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Effect of slow release urea sources and nitrogen levels on growth and productivity of rice (*Oryza sativa* L.)

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Abstract
A field experiment was conducted at ICAR-Indian Institute of Rice Research, Rajendranagar, Hyderabad, during the *kharif* seasons of 2023 and 2024 to evaluate the effect of slow-release urea sources and nitrogen levels on growth and productivity of rice (*Oryza sativa L.*). The study was laid out in a randomized block design with sixteen treatments and three replications, comprising five urease inhibitor-coated urea sources neem-coated urea, allicin-coated urea (2000 ppm), eucalyptus-coated urea (2000 ppm), NBPT coated urea (1000 ppm), and cedar wood oil coated urea (2000 ppm) applied at 100%, 75%, and 50% of the recommended nitrogen dose, along with a control. Results revealed that 100% RDN through CWO coated urea produced the highest number of tillers (355 m^{-2}), dry matter accumulation (13,319 kg ha^{-1}), and leaf area (765 cm^2 $hill^{-1}$), resulting in the maximum grain yield (6641 kg ha^{-1}) and straw yield (8139 kg ha^{-1}), followed by 100% RDN through NBPT-coated urea (6348 and 7956 kg ha^{-1}, respectively). Notably, 75% RDN through CWO coated urea achieved a grain yield of 6363 kg ha^{-1}, statistically comparable to full-dose applications of other coated urea sources, indicating a potential nitrogen saving of 25% without a yield penalty. The findings confirm that slow-release urea sources, particularly those coated with CWO and NBPT, significantly enhance nitrogen use efficiency and sustain higher rice productivity under irrigated conditions.

Keywords: Rice, cedar wood oil coated urea, NBPT, nitrogen use efficiency, slow release fertilizers, grain yield

Introduction
Rice (*Oryza sativa* L.) is one of the most important staple food crops globally, providing food security to more than 60% of the world's population, particularly in Asia. India remains the largest rice-producing country with an estimated area of 51.42 million hectares and production of 151 million tonnes in 2024-25, achieving an average productivity of 3.3 t ha^{-1}. In Telangana, rice occupies about 4.81 million hectares, contributing 17.09 million tonnes with a productivity of 3.20 t ha^{-1} (DA&FW, 2024-25) [4]. The growing global population, projected to reach 9.8 billion by 2050, demands enhanced rice productivity from existing agricultural land while maintaining environmental sustainability.
Nitrogen is the most critical nutrient limiting rice productivity, with conventional urea being the predominant source of nitrogen used by farmers. However, conventional urea application is associated with significant nitrogen losses of 30-70% through various pathways including ammonia volatilization, denitrification, and leaching, resulting in poor nitrogen use efficiency (NUE) of only 31% in irrigated rice systems in Asia (Cameron *et al*. 2013 and Cassman *et al*. 2022) [2, 3]. These losses not only reduce crop productivity but also contribute to environmental pollution, groundwater contamination, and greenhouse gas emissions.
Low nitrogen use efficiency and losses through different pathways due to high solubility of conventional fertilizers necessitate the development of slow-release or controlled-release fertilizers. There are broadly two types: coated conventional fertilizers or inherently low-solubility fertilizers. Conventional nitrogen fertilizers can be coated with permeable or semi-permeable substances, such as sulfur, oilseed cakes, polymers, or resins, to control nitrogen release (Trenkel M. E. (2010) [9]. The applied nitrogen through slow-release fertilizers releases

nitrogen slowly over a more extended period during the crop growth cycle, mainly governed by the urease enzyme and microbial processes.Among the known soil urease inhibitors, the chemically synthesized N-(n-butyl) thiophosphoric triamide (NBPT) is currently the most efficient compound. In the presence of soil microbiota, NBPT is converted to its oxo-analogue called N- (n-butyl) phosphoric triamide (oxo-NBPT) which exhibits high capacity for inhibiting soil urease. However, synthetic inhibitors have been reported to cause some adverse effects on plant structure, creating the need for natural alternatives.

Natural urease inhibitors derived from plant sources are increasingly recognized as eco-friendly alternatives to synthetic compounds. Substances such as allicin (from garlic), natural oils like cedar wood oil and eucalyptus oil have demonstrated inhibitory effects on urease enzyme activity. Although their inhibition capacity may be slightly lower than synthetic compounds, these natural inhibitors enhance soil microbial activity, improve soil health, and offer long-term sustainability.

Recent studies have highlighted the effectiveness of various slow-release nitrogen sources in improving the growth and productivity of rice. The application of STCR-based neem-coated urea has been reported to significantly enhance dry matter accumulation and grain yield compared to conventional nitrogen fertilizers (Sowmya *et al*., 2025) [7]. Similarly, urease inhibitors such as allicin and NBPT have shown superior performance over traditional neem-coated urea, even at reduced nitrogen levels, indicating improved nitrogen use efficiency and reduced losses (Surekha *et al*., 2024) [8]. Additionally, the use of silicon-coated urea has been shown to enhance yield and economic returns, particularly in wet direct-seeded rice cultivation (Aruna *et al*. 2023) [1]. Collectively, these findings suggest that slow-release and inhibitor-coated urea formulations play a crucial role in enhancing nitrogen use efficiency and maintaining rice productivity under various management conditions.

Despite extensive research on individual urease inhibitors, comprehensive comparative studies evaluating multiple slow-release nitrogen sources at different application rates under uniform experimental conditions are limited. Furthermore, cedar wood oil and eucalyptus oil as natural coating materials for urea have received limited attention in field studies.

Therefore, the present study was conducted to evaluate the efficacy of various slow-release urea sources on the growth, yield, and nitrogen use efficiency of rice under irrigated conditions.

Materials and Methods

An experiment was conducted during the *kharif*, seasons of 2023 and 2024 at the research farm of ICAR-Indian Institute of Rice Research (ICAR-IIRR), Rajendranagar, Hyderabad, Telangana, to evaluate the effect of different urease inhibitor-coated urea sources and nitrogen levels on growth, yield, and nitrogen use efficiency of rice. The site is situated at 17°19' N latitude and 78°23' E longitude with an altitude of 542.3 m above mean sea level, representing the Southern Telangana agro-climatic zone and falling under the semi-arid tropics as per Troll's classification. The experimental soil was clay loam in texture, slightly alkaline in reaction (pH 8.05), low in available nitrogen (201.2 kg ha^{-1}) and phosphorus (24.0 kg ha^{-1}), and high in available potassium (404.2 kg ha^{-1}), with 0.55% organic carbon and electrical conductivity of 0.6 dS m^{-1}. The experiment was laid out in a randomized block design with sixteen treatments replicated three times, comprising a total of forty-eight plots, each measuring 5.0 × 4.0 m. The treatments consisted of five different urease inhibitor-coated urea sources applied at three nitrogen levels (100%, 75%, and 50% of the recommended dose of nitrogen RDN) along with a control (no nitrogen application). The treatments were as follows: T_1, 100% RDN through neem-coated urea (NCU); T_2, 100% RDN through allicin-coated urea @ 2000 ppm; T_3, 100% RDN through eucalyptus-coated urea @ 2000 ppm; T_4, 100% RDN through NBPT-coated urea @ 1000 ppm; T_5, 100% RDN through cedar wood oil (CWO)-coated urea @ 2000 ppm; T_6, 75% RDN through NCU; T_7, 75% RDN through allicin-coated urea @ 2000 ppm; T_8, 75% RDN through eucalyptus-coated urea @ 2000 ppm; T_9, 75% RDN through NBPT-coated urea @ 1000 ppm; T_{10}, 75% RDN through CWO-coated urea @ 2000 ppm; T_{11}, 50% RDN through NCU; T_{12}, 50% RDN through allicin-coated urea @ 2000 ppm; T_{13}, 50% RDN through eucalyptus-coated urea @ 2000 ppm; T_{14}, 50% RDN through NBPT-coated urea @ 1000 ppm; T_{15}, 50% RDN through CWO-coated urea @ 2000 ppm; and T_{16}, control (no nitrogen application). The recommended fertilizer dose was 120:60:40 kg ha^{-1} of N: P_2O_5:K_2O. The short-duration rice variety DRR Dhan-64 (115-120 days; yield potential 6.0-6.5 t ha^{-1}) was used for the study. Seeds were soaked for 24 hours, incubated, and sown in raised nursery beds, and 20-25-day-old seedlings were transplanted at 20 × 15 cm spacing with 2-3 seedlings per hill. Phosphorus (60 kg P_2O_5 ha^{-1}) was applied as basal through single super phosphate, potassium (40 kg K_2O ha^{-1}) through muriate of potash in two splits 75% as basal and 25% at 75 days after transplanting and nitrogen as per treatment through coated urea in three splits (50% basal, 25% at tillering, and 25% at panicle emergence). A water depth of 2-5 cm was maintained during the crop period with drainage at maximum tillering and before fertilizer application, and continuous flooding was followed from panicle initiation to 21 days after flowering. Pretilachlor 50% EC @ 1250 ml ha^{-1} was applied as pre-emergence herbicide followed by one hand weeding at 30 days after transplanting, and Chlorpyriphos @ 2 ml l^{-1} was sprayed at 45 days after transplanting for stem borer control. Observations on tiller number, dry matter accumulation, and leaf area were recorded at major growth stages, while grain and straw yields were measured from the net plot area (16 m²) after drying, threshing, and cleaning. Data were analyzed using ANOVA for randomized block design, and treatment means were compared using the LSD test at 5% significance level (Gomez and Gomez, 1984) [5].

Results

Significant variations were observed in the growth and yield parameters of rice as influenced by different slow-release urea fertilizers during both years of experimentation.

The number of tillers m^{-2} increased markedly with the application of 100% RDN through cedar wood oil (CWO)-coated urea @ 2000 ppm, which recorded the highest values of 350 and 359 m^{-2} during *kharif* 2023 and 2024, respectively, with a pooled mean of 355 m^{-2}. This treatment was followed by 100% RDN through NBPT-coated urea @ 1000 ppm (pooled 327 m^{-2}) and 75% RDN through CWO-coated urea @ 2000 ppm (pooled 326 m^{-2}), while the lowest number of tillers (pooled 173 m^{-2}) was observed in the control (no application of urea fertilizer). A similar trend was recorded at all successive growth stages, with 100% RDN through CWO-coated urea @ 2000 ppm maintaining the maximum number of tillers at panicle emergence (441 m^{-2}), flowering (418 m^{-2}), and maturity (386 m^{-2}).

Dry matter accumulation followed a similar pattern, wherein

100% RDN through CWO-coated urea @ 2000 ppm recorded the maximum values (2649 and 2567 kg ha⁻¹ at tillering; 13685 and 12953 kg ha⁻¹ at harvest, with a pooled mean of 13319 kg ha⁻¹). These values were statistically comparable with 100% RDN through NBPT-coated urea @ 1000 ppm (pooled 13115 kg ha⁻¹) and 75% RDN through CWO-coated urea @ 2000 ppm (pooled 13169 kg ha⁻¹), whereas the minimum dry matter accumulation (pooled 6934 kg ha⁻¹) was recorded in the control.

Leaf area was also significantly influenced by the treatments. The highest leaf area (772 and 759 cm² hill⁻¹ during 2023 and 2024, with a pooled mean of 765 cm² hill⁻¹) was observed under 100% RDN through CWO-coated urea @ 2000 ppm, followed by 100% RDN through NBPT-coated urea @ 1000 ppm (pooled 716 cm² hill⁻¹) and 75% RDN through CWO-coated urea @ 2000 ppm (pooled 736 cm² hill⁻¹). The control recorded the lowest leaf area (pooled 460 cm² hill⁻¹).

Grain and straw yields showed similar responses to slow-release nitrogen sources. The treatment receiving 100% RDN through CWO-coated urea @ 2000 ppm produced the highest grain yield (6722 and 6560 kg ha⁻¹ during 2023 and 2024, respectively, with a pooled mean of 6641 kg ha⁻¹). This was statistically on par with 75% RDN through CWO-coated urea @ 2000 ppm (pooled 6363 kg ha⁻¹) and 100% RDN through NBPT-coated urea @ 1000 ppm (pooled 6348 kg ha⁻¹), while the control recorded the lowest yield (pooled 2847 kg ha⁻¹). Compared with 100% RDN through neem-coated urea, grain yield improved by 12.8% under 100% RDN through CWO-coated urea @ 2000 ppm and by 15.1% under 75% RDN through CWO-coated urea @ 2000 ppm.

A similar trend was recorded for straw yield, where 100% RDN through CWO-coated urea @ 2000 ppm recorded the maximum (8206 and 8073 kg ha⁻¹ during 2023 and 2024, respectively, with a pooled mean of 8139 kg ha⁻¹), followed by 100% RDN through NBPT-coated urea @ 1000 ppm (pooled 7956 kg ha⁻¹) and 75% RDN through CWO-coated urea @ 2000 ppm (pooled 7930 kg ha⁻¹). The control recorded the minimum straw yield (pooled 3973 kg ha⁻¹). The relative improvement in straw yield over neem-coated urea was 10.6% at 100% RDN and 15.5% at 75% RDN through CWO-coated urea @ 2000 ppm.

The superior performance of CWO- and NBPT-coated urea treatments can be attributed to their ability to synchronize nitrogen release with crop demand, thereby minimizing losses and ensuring continuous nutrient availability throughout the crop growth period. Cedar wood oil, rich in bioactive compounds such as cedrol, α-cedrene, and β-cedrene, forms a hydrophobic coating around urea granules, reducing urea hydrolysis and volatilization while moderating urease activity. The sustained nitrogen supplies improved tiller initiation, leaf expansion, photosynthetic efficiency, and assimilate translocation, resulting in higher dry matter accumulation and yield. The ability of 75% RDN through CWO-coated urea to produce yields comparable to 100% RDN treatments indicates a potential 25% nitrogen saving without yield penalty, contributing to economic and environmental sustainability. These results agree with Liu *et al*. (2013) [6], Surekha *et al*. (2024) [8], and Yang *et al*. (2021) [10], who also reported improved nitrogen use efficiency and yield with slow-release and urease inhibitor-coated urea sources. Furthermore, the enhanced performance of organic coatings such as CWO, allicin, and eucalyptus suggests that bioactive components in these materials may not only regulate nitrogen release but also impart additional biochemical benefits that enhance nutrient utilization and crop productivity.

Table 1: Effect of various sources and levels of slow-release urea fertilizers on the number of tillers per m^2 of rice at active tillering, panicle emergence, flowering, and maturity stages during *Kharif*, 2023 and 2024.

Trt. No	Treatments	Number of tillers m^{-2} at different stages											
		Active tillering			Panicle emergence			Flowering			Harvest		
		2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T_1	100% RDN-NCU	290	298	294	385	396	390	356	364	360	330	324	327
T_2	100%RDN-Allicin coated urea @2000 ppm	309	317	313	407	418	412	378	372	379	352	333	342
T_3	100% RDN-Eucalyptus coated urea@2000 ppm	297	306	302	394	405	399	379	373	376	339	330	334
T_4	100% RDN- NBPT coated urea@1000 ppm	323	331	327	434	440	437	419	408	414	379	368	374
T_5	100% RDN- CWO coated urea@2000 ppm	350	359	355	435	446	441	420	415	418	384	388	386
T_6	75% RDN-NCU	256	266	261	351	359	355	331	346	339	301	296	299
T_7	75% RDN-Allicin coated urea@2000 ppm	304	314	309	409	417	413	366	359	372	339	329	334
T_8	75% RDN-Eucalyptus coated urea@2000 ppm	263	273	268	359	366	363	349	353	346	315	293	304
T_9	75% RDN- NBPT coated urea@1000 ppm	308	323	315	396	428	412	383	389	391	346	359	353
T_{10}	75% RDN- CWO coated urea@2000 ppm	321	331	326	419	436	427	409	396	402	369	363	366
T_{11}	50% RDN-NCU	234	243	239	314	322	318	289	288	289	249	252	251
T_{12}	50% RDN-Allicin coated urea@2000 ppm	246	255	251	326	334	330	301	300	301	261	262	261
T_{13}	50% RDN-Eucalyptus coated urea@2000 ppm	235	244	239	315	322	319	290	289	289	260	257	258
T_{14}	50% RDN- NBPT coated urea@1000 ppm	257	266	261	337	344	341	312	314	313	272	276	274
T_{15}	50% RDN- CWO coated urea@2000 ppm	263	272	268	343	351	347	318	317	317	278	279	278
T_{16}	Control (No N)	166	179	173	230	233	231	195	218	206	180	218	199
SEm±		12.75	12.48	12.52	7.66	6.60	6.48	11.0	12.0	9.0	7.23	11.63	7.22
CD or LSD		37.0	36.0	35.0	22.0	19.0	19.0	32.0	35.0	27.0	21.0	34.0	21.00

Table 2: Effect of various sources and levels of slow-release urea fertilizers on dry matter accumulation (kg ha^{-1}) of rice crop at active tillering, panicle emergence, flowering, and maturity stages during *Kharif*, 2023 and 2024.

Trt. No	Treatments	Dry matter accumulation (kg ha^{-1}) at different stages											
		Active tillering			Panicle emergence			Flowering			Harvest		
		2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T_1	100% RDN-NCU	2360	2343	2352	5326	5156	5241	8930	7956	8443	12856	12242	12549
T_2	100%RDN-Allicin coated urea @2000 ppm	2467	2404	2436	5648	5104	5376	8993	8185	8589	13079	12079	12579
T_3	100% RDN-Eucalyptus coated urea@2000 ppm	2394	2368	2381	5570	5311	5441	8952	8159	8555	12876	12222	12549
T_4	100% RDN- NBPT coated urea@1000 ppm	2530	2486	2508	5874	5574	5724	9307	8576	8942	13676	12553	13115
T_5	100% RDN- CWO coated urea@2000 ppm	2649	2567	2608	6115	5631	5873	9407	8788	9098	13685	12953	13319
T_6	75% RDN-NCU	2231	2248	2239	4741	4652	4696	7909	7496	7703	11909	11477	11693
T_7	75% RDN-Allicin coated urea@2000 ppm	2422	2314	2368	4993	4474	4733	8162	7309	7736	12173	11172	11673
T_8	75% RDN-Eucalyptus coated urea@2000 ppm	2363	2293	2328	4926	4870	4898	8257	7716	7986	12207	11849	12028
T_9	75% RDN- NBPT coated urea@1000 ppm	2444	2431	2438	5049	5445	5247	8791	8264	8528	13221	12467	12844
T_{10}	75% RDN- CWO coated urea@2000 ppm	2567	2444	2505	5814	5537	5675	9389	8916	9152	13882	12455	13169
T_{11}	50% RDN-NCU	1980	1981	1981	4259	4200	4229	6367	6393	6380	10493	10160	10326
T_{12}	50% RDN-Allicin coated urea@2000 ppm	2020	2031	2026	4565	4086	4326	7238	7172	7205	11372	11039	11205
T_{13}	50% RDN-Eucalyptus coated urea@2000 ppm	1994	2042	2018	4501	4368	4434	6525	6609	6567	10759	10525	10642
T_{14}	50% RDN- NBPT coated urea@1000 ppm	2083	2046	2065	4682	4349	4516	6518	6586	6552	10886	10572	10729
T_{15}	50% RDN- CWO coated urea@2000 ppm	2088	2069	2079	4841	4522	4682	6628	6606	6617	11016	10310	10663
T_{16}	Control (No N)	1699	1665	1682	2825	2625	2725	3989	3322	3656	7027	6841	6934
SEm±		64	49.0	43.0	117.9	73.82	63.13	126.0	195.7	127.2	151.8	191.0	140.0
CD or LSD		185	142.0	124.0	340.0	213.0	182.0	364.0	565.4	368.0	439.0	552.0	404.0

Table 3: Effect of various sources and levels of slow-release urea fertilizers on rice leaf area (cm^{-2} $hill^{-1}$) at active tillering, panicle emergence and flowering stages during *Kharif*, 2023 and 2024.

Trt. No	Treatments	Leaf area (cm^{-2} $hill^{-1}$) at different stages								
		Active tillering			Panicle emergence			Flowering		
		2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T_1	100% RDN-NCU	620	594	607	1142	1121	1131	1266	1251	1259
T_2	100%RDN-ALCU @2000 ppm	693	650	672	1180	1184	1182	1322	1301	1311
T_3	100% RDN-EUCU@2000 ppm	681	648	664	1173	1136	1154	1313	1297	1305
T_4	100% RDN- NBPT coated urea@1000 ppm	733	700	716	1237	1318	1278	1369	1360	1365
T_5	100% RDN- CWO coated urea@2000 ppm	772	759	765	1271	1326	1299	1390	1430	1410
T_6	75% RDN-NCU	550	582	566	838	920	879	1040	984	1012
T_7	75% RDN-ALCU @2000 ppm	608	587	597	979	994	987	1067	1106	1086
T_8	75% RDN-EUCU@2000 ppm	560	583	572	939	933	936	1059	1067	1063
T_9	75% RDN- NBPT coated urea@1000 ppm	679	689	641	1094	1215	1154	1243	1358	1300
T_{10}	75% RDN- CWO coated urea@2000 ppm	711	715	713	1251	1273	1262	1362	1373	1367
T_{11}	50% RDN-NCU	537	523	530	761	814	787	815	869	842
T_{12}	50% RDN-ALCU @2000 ppm	553	530	542	829	914	871	865	888	876
T_{13}	50% RDN-EUCU@2000 ppmppm	539	523	531	782	896	839	834	879	857
T_{14}	50% RDN- NBPT coated urea@1000 ppm	598	543	570	933	1047	990	902	909	905
T_{15}	50% RDN- CWO coated urea@2000 ppm	604	559	581	982	1064	1023	1018	992	1005
T_{16}	Control (No N)	475	444	460	579	647	613	716	736	726
SEm±		20	26	18	27	41	27	26	26	16
CD or LSD		59	74	52	78	119	79	74	74	47

RDN: Recommended dose of Nitrogen **NCU:** Neem Coated Urea **ALCU:** Allicin Coated Urea
EUCU: Eucalyptus coated urea **NBPT:** N-(n-Butyl) Thiophosphoric Triamide **CWO:** Cedar wood oil

Table 4: Effect of various sources and levels of slow-release urea fertilizers on Grain yield (kg ha^{-1}) and Straw yield (kg ha^{-1}) of rice during *Kharif*, 2023 and 2024.

Trt. No.	Treatments	Grain yield (kg ha^{-1})			Straw yield (kg ha^{-1})		
		2023	2024	Pooled	2023	2024	pooled
T_1	100% RDN-NCU	5945	5833	5889	7457	7257	7357
T_2	100% RDN-Allicin coated urea@2000 ppm	6096	6041	6068	7610	7432	7521
T_3	100% RDN-Eucalyptus coated urea@2000 ppm	6075	6007	6041	7717	7425	7571
T_4	100% RDN- NBPT coated urea@1000 ppm	6311	6385	6348	8042	7870	7956
T_5	100% RDN- CWO coated urea@2000 ppm	6722	6560	6641	8206	8073	8139
T_6	75% RDN-Neem coated urea	5473	5584	5529	6801	6934	6868
T_7	75% RDN-Allicin coated urea@2000 ppm	5752	5763	5758	7186	7132	7159
T_8	75% RDN-Eucalyptus coated urea@2000 ppm	5516	5625	5571	6852	6984	6918
T_9	75% RDN- NBPT coated urea@1000 ppm	6028	6238	6133	7574	7685	7630
T_{10}	75% RDN- CWO coated urea@2000 ppm	6362	6363	6363	8041	7819	7930
T_{11}	50% RDN-Neem coated urea	4785	4837	4811	6042	6104	6073
T_{12}	50% RDN-Allicin coated urea@2000 ppm	5009	5271	5140	6311	6624	6468
T_{13}	50% RDN-Eucalyptus coated urea@2000 ppm	4846	5040	4943	6148	6382	6265
T_{14}	50% RDN- NBPT coated urea@1000 ppm	5283	5419	5351	6607	6770	6688
T_{15}	50% RDN- CWO coated urea@2000 ppm	5529	5564	5546	6985	7026	7006
T_{16}	Control (No N)	2586	3108	2847	3619	4326	3973
SEm±		196	182	108.0	116.0	206.21	138.0
CD (p=0.05)		565	527.0	312.0	335.0	595.0	397.0

Conclusion
It was concluded that the application of 100% RDN through cedar wood oil (CWO)-coated urea proved to be the most effective treatment, resulting in significantly higher growth and yield parameters of rice. This treatment was statistically comparable with 100% RDN through NBPT-coated urea and 75% RDN through CWO-coated urea, which produced yields on par with full nitrogen doses, indicating a 25% saving in nitrogen without yield reduction. These treatments enhanced tiller production, dry matter accumulation, and grain and straw yields by ensuring synchronized nitrogen release, reduced nutrient losses, and improved nitrogen use efficiency. Hence, the use of CWO- and NBPT-coated urea can be recommended as efficient and sustainable alternatives to conventional urea for achieving higher productivity and better nitrogen utilization in rice cultivation.

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