Original Research Article

Biopolymer Urea Composite for Enhancing Nitrogen Use Efficiency in Coastal Sandy Soils of Kerala

ABSTRACT

Aim: To formulate biopolymer urea composites in pellet form and to test their efficacy on the release and leaching of nitrogen (N) in northern coastal sandy soils of Kerala.

Experimental design: Completely Randomised Design

Place and duration of study: Department of Agronomy, College of Agriculture, Padannakkad, Kasaragod, Kerala agricultural University, between May 2023 and March 2024.

Methodology: Pellets of biopolymer urea composites were formulated by mixing prilled urea with coconut shell charcoal (C1), gypsum (C2), rice husk biochar (C3), and zeolite (C4) as coating materials and potato starch (S1) and tapioca starch (S2) as binding materials in different ratios (25, 50 and 75% w/w). Castor oil was uniformly sprayed on the composites after formulation. These composites were tested against urea for their N content and pH, N release behaviour in soil and distilled water and N leaching behaviour in the soil. The treatments were: T1: Urea, T2: BUC 1 (C1S1), T3: BUC 2 (C1S2), T4: BUC 3 (C2S1), T5: BUC 4 (C2S2), T6: BUC 5 (C3S1), T7: BUC 6 (C3S2), T8: BUC 7 (C4S1), T9: PUC 8 (C4S2) and T10: Control (Soil).

Results: Total N was not significantly varied across different treatments, but the increase in pH was significant for the treatment, C4. N release in distilled water revealed marked differences among the treatments. Urea exhibited significantly elevated N release on first day compared to BUC treatments, whereas T9 and T4 initially showed substantially lower values, which gradually increased, reaching significantly higher levels by day 30. The soil incubation study demonstrated that urea exhibited significantly higher values of ammoniacal and nitrate N release on the 7th day, reaching their maximum by 14 days and then decreased gradually till 30 days. All other BUC treatments showed significantly lower release of ammonia into the soil, followed by a gradual increase, reaching a maximum at 90 days. Leaching of ammoniacal and nitrate N was maximum in the urea treatment on day 8 and lower in BUC treatments. Significantly lower nitrate N leaching values were recorded by T9 towards the end of the experiment.

Conclusion: T9 showed initial release of nutrients at significantly lower rates. Furthermore, it had a significantly higher pH compared to other treatments, rendering its suitability for acidic soil.

Key words: Biopolymer; urea; nitrogen; coconut shell charcoal; rice husk biochar; gypsum; zeolite

1. INTRODUCTION

Urea, containing 46% nitrogen (N), is the most widely used nitrogenous fertilizer globally due to its high nutrient concentration and affordability, with India alone consuming 35 million tonnes annually (FI,

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2023). The ~~nitrogen~~ N use efficiency of urea is between 30 and 50%, with 2-20% loss through volatilization, 15-25% reacting with organic matter in the soil, and 2-10% leaching into water sources (Versino *et al*., 2019). These ~~nitrogen~~ N losses lead to reduced yield, economic setbacks and environmental risks. The rapid ~~nitrogen~~ N release from conventional urea can be addressed through controlled and slow-release mechanisms, which ensure a steady nutrient supply to crops, improving efficiency and promoting healthy crop growth. This is achieved by coating urea with materials that reduce its solubility in water, slowing its release into the soil. These coatings physically form a barrier during dissolution and control the nitrogen release rate (Guo *et al*., 2005).

Various processes and procedures have been used to coat fertilisers to make them available to crops for a longer period. The coating materials can be split into two major types: inorganic mineral and organic polymer (Zou *et al*., 2009). Most of these polymers are not immediately biodegradable following total nutrient release, which provides a new source of soil contamination by causing an undesired accumulation of plastic residues up to 50 kg/ha/year (Trenkel, 1997). Biopolymers are a sustainable alternative to synthetic polymers for encapsulating agrochemicals (Fertahi *et al*., 2021).

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Many coatings have properties between hydrophobic and hydrophilic, allowing water to penetrate and release nitrogen gradually while preventing rapid nutrient loss due to their water-repellent nature (Meisen and Choi, 1997; Chen *et al*., 2010). Coating of prilled urea lowers the nitrogen release rate and makes the fertilizer more environment friendly. The physical properties of coating materials play a key role in regulating nutrient release (Babadi *et al*., 2014). A fertilizer containing a mixture of biochar and urea had the hydrophobic surfaces of the biochar, which prevented the movement of water in part and delayed the rate of ~~nitrogen~~ N release (Zhong *et al*., 2017). When zeolite coated urea was applied to spodosol and alfisol soils, a decrease in NH_3 volatilisation was observed by 47% and 32%, respectively, as compared to urea fertiliser (Ahmad *et al*., 2021). The dissolving rate of fluidized bed coating with phosphogypsum results revealed that coating reduces the dissolution rate, which is directly connected to ~~nitrogen~~ N use efficiency, resulting in coated urea with a high moisture holding capacity (Vashishtha *et al*., 2010). Polyurethane based on castor oil had better wetting characteristics on the urea surface and therefore longer release time (Bortoletto-Santos *et al*., 2020). Considering these aspects, this experiment was carried out to develop an effective bio-polymer urea composite for northern coastal sandy soils of Kerala. The materials used, methodologies followed, findings gained, and future studies are described here.

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2. MATERIALS AND METHODS

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2.1 Soil

The soil sample (0-15 cm) for the present study was collected from the experimental field of College of Agriculture, Padannakkad, Kasaragod, Kerala which was sandy belonging to the soil order, Entisol. The soil sample was air dried in shade, ground to pass through a 2 mm sieve and stored in plastic bags at room temperature for incubation study.

2.2 Formulation of Biopolymer Urea Composites

Biopolymer urea composites (BUCs) were formulated in pellet form. The raw materials used in the synthesis were coconut shell charcoal, gypsum, rice husk biochar and zeolite as coating materials and potato starch and tapioca starch as binding materials. All these materials were available from commercial sources. Coating and binding materials were mixed in different ratios (25, 50, 75% w/w) and tested for the consistency of the products. Accordingly, the best ratio (75% coating material and 25% binding material) for each mixture was used for coating on prilled urea in 1:1 ratio. The physical composition of the formulations is described in Table 1. After formulation, castor oil was sprayed uniformly on the products. Nitrogen content of the formulations were analysed using standard procedures (Single acid digestion followed by distillation).

Table 1. The physical composition of biopolymer urea composites

Biopolymer urea composite (BUC) (1:1 ~~urea:coating~~urea: coating mixture)	Coating material (C) (75% w/w coating mixture)	Binding material/ Starch (S) (25% w/w coating mixture)
BUC 1 (C1S1)	Coconut shell charcoal	Potato starch
BUC 2 (C1S2)	Coconut shell charcoal	Tapioca starch
BUC 3 (C2S1)	Gypsum	Potato starch
BUC 4 (C2S2)	Gypsum	Tapioca starch
BUC 5 (C3S1)	Rice husk biochar	Potato starch
BUC 6 (C3S2)	Rice husk biochar	Tapioca starch
BUC 7 (C4S1)	Zeolite	Potato starch
BUC 8 (C4S2)	Zeolite	Tapioca starch

2.3 Release Behaviour of N from BUCs in Soil

An incubation study was conducted under laboratory conditions for 90 days to test the nutrient release pattern of different BUCs. The experiment was laid out in a completely randomized design (CRD) with 10 treatments replicated thrice. The ten treatments for this experiment included T1: Urea (control), the eight urea composites (BUC 1 to BUC 8), respectively from T2 to T9 and T10: blank (soil without fertilizer). Three replications were carried out for each treatment. Each pot was filled with 5 kg soil. Urea and its composites were added ~~@~~ rate ~~200~~of 200 mg N kg^{-1} of soil per pot at a depth of 10 cm and incubated for 90 days at room temperature and field capacity moisture level. Soil samples were drawn 7, 14, 30, 45, 60, 75, and 90 days after incubation and analysed for the availability of nitrate and ammoniacal nitrogen with the Kjeldahl distillation in the presence of Devarda alloy.

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2.4 Release Behavior of N from BUCs in Distilled Water

200 mg of nitrogen-containing fertilizer samples were accurately weighed, transferred into cotton bags, and placed in plastic bottles containing 250 mL distilled water. The nine treatments for this experiment included T1: Urea (control) and the eight urea composites (BUC 1 to BUC 8), respectively from T2 to T9. Three replications were carried out for each treatment. Total N content (%) in aqueous solution was determined following Kjeldahl method at 1, 7, 10, 14 and 30 days after the addition of fertilisers, from which the N release curve for different composites including conventional prilled urea (control) were obtained.

2.5 Leaching Behaviour of BUCs in Soil Column

The leaching studies were carried out using PVC tubes of 50 cm length and 6 cm diameter and filled with 1200 g soil ~~upto~~up to 30 cm height. One end of the column was sealed by a cotton cloth so that all drained water could come out through it. The tube was connected to a flexible plastic bottle of 10 cm length. The ten treatments for this experiment included T1: Urea (control), the eight urea composites (BUC 1 to BUC 8), respectively from T2 to T9 and T10: blank (soil without fertilizer). Three replications were carried out for each treatment. Fertiliser was applied at the rate of 200 mg N kg^{-1} soil. The columns were covered using a steel cap. The soil columns were fixed vertically on a wall. 100 ml of water was poured into the column periodically and leachate was collected at 8, 15, 22, and 29 days for ammoniacal-N and Nitrate -N estimation.

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2.6 Statistical Analysis

The statistical analysis was done as per standard ANOVA of CRD. The values of ammoniacal ~~nitrogen~~ N (NH_4^+ - N) and nitrate ~~nitrogen~~ N (NO_3^- - N) of blank treatments were deducted from the corresponding values of BUCs and control treatments for soil column and incubation studies.

3. RESULTS AND DISCUSSION

3.1. Total Nitrogen (%) and pH of BUCs

The total N content (%) of BUCs did not vary significantly by the effect of either the coating material, the binding material or their interaction as shown in Table 2.

The treatments had significant effect on the pH of urea composites (Table 2) with C4 recorded the highest pH (9.698), followed by C3 (8.738), while C1 (8.182) and C2 (7.905) showed lower pH values. In contrast, the type of binding material (starch) did not have a significant effect on pH. The interaction of binding material and coating material had no significant effect on the pH. These results imply that while the binding material has little effect on changing the pH, the coating material is crucial for affecting pH. The pH of rice husk biochar is typically alkaline, ranging from 7.1 to 10.5 while the zeolite aqueous solution is found to be in the alkaline area (10.0–10.5) (Khaleque *et al*., 2020). Numerous studies have evaluated the pH of gypsum solutions, which frequently range from neutral to slightly acidic.

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3.2 Release Pattern of Nitrogen from BUCs in Distilled Water

The data on the release pattern of N from BUCs in distilled water given in Table 3 revealed varying N content (in ppm) across different treatments over time. Treatment T1 exhibited the highest ~~nitrogen~~ N release on the first day itself. T9 began with 149.33 ppm on day 1 and gradually increased to 636.67 ppm by day 30, demonstrating a steady and consistent release of N over the entire period. This slow and sustained release profile makes T9 particularly suitable as a slow-release fertilizer. In comparison, treatment T1, although releasing the highest N content (644.67 ppm) by day 30, showed a faster release pattern, which might not be ideal for long-term nutrient supply. Treatments such as T2, T3, and T4 showed moderate N release, but T9's gradual increase in N content from 149.33 ppm to 636.67 ppm over 30 days suggests a more controlled and sustained release. Other treatments like T5, T6, T7, and T8 displayed varying release patterns, but none matched the slow, steady release observed in T9 (Fig. 1). For crops with long development periods or those that need a balanced nutrient availability to prevent peaks and deficits, this slow-release profile is perfect for sustaining a steady nutrient supply throughout the period.

3.3 Release Pattern of NH_4^+-N (mg/kg) from BUCs in Soil

The data presented in Table 4 shows the release pattern of ammoniacal N (NH_4^+-N) from BUCs in soil over 90 days. Treatment T1 exhibited the highest NH_4^+-N content at all time points, starting with 42.34 mg/kg on day 7, peaking at 56.97 mg/kg on day 14, and then gradually decreasing to 12.84 mg/kg by day 90. This suggests a rapid initial release of ammoniacal N followed by a steady decline over time. Treatments T2, T6, and T7 displayed lower initial release, with T2 starting at 13.57 mg/kg and reaching 36.11 mg/kg by day 90, indicating a slower release pattern compared to T1. Treatment T6 started with 16.34 mg/kg on day 7, gradually declining to 36.64 mg/kg by day 90, while T7 exhibited a similar trend, starting at 16.90 mg/kg and reaching 35.31 mg/kg by day 90. Treatment T3 and T4 showed moderate levels of NH_4^+-N release. T3 started at 25.52 mg/kg on day 7 and peaked at 44.31 mg/kg by day 90, while T4 began with 25.97 mg/kg and ended with 45.87 mg/kg, indicating a steady release of ~~nitrogen~~ N throughout the period of 90 days. Treatments T5, T8, and T9 showed relatively lower initial releases, with T5 starting at 11.00 mg/kg and T9 starting at 8.67 mg/kg, both increasing gradually and maintaining a moderate level of NH_4^+-N over time. Treatment T8 had a slightly higher initial release, starting at 12.37 mg/kg, and maintained a steady release, reaching 42.01 mg/kg by day 90.T1 showed the fastest release with a peak at day 14, while treatments like T2, T5, and T7 had slower release patterns. Treatments T3, T4, T8, and T9 demonstrated more balanced, sustained release over the 90 days, with T3 and T4 showing the highest levels of NH_4^+-N at the end of the study (Fig. 2). These treatments may be less successful for crops with longer nutrient demands but more appropriate for crops with intermediate nutrient uptake times. Zeolite is a good choice for slow-release fertilisers because of its special qualities, which include porosity and cation exchange capacity, which improve its potential to regulate ~~nitrogen~~ N release. Zeolite's porosity and cation exchange ability improve nutrient retention, resulting in longer nutrient release and less leaching (Soltys *et al*., 2020).

3.4 Release Pattern of NO_3^- - N (mg/kg) from BUCs in Soil

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The result presented in Table 5 shows the release pattern of nitrate N (NO_3^--N) from BUCs in soil over 90 days. Treatment T1 exhibited the highest initial NO_3^--N release, with 19.90 mg/kg on day 7, reaching a peak of 31.74 mg/kg on day 14, before gradually decreasing to 3.80 mg/kg by day 90. This indicates a rapid release of NO_3^--N at the beginning, followed by a steady decline over time. Such a release profile may result in early nutrient surpluses, followed by deficiencies in later growth stages, making it less suitable for crops with extended nutrient requirements. Treatments T2, T3, and T5 demonstrated relatively consistent release patterns, with T2 starting at 9.33 mg/kg on day 7, peaking at 34.67 mg/kg on day 45, and then decreasing to 26.77 mg/kg by day 90. T3 followed a similar trend, starting at 2.73 mg/kg on day 7, peaking at 41.07 mg/kg on day 75, and ending at 36.34 mg/kg on day 90. T5 showed a moderate release pattern, with 7.73 mg/kg on day 7, peaking at 34.90 mg/kg on day 75, and ending at 34.97 mg/kg by day 90. Treatment T4 showed the lowest initial release at 0.97 mg/kg on day 7, with a peak at 23.43 mg/kg on day 45, and a decrease to 31.24 mg/kg by day 90, indicating a slower and more steady release of NO_3^--N. Treatments T6, T7, and T8 had varied release profiles, with T6 starting at 11.50 mg/kg and increasing to 39.00 mg/kg by day 75, and T7 starting low at 1.67 mg/kg, peaking at 32.47 mg/kg on day 75. Treatment T8 showed a relatively moderate release, starting at 10.10 mg/kg on day 7 and reaching 31.74 mg/kg by day 90. Treatment T9 showed a low initial release of 1.10 mg/kg on day 7, peaking at 39.14 mg/kg on day 75, and ending at 33.84 mg/kg on day 90 (Fig. 3). When compared to uncoated urea, zeolite-coated urea with acrylic polymer binder displayed a ~~nitrogen~~ N release control of 54.7% over 30 days, notably lowering ~~nitrogen~~ N leaching by 65% (Dubey and Mailapalli, 2019).

3.5 Leaching Pattern of NH_4^+ - N (mg/L) from BUCs in Soil Column

The leaching pattern of ammoniacal N (NH_4^+-N) from BUCs in the soil column varied across treatments and time (Table 6). On day 8, T1 showed the highest leaching (26.71 mg/L), indicating rapid release, while T8 had the lowest (1.34 mg/L), suggesting strong retention. By day 15, T2, T3, T5, and T7 exhibited peak leaching values between 28.27 and 29.59 mg/L, whereas T1 and T4 showed more controlled release. On day 22, T9 recorded the highest leaching (33.04 mg/L), reflecting its peak release phase, while T1 and T5 had the lowest leaching (14.21 and 14.82 mg/L, respectively). By day 29, T9 maintained the highest leaching (28.93 mg/L), indicating sustained release, while T1 exhibited minimal loss (2.77 mg/L). Overall, T9 demonstrated an effective slow-release profile, balancing early retention with sustained nutrient availability, making it the most promising treatment for controlled N release (Fig. 4). The delayed peak in ~~nitrogen~~ N leaching indicates the effectiveness of the coating in regulating the release rate, reducing the risk of early nutrient losses through leaching. According to the study, BUCs exhibit a noticeably reduced early ~~nitrogen~~ N release and a progressive nutritional release when compared to urea. Guo *et al.* (2005) obtained similar results with superabsorbent and slow-release urea formaldehyde.

3.6 Leaching Pattern of NO_3^- - N (mg/L) from BUCs in Soil Column

The leaching pattern of nitrate N (NO_3^--N) from BUCs in the soil column exhibited significant variation across the treatments and sampling days (Table 7). On day 8, T1 showed the highest leaching (4.40

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mg/L), indicating faster nitrate release, while T9 demonstrated the lowest (0.63 mg/L), reflecting effective nitrate retention. By day 15, T1 continued to have the highest leaching (4.18 mg/L), whereas T2, T3, and T9 displayed minimal values (0.09–0.43 mg/L). On day 22, T2 peaked at 7.16 mg/L, highlighting a delayed release, while T9 maintained a controlled release at 2.86 mg/L. By day 29, T7 recorded the highest leaching (6.71 mg/L), indicating a prolonged release phase, whereas T9 remained the most controlled with only 2.61 mg/L. Overall, T9 consistently exhibited the lowest nitrate leaching across all time points, making it the most effective treatment for minimizing nitrate loss through leaching. The low leaching levels highlight the potential of T9 to mitigate environmental risks such as groundwater contamination and eutrophication. In contrast, urea treatment (T1) showed relatively high nitrate N leaching levels initially, peaking at 4.40 mg/L on day 8 and maintaining higher levels through day 29 (Fig. 5). This rapid release may lead to significant nitrogen losses early in the crop cycle, reducing long-term nutrient availability and increasing environmental risks. In a soil column leaching investigation, urea combined with clinoptilolite zeolite reduces leaching losses and exhibits better control over NH_4^+ and nitrate (NO_3^-) release than normal urea (Omar *et al.*, 2015).

4. CONCLUSIONS

For increasing the nitrogen (N) use efficiency of urea, it can be coated or mixed with various materials of organic and inorganic nature. Even though the synthetic polymers can contribute well in the controlled release of N from urea, it is questionable whether any of these materials is environmental friendly. Four different organic coating materials and two different natural starch polymers were mixed with urea in different compositions to test the efficacy of formulations (Fig. 6) in releasing N and the statistical analysis of data proved that the treatment, T9 (Zeolite as the coating material and Tapioca starch as the binding material) demonstrated an initial release of significantly lower values, gradually attaining a maximum in both distilled water and soil. Furthermore, it had a significantly higher pH compared to other treatments, rendering its suitability in coastal saline acid soil of Kerala.

COMPETING INTERESTS

We, the authors declare that no competing interests exist.

AUTHORS' CONTRIBUTIONS:

Mohammed Midlaj, C. P.: Conduct of experiment, data collection, analysis and preparation of manuscript

Jinsy, V. S.: Idea conception, implementation of the research

Sumesh, K. V., N. Manikandan, Sajitha Rani T. and Nideesh P.: Reviewing and editing of manuscript

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Table 2. Effect of treatments and their interaction on total nitrogen content (%) and pH of biopolymer urea composites

Treatments	N (%)	pH
Coating material (C)		
C1	14.155	8.182[c]
C2	14.123	7.905 [d]
C3	14.307	8.738 [b]
C4	14.417	9.698 [a]
SEm (+)	0.40	0.04
CD (*P=0.05*)	NS	0.117
Binding material/ Starch (S)		
S1	14.248	8.653
S2	14.253	8.608
SEm (+)	0.28	0.03
CD (*P=0.05*)	NS	NS
Interaction (C x S)		
C1S1	14.310	8.183
C1S2	14.000	8.180
C2S1	14.100	7.957
C2S2	14.147	7.853
C3S1	14.147	8.760
C3S2	14.467	8.717
C4S1	14.433	9.713
C4S2	14.400	9.68

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SEm (±)	0.56	0.05
CD (*P=0.05*)	NS	NS

~~**Table 2. Effect of treatments and their interaction on total nitrogen content (%) and pH of biopolymer urea composites**~~

Table 3. Effect of treatments on release pattern of N from BUCs in distilled water (total N (ppm) in aqueous solution)

Treatment	Day 1	Day 7	Day 10	Day 14	Day 30
T1 (Urea)	492.667^{a}	565.67 ^{a}	614.67 ^{a}	630.67 ^{a}	644.67 ^{a}
T2 (BUC 1)	204.00^{c}	276.33 ^{c}	376.33 ^{bcd}	460.33 ^{bcd}	582.00 ^{abc}
T3 (BUC 2)	156.33^{cd}	201.00 ^{d}	336.67 ^{cd}	420.00 ^{cde}	487.00 ^{d}
T4 (BUC 3)	179.33 ^{cd}	208.33 ^{d}	294.00 ^{d}	364.00 ^{e}	582.00 ^{abc}
T5 (BUC 4)	135.33^{d}	176.00 ^{d}	349.67 ^{bcd}	508.67 ^{b}	538.67 ^{bcd}
T6 (BUC 5)	328.33 ^{b}	391.00 ^{b}	411.67 ^{bc}	481.67 ^{bcd}	518.00 ^{cd}
T7 (BUC 6)	374.67 ^{b}	406.00 ^{b}	424.33 ^{b}	494.33 ^{b}	601.67 ^{ab}
T8 (BUC 7)	195.67 ^{c}	224.00 ^{cd}	327.00 ^{d}	487.67 ^{bc}	599.00 ^{ab}
T9 (BUC 8)	149.33 ^{cd}	176.00 ^{d}	318.33 ^{d}	416.33 ^{de}	636.67 ^{a}
SEm (±)	19.25	22.73	28.28	22.88	25.99
CD (*P=0.05*)	57.196	67.545	84.036	67.966	77.213

Table 4. Effect of treatments on release pattern of NH_4^+ - N (mg/kg) from BUCs in soil

Treatment	Day 7	Day 14	Day 30	Day 45	Day 60	Day 75	Day 90
T1 (Urea)	42.3374[a]	56.97 [a]	45.10 [a]	33.90 [a]	32.80 [ab]	23.71 [c]	12.84 [d]
T2 (BUC 1)	13.57 [cde]	16.30 [b]	11.27[cde]	20.77 [d]	35.23 [a]	33.67 [b]	36.11 [c]
T3 (BUC 2)	25.517 [b]	16.18 [b]	12.47 [cde]	23.34 [bcd]	28.70 [cd]	41.24 [a]	44.31[a]
T4 (BUC 3)	25.97 [b]	14.13 [b]	13.07 [cd]	23.34 [bcd]	28.97 [cd]	42.51 [a]	45.87 [a]
T5 (BUC 4)	11.00 [de]	15.17 [b]	10.47 [cde]	23.40 [bcd]	27.30 [de]	41.27 [a]	42.71 [a]
T6 (BUC 5)	16.34 [cd]	8.23 [c]	8.93 [e]	21.94 [cd]	24.10 [e]	33.14 [b]	36.64 [bc]
T7 (BUC 6)	16.90 [c]	4.77 [d]	9.07 [de]	21.34 [cd]	26.47 [de]	33.34 [b]	35.31 [c]
T8 (BUC 7)	12.37 [cde]	7.80 [c]	17.60 [b]	27.27 [b]	31.33 [bc]	41.64[a]	42.01 [a]
T9 (BUC 8)	8.67 [e]	8.37 [c]	13.97 [bc]	25.34 [bc]	31.67 [bc]	41.81 [a]	41.94 [ab]
SEm (±)	1.83	0.84	1.36	1.48	1.18	1.63	1.79
CD (*P=0.05*)	5.427	2.506	4.054	4.404	3.513	4.842	5.313

Table 5. Effect of treatments on release pattern of NO_3^- - N (mg/kg) from BUCs in soil

Treatment	Day 7	Day 14	Day 30	Day 45	Day 60	Day 75	Day 90
T1 (Urea)	19.90 ^{a}	31.74 ^{a}	18.57 ^{a}	16.50 ^{cd}	10.94 ^{c}	7.30 ^{e}	3.80 ^{e}
T2 (BUC 1)	9.33 ^{bc}	18.54 ^{b}	18.51 ^{a}	34.67 ^{a}	21.84 ^{b}	31.70 ^{cd}	26.77 ^{d}
T3 (BUC 2)	2.73 ^{d}	13.41 ^{c}	13.91 ^{b}	24.53 ^{b}	22.34 ^{b}	41.07 ^{a}	36.34 ^{ab}
T4 (BUC 3)	0.97 ^{d}	8.24 ^{d}	12.74 ^{b}	23.43 ^{b}	19.27 ^{b}	29.34 ^{d}	31.24 ^{c}
T5 (BUC 4)	7.73 ^{c}	11.24 ^{cd}	14.64 ^{b}	25.70 ^{b}	21.30 ^{b}	34.90 ^{bc}	34.97 ^{abc}
T6 (BUC 5)	11.50 ^{b}	0.47 ^{e}	14.07 ^{b}	23.63 ^{b}	29.27 ^{a}	39.00 ^{ab}	38.94 ^{a}
T7 (BUC 6)	1.67 ^{d}	0.47 ^{e}	6.07 ^{c}	18.80 ^{c}	21.90 ^{b}	32.47 ^{cd}	34.17 ^{bc}
T8 (BUC 7)	10.10 ^{bc}	7.61 ^{d}	6.34 ^{c}	14.50 ^{d}	18.00 ^{b}	30.57 ^{cd}	31.74 ^{c}
T9 (BUC 8)	1.10 ^{d}	7.77 ^{d}	11.67 ^{b}	23.40 ^{b}	29.14 ^{a}	39.14 ^{ab}	33.84 ^{bc}
SEm (±)	1.20	1.56	1.08	1.36	1.65	1.57	1.37
CD (*P=0.05*)	3.557	4.621	3.195	4.031	4.897	4.664	4.059

Table 6. Effect of treatments on ~~leaching~~leaching pattern of NH_4^+ - N (mg/L) from BUCs in soil column

Treatment	Day 8	Day 15	Day 22	Day 29
T1 (Urea)	26.71 ^{a}	12.34 ^{d}	14.21 ^{e}	2.77 ^{e}
T2 (BUC 1)	9.58 ^{b}	28.27 ^{a}	20.84 ^{c}	25.82 ^{abc}
T3 (BUC 2)	2.51 ^{d}	28.64 ^{a}	24.87 ^{b}	22.33 ^{cd}
T4 (BUC 3)	5.14 ^{c}	13.00 ^{d}	24.91 ^{b}	21.93 ^{d}
T5 (BUC 4)	6.04 ^{c}	29.50 ^{a}	14.82 ^{e}	26.43 ^{ab}
T6 (BUC 5)	5.41 ^{c}	23.17 ^{b}	19.93 ^{cd}	21.37 ^{d}
T7 (BUC 6)	2.26 ^{de}	29.59 ^{a}	17.34 ^{de}	24.90 ^{bcd}
T8 (BUC 7)	1.34 ^{e}	16.47 ^{c}	16.74 ^{e}	24.13 ^{bcd}
T9 (BUC 8)	2.13 ^{de}	21.17 ^{b}	33.04 ^{a}	28.93 ^{a}
SEm (±)	0.37	0.99	1.07	1.23
CD (*P=0.05*)	1.086	2.95	3.178	3.654

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Treatment	Day 8	Day 15	Day 22	Day 29
T1 (Urea)	4.40 [a]	4.18 [a]	4.19 [bc]	2.71 [c]
T2 (BUC 1)	3.70 [ab]	0.09 [e]	7.16 [a]	5.57 [ab]
T3 (BUC 2)	2.63 [c]	0.32 [e]	3.99 [bc]	5.00 [ab]
T4 (BUC 3)	1.77 [d]	3.02 [b]	4.94 [b]	4.33 [bc]
T5 (BUC 4)	3.40 [b]	0.95 [cd]	4.06 [bc]	3.89 [bc]
T6 (BUC 5)	3.67 [ab]	1.48 [c]	2.13 [d]	4.52 [bc]
T7 (BUC 6)	1.47 [d]	0.29 [e]	3.39 [bcd]	6.71 [a]
T8 (BUC 7)	1.50 [d]	1.12 [c]	3.61 [bcd]	5.51 [ab]
T9 (BUC 8)	0.63 [e]	0.43 [de]	2.86 [cd]	2.61 [c]
SEm (+)	0.26	0.19	0.55	0.73
CD (*P=0.05*)	0.757	0.574	1.63	2.165

~~**Table 7. Effect of treatments on leaching pattern of NO_3^- - N (mg/L) from BUCs in soil column**~~

Table 7. Effect of treatments on leaching pattern of NO_3^- - N (mg/L) from BUCs in soil column

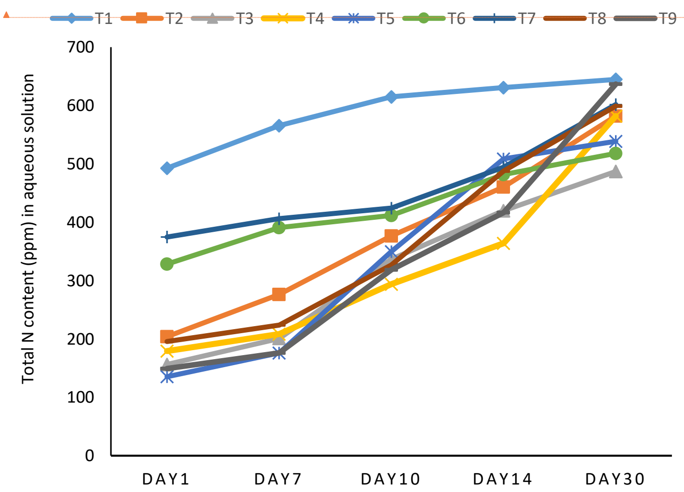

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Fig. 1 Total N content (ppm) in aqueous solution

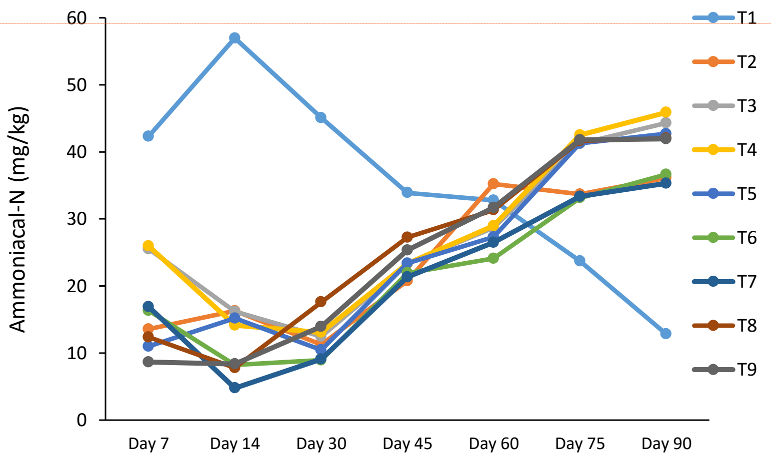

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Fig. 2 Release pattern of NH_4^+ - N (mg/kg) from BUCs in soil

~~**Fig. 2 Release pattern of NH_4^+ - N (mg/kg) from BUCs in soil**~~

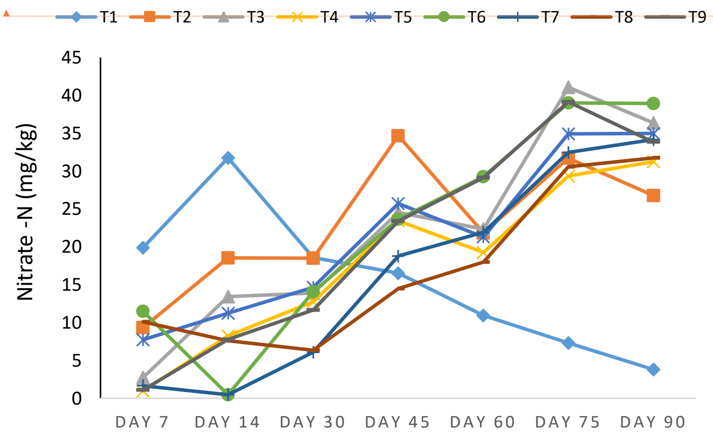

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Fig. 3 Release pattern of NO_3^- - N from BUCs in soil

Fig. 3 Release pattern of NO_3^- - N from BUCs in soil

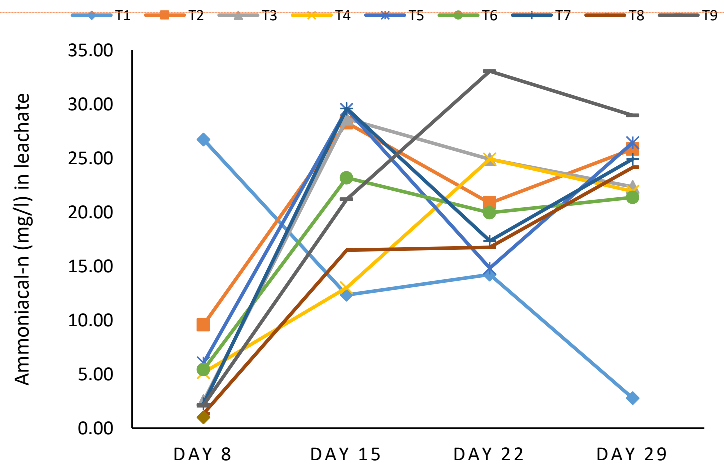

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Fig. 4 Leaching pattern of NH_4^+ - N (mg/L) from BUCs in soil column

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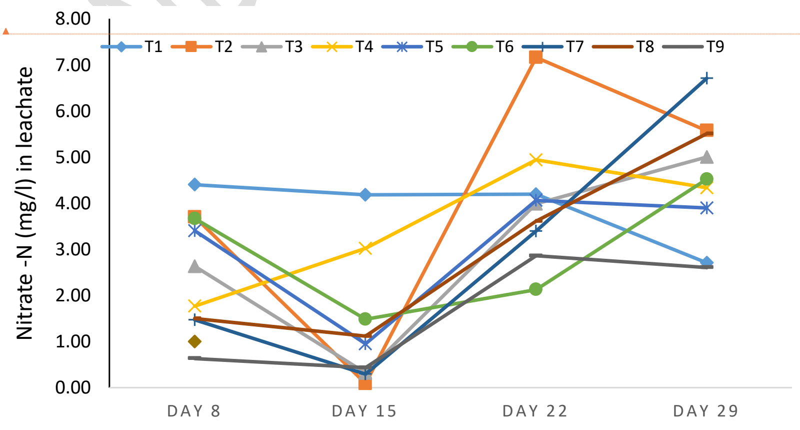

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Fig. 5 Leaching pattern of NO_3^- - N (mg/L) from BUCs in soil column

Fig. 6 Biopolymer urea composites

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