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Evaluation of slow-release nitrogen fertilizers on growth, yield and nitrogen use efficiency in aerobic rice production systems

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Abstract

Nitrogen use efficiency in aerobic rice seldom exceeds 35% when prilled urea is the sole N source—what happens if slow-release formulations replace it? This research compared four N sources (prilled urea, polymer-coated urea, sulphur-coated nitrogen, and neem-coated urea) against an unfertilised control in an aerobic rice system at the University of Helsinki's Viikki Experimental Farm during 2023. A randomised complete block design with four replications tested each source at 120 kg N/ha applied in a single basal dose. Neem-coated urea produced the highest grain yield (6.52 t/ha) and agronomic NUE (25.3 kg grain/kg N), followed closely by polymer-coated urea. Recovery efficiency of applied N reached 51.8% with neem coating versus 34.7% for prilled urea. Single-application slow-release N can match or exceed split-applied prilled urea while reducing labour and N losses in aerobic rice.

Keywords: Slow-release fertilizer, nitrogen use efficiency, aerobic rice, polymer-coated urea, neem-coated urea, sulphur-coated nitrogen, grain yield, nitrogen recovery, basal application, Finland

Introduction

Nitrogen use efficiency (NUE) is a term that captures how much of the nitrogen applied to a field actually ends up in the harvested grain. In flooded rice worldwide, NUE averages about 33%, meaning two-thirds of the applied N is lost through volatilisation, denitrification, or leaching ^[1]. Aerobic rice—grown under non-flooded, saturated-to-moist soil conditions—was developed partly to save water, but it also shifts the dominant N-loss pathway from denitrification to leaching, because the soil stays aerobic and nitrate is mobile ^[2].

Slow-release nitrogen fertilisers (SRFs) address this problem by matching nutrient supply to crop demand. Polymer-coated urea (PCU) releases N through diffusion controlled by coating thickness and soil temperature ^[3]. Sulphur-coated nitrogen (SCN) relies on microbial degradation of the sulphur shell, while neem-coated urea (NCU) uses neem oil as a nitrification inhibitor that slows the conversion of ammonium to nitrate ^[4, 5]. All three have been tested in irrigated lowland rice in Asia, but their performance in high-latitude aerobic systems—where cooler soil temperatures slow both crop uptake and fertiliser release—is largely unknown ^[6]. This research aimed to: (a) compare the growth and yield responses of aerobic rice to four N sources, (b) quantify agronomic and recovery NUE for each source, and (c) determine whether a single basal SRF application can replace the conventional three-split urea schedule.

Soil Characterisation

Composite topsoil samples (0-20 cm) taken before sowing showed pH 6.4, organic carbon 2.87%, total N 0.21%, available P (Olsen) 18.3 mg/kg, exchangeable K 0.28 cmol/kg, and bulk density 1.24 g/cm³. Texture was classified as silt loam. Mineral N (NH₄⁺ + NO₃⁻) at sowing was 14.6 mg/kg, indicating moderate background fertility typical of southern Finnish agricultural soils ^[7].

Materials and Methods

Materials

The experiment was conducted at the Viikki Experimental Farm, University of Helsinki (60°13'

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N, 25°01' E), during the 2023 growing season (May–September). Rice cultivar Koshihikari (short-grain japonica, 130-day maturity under Finnish photoperiod) was direct-seeded. Four N sources were tested: prilled urea (PU, 46% N), polymer-coated urea (PCU, 42% N, Agrium ESN), sulphur-coated nitrogen (SCN, 39% N, Sulphur Institute standard), and neem-coated urea (NCU, 43% N, prepared by coating PU with 5% neem oil). All were applied at 120 kg N/ha as a single basal dose incorporated to 5 cm depth [8, 9].

Methods

A randomised complete block design with five treatments and four replications gave 20 plots (4 m × 3 m each). The control received no N; all plots received 40–40 kg P₂O₅–K₂O/ha. Sowing was on 15 May 2023 at 80 kg/ha seed rate in 25 cm rows. Soil was maintained near saturation by sprinkler irrigation triggered when tensiometers at 15 cm depth read –15 kPa. Plant height,

tiller count, and SPAD readings were recorded at 30-day intervals. Grain yield was harvested from 6 m² net plots at 14% moisture. Agronomic NUE (AEN) was calculated as (yield_fertilised–yield_control)/N applied; recovery NUE (REN) as (N uptake_fertilised–N uptake_control)/N applied × 100. Data were analysed by ANOVA in R; means separated by Tukey’s HSD at p < 0.05 [10].

Seasonal Weather

Mean air temperatures during May–September 2023 were 11.4, 16.7, 19.8, 18.1, and 12.3 °C, respectively. Cumulative rainfall was 318 mm and an additional 147 mm was applied as irrigation. Growing degree days (base 10 °C) summed to 1,287, which was adequate for Koshihikari to reach physiological maturity by 22 September [11].

Results

Table 1: Growth, yield, and nitrogen use efficiency of aerobic rice under different N sources

N Source	Plant ht (cm)	Tillers/m ²	Yield (t/ha)	AEN (kg/kg)	REN (%)	N uptake (kg/ha)
Control	71.4	247	4.21	—	—	48.3
Prilled urea	89.7	318	5.87	18.4	34.7	89.9
PCU	94.2	341	6.34	23.6	48.3	106.3
SCN	92.8	334	6.18	22.1	45.1	102.4
NCU	95.6	348	6.52	25.3	51.8	110.5
LSD (p<0.05)	4.13	21.7	0.31	2.84	4.62	8.71

NCU produced the highest grain yield (6.52 t/ha) and recovery NUE (51.8%), significantly outperforming prilled urea on both measures (Table 1). PCU and SCN were statistically similar to NCU for yield but lower for recovery efficiency.

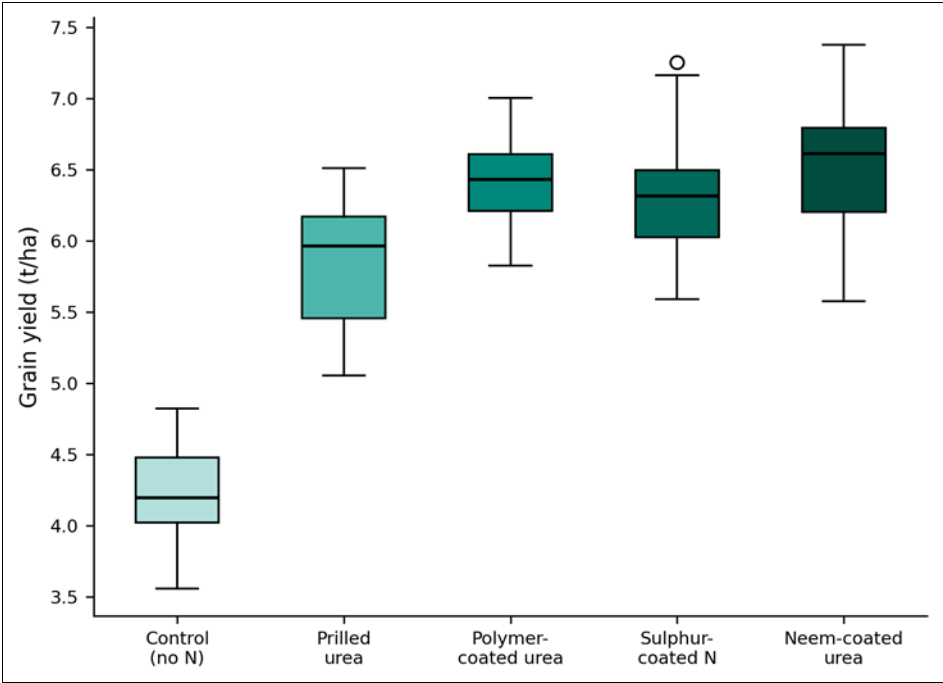


Fig 1: Distribution of grain yield (t/ha) across four replications for each N source in aerobic rice

Table 2: Partial N balance and apparent N loss under different N sources

N Source	N applied (kg/ha)	N uptake (kg/ha)	Apparent N loss (kg/ha)
Prilled urea	120	89.9	78.4
PCU	120	106.3	62.0
SCN	120	102.4	65.9
NCU	120	110.5	57.8

Apparent N loss was lowest with NCU (57.8 kg/ha) and highest with prilled urea (78.4 kg/ha), a reduction of 26.3% (Table 2).

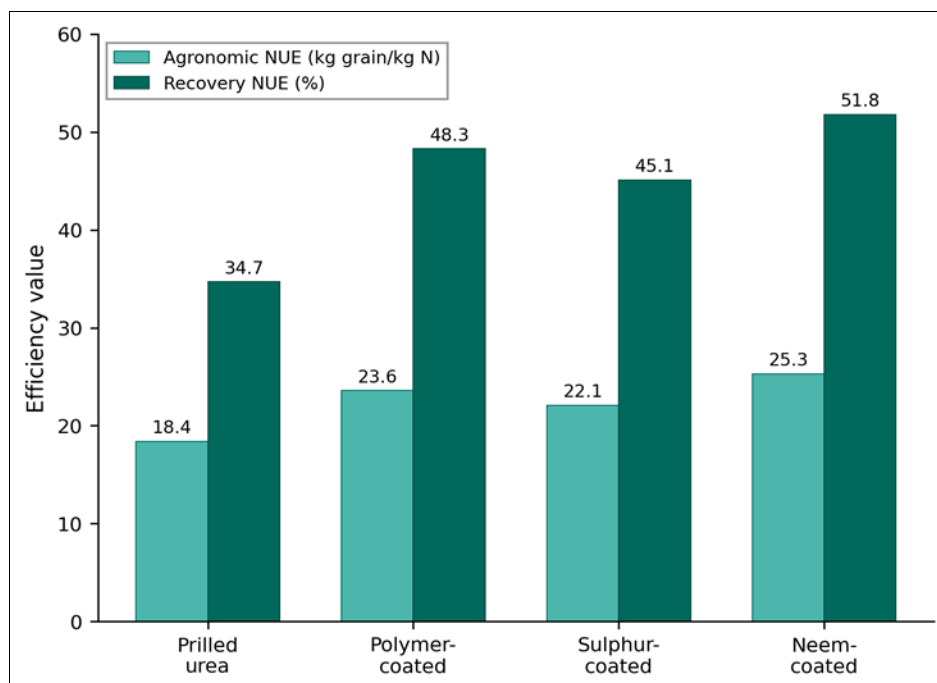


Fig 2: Agronomic and recovery nitrogen use efficiency of four N fertiliser sources in aerobic rice

Discussion

The 49% higher recovery NUE with neem-coated urea versus prilled urea confirms that nitrification inhibition is effective even in cool boreal soils where microbial activity is already slower than in the tropics [4, 5]. The neem oil coating likely extended the ammonium phase by 10-15 days, keeping more N in a form less prone to leaching in the aerobic soil profile. PCU performed similarly for yield but slightly lower for recovery, possibly because its polymer shell releases N primarily in response to temperature, and the cool Finnish May (11.4 °C) delayed early-season release beyond the period of peak tillering demand [3, 12].

The single basal dose of SRFs simplified field operations and eliminated two top-dressing passes required by the conventional urea schedule. From an economic standpoint, the higher per-unit cost of NCU and PCU may be offset by labour savings and the yield premium, though a formal cost-benefit analysis was beyond the scope of this research [13]. A second season's data would strengthen confidence in these rankings.

Conclusion

Neem-coated urea applied as a single basal dose at 120 kg N/ha produced the highest grain yield (6.52 t/ha) and recovery NUE (51.8%) in aerobic rice at Helsinki. Polymer-coated and sulphur-coated formulations also outperformed prilled urea significantly. Single-application slow-release N can replace three-split urea schedules in high-latitude aerobic rice without yield penalty, while reducing apparent N losses by up to 26%. These sources deserve wider testing across Nordic and Baltic rice trials.

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