Research article

Field evaluation of slow-release nitrogen fertilizers and real-time nitrogen management tools to improve grain yield and nitrogen use efficiency of spring maize in Nepal

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ABSTRACT

Several innovative fertilizers and application methods, along with different decision support tools have been developed to improve nitrogen use efficiency (NUE) and crop yields, but their comparative study in maize is yet to be done in Nepal. Thus, we evaluated different slow-release N fertilizers and decision-making tools for real-time N management compared with the common urea on their effectiveness in increasing NUE, grain yield and economic return of spring maize (*Zea mays* L. cv. Rampur Hybrid-10). A field trial was conducted at Dang Valley of Nepal in a Randomized complete block design with three replications and seven treatments; N omission- (0 kg N ha^{-1}), normal urea at 120 kg N ha^{-1} (recommended dose, N120), and 180 kg N ha^{-1}(N180), Polymer Coated Urea (PCU-90 kg N ha^{-1}), Urea Briquette-deep placement (UDP- 90 kg N ha^{-1}), GreenSeeker (GS- 143 kg N ha^{-1}) and Leaf Color Chart based N management (LCC- 143 kg N ha^{-1}). N application based on decision support tools (LCC and GS) and innovative fertilizers (UDP, PCU) yielded 17.35–45.81% more grain yield than recommended dose (RDF). The real time nitrogen application through LCC and GreenSeeker and slow release N fertilizer (PCU and UDP) resulted in higher agronomic efficiency of nitrogen- AEN (21.30–27.82 kg grain kg^{-1} N) compared to RDF (12.15 kg grain kg^{-1} N) and N180 (19.87 kg grain kg^{-1} N). UDP, with 25% less N compared to RDF, resulted in higher grain yield (5.25 t ha^{-1}), partial factor productivity of N– PFPN (58.37 kg grain kg^{-1} N) and AEN (27.82 kg grain kg^{-1} N). Based on the economic return and ease in the application, both UDP and LCC based N application seem promising in Nepalese conditions. However, their effectiveness should be validated across diverse agro-ecologies, soil types and climatic conditions for a general recommendation.

1. Introduction

Maize is the second most important crop of Nepal after rice. It is cultivated in an area of 959,655 ha and the average productivity is 3.05 t ha^{-1} (MoF, 2021). In recent years, cultivated area, total production and productivity of maize have been increased by 0.1%, 3.22% and 3%, respectively (MoF, 2021). However, the current average yield is still much lower than the country's attainable yield of 5.7 t ha^{-1} and the average yields of other South-Asian countries (FAOSTAT, 2021; KC et al., 2015). Besides the fact that the country has adopted high yielding varieties and improved agricultural technologies, yield of maize in Nepal is low due to inefficient fertizer management (Dhakal et al., 2021; KC et al., 2015; Paudel et al., 2009). Judicious application of fertilizers following the good agricultural practices, along with the cultivation of high yielding varieties could possibly reduce the yield gap and increase overall maize production (Devkota et al., 2016).

In Nepal, Di-ammonium phosphate (DAP), Urea and potash are the dominant fertilizers used by farmers. Among them, famers prefer urea as it is relatively cheaper (due to government subsidy) and also give quick response to plants (Paudel et al., 2009). However, application of urea is inefficient and more than 50% of applied N is being lost due to leaching, denitrification and volatilization resulting in lower nitrogen use

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efficiency (NUE) (Jun-Gang et al., 2011; Khosla et al., 2002). These losses have not only affected on the yield and soil fertility, but also contribute to climate change and environmental pollution (Cameron et al., 2013). The extent to which the nitrogen gets lost from the applied fertilizer depends on crop management practices, the soils, and climate (Cameron et al., 2013).

The management practices involving new technologies should be adopted to increase NUE and crop productivity. Some of the commonly available strategies to increase NUE and crop yields are real-time N managmeent using Leaf Color Chart (LCC), and GreenSeeker (GS) optical sensor, use of controlled release fertilizers such as Polymer Coated Urea (PCU) and improved application method such as Urea Deep Placement (UDP) (Cameron et al., 2013; Ladha et al., 2005). PCU is one of the promising controlled release nitrogen fertilizers coated with polymer, which is water insoluble and release N slowly synchronizing plant demand. Release of N is controlled by the soil temperature (LeMonte et al., 2016). When the temperature is warm enough the PCU releases nitrogen and plants can absorb it, and during cool periods, it allows protection of N (Hopkins et al., 2008). Similarly, urea briquette (physically compressed prilled urea to a larger granule, or urea super granule) applied as deep placement, commonly known as UDP (Deo et al., 2019), retains plant available N for a prolonged period (Gaihre et al., 2015). In Nepal, Dhakal et al. (2020) had reported that UDP technology reduced 25% nitrogen input while producing similar yields with relatively higher agronomic and economic efficiencies compared to recommended dose of fertilizers. Due to slow release mechanism and reduced losses, in most of the studies, both PCU and UDP have been applied in less amount compared to normal urea. Nitrogen rate in UDP and PCU reduced by up to 25–40% compared with government fertilizer recommendations (Baral et al., 2021; Dhakal et al., 2020).

Real-time N managmeent using different decision support tools such as LCC and GS optical sensor are effective to increase NUE and Yields (Ladha et al., 2005; Swamy et al., 2016). The LCC is a health indicator tool, which is inexpensive, easy to use-farmers can use it based on the visual observation of leaves (Ladha et al., 2005). Comparison of LCC based nitrogen application starting from V6 stage to before R1 (silking) stage at threshold value 5, 5.5 and 6 with blanket recommendation in maize reported that LCC threshold value at 5 saved 20–50% of fertilizer N (Singh et al., 2014). Similarly, in sweet corn, LCC threshold at 5 and GS optical sensor threshold at NDVI 0.8 provided higher economic return than the blanket recommendation of same dose (Swamy et al., 2016).

GreenSeeker is a remote sensing tool equipped with an active sensor that emits its own radiation and calculates the normalized difference vegetative index (NDVI) value of the plant. NDVI measures the greenness of the vegetation and the index varies from 0 to 1 where value less than zero includes no vegetation or non-green vegetation, greater than zero represents the vegetation with varied level of greenness. Based on the NDVI value, nitrogen is applied in the soil either using algorithm or based on threshold levels (Paik, 2018; Swamy et al., 2016).

The blanket recommendation (the same rate across diverse soil and agroecologies) of fertilizers in Nepal has not been effective as the nitrogen requirement varies with the locations due to differences in microclimate and soil conditions, and the rate and time of fertilizer application may not synchronize the crop N demand (Alam et al., 2013; Baral et al., 2021). Moreover, the most common method of fertilizer application adopted by Nepalese farmers is broadcasting (Alomia-Hinojosa et al., 2018), which further increases the nutrient loss through denitrification, volatiliization and surface runoff (Cai et al., 2002; Datta et al., 1991). Few studies were conducted in slow release fertilizers such as PCU and improved application methods such as UDP in maize. However, studies on the effectiveness of real-time N management using decision support tools on NUE and maize yields are limited in Nepal. Therefore, this study was conducted to evaluate decision support tools- LCC and Green Seeker compared with PCU, UDP and common urea for grain yield, NUE and economic return of spring maize at Mid-Western Terai region of Nepal.

2. Materials and methods

2.1. Experimental site, soil and climate

A field experiment was conducted at Gadwa Rural Municipality- 05, Bodhipur, Dang, Nepal (latitude: 27.826043N; longitude: 82.539683E, altitude: 269.32 m above sea level) from January to June, 2020 (Figure 1). The monthly mean temperature was highest in May (36 °C) and lowest in January (17 °C). Similarly, the highest monthly rainfall was observed in June (447.9 mm) and the lowest in February (14.2 mm). The weather data from January to June is given in Figure 2. A composite soil sample (0–15 cm depth) was analyzed for soil pH, organic matter (OM), available P_2O_5 and K_2O following the standard protocols. Analysis report indicated that the soil was alkaline (pH- 7.90) with medium organic matter (3.20%), and nitrogen (0.16%), and higher P_2O_5 (324.78 kg ha^{-1}) and K_2O (419 kg ha^{-1}), respectively.
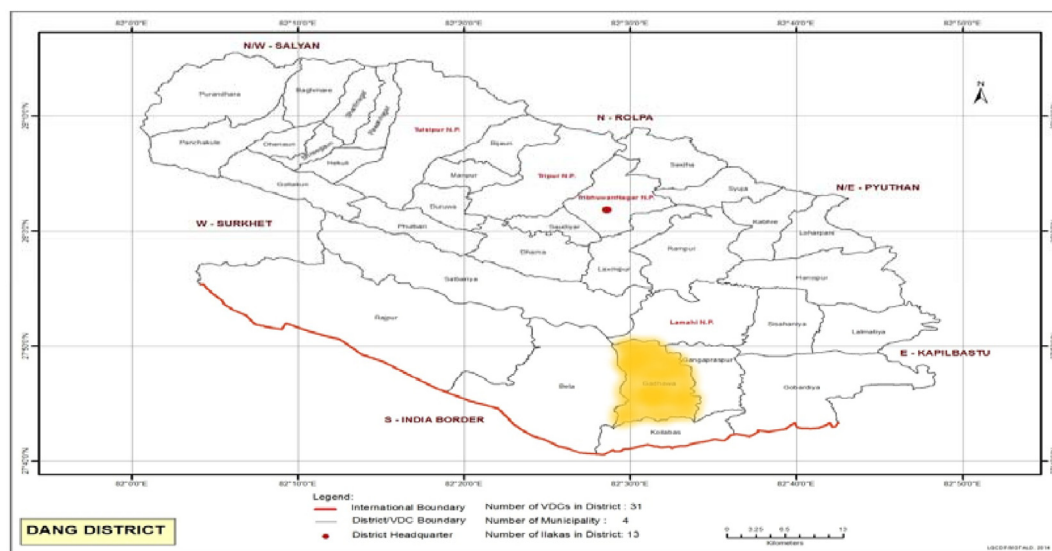

Figure 1. Map of Dang district (Mid-western terai region of Nepal) showing the study site at Gadwa rural municipality. The section with yellow color represents the study area. Source: http://lgcdp.gov.np/sites/default/files/GIS/56_Dang.jpg.
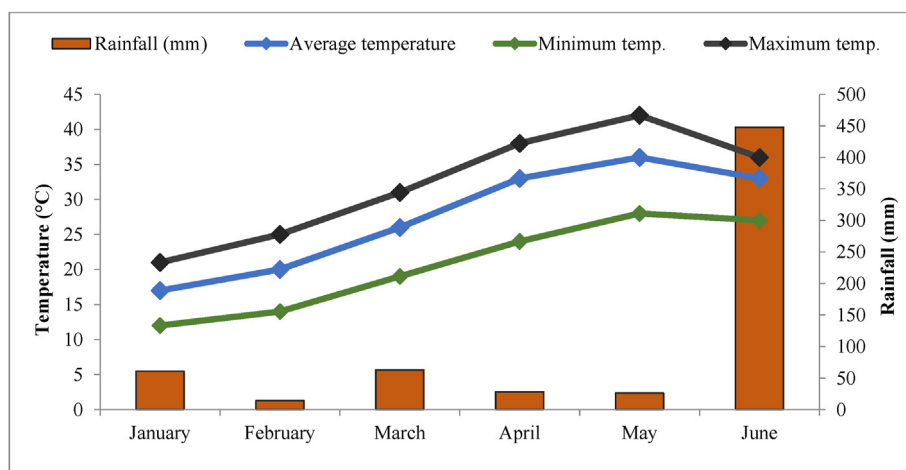
Figure 2. Average monthly rainfall and air temperature recorded during the study period (Jan–June, 2020). Minimum, average and maximum temperatures are represented in primary vertical axis, whereas rainfall is in a secondary vertical axis. Weather data was obtained from world weather online database for Dang district of Nepal (https://www.worldweatheronline.com/dang-weather-averages/np.aspx).

2.2. Field experiment

2.2.1. Research design

Seven fertilizer treatments (Table 1) were arranged in a Randomized Complete Block Design with three replications. Size of each experimental plot was 10.8 m^2 (3.6 m × 3 m). The alley between replication was 50 cm wide while a 10 cm spacing was maintained between plots within the replication. The net harvest area was 5.4 m^2. A hybrid variety of maize (Rampur hybrid- 10) was used for sowing at a spacing of 60 cm × 25 cm. All the cultural practices were performed as recommended by the government of Nepal.

2.2.2. Fertilizer management practice

In each treatment, P_2O_5 and K_2O were applied after final land preparation before seed sowing at the rate of 60 and 40 kg ha^{-1} in the form of Diammonium phosphate (DAP) and Murate of Potash (MoP), respectively. However, for treatment with no nitrogen (N0) plot, single super phosphate (SSP) was applied to ensure zero N input. Side placement was performed for all the fertilizers except for UDP. Urea Deep Placement was applied to the spots created between the two adjacent maize plants within a row at a rate of one granule (approximately 2g) per spot at a depth of 6 cm below the surface after emergence of the plant. In PCU

treatment, side placement at 5 cm away from the spot and 4 cm deep was performed during sowing. Urea application for RDF and N180 treatments was done in three equal splits at basal, V6 and V10 stages (top dressings).

For Leaf Color Chart based measurement, ten plants from each plot were randomly selected and a fully matured penultimate leaf was matched with the leaf color chart. When six plants showed the reading less than 5, urea was applied at the rate of 30 kg per hectare. In case of Green Seeker, it was engaged and moved along the row of maize plot and data was recorded. If the data did not meet the threshold value 0.8, urea was applied at 30 kg per hectare rate to the plot. Four LCC and GS based readings were taken at a 15 days interval. The total of 120 kg ha^{-1} N; 30 kg ha^{-1} each-four times, was applied based on LCC and GS readings, and additional 23 kg ha^{-1} N was applied through DAP (18% N and 46% P_2O_5), thus 143 kg ha^{-1} N application was done in both the treatments.

2.3. Plant sampling and data recording

Data related to yield and yield attributes viz. plant (PH- cm) and ear height (EH- cm), plant population at harvest (PPH), number of ears per plot (NOE), stover yield (SY- t ha^{-1}), thousand grain weight (TKW- gm), grain yield (GY- t ha^{-1}) and plant sterility were recorded from net harvested area at the maturity stage before harvesting, while TKW and GY were recorded after shelling and proper drying of the grains. Cob length (CL-cm), number of rows per cob (NORPC), and number of kernels per row (NOKPR) were recorded after harvesting and proper drying of cobs.

PH was recorded as a length from ground surface to the first tassel branch, while EH was recorded as a length from ground surface to the base point of ear in the plant. Stover yield was determined based on the oven dried weight. Grain and stover yields from each treatment were converted to tons per hectare using Eqs. (1) and (2), respectively (Dhakal et al., 2020). Moisture content of the grain was recorded using Wile-55 moisture meter and adjusted at 14%. Harvest index (HI) was calculated as a ratio of grain yield to the overall biological yield (grain + stover yield). Thousand grains were counted from the dried grains and weighed to determine TKW in grams. Agronomic efficiency (AEN- kg grain yield kg^{-1} N) and partial factor productivity (PFPN) of N were calculated using Eqs. (3) and (4), respectively (Ladha et al. (1998).

Table 1. Details of the treatments employed in the field experiment.

Treatments	Abbreviations	Treatment details
T1	N0	0:60:40 kg $NP_2O_5K_2O$ ha^{-1}, SSP is used as source of phosphorus
T2	RDF	120: 60:40 $NP_2O_5K_2O$ ha^{-1},N applied from normal urea at three splits at basal, V6 and V10 stages
T3	N180	180:60:40 $NP_2O_5K_2O$ ha^{-1}, N applied from normal urea at three splits at basal, V6 and V10 stages
T4	PCU	90:60:40 kg $NP_2O_5K_2O$ ha^{-1}. N applied from Polymer Coated Urea (PCU) as a basal dose
T5	UDP	90:60:40 kg $NP_2O_5K_2O$ ha^{-1}, N applied from Briquette Urea as a basal dose (applied as urea deep placement (UDP))
T6	LCC	143:60:40 kg $NP_2O_5K_2O$ ha^{-1}, N applied based on LCC at critical value ≤4; 30 kg N ha^{-1} applied when threshold was met
T7	GS	143:60:40 kg $NP_2O_5K_2O$ ha^{-1}, N applied based on GreenSeeker value (NDVI value) at 0.8, 30 kg N ha^{-1} applied when threshold data was not obtained.

Remarks: SSP- single super phosphate (0:16:0 NPK), N- nitrogen, DAP- diammonium phosphate, MoP- murate of potash, RDF- government recommended dose of fertilizers.

$$GY \ (t \ ha^{-1}) = \frac{Plot \ yield \ (Kg)}{Net \ harvested \ area \ (m^2)}$$
$$\times \frac{(100 - \ recorded \ moisture)}{(100 - adjusted \ moisture)} \times \frac{10000}{1000} \qquad (1)$$

Table 2. Effect of different N treatments on yield attributing traits of maize (cv, Rampur hybrid- 10).

Treatments	PH (cm)	EH (cm)	PPH	NOE	NORPC	NOKPR	CL (cm)	TKW (g)	SY (t ha^{-1})	HI
N0	150.67 b	69.22 d	64815	33	12	18 b	10.97 b	294.33 e	9.16 c	0.23 b
RDF	180.25 a	87.13 bc	64197	34	13	24 a	13.45 a	310.67 d	10.26 bc	0.29 a
N180	191.33 a	94.14 ab	63580	34	13	27 a	14.15 a	352.00 a	12.26 a	0.34 a
PCU	191.81 a	85.71 bc	64815	34	13	24 a	13.37 a	313.33 d	11.81 ab	0.29 a
UDP	184.17 a	96.46 a	63580	34	13	26 a	12.91 a	327.33 c	12.05 a	0.30 a
LCC	181.87 a	85.15 c	61728	33	14	25 a	13.73 a	340.00 b	13.00 a	0.32 a
GS	179.27 a	82.11 c	65432	33	14	25 a	13.61 a	332.67 bc	11.80 ab	0.33 a
Grand mean	179.91	85.7	64021.16	33.67	13.37	24.25	13.17	324.33	11.48	0.3
P- value	0.02*	<0.001**	0.6 ns	0.92 ns	0.17 ns	0.02*	0.03*	<0.001**	<0.01**	0.02*
StdMSE	11.8	5.05	2385.03	1.67	0.64	2.4	0.98	6.52	0.92	0.03
LSD	20.98	8.98	4242.95	2.97	1.13	4.28	1.73	11.59	1.64	0.06
CV (%)	6.56	5.89	3.73	4.96	4.76	9.92	7.4	2.01	8.05	10.5

Remarks: PH- plant height, EH- ear height, PPH- plant population at harvest, NOE-number of ears per plot, NORPC- number of rows per cob, NOKPR-number of kernels per row, CL-cob length, TKW- thousand kernel weight, SY- straw yield, HI- harvest index, N0- 0 kg N ha^{-1}, RDF- 120 kg N ha^{-1}, N180- 180 kg N ha^{-1}, PCU- polymer coated urea (90 kg N ha^{-1}), UDP- urea briquette deep placement (90 kg N ha^{-1}), LCC- Leaf Color Chart (143 kg N ha^{-1}), GS- GreenSeeker (143 kg N ha^{-1}), StdMSE-standard mean sum of error, LSD-least significant difference, CV- coefficient of variation, * indicates significant difference at P < 0.05, ** indicates significant difference at P < 0.01, similar statistical letters within the column indicates non-significant effect of the treatments (P < 0.05).

$$\text{Stover yield } (\text{t ha}^{-1}) = \frac{\text{Plot yield (Kg)}}{\text{Net harvested area } (\text{m}^2)} \times \frac{10000}{1000} \qquad (2)$$

$$\text{Agronomic efficiency of N } (\text{AEN}) = (GY_N - GY_0)/FN \qquad (3)$$

$$\text{Partial Factor Productivity of N } (\text{PFPN}) = \frac{GY_N}{FN} \qquad (4)$$

In the above equations (Eqs. (1) and (2)), multiplication factors 10000 and 1000^{-1} were applied to convert m^2 to hectare (area), and kilograms to metric tons (yield). Similarly, GY$_N$, GY$_0$, and FN represent grain yield (kg ha^{-1}) in nitrogen treated plots, grain yield in nitrogen omission-control treatment (kg ha^{-1}), and doses of N applied (kg ha^{-1}), respectively.

2.4. Economic analysis (partial budget analysis)

Costs related to the cultural and fertilizer management practices were considered for economic analysis of each treatment. The actual grain and straw yields were reduced by a factor of 0.1 as suggested by Badu-Apraku et al. (2012). The B:C ratio was calculated using the following equation (Dhakal et al., 2021).

$$\text{Benefit : Cost ratio} = \frac{\text{Gross Return}}{\text{Gross production cost}} \qquad (5)$$

2.5. Statistical analysis

Microsoft excel 2007, and ADEL-R software (Pacheco et al., 2017) were used for data compilation and analysis. One way analysis of variance (ANOVA) of response variables was done with ADEL-R and mean comparison of the statistically significant variable was done by least significant difference test (p ≤ 0.05).

3. Results and discussion

3.1. Agronomic and yield attributing traits

Different N treatments had a significant (p < 0.05) effect on plant height, ear height, number of kernels per row, cob length, thousands kernel weight, stover yield, and harvest index. The lowest plant height was recorded in N omission treatment (no N application), while the highest was in PCU (Table 2). The adequate supply of nitrogen at

appropriate growth stages of maize could increase plant growth, the number of nodes and internodes, resulting in increased plant height (Adhikari et al., 2016). Similarly, the number of kernels per row, cob length, and harvest index were recorded the highest in N180 treatment, while all other treatments were statistically similar except for the N omission treatment (N0). The statistically similar harvest index in different N treatments demonstrated that UDP and PCU were able to improve maize reproductive efficiency despite its application in reduced doses. In addition to fertilizers, harvest index could also be affected by climatic and soil conditions; thus, favorable conditions tend to improve the harvest index in maize (Ion et al., 2015). Different sources and methods of N- application resulted non-significant effect in number of ears per plot (NOE) and number of kernel rows per cob (NORPC) (Table 2). These traits might be genetically controlled, thus N dose could not effect on them (Dhakal et al., 2021). In accordance with these results, several researchers reported non-significant effect of N doses on NOE and NORPC in maize (Adhikari et al., 2021; Dhakal et al., 2021; Ngosong et al., 2019; Sharma et al., 2019).

Nitrogen treatments had significant effects on thousand grain weight. The N180 treatment had the highest thousand grain weight. Slow nitrogen release fertilizers and decision support tools (LCC and Green-Seeker), produced significantly higher (p < 0.5) thousand kernel weight compared to RDF. The lower thousands kernel weight in slow-release nitrogen fertilizers and decision support tools compared to the N180 could be due to less amount of nitrogen applied in these treatments. Higher N application could increase dry matter deposition in grains compared to lower doses, thus TKW was higher in N180 (Dhakal et al., 2021). Corroborating our results, Ding et al. (2005) and Cheetham et al. (2006) reported higher dry matter deposition in grain at higher doses of N application.

In terms of stover yield, LCC-based nitrogen application, UDP and N180 treatments produced significantly higher yield compared to RDF. However, the yield differences among these treatments were statistically similar. These results further support the findings of previous studies which depicts that with increase in nitrogen doses, stover yield and thousands kernel weight of hybrid maize increased in Nepalese condition (Dawadi and Sah, 2012; Dhakal et al., 2020; Sapkota et al., 2017). Majority of agronomic and yield attributing traits were positively influenced by the application of slow-release and deep placed N fertilizers, the slow-release nature of these fertilizers and the improved application method might have enhanced supply and uptake of N, and attributed to increase in photosynthesis, inter-node elongation and overall vegetative performance of the crop (English et al., 2017; Adhikari et al., 2016).
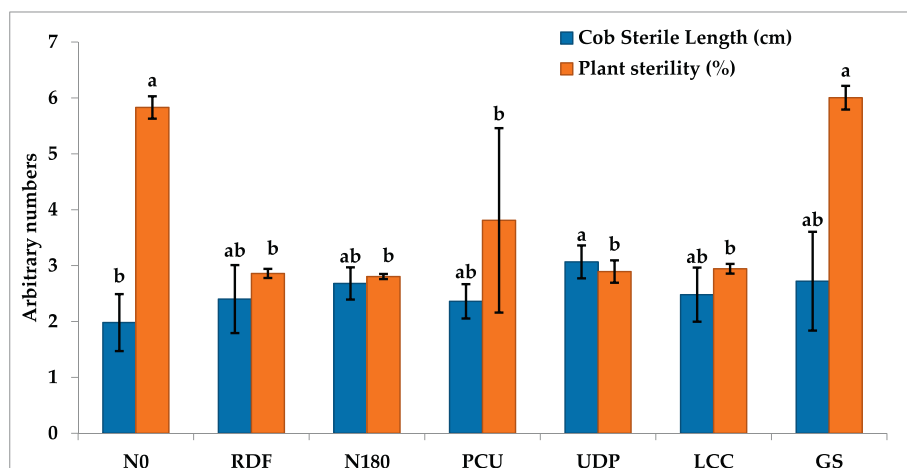
Figure 3. Plant and cob length sterility in Rampur hybrid-10 variety of maize as influenced by different N treatments. Length of the cob from the tip without kernels was recorded as cob sterile length. N0- 0 kg N ha^{-1}, RDF- 120 kg N ha^{-1}, N180- 180 kg N ha^{-1}, PCU- polymer coated urea (90 kg N ha^{-1}), UDP- urea briquette deep placement (90 kg N ha^{-1}), LCC- Leaf Color Chart (143 kg N ha^{-1}), GS- GreenSeeker (143 kg N ha^{-1}), similar statistical letters within the column indicates non-significant effect of the treatments (P < 0.05).

3.2. Plant and cob length sterility

As shown in Figure 3, different nitrogen sources had a significant (p < 0.05) effect on both cob sterile length and plant sterility of hybrid maize. Plant sterility was found to be highest in the N omission treatment (N0) and GS-based treatments, with all other treatments being statistically similar. However, the sterility percentage was at or below 6% (Figure 3) in all the treatments. Marahatta (2020) reported that nitrogen levels do have its influence on plant and cob sterility and it decreases with increase in nitrogen levels. However, our finding is contrasting to the previous findings, it may be because sterility varies with genotypes, environmental conditions, nitrogen levels and sources and their integration (Marahatta, 2020; Olness et al., 1990; Subedi et al., 2006).

3.3. Grain yield

Nitrogen fertilizer treatments (sources and application methods) had significant (p < 0.05) effects on grain yields, with an average mean grain yield of 5.45 t ha^{-1} for N applied treatments (Figure 4). Treatment N180 produced the highest grain yield (6.39 t ha^{-1}). LCC (6.12 t ha^{-1}) and GreenSeeker (5.80 t ha^{-1}) at the reduced dose (143 kg N ha^{-1}), produced statistically similar grain yields with N180. This could be due to the fact that the LCC and GS-based N were able to synchronize the plant N demand due to the split application of N in small doses (Sruthi et al., 2018). Our results are in close agreement with previous studies (Shrestha et al.,

2018; Srivastava et al., 2018). In addition, LCC and GreenSeeker yielded 45.8% and 37.52% more maize grain yield than the recommended dose (4.20 t ha^{-1}), respectively. Our results are consistent with the earlier reports where real-time nitrogen application increased maize grain yield (Biradar et al., 2012; Sruthi et al., 2018; Swamy et al., 2016).

Despite the fact that less nitrogen was applied, UDP (5.25 t/ha) and PCU (4.94 t/ha) yielded 24.7 and 17.33% more grain than the recommended dose (Figure 5). Since UDP and PCU are deep placed at plant root zone, they might have reduced N losses through volatilization, and denitrification, contributing to an increase in grain yield (Beshir et al., 2019; Dhakal et al., 2020; Umesha et al., 2017). The yield gap between real-time nitrogen application and slow nitrogen release fertilizers is 1 t ha^{-1}. The reason for this could be that more nitrogen was applied in LCC and GS-based N management than in UDP and PCU. Higher N application increased dry matter deposition in grains compared to lower doses (Dhakal et al., 2021; Ding et al., 2005; Cheetham et al., 2006). The overall comparison shows that normal urea has a low use efficacy in terms of grain yield when compared to real-time N application methods and slow-release nitrogen fertilizers. Though, P$_2$O$_5$ and K$_2$O were applied at the recommended dose in N control (N0) treatment, they could not significantly effect on grain yield of the hybrid maize. Availability of N fertilizer to crops is greatly limited by the phosphorous amount present in the soil. The higher P$_2$O$_5$ content in soil (external supply- 60 kg ha^{-1} and higher indigenous supply- 324.78 kg ha^{-1}) might have affected in soil N availability in N0 treatments, despite N content in soil was medium-
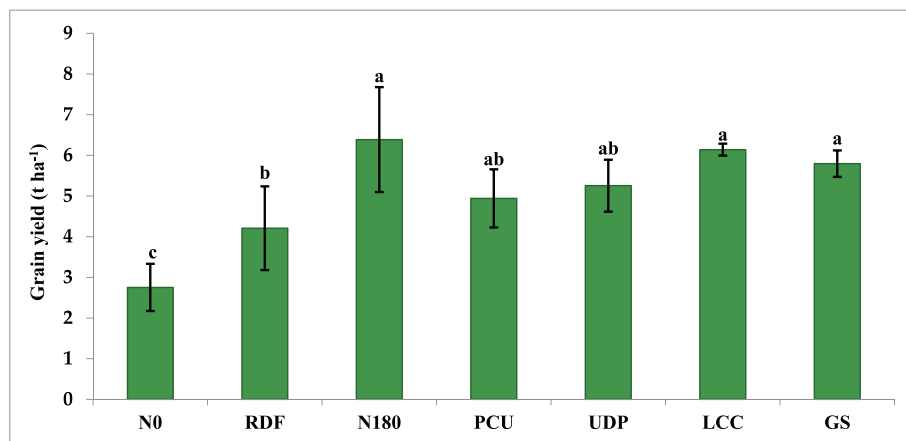

Figure 4. Grain yield of Rampur hybrid- 10 maize variety as influenced by different N treatments. N0- 0 kg N ha^{-1}, RDF- 120 kg N ha^{-1}, N180- 180 kg N ha^{-1}, PCU-polymer coated urea (90 kg N ha^{-1}), UDP- urea briquette deep placement (90 kg N ha^{-1}), LCC- Leaf Color Chart (143 kg N ha^{-1}), GS- GreenSeeker (143 kg N ha^{-1}), similar statistical letters within the column indicates non-significant effect of the treatments (P < 0.05).
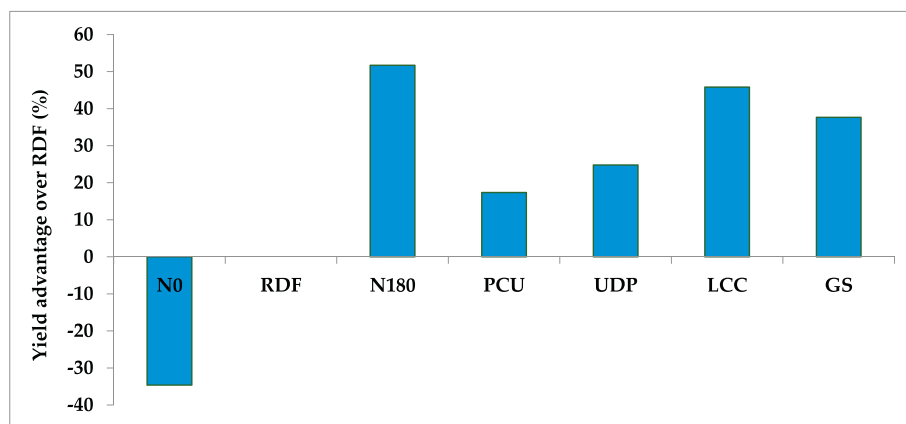
Figure 5. Yield advantage of different N treatments over the recommended doses of fertilizers (RDF). Mean grain yield value was used to calculate yield advantage over RDF. N0- 0 kg N ha^{-1}, RDF- 120 kg N ha^{-1}, N180- 180 kg N ha^{-1}, PCU- polymer coated urea (90 kg N ha^{-1}), UDP- urea briquette deep placement (90 kg N ha^{-1}), LCC- Leaf Color Chart (143 kg N ha^{-1}), GS- GreenSeeker (143 kg N ha^{-1}).

0.16% (Liu et al., 2020). Similarly, the use of P$_2$O$_5$ in soil above the critical level (10.9–21.4 mg kg^{-1}) is ineffective towards increment of grain yield (Bai et al., 2013). Likewise, Potassium content in the experimental soil was higher (419 kg ha^{-1}, equivalent to 209.5 mg kg^{-1}), and within the critical range of 109–340 mg kg^{-1} (Van Biljon et al., 2008). Thus, both the phosphorus and potassium fertilizers though present in sufficient amount, could not effect on grain yield as these fertilizers are effective when they are integrated with nitrogenous fertilizers (Sangakkara et al., 2011). These evidences support that the nitrogen is a critical limiting nutrient for maize cultivation in this study site.

3.4. Nitrogen use efficiency

Different N treatments significantly (p < 0.05) influenced the PFPN and AEN of N fertilizer (Figure 6). Urea Deep Placement had the highest value of PFPN (58.37 kg grain kg^{-1} N) followed by PCU (54.89 kg grain kg^{-1} N), while N180 had the lower PFPN (35.48 kg grain kg^{-1} N). Real time nitrogen application through LCC and GreenSeeker and slow-release N fertilizers (PCU and UDP) resulted higher PFPN compared to RDF. This might be because, LCC, GreenSeeker, UDP and PCU were capable to synchronize the N supply with the plant demand and reduced the losses of nitrogen (Ladha et al., 2005). Urea Deep Placement resulted in 66.43% more PFPN compared to RDF while PCU resulted in 56.51% more PFPN. Both PCU and UDP are placed deeply (root-zone placement) in soil and

releases N in controlled manner which decreases the loss and increases the nutrient use efficiency (Cheng et al., 2020; Ladha et al., 2005). The findings from the present study are in line with previous studies conducted in Nepal and other countries (Dhakal et al., 2020; Gagnon et al., 2012; Halvorson and Bartolo, 2014; OO et al., 2018).

Likewise, LCC and GreenSeeker also resulted in 22.41% and 15.5% higher PFPN compared to the recommended dose as reported by other literatures (Prakasha et al., 2020; Jyothsna et al., 2021). However, in contrast to these studies, GreenSeeker resulted in lesser PFPN compared to LCC. It is because nitrogen use efficiency varies with crop, climate, soil type, nitrogen application method, amount, and sources (Cheng et al., 2020; Prakasha et al., 2020). This reason also explains the higher PFPN of UDP and PCU compared to LCC and GreenSeeker as UDP and PCU were deeply placed and the lesser amount of nitrogen was used comparatively. Moreover, the real-time nitrogen application through LCC and Green-Seeker, and slow-release N fertilizers (UDP and PCU) resulted in higher agronomic efficiency of nitrogen (21.30–27.82 kg grain kg^{-1} N) compared to RDF (12.15 kg grain kg^{-1} N) and N180 (19.87 kg grain kg^{-1} N) as shown in Figure 6. This might be attributed to split application in LCC and GreenSeeker which synchronized the N supply with plant demand (Jyothsna et al., 2021). Based on individual performance, highest AEN was found in UDP followed by PCU and the lowest in RDF. These findings are in accordance with Prakasha et al. (2020) and Jyothsna et al. (2021).
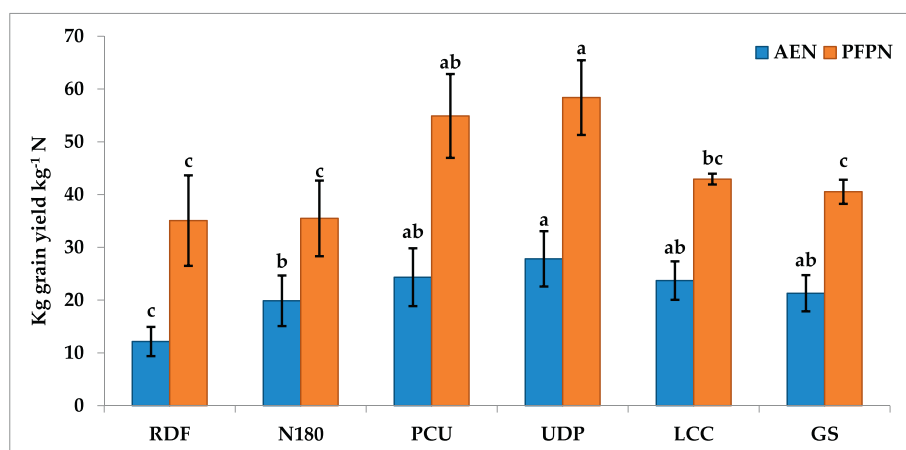

Figure 6. Partial factor productivity (PFPN) and agronomic efficiency (AEN) of N as influenced by different N treatments in Rampur hybrid- 10 variety of maize. RDF- 120 kg N ha^{-1}, N180- 180 kg N ha^{-1}, PCU- polymer coated urea (90 kg N ha^{-1}), UDP- urea briquette deep placement (90 kg N ha^{-1}), LCC- Leaf Color Chart (143 kg N ha^{-1}), GS- GreenSeeker (143 kg N ha^{-1}), similar statistical letters within the column indicates non-significant effect of the treatments (P < 0.05).

Table 3. Partial economic analysis of different N treatments for the cultivation of Rampur hybrid- 10 variety of maize in a hectare of land (1 USD = 120.89 NRs.).

Treatments	Adjusted yield (t ha^{-1})		Total cost (USD)	Total income (USD)	Net income (USD)	B:C ratio	Total cost over RDF (USD)	Net income over RDF (USD)
	Grain	Straw						
N0	2.48	8.24	921.87	989.60	67.73	1.07	-107.27	-221.07
RDF	3.79	9.23	1029.14	1317.94	288.80	1.28	0	0
N180	5.75	11.03	1072.15	1827.69	755.53	1.70	43.01	466.73
PCU	4.45	10.63	1016.9	1534.97	518.08	1.51	-12.24	229.28
UDP	4.73	10.85	960.15	1605.78	645.63	1.67	-68.99	356.82
LCC	5.52	11.69	1045.35	1819.62	774.27	1.74	16.21	485.46
GS	5.22	10.62	1045.35	1693.70	648.34	1.62	16.21	359.54

Remarks: N0- 0 kg N ha^{-1}, RDF- 120 kg N ha^{-1}, N180- 180 kg N ha^{-1}, PCU- polymer coated urea (90 kg N ha^{-1}), UDP- urea briquette deep placement (90 kg N ha^{-1}), LCC- Leaf Color Chart (143 kg N ha^{-1}), GS- Green Seeker (143 kg N ha^{-1}), NRs- Nepalese rupees, USD- United States Dollar.

3.5. Partial economic analysis

The efficient use of inputs including fertilizers determines the overall economic benefit from the cropping system (Dhakal et al., 2021). The cost of production rises with inefficient application of manure and fertilizers as these are the key factors boasting highest share among the farm inputs (Paudel and Matsuoka, 2009; Dahal and Rijal, 2019). It is common in observation that Nepalese farmers are not using balanced fertilization, thus, produced lower yields. Appropriate application of fertilizers not only increases the crop yields, but also decreases the cost of cultivation; a must-do activity by Nepalese farmers (Paudel and Matsuoka, 2009). Thus, we performed partial economic analysis of different treatments under study and compared their relative efficiencies (Table 3). The UDP based nitrogen source had the least cost of production (USD 960.15) among the nitrogen applied treatments, while N180 (180 kg N ha^{-1}) incurred highest cost of production (USD 1072.15). Likewise, real-time nitrogen management technique found less economical compared to slow-release N fertilizers as more nitrogen was applied and labor cost was high for these treatments due to multiple split applications. The cost of production of UDP and PCU were less compared to RDF while LCC and GreenSeeker had greater cost of production than RDF (Table 3).

Among all the treatments, the highest net income was obtained from LCC followed by N180 and the lowest was obtained from N omission treatment. In addition, the net income obtained from UDP (income over RDF- USD 356.82) and PCU (income over RDF- USD 229.28) were higher compared to RDF and the net income obtained from GreenSeeker was higher than UDP and PCU (Table 3). It depicts that use of slow-release nitrogen fertilizers and decision support tools increased the net income of farmers compared to RDF. Furthermore, the B:C ratio of UDP, PCU, LCC and GreenSeeker were higher compared to the recommended dose, and LCC gave the highest B:C ratio among all the treatments which makes the LCC based application more profitable (Table 3). Swamy et al. (2016) also reported similar findings as in our present study. In a study conducted in Khumal hybrid-2 maize, a net benefit of USD 912 was reported from UDP application at 90 kg ha^{-1} N (Dhakal et al., 2020). Those studies also suggested the use of innovative fertilizers and improved application method to increase the productivity and economic return in maize with the reduction of 25–45% fertilizer dose and increase in agronomic efficiency up to 24–28 kg grain per kg N application (Dhakal et al., 2020; Beshir et al., 2019).

4. Conclusions

The present study identified some innovative slow-release N fertilizer and efficient decision support tool for increasing NUE in maize crop. Based on the economic return and ease in the application, urea briquette (UDP) and Leaf Color Chart (LCC) based N application seems promising in Nepalese conditions. UDP can be applied behind the local plows, or during the earthing up activity in maize. LCC- a simple technology can be adopted at farmer's level with some training on its application

procedures. This study also suggests further evaluation of these innovative fertilizers and decision support tools at different agro-ecologies, soil types and climatic conditions for the validity of its effectiveness and general recommendations to the farmers.

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