Nitrogen use efficiency and maize performance through application of urea stable and urea in highland Nitisol of Midakegn and Toke Kutaye districts

Abstract

The field experiment was conducted in 2018 and 2019 cropping season to determine the effects of urea stable and urea on nitrogen use efficiency and maize performance in highland Nitisol of Midakegn and Toke Kutaye districts. The experiment was laid out in randomized complete block design with three replications. Nine treatments of urea stable and urea with different application times was used. Application of different nitrogen rate from urea stable and urea were significantly ($P < 0.05$) influenced mean plant height, leaf area index, dry biomass, grain yield, thousand seed weight and harvest index of maize crop. Significantly higher mean leaf area index (4.1), thousand seed weight (357 g), dry biomass (16472 kg ha^{-1}) and grain yield (5475 kg ha^{-1}) were recorded from split application of 138 kg N ha^{-1} from urea stable whereas higher mean plant height was recorded from split application 138 kg N ha^{-1} from urea. Application of nitrogen rate were also affected nitrogen uptake and agronomic nitrogen efficiency of maize. Mean agronomic nitrogen efficiency showed decreasing trend with increasing of nitrogen fertilizer application. Significantly higher and lower value of agronomic nitrogen efficiency were obtained from split application of 46 kg N ha^{-1} from urea stable and 138 kg N ha^{-1} from urea stable applied at planting. Agronomic parameters and nitrogen uptake were only influenced by nitrogen rate indicating slow releasing of nitrogen from urea stable and confirmed this form fertilizer reduce N loss. Both urea stable and urea sources of nitrogen gave similar yield at the same rates. Therefore, urea stable could be used as alternative nitrogen source in addition to urea if the cost and accessibility of this fertilizer is the same for the area.

Key words: nitrogen, maize, urea, urea stable, agronomic efficiency, nitrogen uptake

INTRODUCTION

Maize (*Zea mays* L.) is an important food crop in sub-Saharan Africa and significantly contributes to food security and income generation for many smallholder farmers [1] [2]. In Ethiopia it is also one of the most important stable food crops ranks second in terms of area coverage after teff and first in total production with an average yield of 3.94 t ha^{-1} [3]. However, soil nutrient is a major challenge to production of this crop in Ethiopia [4]. Maize is an exhaustive crop that requires high dose of nitrogen. Despite of improving performance of maize crop, nitrogen also mediates uptake and utilization of other nutrients that contributes to maize growth and yield [5]. However, the crops use only less than half amount of N applied [6]. Most of N applied losses from the soil plant system by denitrification in the form of gaseous dinitrogen (N_2), nitrous oxide (N_2O) and nitric oxide (NO), volatilization of ammonia (NH_3), leaching of nitrate (NO_3), runoff and erosion [6] [7]). Excess application or inappropriate use of nitrogen fertilizer also leads to N pollution that can be adversely affected human and ecological health. When nitrogen from normal urea applied to the soil, urea is exposed to urease enzyme activity, which is found in plants, bacteria, fungi and algae [8].

Therefore, agronomic efficiency of nitrogen fertilizers and the reduction of nitrogen (N) loss are the main objectives in fertility management because these practices reduce the production costs and negative impacts of nitrogen on environment [9] [10]. As a result, numerous new technologies have been developed in recent years to overcome this problem through using good agronomic management and producing better source of nitrogen fertilizer that can inhibit ammonia volatilization and leaching of N in form of nitrate [11]. The type of fertilizers and their management in agriculture should be taken to consideration to improve the global N balance in the short- and long-term.

Currently various products have been developed to reduce nitrogen loss and to improve synchronization of crop demand and nitrogen supply [12]. For instance, coated or encapsulated fertilizers that are produced by addition of compounds that cover the urea granules enable to reduce their exposure to water and air, and block volatilization [10]. Enhanced-efficiency fertilizers area new tool to stabilize fertilizer consumption and minimize environmental pollution [13] [14]). The use of slow-release N fertilizer reduces the need for splitting fertilization [15].

Barati *et al*.[16] detected greater N recovery from sulfur-coated urea than from ammonium chloride and urea. Slower release from fertilizer reduced nutrient losses, resulting in higher plant uptake [17]. Despite the potential of slow-release fertilizers of increasing the N fertilizer use efficiency, the high cost of these products, compared to traditional fertilizers, limits their use [18]. The high cost of coating the granules has been the limiting factor in extending their use to large-scale agriculture [19]. In addition to granular urea that have coated by plastic resins with polymers other efforts have also made by fertilizer producers to produce urea with inhibitors (stable urea) that can increase applied urea efficiency by inhibiting urease enzyme activity in the soil [20]. The use of urea stable has been described as a new option for N volatilization reduction, but no information is known yet for maize production in the country. By considering the value of these slow releasing nitrogen (urea stable) this activity was done to ascertain efficiency of urea stable over urea that have used for a four decades in the study area. Therefore, the objective was to determine the of effects urea stable and urea on nitrogen use efficiency and maize performance in highland Nitisol of Toke Kutaye and Mida kagn districts.

MATERIALS AND METHODS

Description of study area

The study was conducted for two consecutive years during 2018 and 2019 cropping seasons in Nitisol of Midakegn and Toke Kutaye districts, West Showa Zone of Oromia National Regional State, Ethiopia. According to traditional climate classification of Ethiopian the study area is categorized in highland sub humid climate. The area receives mean annual rain fall of 1,026 mm with unimodal distribution. It has a cool humid climate with the mean minimum, mean maximum, and average air temperatures of 8.51, 18.48, and 13.49°C, respectively. The study area obtains high rainfall during May to September and low rainfall from December to February.

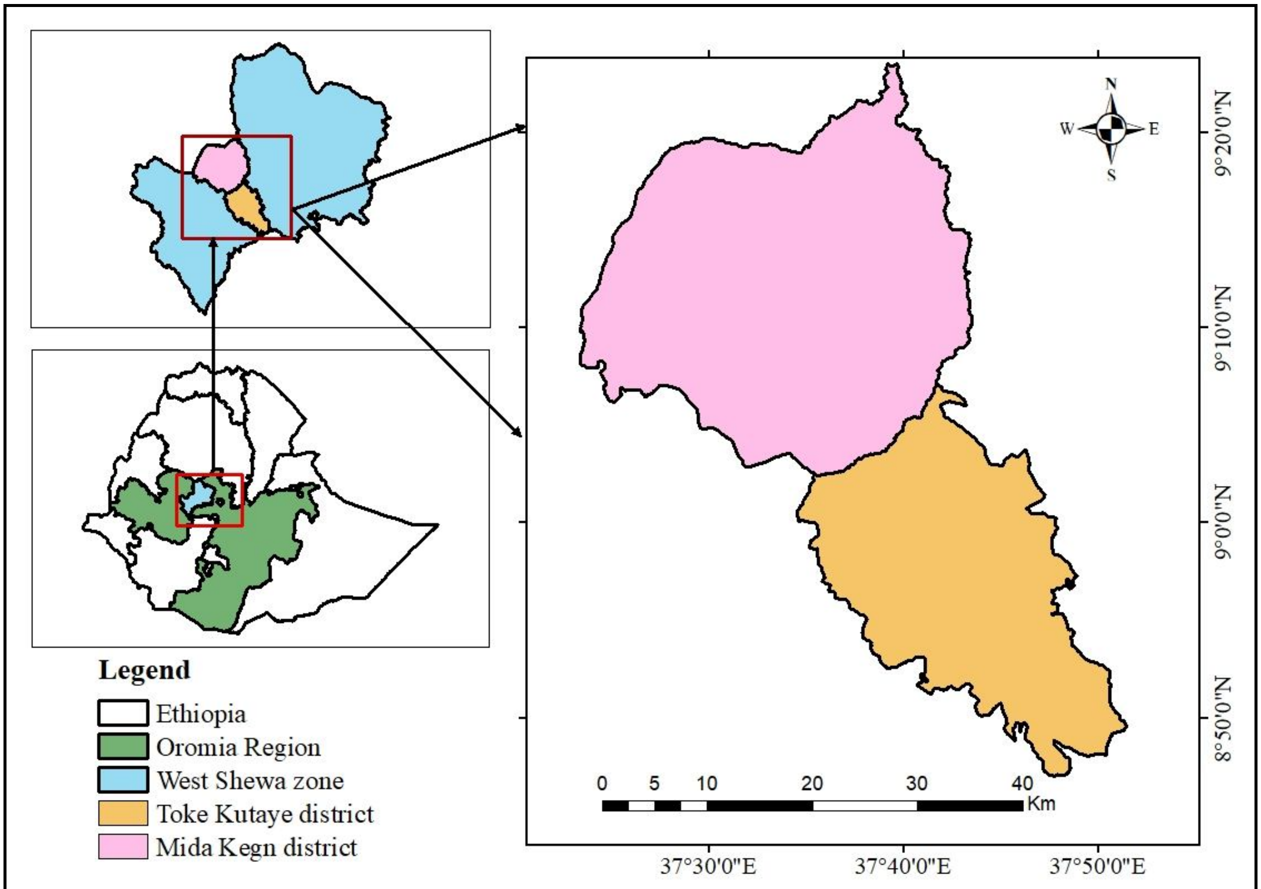

Figure 1: Map of the study area

Experimental procedures and field managements

The experimental field was ploughed and prepared according to farmers' conventional farming system in the study area. The field had ploughed three times exclusively using oxen-drawn implements. The experiment was laid out in randomized complete block design with three replications. The nine total treatments comprising of control, 46 kg N ha^{-1} from urea stable (US) at planting, 46 kg N ha^{-1} from US in split, 92 kg N ha^{-1} from normal urea (NU) in split, 92 kg N ha^{-1} from US at planting, 92 kg N ha^{-1} from US in split, 138 kg N ha^{-1} from US in split, 138 kg N ha^{-1} from NU in split, 138 kg N ha^{-1} from US at once (at planting) were used in experiment. The plot size was 4.5 m x 5 m (20.25 m^2) and path of 1m and 1.5m between each plots and blocks were used respectively. The recommended phosphorus rate (69 kg P ha^{-1}) from Triple super phosphate fertilizer were applied uniformly to all plots during planting. Nitrogen from normal urea and urea stable were applied at respective rate and time as specified in treatment arrangement. Improved maize hybrid Jibat (AMH 851) variety was used as test crop for this experiment. The trial was planted at the first two week of May in both years. Recommended agronomic practices like hoeing and hand weeding were uniformly adopted to all experimental plots.

Soil and Plant Sample collection

Prior to planting 10 soil samples were collected to the depth of 0–20 cm across the experimental field. Immediately after sampling the total of 10 samples was thoroughly mixed in the field, about 1 kg composite and homogenized sample was taken and put into the labeled plastic bag. After harvesting, soil samples were collected from all plots in the experimental field. The samples were taken from central rows of the plots along which fertilizer was applied. Then the sample was taken to Ambo Agricultural research Center for sample preparation. Then the soil samples were spread on the sheet and dried with aid of air in the room. The air-dried soil samples were milled using mortar and Pestle, then sieved through a 2 mm diameter sieve for analysis of nitrogen. Similarly, representative of maize sample was collected from each plot and brought to research center for sample preparation. Similarly, the grain sample was taken during threshing. Then the maize plant tissue was chopped and air dried in the room. Finally, both soil and plant sample were taken to Holetta Agricultural Research Center soil and plant laboratory for nitrogen and other soil parameters analysis. The soil sample after harvesting in 2018, soil and plant samples in 2019 collected and submitted to laboratory and for analysis and waiting for the result.

Soil and plant Sample Analysis

The soil collected prior to planting and plant samples collected during first year (2018) were analyzed at Holetta Agricultural Research Center Soil and Plant Laboratory. Soil samples were collected before treatment application and planting of maize from 10 randomly picked points and composited. The collected soils were prepared following standard procedures and analyzed at Holetta and Kulumsa Agricultural Research Center Soil and Plant Analysis Laboratory in Ethiopia. Determination of soil particle size distribution was carried out using the hydrometer method [21] [22]). The soil pH was measured with digital pH meter potentiometrically in the supernatant suspension of 1:2.5 soils: distilled water ratio. The exchangeable K and Na were determined by flame photometer. The cation exchange capacity of the soil was determined from 1MNH_4OAC-saturated samples [23]. Exchangeable acidity was determined by saturating the soil samples with 1 *M* KCl solution and titrated with sodium hydroxide as described by McLean [24]. Organic carbon was determined following wet digestion method as described by Walkley and Black [25] whereas the Kjeldahl procedure was used for the determination of total nitrogen as described by Jackson [26]. Total phosphorous was determined following Bray-I procedure as described by Bray and Kurtz [27].

Plant sample was also analyzed for nitrogen content and the nitrogen uptake is nitrogen concentration x dry biomass weight (kg ha^{-1}) of crops/100. The nitrogen use efficiency was calculated for different nitrogen efficiencies such as Agronomic efficiency was calculated by multiplying the grain yield and applied N [28].

$$AE\ (\text{kg grain / kgN}) = \frac{Yn - Yo}{Fn}$$

Whereas AE= Agronomic efficiency Yn and Yo are the grain yield with or without N applied respectively and Fn is the amount of nitrogen fertilizer applied

Plant nitrogen use efficiency/ physiological efficiency was calculated by dividing the total dry matter produced to a unit of N absorbed as indicated below:

$$PE\ \text{kg grain /kgN} = \frac{Yn - Yo}{Un - Uo}$$

Where PE= physiological efficiency, Un and Uo are nutrient uptake in fertilized and control plot respectively; Yn and Yo are the grain yield in fertilized and control plot respectively

Agronomic Data Collection

Data on growth parameters, yield and yield components of maize were collected from four central rows of each plot. Growth and agronomic data such as leaf area index and plant height were measured before harvesting the crop. Leaf Area Index of maize was calculated as leaf length and leaf width was taken from 10 randomly selected plants per plot. Then leaf area was calculated by multiplying 0.75 x width x length for all leaves per plants. The leaf area index was calculated by dividing sum of leaf area per plant to the area under the plant leaves coverage (0.25m x 0.75 m). The plant height measured from the base of the plant at ground level to the base of tassel was taken from 10 randomly selected plants. At physiological maturity maize stand count was recorded from four central rows. Then maize stand was harvested from central rows and the weight of above ground biomass and field weight of maize cob measure using digital balance. Then thousand seed weight and grain moisture were taken immediately at the field. Finally, maize grain yield was adjusted to standard moisture contents to 12.5%. Harvest index was calculated from the ratio of grain yield and dry biomass times 100.

Statistical Data Analysis

The collected data were subjected to analysis of variance using statistical software [28]. Least significance Difference at 5 % probability level was used for mean separation to test significance difference among treatments [29].

RESULTS AND DISCUSSION

Some Soil Chemical and Physical Properties of the Study Area

The result of soil chemical and physical properties of different farmer field's during 2018 were indicated in Table 1. The soil textural distribution of experimental field was clay in textural classes., The soil pH of study area was moderately acidic as rated by Tekalign [30]. Available phosphorus of soil was low and medium at experimental field in Toke kutaye and Midakegn district [31] [32]. Organic carbon content of the soil was medium and high in Midakegn and Toke Kutaye district respectively [31] [30]. The soil at both sites was low in total nitrogen while cation exchange capacity of the soil was medium and low in Midakegn and toke kutaye respectively [31]; [30]).

Effects of Nitrogen Fertilizer Rates on growth, Yield and Yield Components Maize

Plant height

Significant effect of N rate on plant height of maize was observed in both years and combined over years (Table 2). Higher mean plant height (205 cm) was obtained when 138 kg N ha^{-1} was applied from urea stable in split and followed by the second maximum plant height (203 cm) that was gained by applying 138 kg N ha^{-1} from normal urea in split (Table 2). The effect of nitrogen in the form of urea stable on plant height was at par with effect of similar nitrogen rate applied from normal urea. Similarly,[33] were also reported statistically similar effect of Urea and urea+NBPT (inhibitors) on plant heights. Statistically significant difference was not observed among similar nitrogen rate applied at once and in split. This can be due to slow release and low loss of nitrogen applied from urea stable fertilizer or urea with urease enzyme inhibitors.

Mean leaf area index was also statistically influenced by applied different rates of urea stable fertilizer (Table 2). The highest leaf area index of 4.1 and 4 were recorded from plot received 138 kg N ha^{-1} in the form of urea stable and normal urea applied in split respectively. Tajul *et al.*[34] also reported that the increased leaf rea index might be due to the increased availability of N under the higher levels of nitrogen fertilizer with lower plant population, which resulted in larger leaves. Likewise, Wakjira [35] found that significantly the highest leaf area index (4.04) was recorded under application of blended (200 and 150 kg NPS ha^{-1}) fertilizer rates. The response of leaf is index to application time of urea stable and nitrogen source were statistically not significant.

Harvest index and Thousand Seed weight

Harvest index and thousand seed weight were influenced by nitrogen rate (Table 3). Mean harvest index of maize during first year was not significantly affected by nitrogen rate applied from urea and urea stable. Application equal nitrogen rate from urea stable and normal urea was not significantly affected both harvest index and thousand seed weight of maize crop (Table 3). Similarly, applying equal rate of nitrogen from urea stable in split and once (at planting) were not made significant difference on harvest index and 1000 seed weight. Highest mean thousand seed weight (357 g) of maize were obtained from plot received nitrogen in rate of 138 kg N ha^{-1} from urea stable applied in split and followed by 348 g that obtained by applying 138 kg N ha^{-1} from normal urea in split application.

Grain and dry biomass yield of maize

The mean grain yield of maize was significantly influenced by the nitrogen rate applied from urea stable and urea (Table 4). Significantly higher (5475 kg ha^{-1}) and lower (864 kg ha^{-1}) mean grain yield of maize combined over years were recorded from application of 138 kg N ha^{-1} applied in split and control, respectively (Table 4). Source of nitrogen and application time non-significantly (P<0.05) mean grai yield of maize. Likewise, Zavaschi *et al.*[36] reported nitrogen fertilization rates influenced yield, regardless of the use of coating fertilizer or urea. Statistical similar mean grain yield of maize were recored from application of 138 kg N ha^{-1} from urea stable at planting and split application of urea. Similarly, Pereira *et al.* (2009)[37]; Zavaschi *et al.*[36]reported no difference in yield between the application of polymerized and conventional urea on maize. Cantarella *et al.*[20] reported the effect on crop yield and N use efficiency is much more limited and ranges from a yield increase of 5-12% in most studies. Sharma *et al* [38] found that application of 150 kg Nha^{-1}has produced significantly higher grain yield of 10.5 and 7.58 t Nha^{-1} of maize in 2017 and 2018 cropping season.

Mean dry biomass of maize was significantly varied with different rate of nitrogen fertilizers were applied during both years. Mean dry biomass of maize was showed similar trend during the consecutive two cropping seasons. The highest (16472 kg ha^{-1}) and lowest (2886 kg ha^{-1}) mean dry biomass combined over years were harvested from split application of 138 kg N ha^{-1} from urea stable and control, respectively.

The mean dry biomass of maize obtained by split application of 138 kg N ha^{-1} from urea was statistically at par with dry biomass harvested from N rate applied from urea in split and urea stable applied at planting. In contrary, Noellsch *et al.* [17] found higher N uptake and grain yield of maize with application of 168 kg ha^{-1} of polymer-coated urea N as compared to conventional urea. This indicates that slow releasing of nitrogen from urea stable and absense of additional benefit of urea stable over normal urea in the study area.

Nitrogen use efficiency of Maize

Application of different rates of N fertilizers significantly (P ≤ 0.05) influenced agronomic efficiency and nitrogen content of maize crop during 2018 cropping season (Table 5). However, nitrogen rate didn't significantly affect physiological efficiency of the crop during first year of the experiment. The values of agronomic nitrogen efficiency of maize were ranged 34.7 to 63.3 kg grain Kg N $applied^{-1}$ were obtained from application of higher and lower application of 138 and 46 kg N ha^{-1} in the form of urea stable respectively (Table 5). Nitrogen agronomic efficiency of the maize crop was decreasing with increasing of nitrogen dose applied. Therefore, despite high nitrogen source (urea stable and normal urea) used in this experiment the crop showed response to N fertilizer application in the soil study area.

Nitrogen content of the maize crop was also significantly affected with different rate of nitrogen fertilizer. However, the value showed inconsistent trend and nitrogen content of maize grown with 92 and 138 kg ha^{-1} nitrogen from urea stable and normal urea were only significant from that of control treatment. Higher nitrogen content of maize was obtained with application of 92 and 138 kg N ha^{-1}. Similarly, Tajul *et al.*[34] reported that higher N-content was found in the plants treated with 220 kg N ha^{-1} followed by 180 kg N ha^{-1}. Also, Yong *et al.*[39] observed significant increase in N uptake of maize grown with application of 180 kg N ha^{-1}.

CONCLUSION

Application of different nitrogen rate from urea stable and urea were significantly ($P \leq 0.05$) influenced mean plant height, leaf area index, grain yield, dry biomass, harvest index and thousand seed weight of maize in nitisol of Mida Kegn and Toke Kutaye districts of West Showa. Mean grain and dry biomass yield of maize was significantly improved with application of nitrogen rate from urea stable and urea. Significantly improved agronomic nitrogen efficiency of maize was obtained with lower rates of nitrogen application from urea stable and urea. Maize agronomic efficiency and physiological nitrogen efficiency were ranged from34.7 to 63.3 kg grain kg N applied^{-1} and 16.03 to 29.90 kg grain kg N uptake^{-1}**.** Application of equal rates of nitrogen from urea stable and urea gave similar yield of maize. Therefore, urea stable could be used as alternative nitrogen source for sustainable maize production in addition to urea if the cost and accessibility of this fertilizer is the same with urea in the area.

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Table 1. Some physical and chemical properties of soil of experimental site before planting

Experimental site	Soil texture			PH()	Av.P ppm	TN %	CEC	OC %	OM%
	clay	Silt	Sand						
Medakegn	47.5	35	17.5	6.12	16.9	0.10	15.16	1.54	2.66
Toke kutaye	60	25	15	5.64	9.83	0.12	9.18	3.27	5.63

Where is A. P= available phosphorus, TN=Total nitrogen, CEC= cation Exchange capacity, OC=organic carbon and OM= organic matter.

Table 2. Effect of urea stable and urea fertilizer on plant height and leaf area index of maize

Treatment (kg N ha^{-1})	Plant height (cm)			Leaf area index		
	2018	2019	Mean	2018	2019	Mean
0	95^{e}	142^{c}	119^{d}	1.4^{e}	1.7^{d}	1.6^{e}
92 N from NU. in split	159^{abc}	222^{ab}	191^{ab}	3.6^{ab}	3.3^{ab}	3.5^{bc}
92 N from US. at planting	153^{bcd}	230^{ab}	192^{ab}	3.4^{bc}	3.4^{ab}	3.4^{c}
92 N from US. in split	168^{acd}	222^{ab}	195^{ab}	3.6^{ab}	3.5^{ab}	3.6^{bc}
46 N from US. at planting	140^{d}	204^{b}	172^{c}	2.7^{d}	2^{cd}	2.3^{d}
46 N from US. in split	147^{cd}	216^{ab}	182^{bc}	2.8^{cd}	2.8^{bc}	2.8^{d}
138 N from US in split	176^{a}	230^{ab}	203^{a}	4.2^{a}	4^{a}	4.1^{a}
138 N from NU in split	172^{ab}	238^{a}	205^{a}	4.1^{a}	3.9^{a}	4^{ab}
138 N from US at once	168^{acd}	235^{a}	192^{ab}	3.9^{ab}	3.6^{ab}	3.8^{abc}
LSD (5%)	21.77	28.16	17.1	0.66	0.89	0.54
CV (%)	8.3	7.55	7.9	11.3	16.6	14.2

US= urea stable, NU= normal urea, Numbers followed by same letter in the same column are not significantly different at 5% probability level

Table 3. Effect of urea stable and urea fertilizer on harvest index and thousand seed weight of maize

Treatment (kg N ha^{-1})	Harvest Index (%)			Thousand seed weight (g)		
	2018	2019	Mean	2018	2019	Mean
0	25	32.7^{b}	28.8^{b}	244^{c}	242^{b}	243^{d}
92 N from NU. in split	30	31.3^{b}	30.7^{ab}	332^{ab}	290^{ab}	311^{ac}
92 N from US. at planting	34	33.7^{b}	33.6^{ab}	307^{abc}	308^{a}	307^{bc}
92 N from US. in split	31	36^{ab}	33.8^{ab}	328^{ab}	312^{a}	320^{abc}
46 N from US. at planting	31	40^{a}	35.7^{a}	286^{c}	290^{ab}	288^{cd}
46 N from US. in split	29	35^{b}	31.8^{ab}	302^{abc}	290^{ab}	296^{c}
138 N from US in split	32	35.7^{ab}	33.7^{ab}	364^{ab}	349^{a}	357^{a}
138 N from NU in split	32	34.3^{b}	33.1^{ab}	368^{a}	328^{a}	348^{ab}
138 N from US at once	32	33.7^{b}	33^{ab}	355^{ab}	314^{a}	334^{abc}
LSD (5%)	NS	4.8	5.6	79.59	61.18	48.2
CV (%)	20.2	8.1	14.6	14.3	11.7	13.2

US= urea stable, NU= normal urea, Numbers followed by same letter in the same column are not significantly different at 5% probability level

Table 4. Effect of urea stable and urea fertilizer on grain yield and dry biomass yield of maize

Treatment (kg N ha^{-1})	Grain Yield (kg ha^{-1})			Dry biomass (kg ha^{-1})		
	2018	2019	Mean	2018	2019	Mean
0	605^{f}	1123^{d}	864^{e}	2434^{e}	3338^{e}	2886^{e}
92 N from NU. in split	4796^{bc}	4296^{abc}	4546^{b}	16074^{abc}	13714^{abc}	14894^{ab}
92 N from US. at planting	4436^{cd}	4306^{abc}	4371^{bc}	13556^{bcd}	12761^{bc}	13158^{bc}
92 N from US. in split	4556^{c}	4154^{c}	4355^{bc}	15106^{abc}	11649^{cd}	13378^{bc}
46 N from US. at planting	3198^{e}	4019^{c}	3608^{d}	10281^{d}	10175^{d}	10228^{d}
46 N from US. in split	3516^{ed}	4024^{c}	3770^{cd}	12405^{cd}	11427^{cd}	11916^{dc}
138 N from US in split	5790^{a}	5160^{a}	5475^{a}	18445^{a}	14499^{ab}	16472^{a}
138 N from NU in split	5589^{ab}	5233^{a}	5411^{a}	17560^{a}	15324^{a}	16442^{a}
138 N from US at once	5401^{abc}	5042^{ab}	5222^{a}	17047^{ab}	15007^{ab}	16027^{a}
LSD (5%)	968.7	946.3	650	3716.9	2379.2	2120.2
CV (%)	13.3	13.17	13.2	15.7	11.46	14.1

US= urea stable, NU= normal urea, Numbers followed by same letter in the same column are not significantly different at 5% probability level

Table 5. Mean agronomic efficiency, physiological nitrogen efficiency and nitrogen content of maize as influenced by applying rates urea and urea stable fertilizers

Treatment (kg N ha^{-1})	Agronomic Nitrogen Efficiency (kg grain Kg N $applied^{-1}$)	Physiological Nitrogen Efficiency (kg grain kg N $uptake^{-1}$)	Nitrogen Content (%)
0	--	--	1.1c
92 N from NU. in split	45.5bc	16.03	1.9a
92 N from US. at planting	41.6c	19.47	1.7ab
92 N from US. in split	42.9c	16.30	1.9a
46 N from US. at planting	56.4ab	22.43	1.5abc
46 N from US. in split	63.3a	29.90	1.3bc
138 N from US in split	37.6c	20.70	1.6ab
138 N from NU in split	36.1c	17.37	1.8a
138 N from US at planting	34.7c	18.97	1.8ab
LSD (5%)	12.988	NS	0.45
CV (%)	16.6	21.9	16

US= urea stable, NU= normal urea, NS = nonsignificant difference at 5% probability level; numbers followed by same letter in the same column are not significantly different at 5% probability level