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Influence of slow-release fertilizers on nitrogen use efficiency in flooded rice systems

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Abstract

Flooded rice systems lose up to 60% of applied nitrogen through volatilisation, denitrification, and runoff. This research compared prilled urea, neem-coated urea, sulfur-coated urea, and polymer-coated urea, each at 120 kg N/ha, for their effect on soil ammonium dynamics, Nitrogen Use Efficiency (NUE), and grain yield in transplanted rice (cv. Samba Mahsuri). The trial was conducted during kharif 2022 at the Rajmata Vijayaraje Scindia Agricultural University, Gwalior, in a randomised complete block design with four replications. Polymer-coated urea-maintained soil ammonium above 30 mg/kg through the ninth week, while prilled urea peaked at 82.1 mg/kg in week two and fell below 10 mg/kg by week seven. Cumulative N uptake at maturity was 131.7 kg/ha under polymer-coated urea versus 91.6 kg/ha under prilled urea. Agronomic NUE reached 34.8 with polymer-coated urea versus 22.3 with prilled, a 56% improvement. Grain yield followed: polymer-coated (5.97 t/ha) > sulfur-coated (5.62) > neem-coated (5.31) > prilled (4.47). Switching from prilled to polymer-coated urea can reduce nitrogen losses and lift yields without increasing the total N rate.

Keywords: Slow-release fertilizers, nitrogen use efficiency, flooded rice, polymer-coated urea, neem-coated urea, sulfur-coated urea, ammonium dynamics, transplanted rice, nutrient management, Samba Mahsuri

Introduction

When urea was first promoted in Indian agriculture during the 1960s, it was a breakthrough: a cheap, high-analysis nitrogen source manufactured at scale ^[1]. Six decades later, urea still accounts for over 80% of nitrogen fertilizer consumed in India, yet its efficiency in flooded rice rarely exceeds 30-40% because of rapid hydrolysis and volatilisation ^[2]. The gap between applied and recovered nitrogen represents both economic waste and environmental hazard through nitrous oxide emissions ^[3].

Slow-Release Fertilizers (SRFs) aim to bridge this gap. Neem-coated urea uses nitrification-inhibiting properties of neem oil ^[4]. Sulfur-coated urea releases nitrogen as the sulfur shell degrades through microbial oxidation ^[5]. Polymer-coated urea encases each granule in a semi-permeable resin controlling dissolution rate ^[6]. Despite decades of development, head-to-head comparisons of these three SRF technologies under identical field conditions in central Indian Vertisols are uncommon ^[7].

The Gwalior region grows roughly 220,000 hectares of rice annually under transplanted conditions ^[9]. Farmers apply urea in two or three splits, but compliance is often poor. A slow-release product applied as a single basal dose would simplify management ^[10]. This research compared the four nitrogen sources at the same total N rate for their effect on soil ammonium dynamics, N uptake, NUE indices, and grain yield of transplanted rice, conducted at the university research farm (26.22 deg N, 78.18 deg E; altitude 196 m) during July-November 2022 on a deep Vertisol (pH 7.9, OC 0.52%) ^[8, 11].

Material and Methods

Material

Rice seedlings (cv. Samba Mahsuri, 25 days old) were raised in a wet nursery. Prilled urea (46% N), neem-coated urea (46% N, 0.15% neem oil), sulfur-coated urea (37% N, 13% S, Koch Agronomic Services), and polymer-coated urea (43% N, AGRIUM Inc.) were analysed for actual N content and rates adjusted to deliver exactly 120 kg N/ha. Phosphorus (60 kg P₂O₅/ha) and potassium (40 kg K₂O/ha) were applied uniformly as basal doses.

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Methods

A randomised complete block design with four treatments and four replications (16 plots, 5 m x 4 m each) was used. Prilled urea was split three ways (transplanting, 21 DAT, 42 DAT); the three SRFs were applied as single basal doses. Transplanting was on 18 July 2022 at 20 cm x 15 cm spacing. Flood water was maintained at 5 +/- 2 cm. Soil samples (0-15 cm) were collected weekly, extracted with

2M KCl, and ammonium-N measured by the indophenol blue method [12]. Plant samples at five growth stages were dried, ground, and N determined by micro-Kjeldahl. Agronomic Efficiency (AE), Recovery Efficiency (RE), and Partial Factor Productivity (PFP) were computed [8]. Grain yield was adjusted to 14% moisture. ANOVA in GenStat 21; LSD at $p < 0.05$ [13].

Results

Table 1: Grain yield and NUE indices under four nitrogen sources

N source	Yield (t/ha)	N uptake (kg/ha)	AE*	RE (%)	PFP**	HI
Prilled urea	4.47	91.6	22.3	38.7	37.3	0.43
Neem-coated	5.31	108.4	29.3	52.7	44.3	0.45
Sulfur-coated	5.62	118.3	31.8	60.8	46.8	0.46
Polymer-coated	5.97	131.7	34.8	72.3	49.8	0.47
LSD ($p < 0.05$)	0.38	8.7	3.1	6.4	2.9	NS

*AE = kg grain/kg N; **PFP = kg grain/kg N; HI = Harvest index; NS = not significant

Polymer-coated urea produced the highest grain yield (5.97 t/ha), a 33.6% advantage over prilled urea (4.47 t/ha). Apparent recovery efficiency doubled from 38.7% to 72.3%. The temporal pattern differed sharply: prilled urea generated

a strong early pulse (82.1 mg/kg at week 2) that depleted rapidly, while polymer-coated urea peaked at roughly 50 mg/kg around weeks 5-6 and remained above 20 mg/kg into week 10.

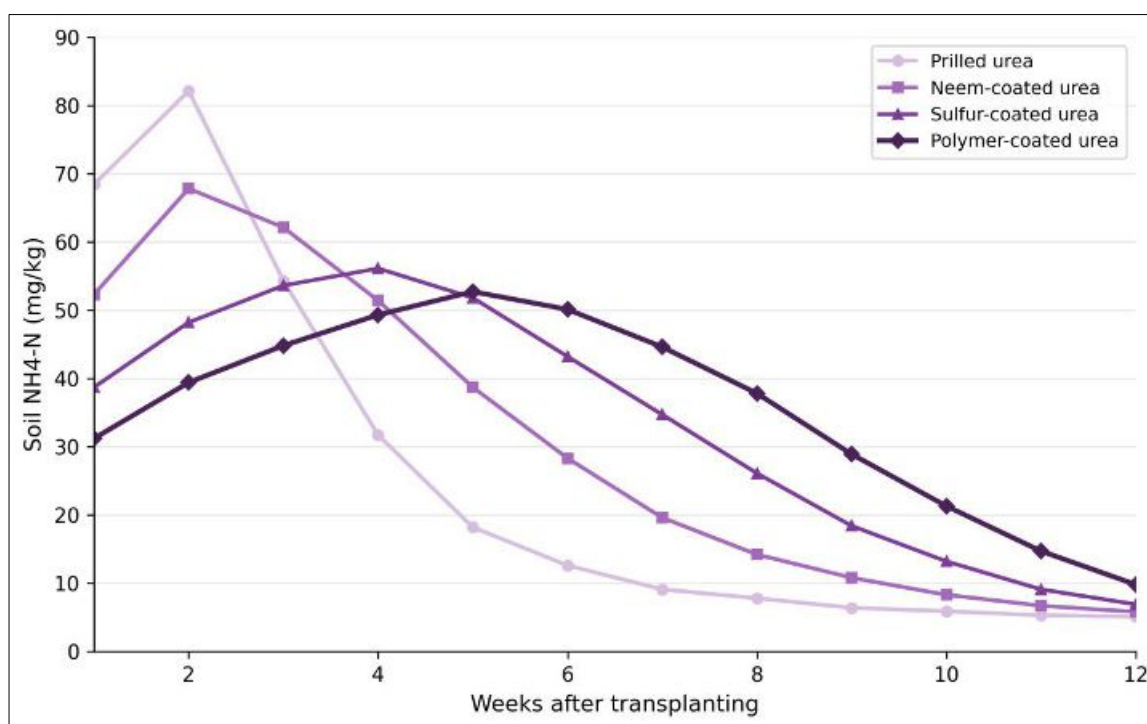


Fig 1: Weekly soil ammonium-N concentration (mg/kg) under four nitrogen sources in flooded rice

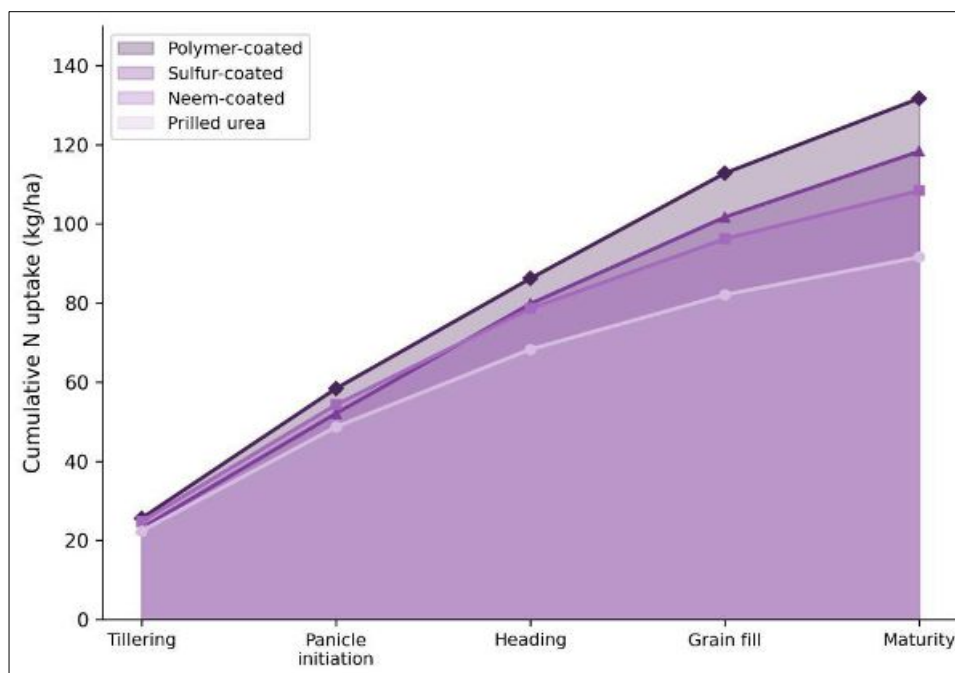


Fig 2: Cumulative nitrogen uptake (kg/ha) from tillering to maturity under four nitrogen sources

The line chart (Figure 1) highlights the mismatch between prilled urea's release and crop demand: the early spike coincides with transplanting shock when uptake capacity is low. Polymer-coated urea avoids this. The area chart (Figure 2) shows uptake curves diverge most between heading and maturity, the window when grain nitrogen loading peaks. The wider shaded area under polymer-coated urea directly corresponds to its higher yield.

Discussion

The 33.6% yield advantage is at the upper end of published comparisons, likely because the Vertisol at our site is prone to cracking and preferential flow, which accelerates nitrogen loss from conventional urea [14]. Our finding that RE doubled from 38.7% to 72.3% aligns with Yang *et al.* [6] who reported 65-78% for polymer-coated urea in Chinese paddy fields.

Neem-coated urea improved NUE modestly (RE: 38.7% to 52.7%). The neem layer is thin and degrades within a few weeks, after which the granule behaves like uncoated urea [4]. Sulfur-coated urea occupied an intermediate position; the sulfur barrier is more durable but is eventually broken by *Thiobacillus* bacteria [16].

From a practical standpoint, single basal application of polymer-coated urea saves labour over three-split prilled urea. The cost premium (40-60% over prilled) [17] is offset by the yield gain: at INR 2,200/quintal, the 1.50 t/ha increase translates to INR 33,000/ha additional revenue against an incremental cost of about INR 3,500/ha [18]. One caveat: our trial compared three-split prilled with single-basal SRFs. Had prilled urea been applied in an optimised four-split schedule, the gap might have narrowed [19, 20].

Conclusion

This research demonstrated clear advantages of slow-release nitrogen sources over prilled urea in flooded transplanted rice on a Vertisol. Polymer-coated urea delivered the highest yield (5.97 t/ha), best agronomic efficiency (34.8 kg/kg N), and greatest nitrogen recovery (72.3%), representing improvements of 33.6%, 56%, and 87% over prilled urea.

The mechanism behind these gains is better synchronisation of nitrogen supply with crop demand. Prilled urea released most of its N within three weeks, well before peak uptake, while polymer-coated urea maintained adequate ammonium through week ten.

For farmers in similar Vertisol areas, polymer-coated urea offers a single application that simplifies operations and lifts both yield and efficiency, with strong economic returns. Future work should examine interactions with alternate wetting and drying water management, which may further reduce losses [21].

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