Research article

EFFECTS OF COATED AND BRIQUETTE UREA ON YIELD AND NITROGEN USE EFFICIENCY OF RICE AT RAMPUR, CHITWAN, NEPAL

S. Marahatta*
Agriculture and Forestry University, Rampur, Chitwan, Nepal

*Corresponding author: smarahatta@afu.edu.np

Received date: 15 January 2021, Accepted date: 18 March 2022

ABSTRACT

Nitrogen is one of the most limiting element for the growth and yield of rice. However, the imbalance use of conventional urea leads to loss of nitrogen from rice field, decrease nitrogen use efficiency, increase environmental pollution and cost of cultivation. This study was done to evaluate the response of polymer coated urea (PCU) and urea briquette (UB) on the yield and nitrogen use efficiencies (NUE) of rice on a sandy loam soil. The experiment was conducted at the agronomy research farm of Agriculture and Forestry University during the rainy season of 2018 in a randomized complete block design with three replications for each treatment (T_1 - control, 0 kg N ha^{-1}; T_2- Prilled urea, 150 kg N ha^{-1}single application at basal; T_3- Prilled urea, 150 kg N ha^{-1} standard split application; T_4-PCU, 150 kg N ha^{-1}single application at basal; T_5-UB, 150 kg N ha^{-1}single application at basal). The data on yield, and NUE were recorded and analyzed by using R studio. The physical and economic maximum dose of Nitrogen for these different types of urea were also calculated. Compared with single application of Prilled urea (3698 kg ha^{-1}), rice fertilized with Prilled urea with standard split application (4747 kg ha^{-1}), single application of PCU (5183 kg ha^{-1}) and BU (4787 kg ha^{-1}) had significantly higher grain yield and NUE. Economic maximum dose of nitrogen was reduced greatly for the single application of PCU (124 kg N ha^{-1}) compared to Prilled urea with standard split application (167 kg N ha^{-1}). Single application of PCU and UB can be considered as an alternative nitrogen fertilizer for rice even in the sandy loam soil.

Keywords: Nitrogen fertilizer, Prilled urea (PU) briquette urea (UB), polymer-coated urea (PCU), rice

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important food crops in the world, especially in Nepal. The national average yield of rice (3.17 t ha^{-1}) (MOF, 2017) is far below the attainable yield of >8.0 t ha^{-1} (Devkota, 2017; Devkota et al., 2016), indicating the huge yield gaps. Current rice production is not sufficient to meet the current national demand. As the possibility of expanding the area under crops in the future is very limited, the required extra production has to come through an increase in productivity. Long-term sustainability and better agronomic management and technological innovations are urgently required to address these issues.

Nitrogen is the most limiting nutrient for rice-based cropping systems (Thuy et al., 2008). The nitrogen use efficiency of lowland rice is very low because of various mechanism of nitrogen loss (Li et al., 2007). In the past various crop management practices were developed to increase nitrogen use efficiencies of the nitrogen fertilizer and minimize the losses (Chen et al., 2015). For the fixed-time adjustable dose N management and real-time N management were been implemented even in the farmers' levels, e.g. computerized decision support tools, chlorophyll meters (SPAD), green seeker (NDVI), leaf color charts, and the site-specific N management (Yadvinder et al., 2007; Huang et al., 2008; Peng et al., 2010). These tools provided a higher yield with slightly low nitrogen requirements and improved the nitrogen use efficiencies mostly in irrigated rice systems. In addition to this, split application of nitrogenous fertilizers is one of the alternative recommended approaches that increased grain yield, NUEs, and production profit with reduced N application simultaneously (Chen et al., 2015). Since farm sizes in Nepal usually being very small, and the labor shortage is always critical, the dissemination of such technologies has its limitation. A simpler and more convenient N fertilizer management is hence required.

Various approaches to N management, such as multiple split application and deep placement, can improve both rice yields and NUE and reduce N losses (Yao et al., 2018; Bandaogo, Bidjokazo, Youl, Safo, Abaidoo, & Andrews, 2015). Several studies have demonstrated the effects of controlled-release N fertilizer in enhancing rice yield and increasing the NUE (Ye et al., 2013; Geng et al., 2015; Zheng et al., 2017) while reducing N loss via ammonia volatilization, nitrous oxide (N_2O) production, surface runoff and leaching

(Chalk, Craswell, Polidoro, & Chen, 2015+; Li et al., 2017). Moreover, the advantage of controlled-release urea (CRU) is that it can be applied as a single basal dose, making it convenient for farmers to implement. Split application of N is more time consuming and labor intensive than is a single basal application (Chen, Wang, Liu, Chen, Lu., Jia, Grant et al., 2012). Furthermore, it is difficult for farmers to master the proper time of application and amount of topdressing of N fertilizer. CRU is helpful for decreasing the use of N fertilizer and saving time and labor inputs (Li et al., 2017; Grant et al., 2012). Many studies have shown that CRU can be applied once as basal fertilizer with no effect on rice grain yields (Yang, Zhang, Li, Fan, Geng, 2012). Theoretically, the cumulative N release of CRU follows a sigmoid pattern over time, which could provide better synchronization with rice N demands than Prilled urea. Particularly, certain CRUs could provide a sustained N supply to rice crops through prolonged N release, which is crucial for increasing N uptake at late growth stages of rice (Yang et al., 2012; Geng et al., 2015). The results of a field experiment conducted by Li et al. (2017) showed that CRU significantly increased the grain yield of late rice and the apparent N recovery by 6-18% and 3-17%, respectively, compared to urea application at the same N rate. Compared to Prilled urea application, application of CRU increased the agronomic efficiency of nitrogen (AE_N) and partial factor productivity of nitrogen (PFP_N) by 15.0-84.1% and 23.4-29.8% but varied across the soil types, respectively, during 2015-2017 (Chen, Wang, Ma, Zou, & Jianq, 2020). The practice of deep placing urea briquettes (UB) manually after the establishment of transplanted rice seedlings has increased the yields by improving the agronomic efficiency of nitrogen (Bulbule et al. 1996). Urea deep placement (UDP) can substantially increase rice yields by 15-20% and improve NUE up to 50-70% compared with surface broadcasting. Kadam et al. (2001) found that the placement of urea briquette enhances grain yield of rice over split application of urea and the additional yield varied from 0.23 to 1.48 t ha^{-1}. The deep placed Urea-DAP briquette increased grain yield of rice from 11 to 86% and gross yield 9 to 62% prilled urea (Deep, Bachkaiya, Tedia, & Verma, 2020).

Recently, a new type of environment-friendly CRU {polyurethane-coated urea (PCU) containing 44% N, Agrium Inc, 2016} has been introduced to farmers in nearby provinces of China at a lower cost. While UB is manufactured at the national level in Kathmandu. However, the critical physiological factors and agronomical traits that determine the high yield performance in irrigated rice cropping systems using PCU and UB are not yet fully known. Thus, this research was done to examine the response PCU and urea briquette UB on the yield, and nitrogen use efficiencies (NUE) in rice on sandy loam soil.

MATERIALS AND METHODS

Site description

The experiment was conducted at the research block of Agronomy Farm of Agriculture and Forestry University (AFU), Rampur, Chitwan district of Bagmati Province of Nepal (27°40' N and 84°23' E and 256 masl) from June to October 2019. The soil in the experimental field was sandy loam with slightly acidic pH, medium OM and nitrogen content, high phosphorus and medium potassium content (Table 1) according to the standard rating of the Government of Nepal, Kathmandu.

Table 1. Physico-chemical properties of the soil at Agronomy farm of Agriculture and Forestry University (AFU), Rampur, Chitwan, 2018/19

S.N.	Properties	Average Content	Rating	Methods and References
1.	Physical properties			
	Sand (%)	62.50	Sandy loam	Hydrometer(Estefan, Sommer & Ryan, 2014)
	Silt (%)	29.00		
	Clay (%)	8.50		
2.	Chemical properties			
	Soil pH	6.50	Acidic	Beckman Glass Electrode pH meter (Estefan et al., 2014)
	Soil organic matter (%)	3.00	Medium	Walkey and Black (Estefan et al., 2014)
	Total nitrogen (%)	0.14	Medium	Micro Kjeldhal Distillation (Estefan et al., 2014)
	Available phosphorus (kg ha $^{-1}$)	83.70	High	Modified Olsen's method (Estefan et al., 2014)
	Available potassium (kg ha $^{-1}$)	210.61	Medium	Ammonium Acetate method (Estefan et al., 2014)

The experimental site lies in the subtropical humid climate belt of Nepal. The area has the sub-humid type of weather condition with cool winter, hot summer, and distinct rainy season with an annual rainfall of about 2000 mm. The weather data during the cropping seasons were recorded from the NASA Power (https://power.larc.nasa.gov/data-access-viewer/) (Figure 1). During the growth period of crop i.e. from the third week of June to the last week of October, the total rainfall during the experimental period was 1251 mm and the average maximum temperature was 30.13˚C; the average minimum temperature was 24.06˚C, average relative humidity was 83.72%, and photosynthetic active radiation was 90.71 (Wm^{-2} day^{-1}).

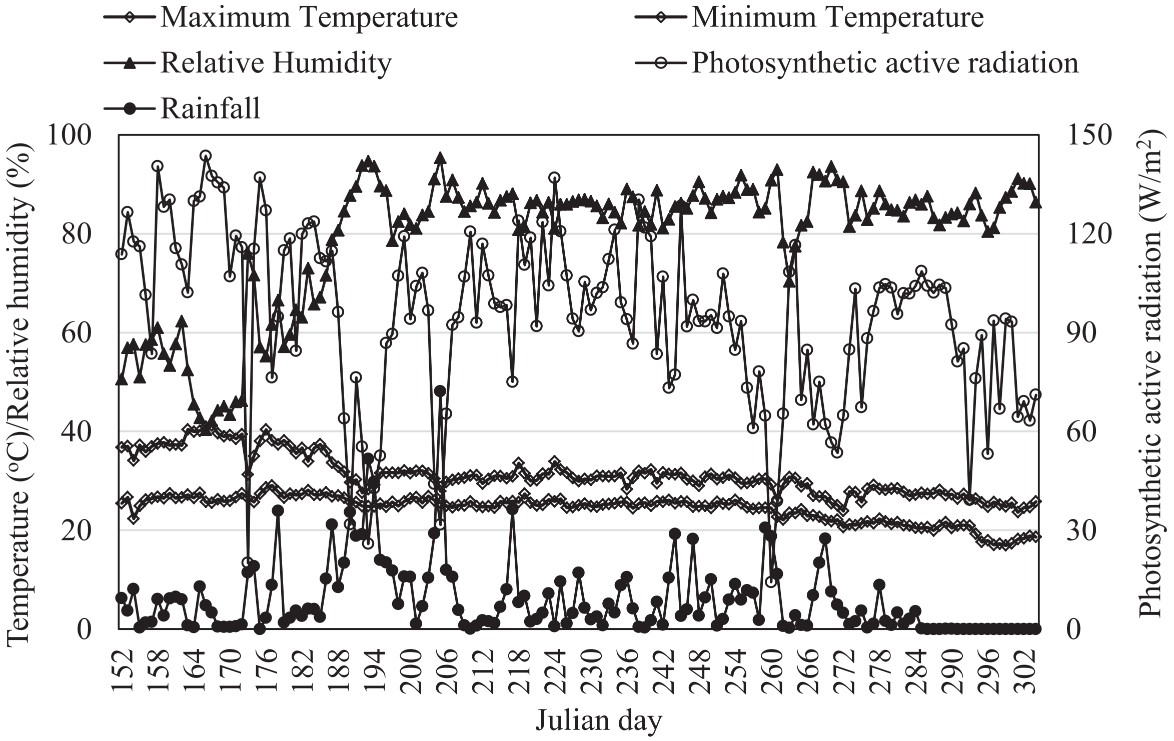


Figure 1. Minimum and maximum daily temperature (°C), daily photosynthetic active radiation (W m^{-2}) rainfall (mm), and daily relative humidity during the experimental period at Rampur, Chitwan, Nepal, 2019 (Source: NASA Power, 2022)

Experimental design and treatments

To evaluate the response PCU and UB on the yield, and nitrogen use efficiencies (NUE), an experiment consisting of five treatments consisting T_1 - control, 0 kg N ha^{-1}; T_2 - Prilled urea, 150 kg N ha^{-1} single application at basal; T_3 - Prilled urea, 150 kg N ha^{-1} standard split application; T_4 - PCU, 150 kg N ha^{-1} single application at basal; T_5 - UB, 150 kg N ha^{-1} single application at basal were laid out in a randomized complete block design with three replications. The variety was US-312, a hybrid rice of maturity days of 120. The plot size of the field was 3 m x 4 m (12 m^2).

Crop management

The field selected for the nursery was plowed 2-3 times till the soil was thoroughly pulverized. The width, length, and height of the seedbed were kept 1.5 m, 8 m, and 7 cm respectively to facilitate sowing, spraying of chemicals, weeding, and irrigation operation. The field was puddled with the help of a cultivator followed by one planking to get a good tilth of soil for transplanting. The 22 days old seedling was transplanted with the spacing of 20 cm x 20 cm row to row and plant to plant distance. Manual weeding was done at 20 and 45 days after transplanting. Fertilizer was applied in the basal dose and top-dress as per treatment.

A full dose of K_2O (80 kg ha^{-1}) and P_2O_5 (60 kg ha^{-1}) was applied through muriate of potash (MOP) and di-ammonium phosphate (DAP) as basal dose whereas N as per the treatment. Nitrogen fertilizer with 150 kg N ha^{-1} is used in the study except for control (0 kg N ha^{-1}). Nitrogen in treatments 2, 4, and 5 was a single basal application. UB was placed deep at 14 days after transplanting. Split application of urea for treatment 2 was 50% at the basal, 25% at the V_2 stage, and 25% at the V_9 stage (Counce, Keisling, & Mitchell 2000).

Data collection

Biomass yield and grain yield of rice were taken at harvesting from net plot i.e. 6.00 m^2. The crop was sun-dried in-situ for 3-4 days then threshed, sun-dried, cleaned, and final weight was taken along with grain moisture percent. The grain yield per hectare was computed for each treatment from the net plot yield. Finally, grain yield was adjusted at 14% moisture using the formula as:

$$\text{Grain yield (kg ha}^{-1}\text{) at 14\% moisture} = \frac{(100-\text{MC})\times\text{plot yield}(\text{kg})\times 10000\left(\text{m}^2\right)}{(100-14)\times\text{net plot area}\left(12.60\ \text{m}^2\right)} \quad (1)$$

Where MC is the moisture content in the percentage of the grains.

NUE can be defined in these indexes: agronomic efficiency (AE), and partial factor productivity of applied N (PFP). These were estimated using the following equations (Peng et al. 2002):

Agronomic efficiency (AE; kg grain kg^{-1} N)

= (grain yield of the treatments received N fertilizer - grain yield in control plot)/rate of N applied

Partial factor productivity of applied N (PFP; kg grain kg^{-1} N)

= grain yield of the treatments received N fertilizer/rate of N applied

Statistical Analysis

The data were subjected to analysis of variance, and Duncan's multiple range test at α level 0.05 (DMRT) for mean separations. Dependent variables were subjected to analysis of variance using the R Studio v 4.3.1 for randomized complete block design. Sigma Plot v. 12 was used for the graphical representation.

RESULTS AND DISCUSSION

Grain yield and nitrogen use efficiency

The grain yield among the different nitrogen sources were significantly different (Table 2). The yield of the control plot was about half of the 150 kg N ha^{-1} application. The application of 150 kg N ha^{-1} all as the basal application had the yield advantages of 61% obtained over control, while with the half nitrogen as basal and half nitrogen as a top dressing in two equal splits (standard split application) resulted in the yield advantage of about 109% over control. The standard split nitrogen application had a yield advantage of 24.8% overall nitrogen application as basal application. The nitrogen application of 150 kg ha^{-1} from PCU and UB in the single application was equally productive as compared to Prilled urea adopting the standard split application, which implies labor-saving under the new approach of nitrogen management. The agronomic efficiency and partial factor productivity of three sources of the nitrogen PCU and BU in the single application and Prilled urea adopting the standard split application were statistically similar to each other and higher than the all nitrogen as the basal application and the control plots.

Table 2. Effect of source of nitrogen on the grain yield and nitrogen use efficiency of US 312 of rice at Rampur, Chitwan Nepal, 2019

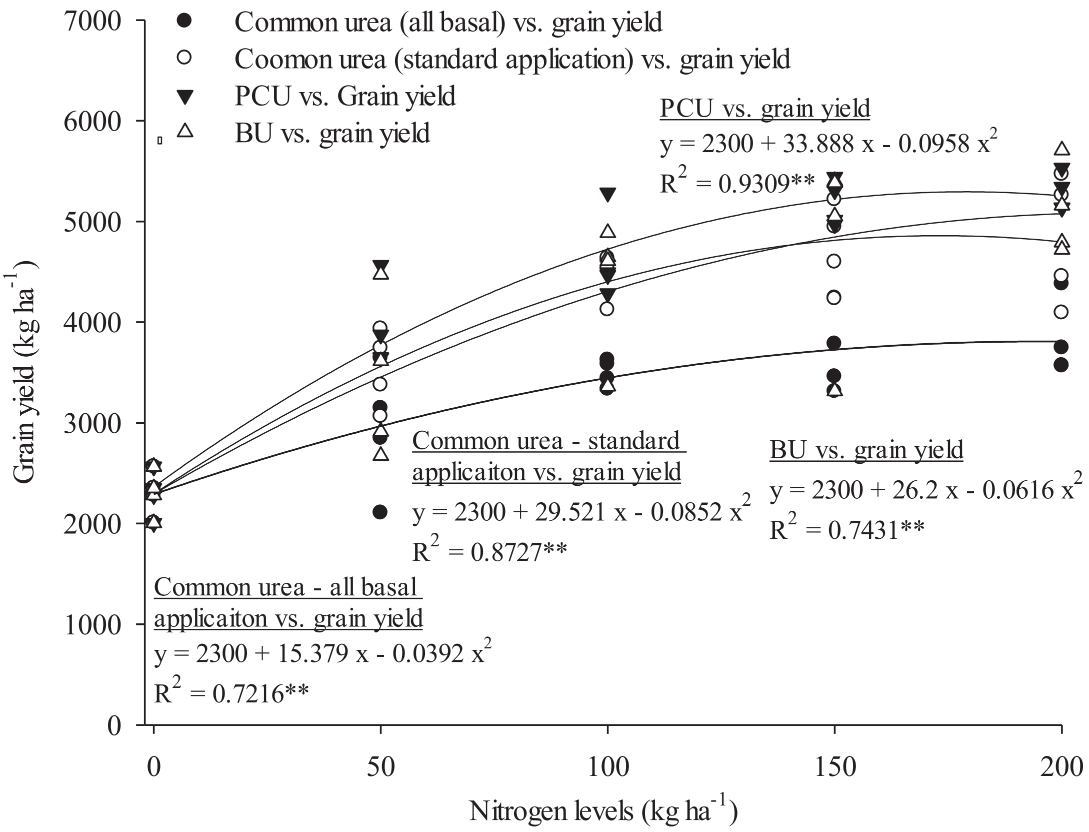
Treatments	**Grain yield (kg ha^{-1})**	**Yield advantage over control (%)**	**Agronomic efficiency (kg grain kg^{-1} of N)**	**Partial factor productivity (kg grain kg^{-1} of N)**
Control (0 kg N ha^{-1})	2300^{c}	-	-	-
Prilled urea -all basal (150 kg N ha^{-1})	3698^{b}	61.39^{b}	9.32^{b}	24.65^{b}
Prilled urea - standard application (150 kg N ha^{-1})	4747^{a}	108.96^{a}	16.31^{a}	31.64^{a}
PCU (150 kg N ha^{-1})	5183^{a}	127.62^{a}	19.22^{a}	34.55^{a}
UB (150 kg N ha^{-1})	4787^{a}	109.24^{a}	16.58^{a}	31.92^{a}
Grand mean	4143	101.80	15.36	30.69
SEm (±)h	285.6	14.14	2.13	2.13
P value	<.001	0.046	0.047	0.047
LSD (0.05)	879.9	45.22	6.80	6.80
CV, %	13.8	27.8	27.7	13.9

Note: SEM, Standard error of the mean; LSD, least significant difference; CV, coefficient of variation.

Treatments mean followed by a common letter (s) within column are not significantly different among each other based on DMRT at 0.05 level of significance.

Optimum level of PCU and UB for hybrid rice

The response of the different nitrogen sources has been presented in Figure 2. For the maximum yield, 196 kg N ha^{-1} must be applied in the case of Prilled urea all as the basal application which produced the yield of only 3,808 kg ha^{-1} whereas application of only 173 kg N ha^{-1} for Prilled urea adopting the standard split application and 177 kg N ha^{-1} for PCU resulted in the yield of 4857 kg ha^{-1} and 5297 kg ha^{-1}respectively. If we look at the economy, the nitrogen required for the Prilled urea all as the basal application was 183 which produced the yield of only 3802 kg ha^{-1} whereas it was only 167 kg N ha^{-1} for Prilled urea adopting the standard split application and 124 kg N ha^{-1} for PCU that resulted in the yield of 4854 kg ha^{-1} and 5029 kg ha^{-1}, respectively, while for the BU it was 195 kg N ha^{-1} that result in the yield of 5067 kg ha^{-1}. The result revealed that both the physical maximum and economic maximum level of the nitrogen were higher for the PCU and BU than the standard split application of the nitrogen.



Level of nitrogen	Conventional urea single application	Conventional urea standard split application	PCU single application	UB single application
Physical maximum levels of nitrogen	196 kg ha^{-1}	173 kg ha^{-1}	177 kg ha^{-1}	213 kg ha^{-1}
Economic maximum levels of nitrogen	183 kg ha^{-1}	167 kg ha-1	124 kg ha^{-1}	195 kg ha^{-1}

Figure 2. Response of nitrogen on grain yield of rice hybrid US 312 of rice at Rampur, Chitwan, Nepal, 2019

Note: **, significant at 0.01 level of significance

Urea fertilizers are being used mainly by the farmers as the main source of nitrogen. Generally, urea is applied as a broadcast method. But, the efficiency of applied N from urea fertilizer is very low which is attributed to losses like volatilization, denitrification, leaching, and surface run-off. These losses can be reduced by management practices deep placement of N fertilizers and polymer coated urea. Among those, deep placement of fertilizers (urea briquette) into the anaerobic soil zone is an effective method to reduce loss of N.

The yield of PCU was the highest, which benefited from its good effect on controlling release (Shaviv, 2001). PCU can release N gradually, but N release rate was dependent on time and temperature (Gandeza & Shoji, 1991; Golden et al., 2011). In field research of polyolefin coated urea, Gandeza & Shoji (1991) expressed the relationships as a quadratic equation between N cumulative release rate and cumulative air temperature. Wilson, Rosen, & Moncrief (2009) suggested cumulative N release rate of this PCU was linear with days after planting. These researches suggested that application of this kind of control release urea can improve N supplement for rice in the whole growing season.

Over 50% of N was lost (Zhu & Chen, 2002). Fageria, Slaton, & Baligar (2003) summarized several lost ways of fertilizer N: ammonia volatilization, denitrification, surface runoff, and leaching. Fertilizer coating can protect nutrient core through physical and chemical ways (Trenkle, 1997). For decades, many control-released fertilizers have been developed and evaluated for increasing yield and fertilizer use efficiencies (Gandeza & Shoji 1991; Trenkle, 1997; Shaviv, 2001; Yang et al., 2012). Ye et al. (2013) reported PCU can improve root growth to increase rice dry matter accumulation and yield. A greenhouse experiment on comparison of conventional urea and PCU suggested there was no significant difference on yield and yield component (Fageria & Carvalho, 2014). The present field study confirmed this view.

Urea as a single basal fertilizer was not a good choice in irrigation rice fertilizer practice, which was a great waste. The agronomy efficiency was only 9.32 kg grain per kg of applied nitrogen (Table 2). Urea does not remain in the soil for a long time, especially in high temperatures. Urea is rapidly hydrolyzed to ammonium in the soil–water system (Fageria, Slaton, & Baligar, 2003). Compared with the relatively lower AE of conventional urea, PCU improved a lot though non-significant. PCU released slowly to reduce N loss through ammonia volatilization, denitrification, surface runoff, and leaching (Trenkle, 1997; Peng et al., 2002; Fageria, Slaton, & Baligar, 2003). PE was a stable index regardless of yield level.

According to Crasswell & de Datta (1980) broadcast application of urea on the surface soil causes losses up to 50% but point placement of urea super granule in 10 cm depth may negligible loss. Urea Super Granule (USG) is a fertilizer that can be applied in the root zone at 8-10 cm depth of soil (reduced zone of rice soil) which can save 30% nitrogen than prilled urea, increase absorption rate, improve soil health and ultimately increase the rice yield. In the present experiment, the agronomy efficiency and partial factor productivity of UB as a single application was similar to the standard split application of conventional urea but significantly higher than the conventional urea as a single application (Table 2). UB applied treatment can be attributed to a reduction in loss of nitrogen in different forms that usually happen with urea broadcasting (Halvorson & Del Grosso, 2013; Jiang, Lu, Zu, Zhou, & Wang, 2018). In Bangladesh, the yield of rice was increased by 15-25% while expenditure on commercial fertilizer was decreased by 24-32% when fertilizer briquettes were used as the source of plant nutrients. Deep placement of fertilizer briquettes also environmental and economic benefits (IFPRI, 2004).

CONCLUSION

The rice grain yield and NUE were higher using PCU and UB urea as compared to conventional urea as a single application but similar with the three standard split application of conventional urea. NUE also had been greatly improved by the use of PCU and UB than conventional urea as a single application. PCU and UB with single application can be considered as an alternative nitrogen fertilizer for rice in sandy loam soil.

ACKNOWLEDGEMENTS

Author greatly acknowledge the reviewers and editorial team of the Journal of Agriculture and Forestry University, Rampur, Chitwan, Nepal for providing the feedbacks and comments on this manuscript.

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