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3. Biodegradable Polymer Coated Urea Fertilizers to Enhance the Nitrogen Use Efficiency in Maize

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Abstract

Maize, being an exhaustive and nutrient-responsive crop, needs appropriate fertilizer management in order to obtain increased yields while sustaining soil fertility and health. The objective of this study is to reduce nitrogen (N) loss and improve nitrogen use efficiency (NUE) by applying different biodegradable polymer coated urea of varying coating thickness to hybrid maize (COH (M) 6). In this study, three different sets of experiments were carried out, *viz.,* (i) laboratory incubation study to determine the N release pattern, ammonia volatilization loss and nitrate leaching loss, (ii) a pot culture experiment to screen the best treatment, and (iii) field experiment to compare the best treatments from the pot culture experiment with popular coated urea fertilizers in the market. The results revealed that, urea coated with less percentage thickness *viz.,* PSCU 5%, POCU 2%, HACU 5% released N very quickly and the maximum release was observed between 5 to 10 DAI. When the percentage of coating increased, N release decreased. The maximum NH_3 volatilization and NO_3 leaching loss was registered in UCU, but urea coated with higher percentage thickness registered minimum NH_3 volatilization losses over a period of time. In pot culture experiment, PSCU 10%, POCU 4% and HACU 15% treatments registered maximum grain yield (75.7, 76.1 and 75.3 g plant^{-1}, respectively) and N uptake (1.58, 1.62 and 1.58 g plant^{-1}, respectively). In the field experiment, The POCU treatment recorded the highest grain (8633 kg ha^{-1}) and Stover (9787 kg ha^{-1}) yield, followed by HACU which recorded a grain yield of 7967 kg ha^{-1}and NOCU (7787 kg ha^{-1}) treatments.

Key words: NUE, Slow-release fertilizers, Volatility, Nitrogen

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INTRODUCTION

India, a home of diversified agro ecology, has roughly around 600 million people relying on it for their primary livelihood. In order to meet the demand of population, government has fixed a demand of 298.3 MT food grain production in the year 2020 -21. In this regard maize is the third most significant cereal crop, behind rice and wheat, and the second most important crop in terms of acreage in India (Sharma *et al.*, 2018). It has a cultivation area estimated around 9.2 million hectares in India and 0.39 million hectares in Tamil Nadu. India is fourth in terms of area and seventh in terms of production among maize-growing countries, accounting for about 4 per cent of global maize area and 2 per cent of total production. Maize demand is expected to reach 45 million tonnes (Mt) by 2022. In the last two decades, maize had the highest compound annual growth rate in terms of area and production, amongst the cereals. Fertilizers being an important input for increasing crop yield have registered a steady increase in its usage over past four decades. For a thickly populated country like India, the dependency on fertilizers for food grain production is an essential prerequisite.

Nitrogenous fertilizers are highly accountable for food grain production over the world, but developing countries (Asia & Africa) are mostly N deficient (Kim and Bevis, 2019).Maize, being an exhaustive and nutrient-responsive crop, needs appropriate fertilizer management in order to obtain increased yields while sustaining soil fertility and health. Worldwide, Urea is an important nitrogenous fertilizer being applied to the crops to increase the production of crops. The Nitrogen Use Efficiency (NUE) of conventional urea is very low 30 – 40 per cent (losses up to 60 per cent) because of volatilization of NH_3, leaching through NO_3, runoff and nitrate denitrification processes (Naz and Sulaiman, 2016). These might lead for high consumption of N fertilizers, and environmental degradation. Slow-release fertilizers (SRFs) have a potential to reduce N losses and improve the N use efficiency of fertilizers. Slow-release fertilizers or controlled release fertilizers are produced to reduce the nitrogen losses and enhance the nitrogen use efficiency of crops.

In past decades, the polymeric materials which are derived from petroleum and plastic products were used for producing the slow-release fertilizers. The materials such as polyethylene, polystyrene, polyacrylamide and polysulfone possess better slow-release characters than other polymers. Indeed, these polymers are poorly degradable and persist in the environment for longer duration. Therefore, the use of bio-degradable products could be a possible solution for decreasing the harmful effects on environment.

Enhancing Nitrogen Use Efficiency of Maize Using Biodegradable Polymers

In this chapter, we discussed about enhancement of nitrogen use efficiency of maize through different biodegradable polymer coated urea as slow-release fertilizers. By using different biodegradable polymers *viz.*, palm stearin, pine oleoresin and humic acid, coated urea fertilizers synthesized at varying thicknesses to delay the release of nitrogen from urea. The source and properties of different biodegradable polymer coated urea are given below.

1. The solid fraction of palm stearin is a palm oil by-product obtained during dry fractionation is often high in lipids derived oleic acid. Palm stearin is widely utilized in the soap and candle industries, as well as a source of hard vegetable fat for food applications.

2. Pine oleoresin (POR) is produced commercially from the pine tree (*Pinus roxburghii*) and contains four resin acids: levopimaric acid (22 per cent), palustric acid (11 per cent), I-abietic acid (10 per cent), and neoabietic acid (15 per cent). The acidic component of the POR is made up of 50-60 per cent of these acids. Levopimaric acid has the most reactive double-bond structure among the four conjugated-diene resin acids and is more resistant to oxidation.

3. Urea coated with humic acid, often known as black urea aids in the retention of nitrogen in the profile and boost nitrogen efficiency by increasing soil microbial activity.

Hence coating urea with the aforesaid coating materials creates a physical barrier that slows the release of nitrogen from urea and lowers volatilization and leaching losses.Three types of coated urea fertilizers were made with each biodegradable polymer coating material in different thicknesses of coating, such as palm stearin coated urea 5, 10, and 15 per cent, pine oleoresin coated urea 2, 4, and 6 per cent, and humic acid coated urea 5, 10, and 15 per cent, under laboratory conditions using a rotating drum.

Various kinds of experiments were conducted such as laboratory incubation experiments, pot culture experiment and field validation experiment to know the effectiveness of biodegradable polymer coated urea fertilizers. A laboratory experiment consisted of three experiments *viz.,* nitrogen release pattern, ammonia volatilization and nitrate leaching from various coated urea fertilizers. For laboratory and pot culture experiments, a same set of treatments were followed under completely randomized design (CRD) *viz.,*T_1- Control (No fertilizers), T_2 - Uncoated urea, T_3 - Palm stearin coated urea 5 per cent, T_4 - Palm stearin coated urea 10 per cent, T_5 - Palm stearin coated urea 15 per cent, T_6 - Pine oleoresin coated urea 2 per cent, T_7 - Pine oleoresin coated urea 4 per cent, T_8 - Pine oleoresin coated urea 6 per cent, T_9 - Humic acid coated urea 5 per cent, T_{10} - Humic acid coated urea 10 per cent and T_{11}- Humic acid coated urea 15 per cent. For validation experiment, best performed treatments from pot culture experiment was brought to the field and compared the efficiency with popular coated urea fertilizers such as neem oil coated urea, sulphur coated urea, pungam oil coated urea and zinc coated urea. The experiment was carried out with nine treatments replicated thrice under randomized block design (RBD) *viz.,* T_1- Control (No fertilizers), T_2 - Uncoated urea, T_3 - Palm stearin coated urea 10 per cent, T_4 - Pine oleoresin coated urea 4 per cent, T_5 - Humic acid coated urea 15 per cent, T_6 – Neem oil coated urea 4 per cent, T_7 – Sulphur coated urea 5 per cent, T_8 – Pungam oil coated urea 4 per cent and T_9 – Zinc coated urea 4 per cent.

Nitrogen release pattern

Various coated urea fertilizers with various coating thicknesses released nitrogen at varying rates depending on the thickness of the coating. The mean N release from various coated urea fertilizers started to increase from first DAI (Day After Incubation) (194.2 kg ha^{-1}) to 10^{th} DAI (271.4 kg ha^{-1}) and attained a maximum, then started declining gradually from 15DAI (266.3 kg ha^{-1}) to 30DAI (216.8 kg

ha^{-1}). Among the fertilized treatments, HACU @ 15 per cent released highest (257.4 kg ha^{-1}) cumulative N followed by HACU 10 per cent (256.5 kg ha^{-1}) treatment. In terms of palm stearin coated fertilizers, PSCU 10 per cent released highest available N (241.5 kg ha^{-1}) followed by PSCU 15 per cent (241.3 kg ha^{-1}) treatments. From pine oleoresin coated urea, POCU 4 per cent released highest available N (247.0 kg ha^{-1}) followed by POCU 6 per cent (241.6 kg ha^{-1}) treatments. When coating thickness increases, the N release was decreased.

Ammonia volatilization

The cumulative NH_3 volatilization loss from various coated urea fertilizers started an increase from first DAI (1.27 mg kg^{-1}) to 10 DAI (5.65 mg kg^{-1}) and attained a maximum, then started declining gradually from 15 DAI (4.67 mg kg^{-1}) to 30 DAI (0.84 mg kg^{-1}). Among the fertilized treatments, UCU treatment lost highest (36.3 mg kg^{-1}) cumulative NH_3 volatilization which contributed 53 per cent of loss from applied N fertilizers. In terms of palm stearin coated fertilizers, PSCU 5 per cent treatment registered highest cumulativeNH_3 volatilization loss (31.3 mg kg^{-1}) which contributed 44.1 per cent of loss from applied N fertilizers. From pine oleoresin coated urea, POCU 2 per cent treatment recorded highest cumulative NH_3 volatilization loss (32.4 mg kg^{-1}) which was 46.1 per cent from applied N fertilizers. From humic acid coated urea, HACU 5 per cent treatment registered highest cumulative NH_3 volatilization loss (31.8 per cent) which was 44.9 per cent loss from applied N fertilizers. Among all the coated urea fertilizers, the lowest cumulative NH_3 volatilization loss was registered in HACU 15 per cent (22.2 mg kg^{-1}), PSCU 15 per cent (23.4 mg kg^{-1}), and POCU 6 per cent (24.4 mg kg^{-1}) which was contributed 27.8, 29.9 and 31.7 per cent of loss from applied N fertilizers.

Nitrate leaching

The cumulative NO_3 leaching loss from various coated urea fertilizers started increasing from first DAI (2.30 mg kg^{-1}) to 20 DAI (11.8 mg kg^{-1}) and attained a maximum, then started declining gradually from 25 DAI (9.96 mg kg^{-1}) to 30 DAI (5.97 mg kg^{-1}). Among the fertilized treatments, UCU treatment lost highest (82.4 mg kg^{-1}) cumulative NO_3 leaching which contributed 46.6 per cent of loss from applied N fertilizers. In terms of palm stearin coated fertilizers, PSCU 5 per cent treatment registered highest cumulative NO_3 leaching loss (78.5 mg kg^{-1}) which contributed 43.8 per cent of loss from applied N fertilizers. From pine oleoresin coated urea, POCU 2 per cent treatment recorded highest cumulative NO_3 leaching loss (73.5 mg kg^{-1}) which was 40.3 per cent from applied N fertilizers. From humic acid coated urea, HACU 5 per cent treatment registered highest cumulative NO_3 leaching loss (77.5 per cent) which was 43.1 per cent loss from applied N fertilizers. Among all the coated urea fertilizers, the lowest cumulative NO_3 leaching loss was registered in POCU 6 per cent (67.0 mg kg^{-1}), PSCU 15 per cent (69.4 mg kg^{-1}), and HACU 15 per cent (71.5 mg kg^{-1}) which was contributed 35.6, 37.4 and 38.9 per cent of loss from applied N fertilizers.

Pot culture experiment

According to the current study, coated urea fertilizer outperformed uncoated urea in terms of maize growth characteristics such as plant height, root length, and root volume which increased significantly as the growth stages progressed. This could be owing to the slow release of nitrogen from coated urea fertilizers, which matched the maize crop's needs. According to Chalk *et al.* (2015), controlled-release urea improved plant proficiency and reduced nitrogen losses by better coordinating nitrogen provision with plant demand. The application of coated urea fertilizers boosted maize yield and yield attributes and differed considerably from uncoated urea and control treatments. The findings suggested that, the nitrogen release properties of controlled release urea closely matched the need for nitrogen in the later phases of crop development. According to the study, higher thickness coated urea, for instance, PSCU 15 per cent and POCU 6 per cent did not deliver the required nitrogen to the crop, however HACU 15 per cent provided. Indeed, soil nitrogen insufficiency or abundance was strongly linked to growth of crop, highlighting the gap between nitrogen supply and crop nitrogen need. The grain and stover yields of maize were affected by different coated urea fertilizers, and they all differed from the uncoated urea fertilizer treatment. The present study revealed that, POCU 4 per cent, PSCU 10 per cent, and HACU 15 per cent yielded 45.5, 44.7, and 43.9 per cent more than UCU treatment, respectively. PSCU 10 per cent produced the largest stover production, which was comparable to all coated urea fertilizers except PSCU 5 per cent and POCU 2 per cent treatments, but significantly different from UCU and control treatments. Furthermore, the harvest index also recorded highest in POCU 4 per cent which was comparable to PSCU 10 per cent, POCU 6 per cent, HACU 10 per cent and HACU 15 per cent treatments.

Coated urea fertilizers treatment is remarkably different from uncoated urea fertilizer treatment in terms of maize nitrogen uptake. According to Xie *et al.* (2020), applied N had substantially greater N uptakes than the conventional urea plot. The present result indicated that, N uptake was particularly rapid in UCU during the vegetative stage, then showed lesser uptake in later stages. This uptake trend was vice versa with the coated urea fertilizers. This could be due to the fact that, UCU released nitrogen early resulting in losses such as ammonia volatilization and nitrate leaching, which prevented plants from receiving nitrogen from the fertilizers in later stages. In contrast, coated urea fertilizers prolong nitrogen release, allowed the plant to absorb more nitrogen especially during later stage of maize. Based on the maize yield and uptake of nutrients from pot culture experiments 10 per cent, POCU 4 per cent and HACU 15 per cent showed superior effect compared with other thickness coated urea fertilizers.

Field experiment

Among the coated urea fertilizers, the PSCU, POCU, and HACU lead to highest maize crop growth rate and yield. Because of the wax found in palm stearin, which is hydrophobic in nature performed effectively by slowing down the N release. It might restrict water from reaching the urea granules and preventing nitrogen from being released quickly. Wax, as the sealant of the porous coating, can limit the nitrogen release rate in two ways. First and foremost, it has the potential to reduce holes and the immediate loss of nitrogen through pores (Li *et al.*, 2012), Secondly, increasing the wax content would transform the coatings hydrophilicity to hydrophobicity, reducing nitrogen dispersal through the coating layer (Yang *et al.*, 2012). According to Subbarao *et al.* (2008), the fatty acid found in palm stearin acts as a nitrification inhibitor. Fatty acids can limit nitrification owing to the presence of lanolin and lanoline acid in its chemical structures.

Coating urea with POR provides a physical barrier for controlled release of N from urea, inhibits enzymatic activity through antibacterial properties, and restricts volatilization loss by acidifying alkaline micro-sites in soil, which might also explain pine oleoresin coated urea increased nitrogen uptake by increasing growth and yield attributes (Kundu *et al.,* 2013). All these mechanisms might play a major role in the availability of nitrogen to plants from POR coated urea.

Humic acid (HA) coated urea has a lot of acidic functional groups, a lot of specific surface area, a lot of cation exchange capabilities, and a lot of absorption properties. These properties are ideal for stimulating plant growth and nutrient uptake, acidifying fertilizer microsites, and conserving NH_4^+, all of which help to reduce ammonia volatilization (El-Mekser *et al.,* 2014; Tan, 2003). The carboxyl groups in HAs potentially react with the acylamino group of urea to form the very stable humic acid-urea complex. Because urea is incorporated into HA, it is protected from fast hydrolysis, allowing for controlled urea release and a constant supply of nitrogen (Dong and Yuan, 2009; Li and Ma, 2004; Selladurai and Purakayastha, 2016). Other coated urea fertilizers, such as NOCU, SCU, PUOCU, and ZCU, produced comparable grain yields to PSCU and HACU, but not to the same extent as POCU. In contrast to uncoated urea fertilizer treatment, all coated urea fertilizer treatments performed effectively.

Nitrogen use efficiency

The nitrogen use efficiency parameters such as agronomic efficiency (AE), recovery efficiency (RE), physiological efficiency (PE), partial factor productivity (PFP), and utilization efficiency (UE) from POCU treatment was 144.6, 135.6, 24.9, 45.2 and 67.0 per cent higher than UCU treatment respectively. In recovery efficiency, HACU and NOCU were on par with POCU treatment. The present result showed, POCU, HACU and NOCU used in the study could effectively improve the NUE of fertilized nitrogen; this might be due to the reduced losses of N due to its great slow-release properties. The POCU had natural urease inhibitor which might have controlled the losses of nitrogen through various pathways and helped the timely uptake of N to enhance the NUE of maize.

CONCLUSION

Based on the outcomes of the investigation, it could be concluded that, application of eco-friendly pine oleoresin coated urea (POCU) does prolonged availability of nitrogen due to the slower and steady release pattern which supplied enough nutrients throughout the growing season to meet the plant demand for optimum growth. This fertilizer can be used as an alternative fertilizer for maize (COH (M) 6) grown under Periyanaickenpalayam soil series (*Verticustropept*) of Tamil Nadu for attaining the targeted yield with STCR based fertilizer doses to gain more profit. Finally, POCU could be a good alternative N source to neem coated urea that is largely in practice in India at present.

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