Comparative effect of various organic extracts coated urea fertilizer on the release pattern of Ammonium and Nitrate in the soil at different time intervals

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Abstract

Nitrogen (N) fertilizer application is a very important commodity in agricultural systems. However, due to the losses of applied N from the soil microenvironment its efficiency is too low. Different strategies like the use of polymer coating and use of chemical nitrification inhibitors had been employed to reduce N losses. But these chemical nitrification inhibitors are very expensive. Thus, a study was conducted to investigate the effects of different concentrations of parthenium extract, neem oil and acidulated cow dung compost extract on N dynamics in the soil. Three concentrations of parthenium extract (5, 10 and 15 %) and neem oil (1, 2 and 3 %) were coated on urea granules after mixing with the polymer material. Three pH (2, 4 & 6 pH) based acidulated cow dung compost extracts were also coated on urea granules in the same pattern. These coated fertilizers and uncoated urea were applied in jars filled with soil (100g per jar) at the rate of 1g of fertilizer per jar. One treatment was kept as control (without any fertilizer). Treatments along three replications were arranged according to the completely randomized design (CRD). Results depicted that all coating materials caused the release of N consistently from applied fertilizers compared to uncoated treatment. In addition, percent nitrified N was also reduced significantly in coated treatments in comparison to the uncoated urea and control treatments. However, the level of concentration effect was not obvious as lower concentrations of these extracts and oil also performed almost equal to that of higher concentrations.

Introduction

The increasing population demands healthy food with more production of crops for which plant nutrients are vitally essential. Chemical-based inorganic fertilizers are of prime importance under soil management strategies to enhance the quality and quantity of agricultural outputs (Itelima et al. 2018). Nitrogen (N) plays an important role in plant growth and development as a prime mineral nutrient. Higher plants require large amounts of N for physiological and biochemical processes that lead to a higher quality of produce and increased yield. Low organic matter contents and several other factors are responsible for the deficiency of N in Pakistani soils. According to an estimate, 78–79 % N is present in the atmosphere but it is in an inert structure. Thus, technical nutrient management practices are required (Leghari et al. 2016; Zhang et al. 2021). In modern agriculture, large amounts of N fertilizers are applied for higher production, but less than 50 % of these applied fertilizers are utilized by the crops (Zhang et al. 2020). Recently, different strategies had been employed to enhance the efficiency of N fertilizers (Gagnon and Zaidi 2010). Urea is the ammoniacal fertilizer that is the cheapest and easily available N fertilizer (Nehring 2013). The manufacturing, storage, transport, distribution and handling of urea is also easier than other N fertilizers (Hauk 1984).

However quick hydrolysis of urea releases plant-available forms of N in the soil suddenly after exposure to moisture in the presence of the urease enzyme. Firstly, NH_4^+ is formed which is a plant available form and immobile in the soil (Lei et al. 2018). Excessive application of N fertilizer at an early stage of the plant induces low use efficiency of applied fertilizer because this excess fertilizer got lost via volatilization, nitrification, denitrification and runoff (Jain and Abrol 2017; Anas et al. 2020). To reduce such losses different strategies had been employed like the 4-R strategy (i.e. considering right source, right rate, right time and right place for fertilizer application), split application of urea and controlled-release urea (Tao et al. 2018; Freedman 2018; Yaseen et al. 2016; Noor et al. 2017). Biodegradable polymer coated urea slows the release kinetics of available forms of N in the soil (Beig et al. 2020). Thus slow-release N fertilizers are very crucial to reduce the losses of N to the environment and groundwater. But N released in the form of NH_4^+ in the soil got converted to the nitrate form via nitrification process if not up-taken by the plants or lost to the atmosphere via volatilization (Sahrawat 2008; Lasisi et al. 2019). During the process of nitrification and subsequent denitrification, nitrous oxide gas got escaped to the atmosphere, in addition to the nitrate leaching, thus nitrification is a less desirable process (Wrage et al. 2001).

To overcome the nitrification losses from agricultural activities different nitrification inhibitors had been used in recent years (Byrne et al. 2020). But commercial nitrification inhibitors are much expensive for small farmers (Hatano et al. 2019). On the other hand, organic extracts and oils are much cost-effective and good nitrification inhibitors in comparison to commercial nitrification inhibitors. As neem oil reduced nitrification losses more effectively than the lower dose of Dicyandiamide (Opoku et al. 2014). *Parthenium hysterophorus* is a well-known invasive weed with plenty of negative roles as agricultural, medicinal and environmental hazards (Kaur et al. 2014). In addition to its other roles, its plant extract is a very good nitrification inhibitor (Mahmood et al. 2014). Kanchan and Jayachandra (1981) also showed that root and leaf extract of *Parthenium hysterophorus* effectively reduced the *Nitrosomonas* and *Nitrobacter* population in the soil resulting in inhibited nitrite production. Low pH also contributes to the inhibition of the nitrification process (Rose et al. 2020). Thus based on these studies, it is clear that coating of organic extracts mixed with the polymer on urea could be beneficial for N management. In this way, an additional benefit of optimization of organic extracts will also be achieved. Thus, it was hypothesized that polymer mixed neem oil, parthenium extract and acidulated cow dung extract may reduce the nitrification losses of nitrogen in addition to slow release of available N from urea fertilizer. So, in the present study effect of polymer mixed neem oil, parthenium extract and acidulated cow dung extract coated urea is compared with the uncoated urea for N release, NH_4^+ and NO_3^- concentrations in the soil and percent nitrified N at different time intervals.

Materials And Methods

A laboratory experiment was performed at Soil Fertility and Plant Nutrition Laboratory (SFPNL), Institute of Soil and Environmental Sciences (ISES), University of Agriculture, Faisalabad (UAF) to investigate the comparative effect of neem oil, parthenium extract and cow dung extract coated urea on nitrification potential and N release kinetics. Three replications of each treatment were designed according to the completely randomized design (CRD). The treatment plan was consisted of:

a. Three concentrations of neem oil (1, 2 and 3 %)
b. Three concentrations of parthenium extract (5, 10 and 15 %)

c. Three pH based cow dung extracts (2 pH, 4 pH and 6 pH)
d. Positive control (uncoated urea)
e. Negative control (without fertilizer)

Urea coating with parthenium extract, neem oil and acidulated cow dung extracts was carried out in Soil Fertility and Plant Nutrition Laboratory (SFPNL), Institute of Soil and Environmental Sciences (ISES), UAF. Neem oil was extracted by using a solvent extraction method (Puri 1999), while parthenium extract was collected by following Anteneh and Mendesil method (Netsere and Mendesil 2011). A 10 % Cow dung manure (with different pH) extract was collected from the Soil and Environmental Microbiology Laboratory, ISES, UAF. Oil and organic extracts were coated on urea granules with polymer as a binding agent. To avoid any contamination, controlled Laboratory conditions were maintained for all activities. Shade drying of coated urea was done and stored at room temperature (25°C).

The experiment was conducted in the incubator by using disposable cups (250 cm^3), and each cup was filled with 100 g soil after determining the physicochemical properties of the soil (Table 1). In all the cups field capacity was maintained after saturation percentage measurement. Urea fertilizer was added in cups at the rate of 1g in each cup (having 460 mg N). After the addition of soil, fertilizer and water, the weight of cups was maintained at an interval of 24 h with distilled water. The whole experiment was carried out at 25 ± 1°C and NH_4^+ and NO_3^- were measured after 20, 40 and 60 days of incubation through the indophenol blue method and phenoldisulphonic acid method respectively (Keeney and Nelson 1989). Sum of NH_4^+ and $NO_3^-$was taken to determine cumulative nitrogen (N), while nitrate to ammonium ratio, percent nitrified N and N release efficiency (Tong et al. 2018) were calculated by using the following formulas:

$$Nitrate\ to\ ammonium\ ratio = \frac{Nitrate\ N\ in\ the\ soil}{Ammonium\ N\ in\ the\ soil}$$

$$Percent\ N\ nitrified = \frac{Nitrate\ N}{Ammonium\ N} * 100$$

$$N\ release\ efficiency\ (\%) = \frac{\text{(Cumulative N in N fertilizer pot – cumulative N in unfertilized pot)}}{\text{Amount of N applied}} * 100$$

Table 1
Pre-analysis of soil for physicochemical properties

Physical properties	Unit	Values
Sand	%	48.03
Silt	%	27.90
Clay	%	24.07
Texture	-	Sandy Loam
Saturation Percentage	%	31
Chemical properties	**Unit**	**Values**
ECe	dSm^{-1}	2.01
pHs	——	7.78
CEC	$cmol_c kg^{-1}$	14.1
Ca^{2+}+ Mg^{2+}	me L^{-1}	9.93
SO_4^{-2}	me L^{-1}	8.65
Cl^{-1}	me L^{-1}	11.69
HCO_3^{-1}	me L^{-1}	2.38
CO_3^{-2}	me L^{-1}	0.29
Organic matter	%	0.68
Soluble Na	me L^{-1}	15.65
Extractable P	mg kg^{-1}	7.20
Soluble K	me L^{-1}	0.03

All collected data were analyzed according to completely randomized design (CRD) with factorial arrangements following Fisher’s analysis of variance (Steel et al. 1997). Mean comparison was done with the Tuckey HSD test.

Results

Ammonium concentration in the soil

Ammonium concentration in the soil was significantly controlled by all three types of extracts used for coating the urea fertilizer (Table 2). Uncoated urea gave the highest concentration of ammonium in the soil at the first interval that was significantly reduced at later intervals. While in the case of coated fertilizers, ammonium concentration showed an opposite trend as ammonium concentration was lower at the first interval, but this release was increased at later intervals. In the case of coated fertilizers, the release was maximum at the second interval in all types of coating materials, even differences were non-significant between organic amendments but in close view Parthenium extract and acidulated cow dung extract showed slightly higher release than neem oil. At the third interval release of ammonium was reduced in comparison to the second interval but still release was significantly higher in coated fertilizers than uncoated fertilizer. Ammonium release was higher at a lower concentration of organic amendments but was reduced with an increase in the concentration.

Table 2
Ammonium concentrations in the soil at 20, 40 and 60 days intervals

Treatment	**NH_4 concentration (mg kg^{-1})**		
	1st interval (20 days)	**2nd interval (40 days)**	**3rd interval (60 days)**
Negative control (without fertilizer)	1.71 N	0.75 N	0.4 N
Positive control (Uncoated fertilizer)	1429.3 B	433.2 L	246.1 M
5 % parthenium extract coated urea	628.7 K	1532 A	1355.8 C
10 % parthenium extract coated urea	629.8 K	1532.6 A	1248.9 D
15 % parthenium extract coated urea	630.9 K	1530.9 A	1090.4 G
1 % neem oil coated urea	629.8 K	1530.4 A	1153.5 E
2 % neem oil coated urea	629.3 K	1529.8 A	1123.9 F
3 % neem oil coated urea	629.3 K	1528.1 A	678.9 J
2 pH acidulated cow dung compost extract coated urea	630.4 K	1528.1 A	1060 H
4 pH acidulated cow dung compost extract coated urea	630.9 K	1532.6 A	948.4 I
6 pH acidulated cow dung compost extract coated urea	623.1 K	1532.6 A	688.4 J

Nitrate concentration in the soil

The uncoated urea showed maximum nitrate concentration at the first interval that was lowered at latter intervals but still higher in comparison to the coated treatments. In coated fertilizer treated jars nitrate concentration was significantly lower in comparison to uncoated urea. At latter intervals, the concentration of nitrate was slightly increased in coated treatments but still lower in comparison to uncoated urea that shows the inhibition of the nitrification process in the soil. Among concentrations of organic amendments lower concentrations shown more reliable results. Among the type of organic amendments, acidulated cow dung extract showed slightly higher nitrate concentration in the soil, while other amendments showed slightly lower concentrations (Table 3).

Table 3
Nitrate concentrations in the soil at 20, 40 and 60 days intervals

Treatment	NO_3 concentration (mg kg^{-1})		
	1st interval (20 days)	2nd interval (40 days)	3rd interval (60 days)
Negative control (without fertilizer)	1 N	0.48 N	0.5 N
Positive control (Uncoated fertilizer)	1176 A	837.5 B	310.5 K
5 % parthenium extract coated urea	272.75 L	383.5 FG	403.5 E
10 % parthenium extract coated urea	374.5 G	349.75 I	405.25 E
15 % parthenium extract coated urea	275.25 L	353.5 HI	477.5 C
1 % neem oil coated urea	273.5 L	371.25 GH	432.75 D
2 % neem oil coated urea	378.25 FG	319.75 JK	403.75 E
3 % neem oil coated urea	302.75 K	396 EF	440.5 D
2 pH acidulated cow dung compost extract coated urea	336 IJ	486 C	402.75 E
4 pH acidulated cow dung compost extract coated urea	339 I	406.75 E	492.5 C
6 pH acidulated cow dung compost extract coated urea	449 D	205.25 M	492 C

Cumulative N concentration in the soil

Table 4 showed that the concentration of cumulative N was significantly lower in the coated treatments in comparison to the uncoated treatment at the first interval. While the release was increased with the passage of time in coated treatments but decreased in uncoated treatment. All organic amendments performed almost equally in N release, though acidulated cow dung extract coated urea showed a slight increase in the N release. At the last interval, N release was decreased in all treatments but the decrease in the release was significantly more in uncoated treatment than coated treatments. It was also observed that lower concentrations of organic extracts gave more trustworthy results as cumulative N release was lower at the first interval but increased at the second interval and this release was more in comparison to higher concentrations, even at third interval release was higher with lower concentrations.

Table 4
Cumulative N concentrations in the soil at 20, 40 and 60 days intervals

Treatment	Cumulative N concentration (mg kg^{-1})		
	1st interval (20 days)	2nd interval (40 days)	3rd interval (60 days)
Negative control (without fertilizer)	2.71 T	1.23 T	0.9 T
Positive control (Uncoated fertilizer)	2605.3 A	1270.7 L	556.6 S
5 % parthenium extract coated urea	901.45 R	1915.5 C-E	1759.3 G
10 % parthenium extract coated urea	1004.3 P	1882.35 EF	1654.15 H
15 % parthenium extract coated urea	906.15 R	1884.4 E	1567.9 I
1 % neem oil coated urea	903.3 R	1901.65 DE	1586.25 I
2 % neem oil coated urea	1007.55 P	1849.55 F	1527.4 J
3 % neem oil coated urea	932.05 R	1924.1 CD	1119.4 N
2 pH acidulated cow dung compost extract coated urea	966.4 Q	2014.1 B	1462.75 K
4 pH acidulated cow dung compost extract coated urea	969.9 Q	1939.35 C	1440.9 K
6 pH acidulated cow dung compost extract coated urea	1072.1 O	1737.85 G	1180.4 M

Nitrate to ammonium ratio

Nitrate to ammonium ratios given in Fig. 1 depicted that nitrate to ammonium ratio was higher in both control treatments. While in organic extracts and oil-coated fertilizer treatments nitrate to ammonium ratios were significantly lower in comparison to treatments without extracts. Though at all intervals nitrate to ammonium ratio was higher in uncoated urea treatment, the highest ratio was observed at the second interval. In coated treatments nitrate to ammonium ratios were higher at the first and last interval in comparison to second intervals. Among extracts, non-significant results were seen between parthenium extract, neem oil and acidulated cow dung extract, though acidulated cow dung showed a slightly higher ratio.

Percent nitrified N (%)

Figure 2 illustrated the percent nitrified N for all treatments at all intervals. These results clearly stated that the nitrification process was significantly reduced with the use of organic extracts coated urea in comparison to treatments not receiving extracts. Though all the extracts performed significantly to lower the nitrification process, the results of parthenium extract were much better. Among the concentrations of these extracts, all concentrations showed significant results, even lower concentrations also performed equally to that of higher concentrations.

N release efficiency (%)

N release efficiency was highest at the first interval for uncoated urea but it was reduced significantly at latter intervals even at 60 days interval its release efficiency was just 12 % (Fig. 3). In the case of coated treatments release efficiency was lower at the first interval but at the second interval, it was increased significantly. At the third interval, a slight decline was seen in N release efficiency by the coated treatments but the release was still much higher than uncoated treatment. Among different types of coating materials, N release efficiency was slightly higher in parthenium extract coated urea than other coating materials.

Discussion

The use of chemical fertilizers is a basic commodity in today's agricultural systems (Yan et al. 2008). Especially nitrogen (N) fertilizers are much important as nitrogen is an essential macronutrient for all plants (Rochester et al. 1994; Dong et al. 2012). But with the addition of N fertilizer in the soil, several problems originate, as much of the applied N is lost via nitrification and subsequent denitrification processes (Cai et al. 2002; Chen et al. 2008; Artola et al. 2010). It is stated in many studies that applied N undergoes several interactions with loss pathways, chemical reactions, soil microbes and plant roots (Shaviv and Mikkelsen 1993). On oxidation, by the nitrifying bacteria, ammonium first converts to nitrite then to nitrate in two consecutive steps. During this process, nitrogen might be lost nitrous oxide or nitrite form (Lunt 1968; Xu et al. 2013). The final product of this reaction that is NO_3^- might also be lost via nitrate leaching or denitrification process resulting in groundwater, surface water and atmospheric contamination (Dave et al. 1999). Thus, it is very crucial to control the nitrogen dynamics in the soil. A laboratory experiment was conducted at SFPN, ISES, UAF to check the effect of polymer mixed organic extracts and oil-coated urea on the N release efficiency, Percent nitrified N and respective ammonium and nitrate concentrations in the soil.

Results depicted that all the coating materials significantly reduced the release of ammonium, nitrate and cumulative N in the soil in comparison to uncoated urea. The delay in the release of N might be due to the controlled release properties of polymer mixed extracts and oil coating. As Shivay et al. (2016) stated that sulfur coated urea slowed the N release due to its control release properties. The dissolution rate of urea was reduced by coating with gypsum-sulfur (Ibrahim et al. 2014). Trinh et al. (2015) established a model to state the release kinetics of N from coated urea which clearly described that the release of N was lower in coated fertilizer than uncoated. N release efficiency was also reduced in our experiment that was consistent with the results of Tong et al. (2018).

Results of nitrate to ammonium ratio and percent nitrified N demonstrated the reduced nitrification process in the organic extracts and oil-coated urea treatments. The reduction in nitrification might be due to the nitrification inhibiting compound present in these organic amendments (Irigoyen et al. 2003; Di and Cameron 2004), as parthenium extract contain parthenin, phenolics and terpenes that are having nitrification inhibiting potential (Raina et al. 2003). Similarly, neem oil contains melacin and other compounds to inhibit the nitrification process (Malla et al. 2005). Acidulated cow dung compost extract at low pH reduced percent nitrified N that could be due to its low pH character, as low pH is itself a nitrification inhibitor. With a decrease in pH, nitrification reduces and even ceases below pH 6 (Hofman and Lee 1973; Harmsen 1987). Low concentrations of these extracts and oil reduced nitrified N percentage in consistence with that of higher concentrations. Thus, 5 % parthenium extract, 1 % neem oil and 2 pH acidulated cow dung compost extract was found sufficient for this purpose in consistence with the findings of Kumar et al. (2011).

Conclusion

Coated fertilizers controlled the release of N very effectively. As all coating materials slowed the cumulative N release at the initial interval that was increased at later intervals. Thus, N release efficiency could be correlated with the crop demand in the field, as crop demand at the initial stage is much lower but after about 40 days of germination, crops need more N. Decrease in percent nitrified N is also very important to control N losses in the form of nitrate leaching and nitrous oxide. All organic extracts and oil performed almost equally in controlling the nitrification process. However, lower concentrations of parthenium extract and neem oil performed very effectively, thus 5 % parthenium extract and 1 % neem oil are sufficient to control the nitrification process instead of applying higher concentrations. Similarly, 2 pH acidulated cow dung compost extract is suitable for coating on the urea granules to control nitrification loss. Conclusively, the coating of polymer mixed organic extracts on the commercial N fertilizers is an effective technique to control both N release and nitrification losses.

Declarations

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Declarations

Conflict of interest

The authors declare no conflict of interest.

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Data availability statement

All data of this manuscript is available with corresponding author on request.

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Figures

Figure 1

Nitrate to ammonium ratios for treatments at 20, 40 and 60 days interval

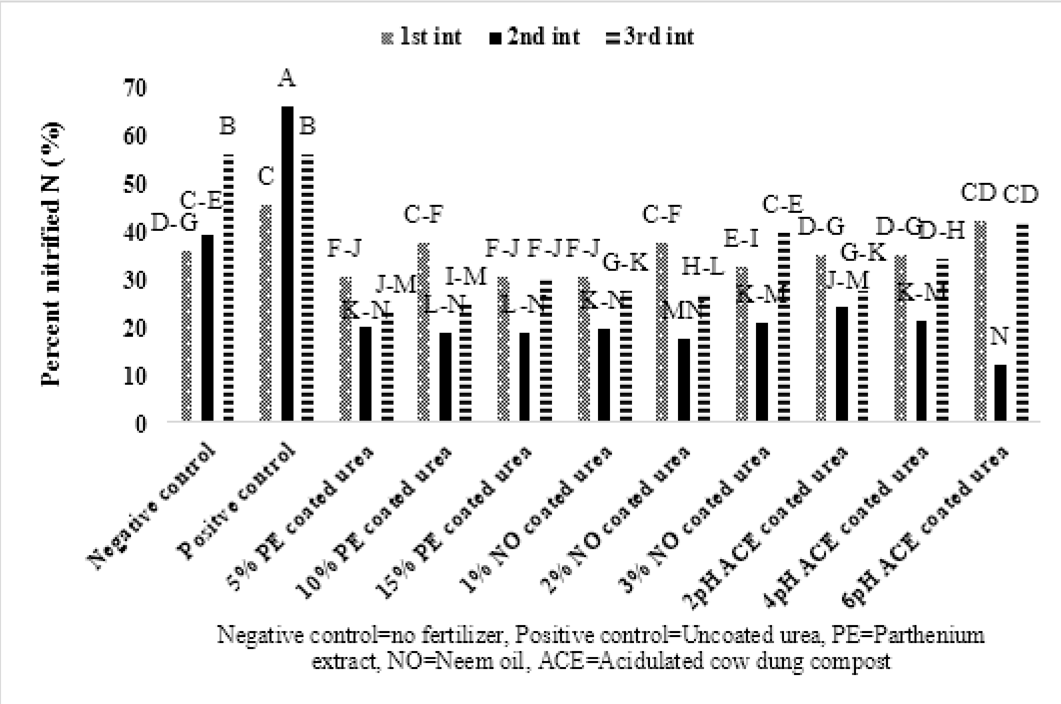

Figure 2

Percent nitrified N (%) for treatments at 20, 40 and 60 days interval

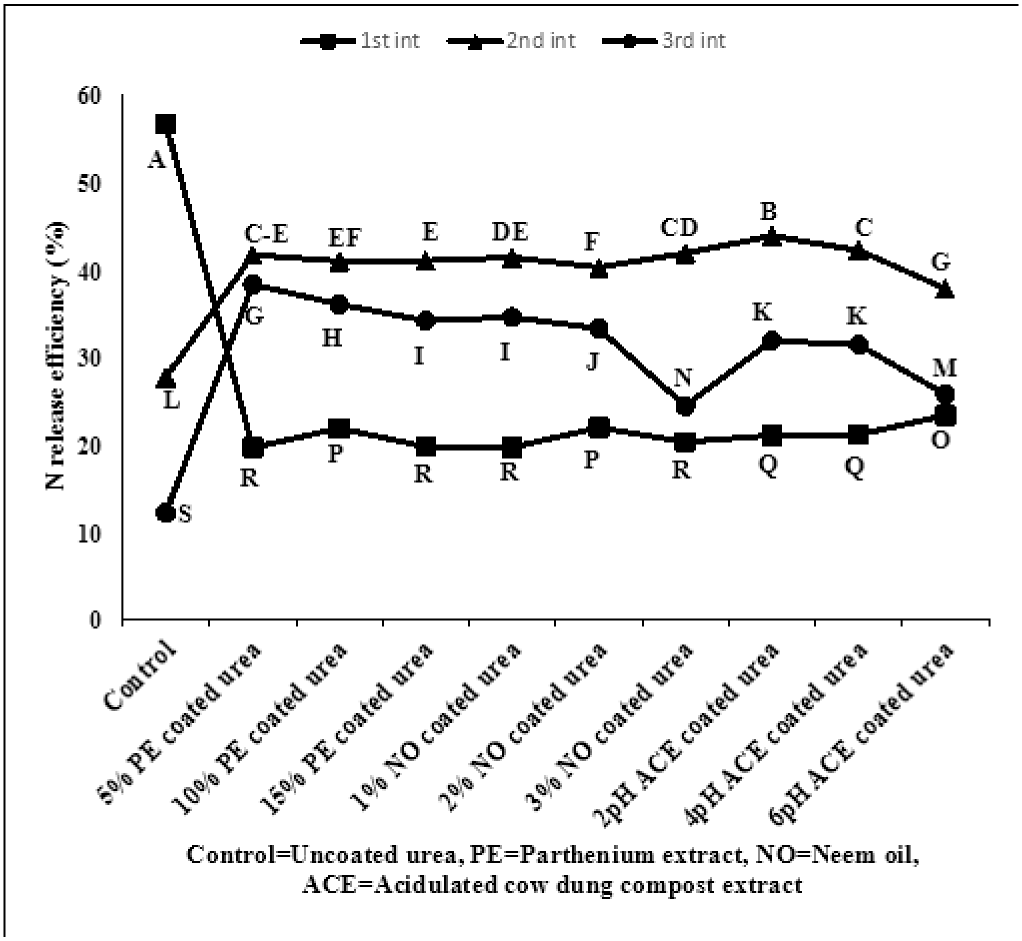

Figure 3

N release efficiency (%) of coated and uncoated fertilizers at 20, 40 and 60 day's interval

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementarydata.xlsx