Journal of Environmental Biology
p-ISSN: 0254-8704 • e-ISSN: 2394-0379 • CODEN: JEBIDP

JEB®

Original Research Paper
Volume 46 Issue 4 July 2025 pp. 508-517
DOI: http://doi.org/10.22438/jeb/46/4/MRN-5568

J. Environ. Biol., 2025
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Journal website : www.jeb.co.in ★ E-mail : editor@jeb.co.in

Enhanced productivity and nitrogen use efficiency in rice and maize with variable-grade urea polyacrylamide fertilizer in Indo-Gangetic plains, UP, India

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Received: 03 October 2024 **Revised:** 21 December 2024 **Accepted:** 02 April 2025

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Abstract

Aim: To assess the effects of various grades of ureapolyacrylamide (UPAM), applied at various phenological growth stages and frequencies, on the growth, yield, and Nitrogen Use Efficiency (N-UE) of maize and rice.

Methodology: Ureapolyacrylamide is a polymerized blend of polyacrylamide and urea. This process results in four UPAM grades, each with specific carbon (C) and N concentrations: UPAM-1 (C-35.35%, N-32.35%), UPAM-2 (27.67, 39.40%), UPAM-3 (25.11, 41.61%), and UPAM-4 (23.83, 42.71%). A field experiment was conducted on Inceptisol soil in a Randomized Block Design having three replications and ten treatments,including absolute control, split application of various grades of UPAM and NCU applied at different crop stages, by following recommended doses (RDF @ 120:60:60 of N: P_2O_5: K_2O).

Results: The results demonstrated that UPAM-2 significantly enhanced both economic and biological yield and N-UE. In maize, two splits of UPAM-2 were most effective, while three splits optimized results in rice. It can be seen that the UPAM-2 grade is an alternative to traditional N fertilizers regarding matching a synergy between crop requirement and availability throughout the growth period.

Interpretation: UPAM-2 consistently outperformed other grades and NCU, making it the most efficient choice for increasing N-UE.

Key words: Environmental footprint, Indo-gangetic plains, Nitrogen use efficiency, Ureapolyacrylamide

How to cite: Suman, J. and A. Rakshit: Enhanced productivity and nitrogen use efficiency in rice and maize with variable-grade urea polyacrylamide fertilizer in Indo-Gangetic plains, UP, India. *J. Environ. Biol.,* **46,** 508-517 (2025).

Introduction

Feeding the increasing population requires more attention to the practical and precise use of mineral fertilizers like nitrogen, phosphorous, and potassium. Food security in the form of nitrogen output and risk of global warming and environmental pollution linked with nitrogen input. Adaptive fertilizer management practices and enhanced nitrogen fertilizers are crucial for productivity without hampering the ecosystem. Maize and rice are nitrogen exhaustive crops that judiciously manage external inputs like nitrogen, phosphorous, and potassium fertilizers.The majority of non-N fixing crops are dependent on introduced synthetic nitrogen fertilizer for growth and establishment (Jesmin *et al.,* 2021; Bennett *et al.,* 2023). Synthetic nitrogen fertilizers have played an exceptional role in increasing crop yield and ensuring food security for rapid population growth. The efficiency of conventional nitrogen fertilizer assimilation by crops is rather low and is a serious problem in the present increasing environmental awareness perspective (Wang *et al.,* 2017; Govindasamy *et al.,* 2023). The recovery efficiency of nitrogen for cereal production has been estimated globally to be only 33% (Jain andAbrol, 2017; Kumar *et al.,* 2024).

The findings by Lassaletta *et al.* (2014) in the early 1960s, 68% of the reactive nitrogen added to cropland was converted into harvested products, but by 2014 the ratio dropped to 47%, while synthetic nitrogen fertilizer input increased by factor of 9 over the same period. A projected 50 to 70% enhancement in cereal production by 2050 will necessitate doubling the nitrogen fertilizer consumption. The low use efficiency of nitrogen fertilizer also reduces economic returns from fertilizer inputs (Bai *et al.,* 2020). N-use efficiency (N-UE) can be improved by reducing nitrogen losses. Plants absorb nitrogen in the form of exchangeable ammonium ($NH4^+$) or nitrates ($NO3^-$), which are highly mobile in soil and can be easily lost by volatilization or leaching, leading to environmental concerns (Achat *et al.,* 2016; Di *et al.,* 2016; Gil-Ortiz *et al.,* 2021: Wang *et al.,* 2018).Traditional nitrogen fertilizers, such as ammonium sulfates, ammonium nitrates, and urea are characterized by high constant N-release kinetics (Ni *et al.,* 2013; Gil-Ortiz *et al.,* 2020). In most soils, ammonium is quickly converted into nitrate, which is not held in soil particles and is easily dissolved and susceptible to leaching (Bijay-Singh and Craswell, 2021).

Therefore, the timing and rates of N fertilization affect plant growth and achieve sustainable yield. Enhanced efficient nitrogen fertilizers (EENFs) with gradual nitrogen release coinciding with plant demand are the most feasible option compared to conventional N fertilizers to supply nitrogen at reduced losses and enhanced N-UE (Xie *et al.,* 2020; Fan *et al.,* 2022; Darzi *et al.,* 2023; Suman *et al.,* 2023). Synthesize an nitrogen fertilizer by partying polyacrylamide (PAM) with urea (U) to form an adduct compound urea polyacrylamide (UPAM), which are hydrogen bonded with one another via using hydrogen atom of $-NH_2$ functionality of urea and oxygen of carbonyl (>C=O) and the nitrogen atom and $–NH_2$ group respectively from PAM. UPAM is a kind of EENFs that has the potential to provide enhanced nitrogen release timing, making it suitable for field crops (Kumar *et al.,* 2011; Cai *et al.,* 2014; Yang *et al.,* 2017, 2021). Anionic PAM has been sold since 1995 to reduce irrigation-induced erosion and enhance infiltration (Sojka *et al.,* 2007). Other study applications of combining straw with PAM (Liang *et al.,* 2009) and urea with PAM (Zhang and Feng, 2013a; 2013b) have significant effects on inhibiting evaporation, increasing crop yields, increasing dry matter, water-use efficiency, and increasing the soil water content (Farrell *et al.,* 2013; Ramos, 2017). Prior reports on the application of UPAM to field crops in the intensive middle Gangetic plains of Northern India are limited. Therefore, this study is novel in its aim to assess the effects of various UPAM grades, applied at different times and frequencies, on the growth parameters, yield, and N-UE of maize and rice. Additionally, it compares the outcome of polymeric N-treated plots with conventional neem-coated urea (NCU) and untreated controls.

Materials and Methods

Material synthesis: In four different round bottom flasks (100 ml), 10 g of acryl amide was dissolved in 40 ml distilled water, followed by addition of urea maintaining the ratio of 1:1, 1:3, 1:5 and 1:7 w/w in different flasks. After the complete dissolution of urea, each solution was purged with nitrogen to remove dissolved oxygen in the solution. Thereafter, 10 mg ceric ammonium nitrate was added to the solution as an initiator under in nitrogen environment, and the temperature was raised to 70°C. After reaching the desired temperature, the reaction mixture was allowed to stir for 3 hr to get a gel-like product. This product was collected in a petri dish and dried in a vacuum oven at 50°C. After drying, a solid snow-white product urea polyacrylamide (UPAM) was obtained, which resulted from urea and polyacrylamide (PAM) adduct formation. All experiments, *i.e.,* 1:1 w/w for UPAM-1, 1:3 w/w for UPAM-2, and 1:5 w/w for UPAM-3 grades gave >95% yield. Notably, experimental grade 1:7 for UPAM-4 w/w did not show an ideal adduct formation and phase separation for urea and PAM. All experiments were also carried out for 1kg batch of acryl amide and different amounts of urea, and it was observed that the results were same for all the experiments. In the synthesis of the UPAM process, it is notable that with increasing amounts of urea in the reaction mixture, phase separation between urea and PAM occurs.

Study area: Field-scale experiments were conducted at the farm of the Institute of Agricultural Science, Banaras Hindu University, Varanasi, India, during two consecutive ecological seasons of 2020-21 and 2021-22. Varanasi is characterized by a semi-arid and sub-humid climate with an annual average rainfall of 1100 mm. The experimental farm falls under the middle Gangetic plains (agro-ecological region) of eastern India. The course of weekly weather conditions during the crop growth period is shown in Fig. 1,2. A composite soil sample was analyzed before crop establishment for texture, soil pH, organic carbon (OC) and available N, P and K following the standard protocols. Analysis report indicated that the soil was sandy clay loam, in texture neutral to slightly alkaline (7.64 and 7.57) with low OC (4.30 and 4.52 g kg^{-1}), and available N (203 and 198 kg ha^{-1}), medium (21.01

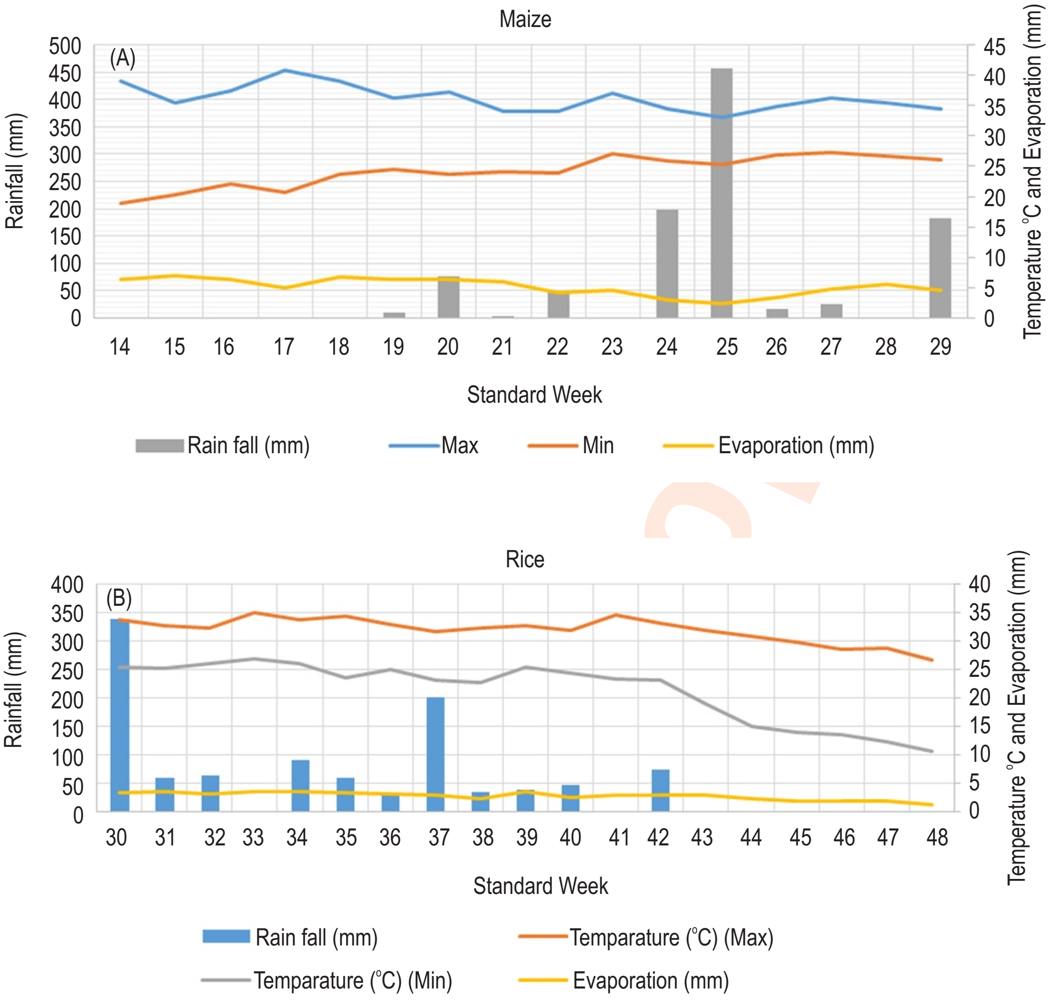


Fig. 1: (A and B) Course of weekly weather conditions during maize and rice growth period 2020-21.

and 18.75 kg ha^{-1}) and high (206 and 210 kg ha^{-1}) levels of available P and K, respectively. In the USDA Soil Taxonomy, this soil is classified as a Typic Ustochrept (order Inceptisol).

Experimental design and test crops: In this experiment, five N-level gradients were set. The field setup was laid out in a randomizedblock design (RBD) with three replications and ten treatments; combinations of various grades UPAM and NCU concerning the number and time of applications and along with mineral fertilizers like single super phosphate (SSP) and muriate of potash (MOP), including one absolute control as consisting of the following T_1: absolute control; T_2: UPAM-1; T_3: UPAM-2; T_4: UPAM-3; T_5: UPAM-4; T_6: UPAM-1; T_7: UPAM-2; T_8: UPAM-3; T_9: UPAM-4 and T_{10}: NCU, here with T_2 to T_5 treatments with two split applications (1st split as basal/pre-transplant and, 2nd split at tasseling and panicle initiation stage of maize and ricecrop) and T_6 to T_{10} treatments (1st split as a basal/pre-transplant, 2nd split at knee height and active tillering stage of maize and rice, 3rd split at tasseling and panicle initiation stage of maize and ricecrop) with three split applications. The recommended dose of fertilizer was applied @ 120:60:60 kg ha^{-1} ($N:P_2O_5:K_2O$) through UPAM (UPAM-1:450; UPAM-2:370; UPAM-3:343; UPAM-4:334 g 12 m^{-2}) and NCU (313 g 12 m^{-2}), SSP (400 g 12 m^{-2}), and MOP (120 g 12 m^{-2}), respectively, in both crops. The full dose of SSP and MOP was applied as basal at the sowing time in all the treatments, except T_1. Two test crops, namely maize (DEKLAB 9108 plus, duration 120 days) and rice (Improved samba mahsuri (RP Bio-226), duration 120 days), were selected as the most suitable crops and popular varieties in the middle Gangetic plains of India.

Biometric observations, yield and N-use efficiency: Growth parameters like plant height, greenness index (SPAD), dry weight and root dry weight were measured for maize and rice crop samples collected at different phenological growth stages, such as knee height (KH), tasselling (TS), grain filling (GF) and harvest (HR) in maize, and active tillering (AT), panicle initiation (PI), heading (HE), and harvest (HR) in rice. Crop biomass from the entire plot was manually harvested at ground level. Grain and

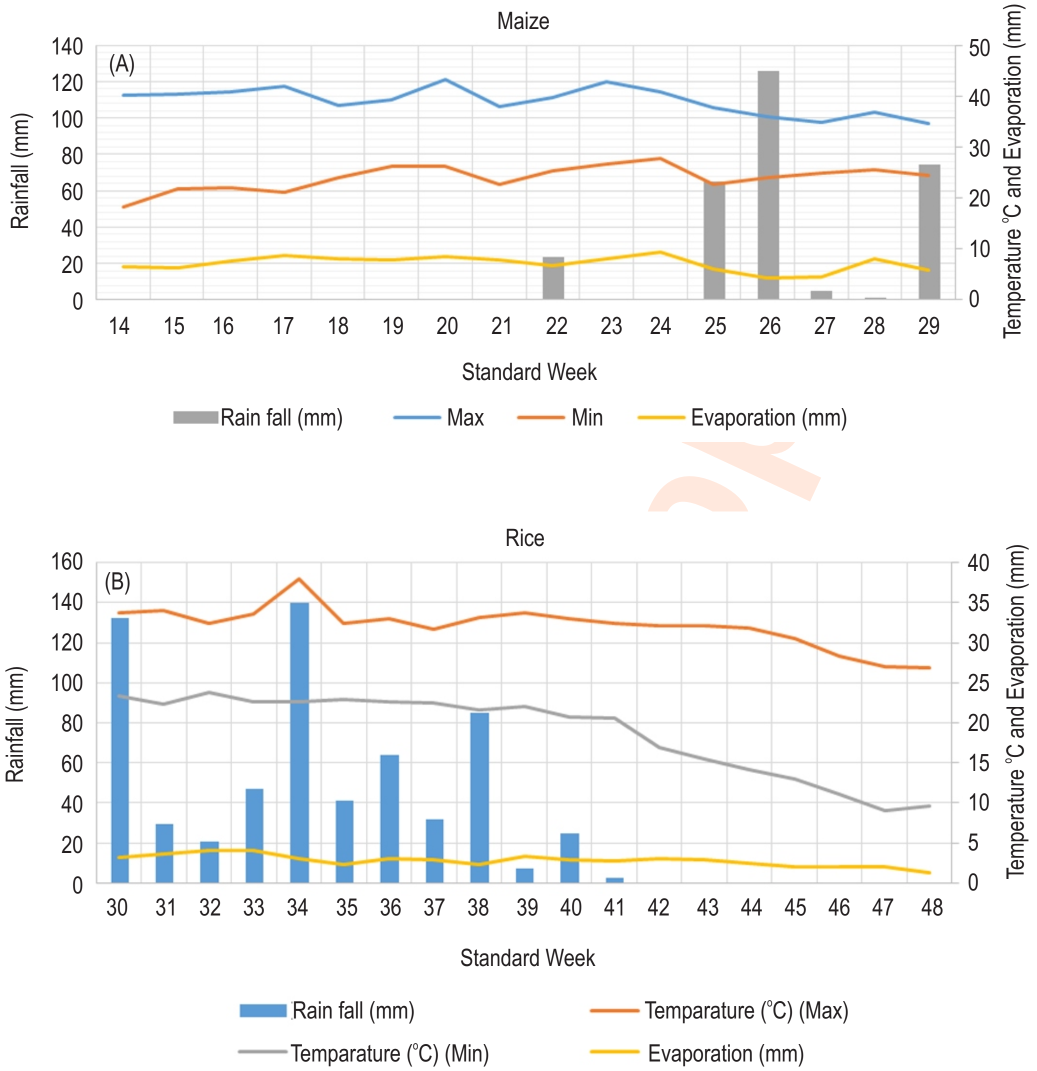


Fig. 2: (A and B) Course of weekly weather conditions during the maize growth period 2021-22.

straw were air-dried, then further dried for 3 days at 65°C to obtain dry matter yields. Grain yield and straw biomass were obtained directly by weighing after threshing crops and subtracting the moisture content. Grain and straw were ground with a ball mill and analyzed for N concentration with an elemental N analyzer (Kjeltron). The crop N uptake and use efficiency were calculated based on the percentage of differences in total N uptake between the N treatment and the absolute control treatment compared with the total N input. Nitrogen uptake (kg ha^{-1}) = NC×Y/100; Agronomic efficiency (kg kg^{-1}) (AGR_N) = Y-Y_O/QNA; Physiological efficiency (kg kg^{-1}) (PUP_N) = Y-Y_O/U-U_O; Apparent recovery efficiency (%) (ANR_N) = U-U_O/QNA×100; Partial factor productivity (kg kg^{-1}) (PFP_N) = Y/QNA; NC-Nitrogen content (%); Y-Yield with applied N (kg ha^{-1}); Y_O-Yield with no applied N; QNA-Quantity of N applied (kg ha^{-1}); U-Total N uptake (kg ha^{-1}) with applied nutrient; U_O-Total N uptake (kg ha^{-1}) with no applied N.

Statistical analyses: Statistical data analysis was conducted using Microsoft Excel 2017 (Microsoft, Redmond, WA, USA) and SAS 8.1 software (SAS Institute Inc. USA). A One-way analysis of variance (ANOVA) was performed to assess the significant differences in the parameters of different treatments. Multiple-mean comparison or significance of the difference between treatments' mean was analyzed using critical difference (CD) and Duncan's Multiple Range Test (DMRT). Lowercase letters in the table indicate statistically significant differences after the least significant difference (LSD) test at P<0.05.

Results and Discussion

This study aims to develop a sustainable and environmentally friendly N fertilizer (UPAM) to reduce N losses and increase N availability and productivity.In previous studies, anionic PAM was used as a soil conditioner; as it has a strong water absorption and cohesion capacities, which helps to maintain a good soil structure (Lentz, 2003; Tang and She, 2018). These characteristics directly or indirectly affect the migration of soil nutrients, improve soil fertility retention, improve soil conditions, offer a suitable environment for plant growth, and increase crop yields (Abulaiti *et al.,* 2023). Few studies have suggested that the combined use of PAM with organic and inorganic materials can maximize their respective advantages. Studies have shown that the application of combining straw with PAM (Liang *et al.,* 2009) and urea with PAM (Zhang and Feng, 2013a,b) had significant effects on inhibiting evaporation, increasing crop yields, increasing dry matter, water-use efficiency (WUE), and increasing the soil water content. When PAM is combined with urea under specified conditions, it behaves like a slow-release fertilizer (Tiwari *et al.,* 2019).

Plant height is a crucial growth index that contributes significantly to yield attributes and overall economic yield (Peng *et al.,* 2014). Various grades of UPAM, differing in application number and timing, significantly affected the plant height at various phenological growth stages in both crops. The pooled data analysis (Fig. 3 a,b) showed that the plant height increased rapidly until the tasselling in maize and at PI stage in rice and thereafter, retarted becoming steady until grain filling and stagnation at harvest across all treatments. Statistically, no significant difference was noted between treatments at the knee height and active tillering stages in maize and rice crops.

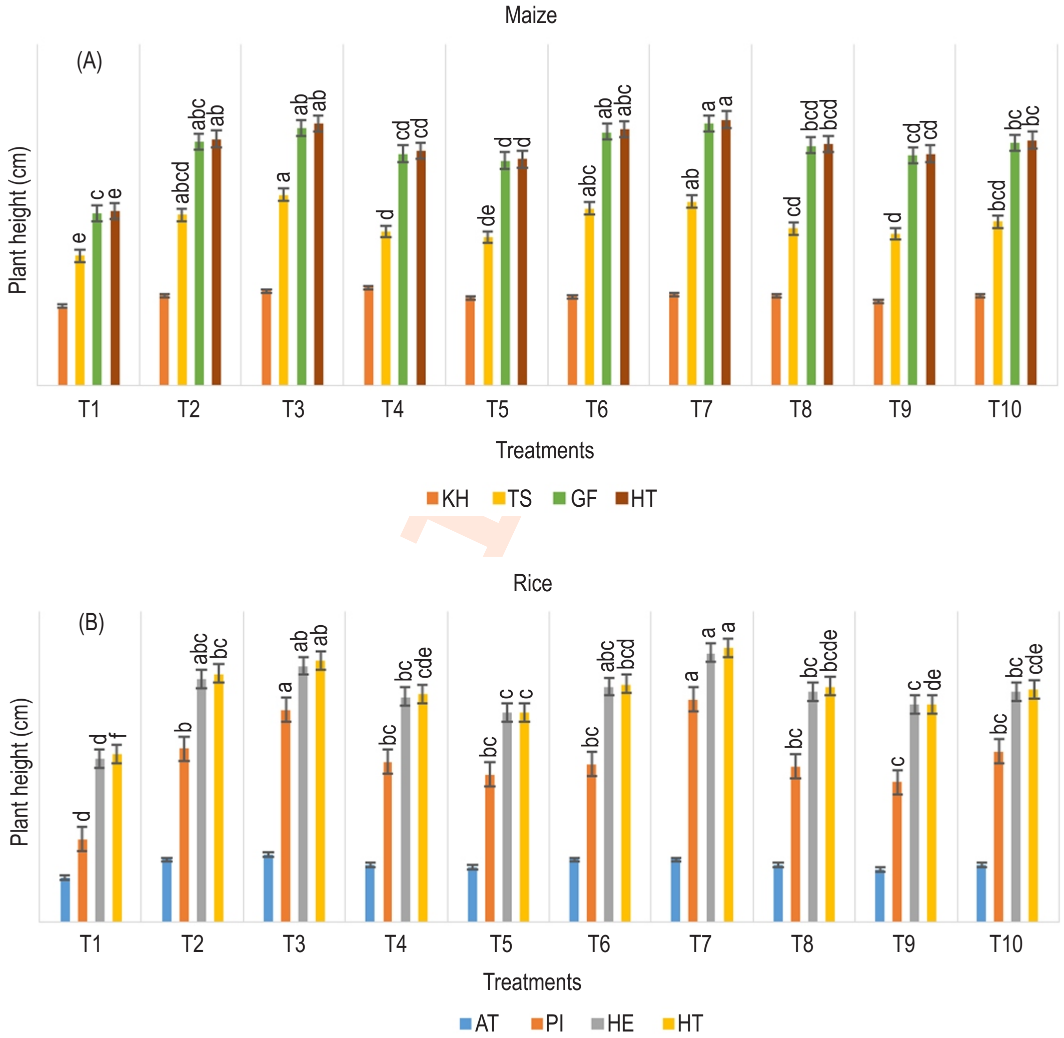


Fig. 3: (A and B) Impact of various grades of polymeric N application (UPAM) on plant height (cm) of maize and rice crop. T_1-absolute control, T_2-UPAM-1, T_3-UPAM-2, T_4-UPAM-3, T_5-UPAM-4, T_6-UPAM-1, T_7-UPAM-2, T_8-UPAM-3, T_9-UPAM-4 and T_{10}-NCU. KH-Knee height; TS-Tasseling; GF-Grain filling; AT-Active tillering; PI-Panicle initiation; HE-Heading; HR-harvest. Differentlowercase letters indicate significant differences between the treatments from One-way ANOVA followed by Duncan's test at $P < 0.05$.

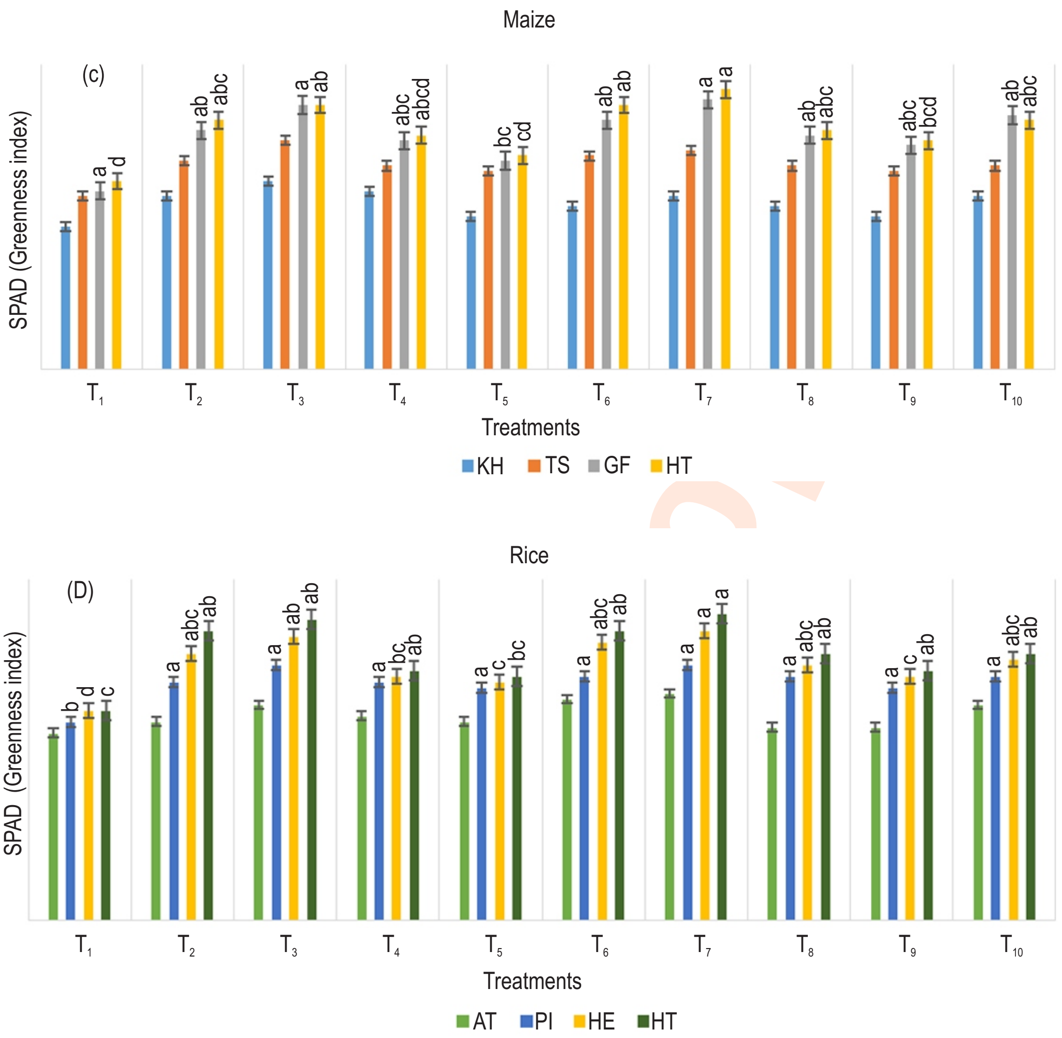
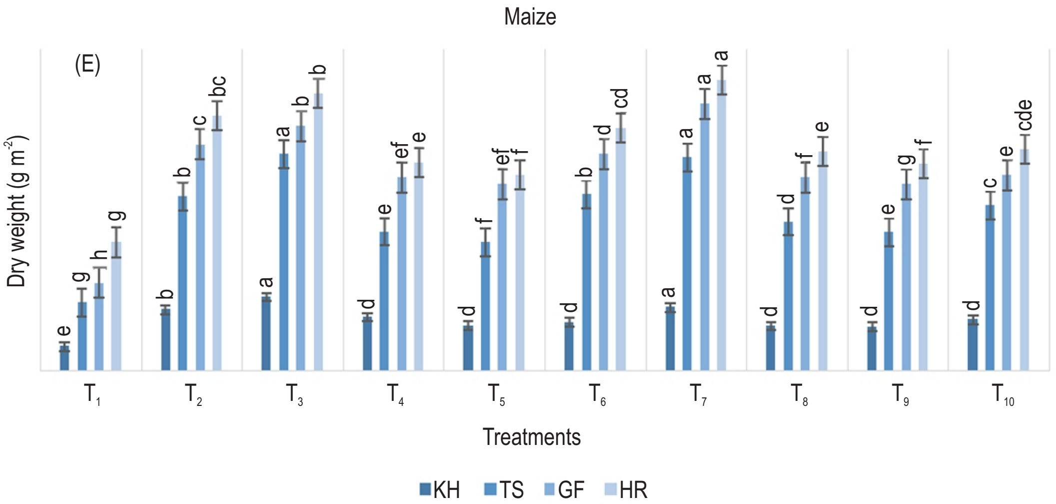


Fig. 4: (C and D) Impact of various grades of polymeric N application (UPAM) on SPAD (greenness index) of maize and rice crops. T_1-absolute control, T_2-UPAM-1, T_3-UPAM-2, T_4-UPAM-3, T_5-UPAM-4, T_6-UPAM-1, T_7-UPAM-2, T_8-UPAM-3, T_9-UPAM-4 and T_{10}-NCU. KH-Knee height; TS-Tasseling; GF-Grain filling; AT-Active tillering; PI-Panicle initiation; HE-Heading; HR-harvest. Differentlowercase letters indicate significant differences between the treatments from One-way ANOVA followed by Duncan's test at $P < 0.05$.

However, significant differences emerged from these stages until harvest in both crops. The highest plant height at tasselling stage in maize was observed in T_3 (UPAM-2), T_3 was statistically similar to T_7, T_6 and T_2, however, significantly higher than other treatments. In rice, at PI stage, T_7 recorded the highest plant height, followed by T_3, T_2, T_{10}, T_4 and T_6 treatments. In contrast, T_3 and T_7 were same grade nitrogen fertilizer treated plots however differed in the number and time of applications. At grain filling, heading and harvest stages, T_7 consistently showed the highest plant height in both crops. T_1 had the lowest plant height at all stages and harvest. These results corroborate with the findings of Adhikari *et al.* (2016), who elucidated that the adequate supply of nitrogen at appropriate growth stages of maize can increase plant growth and number of nodes and internodes, resulting in increased plant height. Zhu *et al.* (2020) showed that the height of maize was significantly augmented with nitrogen availability in soil respective to time and number of applications.

SPAD (greenness index) (Fig. 4 c,d) for maize and rice were recorded at various growth stages, showing non-significant differences between the treatments at the knee height and tasseling stages in maize, however, significant difference was observed at the gram filling and harvest stages. In rice, a non-significance was noted at active tillering stage, but significant differences were observed from this stage until harvest. The differences in SPAD values with the soil nitrogen availability, affecting chlorophyll content and leaf senescence rates. The highest SPAD (55±5 and 54±6.24) values were found in the plots



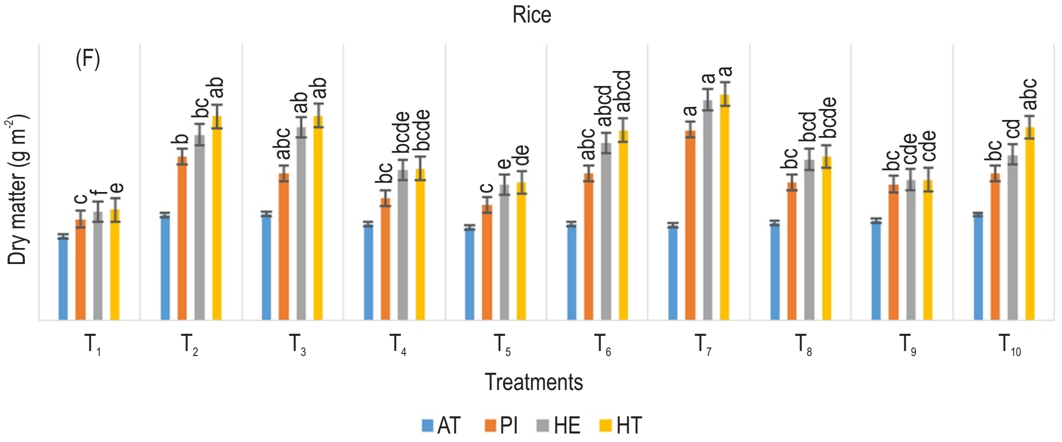


Fig. 5: (E and F) Impact various grades of polymeric N application (UPAM) on dry weight (g m^{-2}) of maize and rice crops. T$_1$-absolute control, T$_2$-UPAM-1, T$_3$-UPAM-2, T$_4$-UPAM-3, T$_5$-UPAM-4, T$_6$-UPAM-1, T$_7$-UPAM-2, T$_8$-UPAM-3, T$_9$-UPAM-4 and T$_{10}$-NCU. KH-Knee height; TS-Tasseling; GF-Grain filling; AT-Active tillering; PI-Panicle initiation; HE-Heading; HR-harvest. Different lower case letters indicate significant differences between the treatments from One-way ANOVA followed by Duncan's test at $P < 0.05$.

with two and three split applications of UPAM-2, followed by UPAM-1 and NCU-treated plots. The lowest SPAD values were noted in T$_1$ treatments, *i.e.,* absolute control (T$_1$; 28±4.7 and 33±4.62).

Dry matter production increased with growth stages, showing peak at maturity. The pooled data (Fig. 6 e,f) indicated that plots treated with UPAM-2 had the highest dry weight, significantly surpassing other grades, including NCU. In maize at, the highest dry weight was recorded at knee height stage with two split applications of UPAM-2 (283 g m^{-1}), followed by UPAM-1 and NCU. At tasseling stage, UPAM-2 recorded the highest dry weight (539 g m^{-1}). At grain filling and harvest stages, T7 recorded the highest dry weight (663 and 723 g m^{-1}). In rice, at active tillering stage, the highest dry weight was observed in NCU-treated plots (115 g m^{-1}), followed by UPAM-2. At the panicle initiation, heading and harvest stages, the highest dry weight was observed in plots with three split applications of UPAM-2. The lowest dry weight was consistently recorded in treatment T$_1$. The above results partially align with the dynamic balance between nitrogen supply and crop physiological demand and reduce the risk of loss of surplus nitrogen from the soil, thereby improving the nitrogen uptake and utilization by crops, which is consistent with the previous studies (Azeem *et al.,* 2014; Granta *et al.,* 2012; Naz *et al.,* 2016; Ye *et al.,* 2020). These results showed that the nitrogen management through fertilizer type, number of applications, and timing can maintain high yields (Mondal *et al.,* 2023; Mosisa *et al.,* 2021). Pool data (Table 1) showed significant differences in yield and yield attributes between two and three split applications of various UPAM grades. In maize, the highest economic yield (T$_3$; 61.28 q ha^{-1}) was achieved with two split applications of UPAM-2 (T$_3$), followed by three splits (T$_7$; 57.56 q ha^{-1}). The absolute control recorded the lowest yield (29.42 q ha^{-1}).

Table 1: Pooled yield data (2020-21 and 2021-22) of maize and rice crop

	Maize					Rice				
Treatments	**Economic yield (t ha^{-1})**	**Straw yield (t ha^{-1})**	**Biological yield (t ha^{-1})**	**Harvest index (%)**	**Seed index (g)**	**Economic yield (t ha^{-1})**	**Straw yield (t ha^{-1})**	**Biological yield (t ha^{-1})**	**Harvest index (%)**	**Test weight (g)**
T_1	2.94^{e}	3.18^{e}	6.12^{f}	0.48	22.22^{d}	2.02^{e}	1.76^{g}	3.79^{e}	0.53	20.67^{e}
T_2	5.53^{ab}	6.34^{abc}	11.89^{abc}	0.47	36.00^{ab}	4.26^{bcd}	5.17^{bcd}	9.43^{bc}	0.48	22^{bcde}
T_3	6.12^{a}	7.22^{a}	13.35^{a}	0.46	37.90^{a}	4.87^{b}	6.18^{ab}	11.05^{ab}	0.47	25^{ab}
T_4	4.39^{cd}	5.17^{cd}	9.56^{de}	0.46	27.17^{bcd}	3.77^{cd}	4.14^{def}	7.92^{cd}	0.48	21^{e}
T_5	4.08^{d}	4.87^{d}	8.95^{e}	0.46	24.22^{cd}	3.55^{d}	3.26^{f}	6.82^{d}	0.52	20.67^{e}
T_6	5.19^{abc}	6.02^{abcd}	11.21^{bcd}	0.46	33.45^{abc}	5.05^{b}	5.56^{abc}	10.62^{b}	0.45	25^{abc}
T_7	5.75^{ab}	6.88^{ab}	12.64^{ab}	0.46	34.83^{ab}	5.96^{a}	6.68^{a}	12.65^{a}	0.44	25.67^{a}
T_8	4.78^{bcd}	5.45^{cd}	10.23^{cde}	0.47	27.27^{bcd}	4.16^{bcd}	4.43^{cdef}	8.59^{cd}	0.48	21.67^{de}
T_9	4.54^{cd}	5.15^{cd}	9.69^{de}	0.47	24.02^{cd}	3.72^{cd}	3.81^{ef}	7.53^{d}	0.49	22^{cde}
T_{10}	5.19^{abc}	5.51^{bcd}	10.70^{cde}	0.49	33.97^{ab}	4.49^{bc}	5.03^{bcde}	9.53^{bc}	0.47	24.67^{abcd}
SEm±	3.370	4.838	6.172		3.232	0.363	0.505	0.896		1.044
CV	12.015	15.013	10.241		18.594	12.489	15.804	3.255		7.886

Mean values within the column with different letters indicate significant differences among the treatments as per DMRT at P=0.05. Columns represent the mean values ± S.D.

Table 2: Pooled N-use efficiency of maize and rice

Treatments	Maize				Rice			
	PUPN (kg kg^{-1})	**AGRN (kg kg^{-1})**	**ANRN (%)**	**PFPN (kg kg^{-1})**	**PUPN (kg kg^{-1})**	**AGRN (kg kg^{-1})**	**ANRN (%)**	**PFPN (kg kg^{-1})**
T_1	-	-	-		-	-	-	-
T_2	46.85	21.76	46.44	46.27	42.77	18.63	43.57	35.51
T_3	41.16	26.55	64.51	51.06	43.35	23.75	54.79	40.63
T_4	51.00	12.08	23.69	36.60	47.38	14.61	30.83	31.48
T_5	50.13	9.54	19.02	34.05	54.44	12.78	23.47	29.65
T_6	44.54	18.77	42.15	43.29	47.82	25.28	52.86	42.15
T_7	44.54	23.45	52.65	47.96	48.07	32.82	68.29	49.70
T_8	48.16	15.39	31.96	39.91	48.49	17.80	36.71	34.68
T_9	47.77	13.33	27.91	37.85	49.62	14.17	28.55	31.04
T_{10}	51.30	18.75	36.55	43.26	46.49	20.58	44.26	37.45

T_1-absolute control, T_2-UPAM-1, T_3-UPAM-2, T_4-UPAM-3, T_5-UPAM-4, T_6-UPAM-1, T_7-UPAM-2, T_8-UPAM-3, T_9-UPAM-4 and T_{10}-NCU. AGRN-Agronomic efficiency of nitrogen; PUPN- Physiological efficiency of nitrogen; ANRN- Apparent nitrogen recovery efficiency; PFPN- Partial factor productivity of nitrogen. NCU-Neem coated urea

Two split applications of UPAM-1 and UPAM-2 resulted in higher yields than three splits, while UPAM-3 and UPAM-4 had higher yields with three splits in maize. In rice, the highest yield was recorded with three split applications of UPAM-2 (T_7; 59.64 q ha^{-1}), followed by UPAM-1 (T_6; 50.58 q ha^{-1}). In both the crops, the higher grain yield and yield attributes were observed with UPAM-2 grade, which might be due to higher nitrogen availability of nitrogen which led to a higher photosynthetic rate, higher growth, and ultimately positive impact on yield and yield attributes along with efficient translocation of photosynthates from source to sink. This is in accordance with the previous studies (Sharma *et al.*, 2007; Murthy *et al.*, 2012; Pradhan *et al.*, 2014). Similarly, Mboyerwa *et al.* (2022), noticed that rice grain yield and higher nitrogen use efficiency could be achieved with optimum dose and time of application, thus reducing cost resulting from fertilizer inputs without compromising other environmental benefits. These findings partially agree with the findings Lentz and Sojka (2007), who elucidated that PAM application increased maize and bean yields up to 11.2 % by improving the physical properties of the soil. The efficacy of applied nitrogen fertilizer was evaluated in terms of AGRN, ANRN, physiological use efficiency, and partial factor productivity (Table 2). The perusal of data showed that the UPAM grades significantly affected N-use efficiency. The highest AGRN, ANRN and PFPN were found in two and three split applications of

UPAM-2 in both crops. AGRN was similar in maize between three split applications of UPAM-1 (18.77 kg kg^{-1}) and NCU (18.75 kg kg^{-1}). In rice, the highest PUEN observed with T$_{10}$ treatment (51.30 kg kg^{-1}), followed by T5 (54.44 kg kg^{-1}), and the lowest was noted in T$_3$ and T$_6$ treatments. With respect to N-UE, the highest was noticed under plots treated with UPAM-2 plot, followed by UPAM-1, NCU, UPAM-3 and UPAM-4. Above results align with Yu *et al*. (2022), compared with the conventional method the combined application of slow release and conventional urea resulted in 27.4-96.5% and 22.8-57.1% higher N-UE in rice and wheat, respectively. Samikshya *et al.* (2022) reported that several innovative, like slow/controlled release fertilizers and their quantity and time of application in maize crops, yielded 17.35-45.81% more grain yield than conventional urea practices in Nepal. Zhu *et al.* (2020) additionally reported that compared to conventional urea, controlled-release fertilizer increased grain yield by 7.23% all the studies in wheat, maize and rice crops.

Results from field experiments indicated that various grades of UPAM in combination with P$_2$O$_5$ and K$_2$O augment the productivity and N use efficiency. Additionally, the results confirmed that UPAM-2 grade in an emerging new polymeric N fertilizer, reaching a potential yield of 61.28 and 59.64 q ha^{-1} in two and three split applications in maize and rice crops, respectively. The present study concludes that the UPAM-2 performed best and is an alternative to traditional nitrogen fertilizers concerning matching a synergy between crop requirements. Extensive field studies under different agroecological are warranted for greater efficiency and consistency of the formulation.

Acknowledgment

The authors are grateful to the Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, BHU, for providing the research facility.

Authors' contribution: J. Suman: Performed the experiments' statistical analysis and drafted the manuscript; **A. Rakshit:** Supervised the work and edited the manuscript.

Funding: The author(s) received no financial support for the research.

Research content: The research content of the manuscript is original and has not been published elsewhere.

Ethical approval: Not applicable.

Conflict of interest: The author declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability: All the data analyzed for this study are included. If needed, any extra data of interest are available upon request.

Consent to publish: All authors agree to publish the original research article in *Journal of Environmental Biology.*

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