INFLUENCE OF BIODEGRADABLE POLYMER COATED UREA ON NITROGEN UPTAKE AND UTILIZATION OF MAIZE (*Zea mays* L.)

Abstract

Controlled release nitrogen fertilizers could be an excellent management approach for improving nitrogen fertilizer efficiency. The nitrogen use efficiency of maize from various biodegradable polymer-coated urea fertilizers, such as palm stearin coated urea (PSCU), pine oleoresin coated urea (POCU), and humic acid coated urea (HACU), was determined in a pot culture experiment conducted at the Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore, during 2021. The coating materials were coated on urea with different coating thicknesses, viz., PSCU - 5, 10, 15%, POCU – 2, 4, 6%, and HACU - 5, 10, 15%. Among the coated urea fertilizers, HACU 15% had the highest grain yield, followed by POCU 4% and PSCU 10%, with 72.0, 69.7, and 69.0g plant^{-1}, respectively. PSCU 10%, HACU 15%, and POCU 4% produced the maximum dry matter, with 186.5, 186.2, and 185.3g plant^{-1}, respectively. POCU 4 % had the highest nitrogen uptake, followed by HACU 15% and PSCU 10%, with 1.62, 1.59, and 1.59g plant^{-1}, respectively. The nitrogen utilization percentage was highest in the POCU 4% treated pot (73.9%). When compared to uncoated urea fertilizer, all coated urea fertilizers outperformed uncoated urea fertilizer in terms of grain yield, dry matter accumulation, and nitrogen uptake. To improve the nitrogen use efficiency, coated urea fertilizers prove to be a promising alternative to uncoated urea fertilizers.

Keywords: *urea, coated fertilizers, nitrogen release, nitrogen utilization, nitrogen uptake*

1. Introduction

Maize (Zea mays L.) is one of the most widely cultivated cereal crops in the world, providing grain, silage, and biofuel (Bono *et al*., 2020). Nitrogen (N) is a chemical element that is required by most cultures of economic interest, and it has the most impact on maize output (Fageria and Baligar, 2005; Marini *et al*., 2015; Arnuti *et al*., 2017). Nitrogen is insufficient in nearly all agricultural soils and cropping systems around the world, it is necessary to use prudent nitrogen management to grow crops to meet the ever-increasing demands of human populations (Mohan *et al*., 2015).

For any agricultural production system, nitrogen is the most important externally provided ingredient. The food supply of half of the world's population is reliant on nitrogenous fertilizers, either directly or indirectly. Rice, wheat, and maize now consume more than 90% of all nitrogenous fertilizer applied to cereals. Underuse of nitrogen is linked to reduced agricultural yields, whereas overuse has several soil and environmental effects. As a result, the response to applied nitrogen and its effectiveness must be carefully evaluated to achieve maximum potential and sustainable yield (Yadav *et al*., 2017).

The consumption of reactive nitrogen (Nr) in the form of fertilizer in India has increased quickly over the last six decades, with an annual rise of 6% since 1970 (Sutton *et al*., 2017 based on FAO, 2016), but cropping system nitrogen use efficiency (NUE) has decreased (Moring *et al*., 2021). This increased fertilizer use has led in increasing Nr losses, one of the clearest signs of which is the yearly emission of ammonia (NH_3), the most common fertilizer related atmospheric Nr loss, which is on the rise (Edgar, 2016).

When urea applied to plants in bare form is prone to losses due to nitrous emissions, leaching, denitrification, and surface runoff (Azeem *et al*., 2014; Trinh *et al*., 2015). Naz *et al*. (2016) reported, this loss leads in economic loss, low plant nutrient use efficiency, and environmental damage due to water eutrophication and nitrous emissions into the stratosphere.

Controlled release urea can be used to prevent granular urea loss due to leaching, ammonia volatilization, and denitrification (Azeem *et al*., 2016). The thickness of the coating film is important for better controlled release qualities (Timilsena *et al*., 2015). The time it takes for a dissolved nutrient to diffuse out of the coated shell and into the bulk water it is immersed in is determined by the diffusional path it must travel (Ito *et al*., 2003).

The main goal of fertilizer research is to increase the efficiency and availability of fertilizers to plants, either by increasing the availability of existing fertilizers or by producing a new high-efficiency fertilizer. The discovery of controlled-release fertilizers (CRFs) boosted fertilizer efficiency by allowing fertilizer to be released over a longer period. CRFs are made by lowering the solubility and mobility of conventional fertilizers through physical or chemical modification (Trenkel, 1997). The present study investigates the low-cost biodegradable polymer coated urea to enhance the nitrogen use efficiency of maize.

2. Material and methods

2.1. Collection and preparation of soil sample

Soil samples were collected from Field No. 37F of the eastern block, Tamil Nadu Agricultural University, Coimbatore. The experimental soil is a mixed black calcareous, fine, montmorillonitic, isohyperthermic which belonged to the Inceptisol order, Periyanaickenpalayam soil series, and classified as Vertic Ustropept taxonomically. The soil was air dried, processed by quartering method, then sieved with a 2mm sieve. Representative sub examples were dispossessed for further soil physico-chemical anaysis by embracing standard analytical procedures are given in the **Table 1.**

Table 1. Physico-chemical characteristics of experiment soil

Soil parameters	Values	Methods
pH (1:2.5 soil/water ratio)	8.17	Jackson (1973)
Electrical conductivity (dS m^{-1}) (1:2.5 soil/water ratio)	0.24	Jackson (1973)
Organic carbon (%)	0.62	Walkley and Black (1934)
Available nitrogen (kg ha^{-1})	179.2	Subbiah and Asija (1956)
Available phosphorus (kg ha^{-1})	16.7	Olsen (1954)
Available potassium (kg ha^{-1})	504.1	Stanford and English (1949)
Bulk density (Mg m^{-3})	1.17	Gupta and Dakshinamurthi (1981)
Particle density (Mg m^{-3})	2.45	Gupta and Dakshinamurthi (1981)
CEC (cmol ($P^{+)}$ kg^{-1})	45.6	Jackson (1973)
Zn (mg kg^{-1})	0.56	Lindsay and Norvell (1978)
Fe (mg kg^{-1})	2.05	Lindsay and Norvell (1978)
Cu (mg kg^{-1})	0.68	Lindsay and Norvell (1978)
Mn (mg kg^{-1})	5.97	Lindsay and Norvell (1978)
Textural class	Sandy clay loam	Piper (1966)

2.2. Synthesis and characterization of coated urea fertilizers

Three types of coated urea fertilizers were made with various biodegradable polymer coating materials in different thicknesses of coating, such as palm stearin coated urea 5, 10, and 15%, pine oleoresin coated urea 2, 4, and 6%, and humic acid coated urea 5, 10, and 15%, under laboratory conditions using a rotating drum. Characterization of the modified products of urea fertilizers were studied under Scanning Electron Microscope (SEM) **(Fig. 1)** to understand the basic structure and coating sequence between urea and coated materials at Department of Nano Science and Technology laboratory, TNAU, Coimbatore.

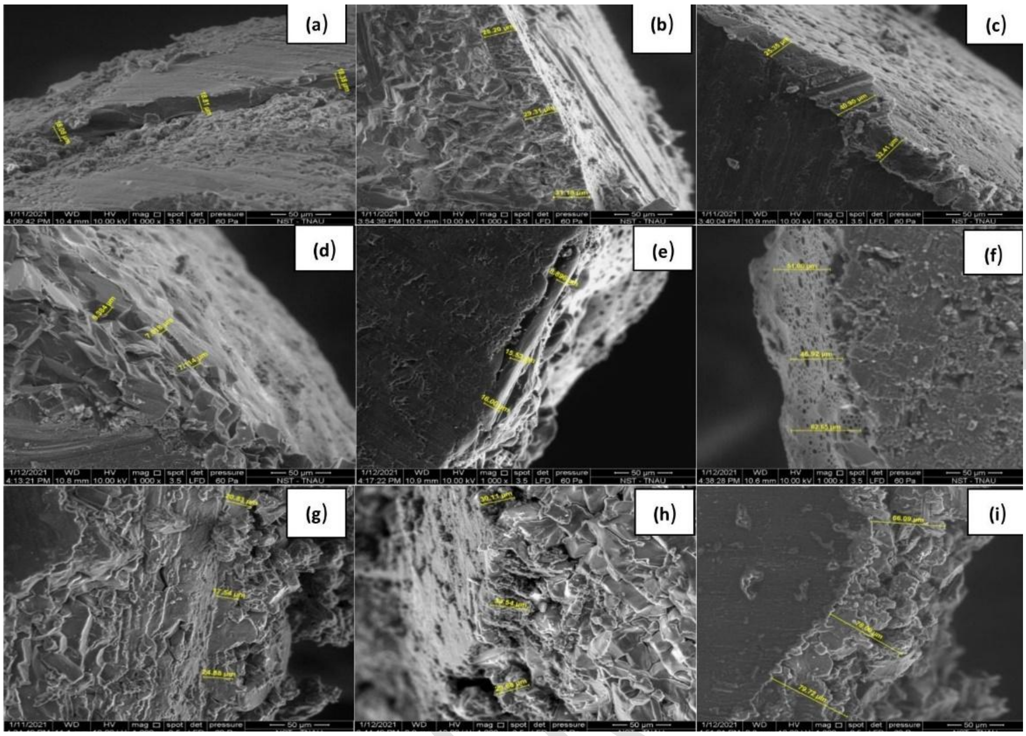

Figure 1. Scanning electron micrograph of (a) palm stearin coated urea 5%, (b) palm stearin coated urea 10%, (c) palm stearin coated urea 15%, (d) pine oleoresin coated urea 2%, (e) pine oleoresin coated urea 4%, (f) pine oleoresin coated urea 6%, (g) humic acid coated urea 5%, (h) humic acid coated urea 10%, (i) humic acid coated urea 15% at x1000 magnification.

About 10kg of soil weighed and filled in each mud pot. After that, maize (COH (M) 6) hybrid seeds were sown. There were eleven treatments and replicated thrice under completely randomized design (CRD). The treatments details of the experiment given in **Table 2**. Recommended dose of fertilizer (1120 mg N pot^{-1}) was applied as three splits (25% basal, 50% at 25 DAS, 25% at 45 DAS), entire dose of Single super Phosphate (SSP) and Muriate of Potash (MOP) applied as basal application. Plant samples were taken at the vegetative, tasseling, and harvest stages of the plant and determined for nitrogen uptake and maize N use efficiency.

Table 2. Treatment details of the experiment

Treatments	**Abbreviations**
T_1 - Control	Control
T_2 - Uncoated urea	UCU
T_3 - Palm stearin coated urea 5%	PSCU 5%
T_4 - Palm stearin coated urea 10%	PSCU 10%
T_5 - Palm stearin coated urea 15%	PSCU 15%
T_6 - Pine oleoresin coated urea 2%	POCU 2%
T_7 - Pine oleoresin coated urea 4%	POCU 4%
T_8 - Pine oleoresin coated urea 6%	POCU 6%
T_9 - Humic acid coated urea 5%	HACU 5%
T_{10} - Humic acid coated urea 10%	HACU 10%
T_{11} - Humic acid coated urea 15%	HACU 15%

Nitrogen uptake and Fertilizer N utilization calculation

$$N\ uptake\ (g\ pot^{-1}) = \frac{N\ concentration\ in\ plant\ (\%)\ x\ weight\ of\ dry\ matter\ (g)}{100}$$

$$Fertilizer\ N\ utilization\ (\%) = \frac{Fertilizer\ N\ uptake\ of\ plant\ (mg)}{Fertilizer\ N\ applied\ (mg)}\ x\ 100$$

2.3. Statistical analysis

Using AGRES statistical package, the data from the experiments were subjected to analysis of variance (ANOVA) to determine significance. Significant critical differences (CD) were calculated at the 5% confidence level wherever treatment differences were found.

3. Results and discussion

3.1. Dry matter production

From the vegetative to the harvest stage, maize crop dry matter production increased **(Table 3)**. Maize dry matter accumulation under different N treatments revealed a typical sigmoidal tendency across the maize growing season, according to Guo *et al*. (2021). The dry matter production of coated urea and uncoated urea differed significantly in the vegetative stage, ranging from 18.7 - 37.2g plant^{-1}. uncoated urea (T_2) treatment (37.2g plant^{-1}) had the maximum dry matter production, while control (T_1) treatment had the lowest dry matter output (18.7g plant^{-1}). Uncoated urea produced more dry matter than any of the coated urea fertilizers at this stage. This could be because uncoated urea's fast dissolution encourages higher crop absorption, whereas coated urea fertilizers slowly deliver nitrogen to the plant at this stage. Slow-release fertilizers may release too slowly from the polymer coating to be a helpful N supply in the early phases of crop development (Farmaha and Sims, 2013). According to Mullen (2011), nitrogen in the soil is lost by volatilization, immobilization, denitrification, and leaching prior to crop uptake, with the volume and pathways of loss affected by environmental conditions such as soil moisture and temperature. The medium thickness coated urea fertilizers, such as PSCU 10%, POCU 4%, and HACU 10%, and the high thickness coated urea fertilizers, such as PSCU 15%, POCU 6%, and HACU 15%, produced lesser dry matter production during the vegetative stage because higher percentage coated urea takes longer to dissolve than lower percentage coated urea. Blends of slow and controlled-release urea, according to Andrade *et al*. (2021), provide better regulated N release to maize plants, giving adequate quantities of N at each growth stage or throughout time than traditional urea.

In tasselling stage, the dry matter production was ranged from 48.6 – 85.3g plant^{-1}. The highest dry matter production was recorded in POCU 4% (T_7) treatment (85.3g plant^{-1}) which is on par with PSCU 10% (T_4), POCU 6% (T_8) and HACU 15% (T_{11}) and the lowest dry matter production was recorded in control (T_1) treatment (48.6g plant^{-1}). When compared to coated urea fertilizer treatments, the uncoated urea treatment produced less dry matter. According to Sofia *et al*. (2019) the vegetative biomass of plants was treated by amended polymer composite fertilizers tend to be higher than positive and negative controls. This is since the maize plants' nitrogen requirements were met by the coated fertilizers. Because nitrogen is released slowly from coated urea fertilizers due to the degradation of coating material as time passes, medium thickness coated urea fertilizers such as PSCU 10% (T_4), POCU 4% (T_7), and HACU 10% (T_{10}) produced more dry matter. The extent of yield improvement with coated fertilizers, according to Guan *et al*. (2014), was largely dependent on the timely release of nutrients coated inside the three layers of fertilizer. Attapulgite coating reduced nutrient loss in the early growing stage as a barrier to chemical fertilizer, allowing maize plants to acquire nutrients in the middle and late developing phases.

In harvest stage, Coated urea dry matter production differed significantly from uncoated urea fertilizers and it was ranging from 127.5 - 186.5g plant^{-1}. PSCU 10% (T_4) treatment had the maximum dry matter accumulation (186.5g plant^{-1}), while control (T_1) treatment had the lowest dry matter production (127.5g plant^{-1}). This could be because the nitrogen supplied from the coated urea meets the crop need whenever it is needed, resulting in higher dry matter output. Grant *et al*. (2012) and Zhang *et al*. (2019) found that the delayed release fertilizer's nitrogen release rate was synced with plant N absorption, resulting in fewer nitrogen losses. The nitrogen release properties of controlled release urea were also synchronised with the N requirements of wheat and maize crops during their whole growth cycles, according to Zheng *et al*. (2017). Among all coated urea fertilizers, the thickest coated urea produced less dry matter. This could be because the nitrogen released from the coated urea was exceedingly sluggish and did not match the crop's requirements. De Almeida *et al*. (2019) found that using urea blends did not increase maize yields, and Garcia *et al*. (2019) found that coated urea did not always match the crop demand, affecting dry mass and nitrogen uptake of crop.

Table 3. Effect of coated urea fertilizers on dry matter production (g plant^{-1}) of maize

Treatments	**Dry matter production (g plant^{-1})**				
	Vegetative	**Tasselling**	**Harvest**		
			Stover	**Grain**	**Total DMP**
T$_1$-Control	18.7	48.6	88.6	32.9	127.5
T$_2$-UCU	37.2	59.8	101.4	46.5	152.3
T$_3$-PSCU 5%	33.2	63.7	106.8	57.5	169.7
T$_4$-PSCU 10%	30.8	82.4	110.8	69.0	186.5
T$_5$-PSCU 15%	28.4	76.5	108.4	61.4	175.4
T$_6$-POCU 2%	32.6	66.2	106.5	57.5	169.6
T$_7$-POCU 4%	26.4	85.3	108.1	69.7	185.3
T$_8$-POCU 6%	25.7	80.6	107.4	63.8	177.8
T$_9$-HACU 5%	30.5	70.3	107.7	60.1	173.4
T$_{10}$-HACU 10%	32.3	74.9	108.3	59.5	174.5
T$_{11}$-HACU 15%	29.9	82.2	109.5	72.0	186.2
Mean	**29.6**	**71.9**	**105.8**	**59.1**	**170.7**
SEd	**1.51**	**3.44**	**4.62**	**2.92**	**7.52**
CD (.05)	**3.13**	**7.14**	**9.57**	**6.05**	**15.6**

3.2. Nitrogen uptake

Nitrogen uptake of maize from coated urea fertilizers significantly differed from uncoated urea fertilizer treatment **(Table 4)**. Applied N exhibited much larger uptakes of N than the typical urea plot, according to Xie *et al*. (2019). In vegetative stage, nitrogen uptake ranged from 0.180 - 0.625g plant^{-1}, with control (T$_1$) and uncoated urea (T$_2$) treatments recording the lowest and highest uptake, respectively. Because nutrient uptake was extremely quick at this stage, uncoated urea nitrogen uptake was at its peak. More thickness coated urea had the lowest nitrogen uptake, while less thickness coated urea had the highest nitrogen uptake. This could be because the thickness of the coating determines the amount of urea released beyond the coated layer. Nutrient release from coated fertilizer may be influenced by coating thickness, according to Shaviv *et al*. (2003). It is vital to remember that the higher the proportion of coated layer content, the lower the nitrogen leakage (Behin and Sadeghi, 2016).

In tasselling stage, control (T_1) and POCU 4% (T_7) treatments had the lowest and maximum nitrogen uptake, respectively, ranging from 0.403 to 1.467g plant^{-1}. When compared to all the coated urea fertilizer treatments, uncoated urea treatments produced less nitrogen uptake. This could be because uncoated urea released nitrogen early and caused losses such as ammonia volatilization and nitrate leaching, preventing plants from absorbing nitrogen from the fertilizer. Coated urea fertilizers, on the other hand, postpone nitrogen release, allowing the plant to absorb more nitrogen during this stage. Andrade *et al*. (2021) reported, Controlled-release urea's and their blends have a delayed N release and promote continuous N uptake after 70 days. Likewise, the applied N rates were also more important than the N fertilizer technologies after 70 days. To help synchronise N release and uptake by maize, an appropriate blend of N fertilizers could be an attractive choice.

In harvest stage, stover nitrogen uptake ranged from 0.470 to 0.835g plant^{-1}, with the lowest and maximum uptakes detected in the control (T_1) and PSCU 15% (T_8) treatments, respectively. When compared to all coated urea fertilizers, the greatest thickness coated urea PSCU 15% registered greater nitrogen uptake in stover, which could be owing to the delayed nitrogen release up until this harvest stage, which induced more nitrogen uptake. The lowest and highest grain nitrogen content were obtained in the control (T_1) and HACU 15% (T_7) treatments, respectively, which varied from 0.323 - 0.885 g plant^{-1}. The absorbed nitrogen from coated urea fertilizers was gladly supplied to the grains at the right period in the crop cycle. According to Noor Affendi, *et al*. (2018), the plots fertilised with Urea coated with Cu and Zn (UCuZn) and UCuZn + nitrification inhibitor had the maximum exported N in stover and grain. Under uncoated urea, grain maize had the lowest exported nitrogen.

The maize crop's total nitrogen uptake ranged from 0.79 - 1.62g plant^{-1}, with the lowest and maximum uptakes recorded in the control (T_1) and POCU 4% (T_7) treatments, respectively. When compared to coated urea fertilizers, uncoated urea had lower total nitrogen uptake. This could be attributed to higher nitrogen losses from uncoated urea and reduced nitrogen losses from coated urea fertilizers. When compared to regular urea, Ning *et al*. (2012) found that controlled release urea can boost total nitrogen uptake by aboveground organs and soil residual while lowering loss. Coated urea fertilizers may reduce nutrient losses by enhancing nutrient utilization efficiency. Control release fertilizers can be used to meet crop nutrient requirements in a single or divided application while also reducing pollution in the environment (Noor Affendi, *et al*., 2018). We might deduce from these findings that the coated fertilizers' release pattern satisfied the crop demand and provided more nitrogen to the plants.

Table 4. Effect of coated urea fertilizers on nitrogen uptake (g plant^{-1}) of maize

Treatments	N uptake (g plant^{-1})				
	Vegetative	Tasselling	Harvest		Total uptake
			Stover	Grain	
T_1-Control	0.180	0.403	0.470	0.323	0.79
T_2-UCU	0.625	0.712	0.608	0.521	1.13
T_3-PSCU 5%	0.485	0.841	0.641	0.667	1.31
T_4-PSCU 10%	0.431	1.343	0.753	0.835	1.59
T_5-PSCU 15%	0.375	1.125	0.835	0.700	1.53
T_6-POCU 2%	0.505	0.907	0.655	0.644	1.30
T_7-POCU 4%	0.391	1.467	0.762	0.858	1.62
T_8-POCU 6%	0.357	1.225	0.773	0.734	1.51
T_9-HACU 5%	0.439	0.942	0.592	0.697	1.29
T_{10}-HACU 10%	0.478	1.071	0.699	0.720	1.42
T_{11}-HACU 15%	0.449	1.299	0.701	0.885	1.59
Mean	**0.429**	**1.030**	**0.681**	**0.689**	**1.37**
SEd	**0.015**	**0.037**	**0.032**	**0.031**	**0.057**
CD (.05)	**0.032**	**0.077**	**0.066**	**0.065**	**0.118**

3.3. Fertilizer Nitrogen utilization

Fertilizer N utilization or nitrogen recovery efficiency (NRE) from the applied fertilizers was calculated based on the nitrogen uptake in treated and control pots of the maize. Fertilizer N utilization was maximum in coated urea fertilizers than uncoated urea fertilizers **(Fig. 2)**. The highest fertilizer utilization was recorded in POCU 4% (T_7) (73.9%) which at par with PSCU 10% (T_4) (71.1%) and HACU 15% (T_{11}) (70.9%) while the lower N utilization efficiency was registered in Uncoated urea (T_2) treatment (30.3%). This was due to the slow release of nitrogen from the coated urea fertilizers to the longer period. Fertilizer N utilization was highest in urea applied with urease inhibitor than in urea applied without urease inhibitor, according to Gans *et al*. (2006). Fertilizer N utilization was 56% in his study, compared to

42.4% for conventional urea. According to Guo *et al*. (2021), the maize crop's nitrogen recovery efficiency ranged between 20.4 and 40.2 percent, with the maximum NRE recorded in urea blended with slow-release nitrogen fertilizer at a ratio of 3:7 and the lowest NRE recorded with uncoated urea fertilizer treatment. According to Andrade *et al*. (2021), due to lower N availability from N sources throughout time, declines in the NRE in uncoated urea are low throughout the cropping periods.

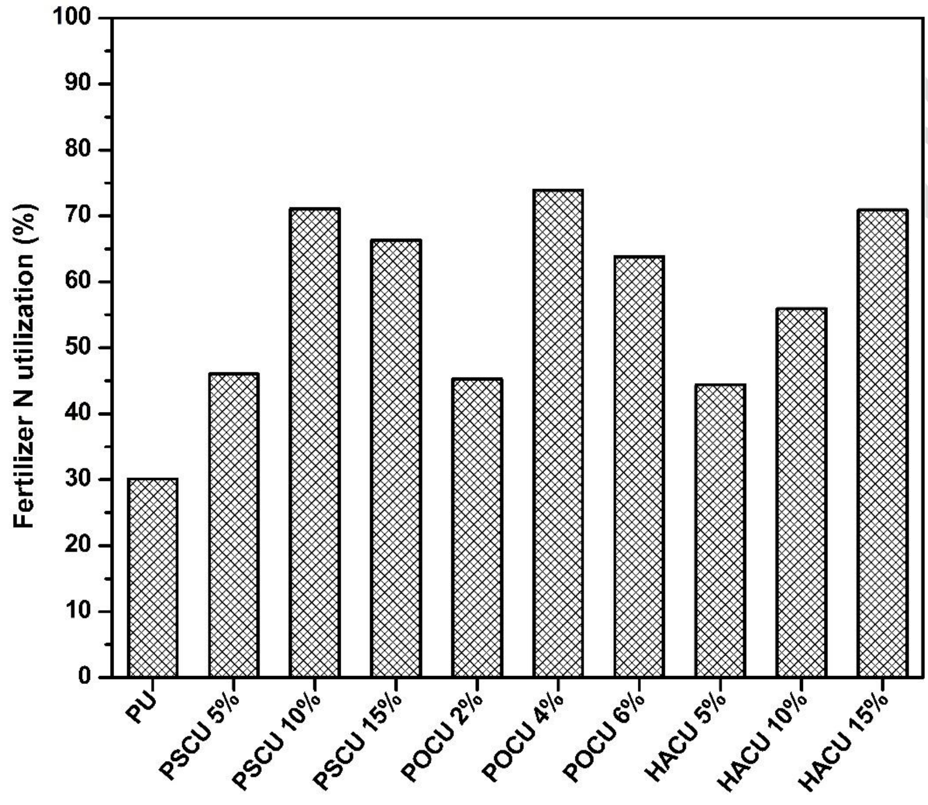

Figure 2. Effect of coated urea fertilizers on fertilizer N utilization (%) of maize

4. Conclusion

According to the result of this study coated urea fertilizer is a good alternative for uncoated urea fertilizers to enhance the nitrogen use efficiency of maize. The application of PSCU, POCU, HACU could be a promising control release nitrogen fertilizer for reducing nitrogen loss and improving nitrogen use efficiency without any negative impact on plant yield because releases rates of N from coated fertilizer corresponded well to the N requirements of maize plants. However, further field investigations are necessary to validate the use of this fertilizer on nitrogen use efficiency.

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