (Liu *et al.* 2023).

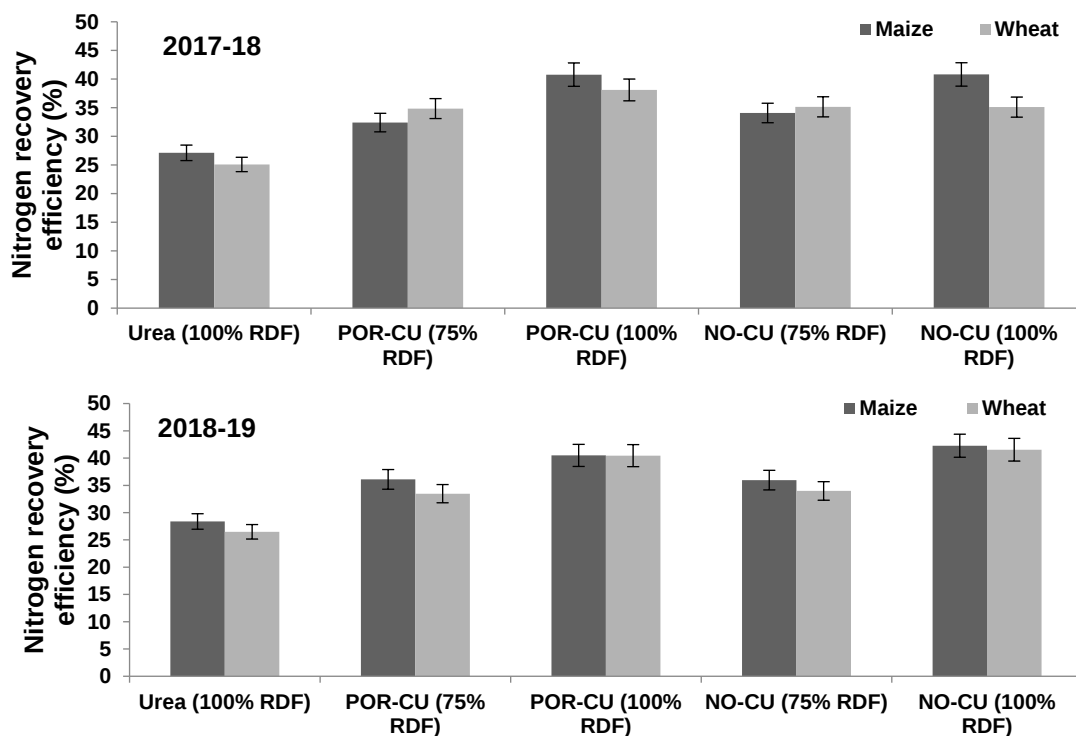


Fig. 2. Nitrogen recovery efficiency as affected by applications of different N sources in maize and wheat crops

The foregoing results suggested that POR-CU and NO-CU resulted in significantly higher RE_N and AE_N over normal urea, and this might be due to the increased uptake of nutrients coupled with increased yield. Coating of urea with POR and NO might have slowed down the availability of N from normal urea because these products act as urease and nitrification inhibitors, which resulted in increased nitrogen-use efficiency (Prasad 2005; Kundu *et al.* 2016). Ning *et al.* (2012) also noticed that when N was applied in the form of CU, the N release rate was slow and the N uptake by crop was increased, which reduced the risk of nitrogen loss and the use efficiency of fertilizer nitrogen increased.

Application of neem cake and neem oil coated urea increased the percent nitrogen content and uptake of nitrogen (Kumar *et al.* 2010). Due to the hydrophobic nature and the antimicrobial properties of POR (Kundu *et al.*, 2013), coated urea dissolves slowly and gradually mineralized by microbes. As a result, these fertilizers can serve as slow-release fertilizers that provide a steady supply of nitrogen to plants. Coated fertilizers have the potential to increase the nutrient availability and crop yield (Dong *et al.* 2016) while enhancing nutrient use efficiency in production system (Zhang *et al.* 2017) by releasing nutrients slowly and extending their availability in the soil.

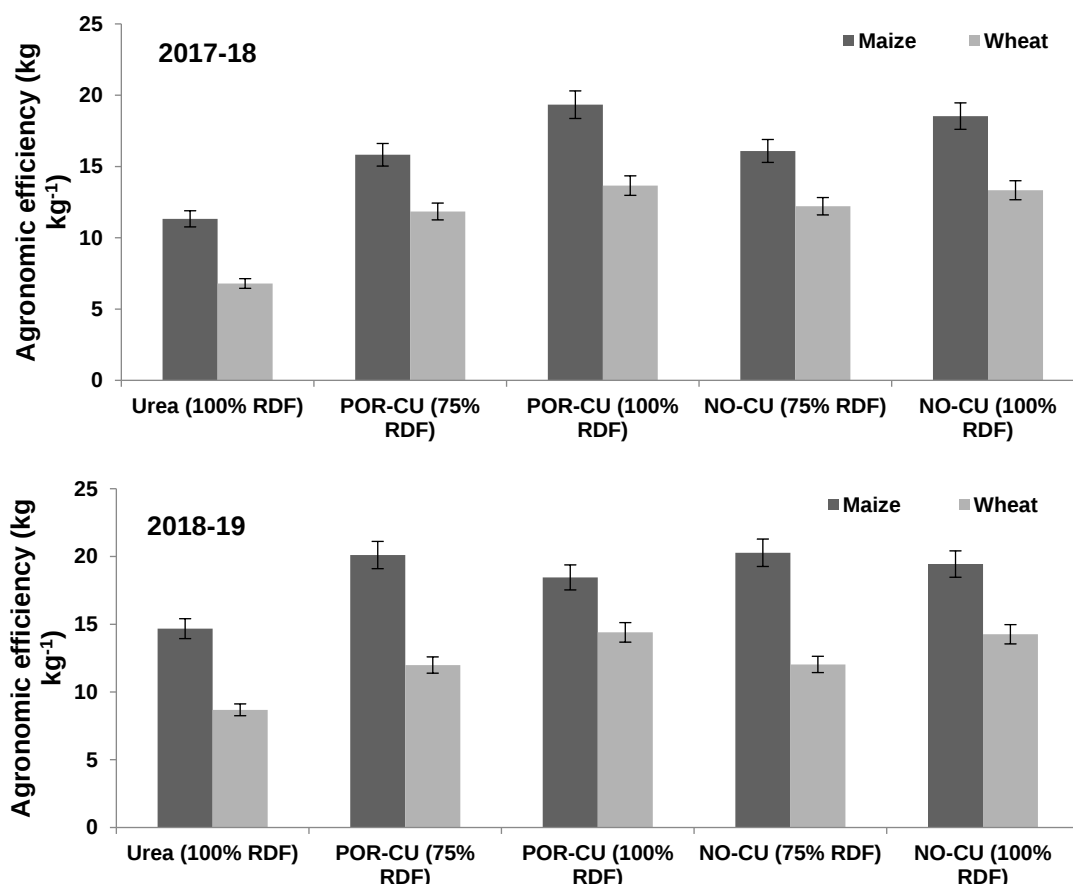


Fig. 3. Agronomic efficiency of N as affected by applications of different N sources in maize and wheat crops

CONCLUSIONS

1. Based on a 2-year study, it can be concluded that application of coated urea (CU) fertilizers *viz.*, pine oleoresin coated urea (POR-CU) and neem oil coated urea (NO-CU) enhanced the crop yield, system productivity, and nutrient use efficiency (NUE) compared to normal urea.
2. Nonetheless, application of these CU fertilizers at 75% recommended dosage of fertilizers (RDF) also fetched equal crop yield as of normal urea at 100% RDF.
3. Further, POR-CU performed similarly to NO-CU with respect to crop yield and nutrient recovery.

4. Thus, POR-CU could be a viable alternative option to NO-CU, which is largely in practice in India, for crop production. However, the efficacy of POR-CU must be further studied in different cropping systems under various climatic conditions.

ACKNOWLEDGMENTS

Authors are thankful to ICAR-Indian Institute of Soil Science (ICAR-IISS), Bhopal for providing all assistance and facilities for smooth conduct of the experiments.

REFERENCESCITED

- Carreres, R., Sendra, J., Ballesteros, R., Valiente, E. F., Quesada, A., Carrasco, D., Leganes, F., and de La Cuadra, J. G. (2003). "Assessment of slow-release fertilizers and nitrification inhibitors in flooded rice," *Biol.Fert. Soil* 39(2), 80-87. DOI: 10.1007/s00374-003-0684-4
- Devkota, M., Martius, C., Lamers, J., Sayre, K., Devkota, K., and Vlek, P. (2013). "Tillage and nitrogen fertilization effects on yield and nitrogen use efficiency of irrigated cotton," *Soil Till. Res.* 134, 72-82. DOI: 10.1016/j.still.2013.07.009
- Dong, Y. J., He, M. R., Wang, Z. L., Chen, W. F., Hou, J., Qiu, X. K., and Zhang, J. W. (2016). "Effects of new coated release fertilizer on the growth of maize," *J. Soil Sci. Plant Nutr.* 16(3), 637-649. DOI: 10.4067/S0718-95162016005000046
- Fan, X., Li, F., Liu, F., and Kumar, D. (2004). "Fertilization with a new type of coated urea: Evaluation for nitrogen efficiency and yield in winter wheat," *J. Plant Nutr.* 27(5), 853-865. DOI: 10.1081/PLN-120030675
- Farmaha, B. S., and Sims, A. L. (2013). "Yield and protein response of wheat cultivars to polymer-coated urea and urea," *Agron. J.* 105(1), 229-236. DOI: 10.2134/agronj2012.0283
- Ghosh, B.N., Chowdhury, H., Kundu, S., and Gupta, H.S. (2002). "Effect of pine needle (*Pinus roxburghii*) and chinaberry (*Melia azaderach*) seed extracts on urea hydrolysis rate in a sandy soil," *J. Indian Soc. Soil Sci.* 50, 309-311.
- Jadon, P. Rajendiran, S., Yadav, S. S., Vassanda Coumar, M., Dotaniya, M. L., Singh, A. K., Bhadouriya, J., and Kundu, S. (2018). "Volatilization and leaching losses of nitrogen from different coated urea fertilizers," *J. Soil Sci. Plant Nutr.* 18(4), 1036-1047. DOI: 10.4067/S0718-95162018005002903
- Junejo, N., Khanif, M. Y., Dharejo, K. A., Abdul-Hamid, H., and Abdu, A. (2012). "Evaluation of coated urea for ammonia volatilization loss, nitrogen mineralization and microsite pH in selected soil series," *Afr. J. Biotech.* 11, 366-378. DOI: 10.5897/AJB11.2355
- Junejo, N., Khanif, M. Y., Dharejo, K. A., Abdul-Hamid, H., and Abdu, A. (2011). "A field evaluation of coated urea with biodegradable materials and selected urease inhibitors," *African J. Biotech.* 10, 19729-19736. DOI: 10.5897/AJB11.2415
- Kashiri, H., Kumar, D., Shivay, Y. S., Kumar, R., and Anand, A. (2013). "Growth, productivity and profitability of aromatic hybrid rice (*Oryza sativa*) as affected by essential oil coated urea under aerobic condition," *Indian J. Agron.* 58(3), 316-321.
- Kishore, A., Sai, R., Bhanu, K., Hussain, S.A., and Madhavi, A. (2024). "Growth, yield and nutrient uptake of brown top millet (*Brachiaria ramosa*) under varying sowing

- dates and nitrogen levels,” *Indian J. Agron.* 69(1), 95-98. DOI: 10.59797/ija.v69i1.5490
- Kjeldahl, J. (1883). “A new method for the estimation of nitrogen in organic compounds,” *Fresenius J. Anal. Chem.* 22, 366-382.
- Kumar, A. (2008). “Productivity, economics and nitrogen use efficiency of specialty corn (*Zea mays*) as influenced by planting density and nitrogen fertilization,” *Indian J. Agron.* 53(4), 306-309.
- Kumar, A., and Thakur, R. B. (1993). “Evaluation of coated urea fertilizer for nitrogen efficiency in rainfed lowland rice (*Oryzasativa*),” *Indian J. Agron.* 38(3), 471-473.
- Kumar, D., Devakumar, C., Kumar, R., Das, A., Panneerselvam, P., and Shivay, Y. S. (2010). “Effect of neem-oil coated prilled urea with varying thickness of neem-oil coating and nitrogen rates on productivity and nitrogen-use efficiency of lowland irrigated rice under Indo-Gangetic plains,” *J. Plant Nutr.* 33(13), 1939-1959. DOI: 10.1080/01904167.2010.512053
- Kumar, V., Dhyani, B.P., Shahi, U.P., Kumar, S., Kumar, A., and Singh, A. (2022). “Effect of nitrogen schedule and management on yield of late-sown wheat (*Triticum aestivum*) in rice-wheat system,” *Indian J. Agron.* 67(2), 144-147. DOI: 10.59797/ija.v67i2.104
- Kundu, S., Adhikari, T., Vassanda Coumar, M., Rajendiran, S., Bhattacharya, R., Saha, J. K., Biswas, A. K., and Subba Rao, A. (2013). “Pine oleoresin: A potential urease inhibitor and coating material for slow-release urea,” *Curr. Sci.* 104(8), 1068-1071.
- Kundu, S., Adhikari, T., Vassanda Coumar, M., Rajendiran, S., Saha, J. K., Subba Rao, A., and Rathore, G. (2016). “A novel urea coated with pine oleoresin for enhancing yield and nitrogen uptake by maize crop,” *J. Plant Nutr.* 39(13), 1971-1978. DOI: 10.1080/01904167.2016.1161788
- Ladha, J. K., Pathak, H., Krupnik, T. J., Six, J., and Van Kessel, C. (2005). “Efficiency of fertilizer nitrogen in cereal production: Retrospect and prospects,” *Adv. Agron.* 87, 85-176. DOI: 10.1016/S0065-2113(05)87003-8
- Liu, R., Wang, Y., Hong, Y., Wang, F., Mao, X., and Yi, J. (2023). “Controlled-release urea application and optimized nitrogen applied strategy reduced nitrogen leaching and maintained grain yield of paddy fields in Northwest China,” *Front. Plant Sci.* 14, article ID1033506. DOI: 10.3389/fpls.2023.1033506
- Lloyd, W. D., and Hedrick, G. W. (1965). “Levopimaric acid,” *Org. Synth.* 45, Article Number 64. DOI: 10.15227/orgsyn.045.0064
- Meena, B. P., Biswas, A. K., Singh, M., Das, H., Chaudhary, R. S., Singh, A. B., Shirale, A. O., and Patra, A. K. (2021). “Energy budgeting and carbon footprint in long-term integrated nutrient management modules in a cereal- legume (*Zea mays*-*Cicer arietinum*) cropping system,” *J. Clean. Prod.* 314, article ID127900. DOI: 10.1016/j.jclepro.2021.127900
- Munoz, F., Mylavarapu, R. S., and Hutchinson, C. M. (2005). “Environmental potato production: A review,” *J. Plant Nutr.* 28(8), 1287-1309. DOI: 10.1081/PLN-200067434
- Ning, T. Y., Shao, G. Q., Li, Z. J., Han, H. F., Hu, H. G., Wang, Y., Tian, S. Z., and Chi, S. Y. (2012). “Effects of urea types and irrigation on crop uptake, soil residual, and loss of nitrogen in maize field on the North China Plain,” *Plant Soil Environ.* 58(1), 1-8. DOI: 10.17221/156/2011-PSE
- Pathak, H., Bhatia, A., Jain, N., and Agarwal, P. K. (2010). “Greenhouse gas emission and mitigation in Indian agriculture,” in: *ING Bulletin on Regional Assessment of*

- Reactive Nitrogen Bulletin No. 19*, SCON-ING, New Delhi, India, pp. 1-34.
- Patra, A. K., and Jain, J. M. (1993). "Transformation of a coal fertilizer ammonium polycarboxylate and potentialities of coal produced nitrification inhibitors," *J. Indian Soc. Soil Sci.* 41, 38-41.
- Prasad, R., Sharma, S. N., Singh, S., Saxena, V. S., and Devakumar, C. (2001). "Pusa neem emulsion as an eco-friendly coating agent for urea quality and efficiency," *Fert. News* 46, 73-74.
- Prasad, R. (2005). "Research of nitrification inhibitors and slow release nitrogen fertilizer in India: A review," *Proc. Natl. Acad. Sci. India Sect. B Biol. Sci.* 75, 149-157.
- Prasad, R., Shivay, Y. S., Kumar, D., Sharma, S. N., and Devakumar, C. (2007). "Neem for sustainable agriculture and the environment," *Proc. Nat. Acad. Sci. India Sec. B* 77, 313-330.
- Prasad, R. (2012). "Fertilizer and manures," *Curr. Sci.* 102(6), 894-898.
- Purkayastha, T. J. (2009). "Evaluation of some modified urea fertilizers applied to rice," *Fert. News* 42, 53-56.
- Sannagoudra, H. M., Dasog, G. S., Patil, P. L., and Hanamaratti, N. G. (2012). "Yield and nitrogen uptake by drill sown paddy as affected by different coatings of urea under two row spacing," *Karnataka J. Agric. Sci.* 4, 535-536.
- Shoji, S., Delgado, J., Mosier, A., and Miura, Y. (2001). "Use of controlled release fertilizers and nitrification inhibitors to increase nitrogen use efficiency and to conserve air and water quality," *Commun. Soil Sci. Plant Anal.* 32(7), 1051-1070. DOI: 10.1081/CSS-100104103
- Suganya, S., Appavu, K., and Vadivel, A. (2009). "Mineralisation pattern of neem coated urea products in different soils," *Int. J. Agric. Sci.* 5(1), 175-179.
- Suri, I. K., Mathews, S., and Saxena, V. S. (2000). "Coating of prilled urea with neem-Trial at KRIBHCO's Hazira plant," *Fert. News* 45, 17-22.
- Thind, H. S., Bijay Singh, Pannu, R. P. S., Singh, Y., Singh, V., Gupta, R. K., Vashistha, M., Singh, J., and Kumar, A. (2010). "Relative performance of neem (*Azadirachta indica*) coated urea vis-à-vis ordinary urea applied to rice on the basis of soil test or following need-based nitrogen management using leaf colour chart," *Nutr. Cycl. Agroecosys.* 87(1), 1-8. DOI: 10.1007/s10705-009-9307-2
- Trapp, S., and Croteau, R. (2001). "Defensive biosynthesis of resin in conifers," *Annu. Rev. Plant Physiol. Plant Mol. Biol.* 52, 689-724. DOI: 10.1146/annurev.arplant.52.1.689
- Wen, G. T., Mori, T., Yamamoto, J., Chikushi, J., and Inoue, M. (2001). "Nitrogen recovery of coated fertilizers and influence on peanut seed quality for peanut plants grown in sandy soil," *Commun. Soil Sci. Plant Anal.* 32(19-20), 3121-3140. DOI: 10.1081/CSS-120001111
- Zhang, H., Yu, X., Jin, Z., Zheng, W., Zhai, B., and Li, Z. (2017). "Improving grain yield and water use efficiency of winter wheat through a combination of manure and chemical nitrogen fertilizer on the Loess plateau, China," *J. Soil Sci. Plant Nutr.* 17(2), 461-474. DOI: 10.4067/S0718-95162017005000033

Article submitted: June 20, 2024; Peer review completed: August 6, 2024; Revised version received and accepted: August 20, 2024; Published: September 3, 2024.
DOI: 10.15376/biores.19.4.7898-7910