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# Effects of liquid urea rates on nitrogen dynamics, growth, and yield of corn (*Zea mays* L.)

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**Abstract**
Arbitrary use of urea fertilizer reduces nitrogen use efficiency (NUE) and increases the risk of environmental pollution. An experiment was conducted at the Universiti Putra Malaysia from November 2019 to March 2020 to evaluate the application methods and rates of liquid urea (LU) on the yield performance of corn. The treatments were, U0 = control, GU100 = Granular urea (GU) 100%, LU100 = LU 100%, LU50 = LU 50% and LU33 = LU 33%, in two equal splits at 10th and 28th days after sowing (DAS) in randomized completely block design, replicates four. Results showed that plant height (206.99 cm, 216.92 cm, 214.61 cm), ear height (88.13 cm, 88.63 cm, 86.00 cm), days of maturity (88.75, 89.00, 86.75 days), number of grains per kernel row (32.25, 34.50, 33.75), fresh cob weight (10,886.60 kg $ha^{-1}$, 10,946.60 kg $ha^{-1}$, 10,927.93 kg $ha^{-1}$) and 100-grain weight (20.51 g, 22.50 g, 21.39 g) of corn were not different significantly ($p \leq 0.05$) in GU100, LU100 and LU50 treatments, respectively. The highest yield of corn was found with LU100 (6249.03 kg $ha^{-1}$) treatment whereas the yield in LU50 (5666.50 kg $ha^{-1}$) and GU100 (5746.64 kg $ha^{-1}$) were not different significantly. Nitrogen (%) in plants was the highest in LU100 followed by LU50 treatment which was significantly higher than GU100 treatment. The total N content was also the highest in LU100 (102.83 kg $ha^{-1}$) though the total N content was not different significantly in LU50 (77.62 kg $ha^{-1}$) and GU100 (83.84 kg $ha^{-1}$) treatments. The NUE was the highest in LU50 (66.92%) treatment followed by LU100 (51.47%) treatment. The results of the study suggested that LU was superior to GU and the LU100 was the best application rate while LU50 treatment was comparable to GU100 in corn cultivation.

**Keywords** Liquid urea · Granular urea · NUE · Grain corn

## 1 Introduction

Corn (*Zea mays* L.) is the largest cereal crop after wheat and rice, adapted to grow under diverse climatic conditions and soils all over the world. It is a multipurpose crop used for food, feed, and even raw materials for biofuel production [11, 34, 53].

Nitrogen management in sustainable corn production is not only essential but also a challenging job. Optimum N application significantly increases crop production, but the application of excess N fertilizers leads to low NUE and high N losses (e.g., leaching), which is a possible reason for economic loss and environmental pollution, and it causes waste of resources and environmental degradation [22].

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Urea is the most important N fertilizer, which plays a vital role in global crop production and food security. Usually, farmers are overusing N fertilizers, particularly synthetic nitrogenous fertilizers like urea, to achieve higher crop production [21, 24]. Yet, there has been no consistent crop yield increment resulting from the increased N fertilizer application [56]. This excess N fertilizer causes lower NUE, lowers farm income, and causes water pollution, atmospheric disruption and soil health degradation [12, 15]. Thus, efficient management of N fertilizer is very important to sustain crop yields and maintain soil quality and reduce environmental threats [45]. The improvement of NUE depends on effective N management, which is the combination of using suitable N sources, appropriate application doses, correct placement, and the timing of fertilizer application [12, 32].

Liquid urea has the potential alternative source of N for improving crop yield as its application resulted in higher N mineralization, exchangeable $NH_4^+$ concentration and NUE of corn while reduced N loss (e.g., $N_2O$ emission, $NH_3$ volatilization and Nitrate leaching) than GU application [27, 30]. Liquid urea can disperse throughout the soil profile and therefore improves the adsorption capacity of $NH_4^+$ by the soil particles, which will reduce the further conversion and retain more N for better availability to the crops [44]. Some researchers recommended LU be used during a warm period of the growing season to reduce gaseous losses. The application of LU recovered N deficiency quickly and gave a better performance for profitable cereal production than GU due to the lower risk of loss and its rapid availability to the crops [25, 55].

Excess use of N fertilizer and faulty application methods lead to lower NUE and higher N loss potential (e.g., nitrate leaching), resulting in huge environmental problems [12, 23, 40]. Liquid urea (e.g., UAN) application reduced total N loss more than GU and recorded about 70% higher uptake efficiency than ammonium nitrate. In addition, LU application significantly minimized the N leaching and GHGs gases (e.g., $N_2O$) emission compared to GU [50, 54]. Liquid N fertilizer application resulted in 19% higher NUE than GU in winter wheat and maintained equilibrium in the soil-crop nutrient mechanism for gradual N uptake by the plant [10, 25]. Fertilizer management method cannot effectively increase the NUE and yield in dry crop cultivation system like corn production. A significant part of applied N remained unexplained due to diversified losses and low uptake potential. It is crucial to increase the N availability of applied urea fertilizer, which can increase the N uptake by the plant. Liquid urea can be distributed rapidly throughout the soil profile and reduce the possible potential loss, which increases the N availability to the plant. The experiment was conducted to investigate the application methods and rates of LU on the growth, development and yield of grain corn and to directly compare the efficiency of LU and GU application on the growth, development and yield of grain corn.

## 2 Materials and methods

### 2.1 Set up of the experiment

The pot experiment was conducted in polybags in the New Glasshouse (03° 00′ 12.6′ N; 101° 47′ 22.4′ E), Ladang 15, Faculty of Agriculture, Universiti Putra Malaysia during November 2019 to March 2020. The location experienced an average yearly rainfall of about 2000 mm along with the temperature ranges between 19 ℃ and 36 °C and relative humidity of 80–90%. The clay loam soil (Bungor soil series) was collected from Jalan Pertanian, UPM Campus, Puchong (03° 00″ 12.6′ N; 101° 47′ 22.4′ E) and the physicochemical properties of the soil were described in the Table 1.

About 18 kg of clean, sieved soil was filled into polybags (18 × 20″), and the moisture content was maintained at field capacity. Three corn seeds (GWG11) were sown in the polybag, and thinning was done after germination, keeping only one healthy and vigorous seedling per polybag arranged according to the Randomized Completely Block Design (RCBD) with 5 treatments and 4 replicates. The treatments used in this study were as shown in Table 2.

The recommended fertilizers (140 kg $ha^{-1}$ N, 100 kg $ha^{-1}$ $P_2O_5$ and 120 kg $ha^{-1}$ $K_2O$) were applied [16] and the plant density was 53,333 plant $ha^{-1}$ [7]. The full amounts of urea, triple superphosphate (TSP), and Mureate of Potash (MoP) were 5.70 g, 4.13 g and 3.74 g per polybag, respectively. Triple superphosphate and MoP were incorporated into the soil 48 h before seed sowing. The urea amount was applied to the plant according to the fertilizer treatment (Table 2). Liquid urea was prepared just before of application to the soil by dissolving respective amount of granular urea to distilled water. Water was added every morning to maintain field capacity moisture level by using portable moisture meter.

**Table 1** Physicochemical properties of the soils

| Soil properties | Values (mean ± SE)<br>Bungor soil series | Method references |
|---|---|---|
| USDA Taxonomic class | Very fine, kaolinitic, isohypertermic, haplic hapludoxs, typic paleudult, Ultisols | [37, 47] |
| USDA soil texture class | Sandy clay loam | |
| Sand (%) | 69.28 ± 0.021 | [52] |
| Silt (%) | 2.28 ± 0.003 | |
| Clay (%) | 28.44 ± 0.21 | |
| Moisture content at field capacity (%) | 23.74 ± 0.051 | [42] |
| pH | 4.93 ± 0.21 | [13, 48] |
| Total C (%) | 1.41 ± 0.041 | [20] |
| Total N (%) | 0.07 ± 0.003 | |
| $NH^{4+}$–N (mg $kg^{-1}$) | 16.31 ± 0.25 | [14, 18] |
| $NO^{3}$–N (mg $kg^{-1}$) | 11.41 ± 0.042 | |
| CEC ($cmol_c$ $kg^{-1}$) | 5.78 ± 0.12 | [4, 18] |
| Exchangeable K ($cmol_c$ $kg^{-1}$) | 0.21 ± 0.003 | |
| Exchangeable Ca ($cmol_c$ $kg^{-1}$) | 1.41 ± 0.024 | |
| Exchangeable Mg ($cmol_c$ $kg^{-1}$) | 0.44 ± 0.008 | [48] |
| Exchangeable Al ($cmol_c$ $kg^{-1}$) | 2.37 ± 0.031 | |
| Available P (mg $kg^{-1}$) | 5.03 ± 0.012 | |

**Table 2** Fertilizer treatments of the experiment

| Label | Fertilizer treatment |
|---|---|
| U0 | No urea (control) |
| GU100 | Granular urea 100% in two equal splits at 10th and 28th DAS |
| LU100 | Liquid urea 100% in two equal splits at 10th and 28th DAS |
| LU50 | Liquid urea 50% in two equal splits at 10th and 28th DAS |
| LU33 | Liquid urea 33% in two equal splits at 10th and 28th DAS |

100% = Full recommended dose of urea; 50% = Half (½) recommended dose of urea and 33% = One-third (1/3) of recommended dose of urea

### 2.2 Statistical analysis

The collected data were subjected to analysis of variance (ANOVA) for a factorial experimental design using Statistical Analysis Software (SAS) [46], and mean comparisons were done by using Least Significant Difference (LSD) at 5% significance level.

### 2.3 Fertilizer and agronomic management

The recommended fertilizer rate of 140 kg $ha^{-1}$ N, 100 kg $ha^{-1}$ $P_2O_5$ and 120 kg $ha^{-1}$ $K_2O$ were applied [16]. The full amounts of urea, triple superphosphate (TSP), and muriate of potash (MoP) were 5.70 g, 4.13 g and 3.74 g per polybag, respectively. Triple superphosphate and MoP were incorporated into the soil 48 h before seed sowing. The urea amount was applied to the plant according to the fertilizer treatment (Table 2). The first dose of N was applied at 10 DAS. Water was added every morning to maintain field capacity moisture level. Weeding was done manually if weed was present.

### 2.4 Data collection and processing

The soil and plant samples were analysed for total N using the dry combustion method on a TruMac, LECO Corporation, USA [20] CNS analyser, cation exchange capacity (CEC) was determined using the leaching method [4], $NH_4^+$-N and $NO_3^-$-N concentrations were estimated by distillation method [17], soil particle distribution was determined using the pipette method [52], gravimetric water content was determined at field capacity [51], and pH was determined in 2.5 (soil: water) ratio and measured using Metrohm827 pH meter (Metrohm AG, Switzerland). The properties of soil are shown in Table 1. The yield contributing parameters and yield data were collected. The N uptake by the biomass, grain and stover were analyzed.

The Plant height (cm) height was measured in the vegetative stage from soil level to the tip of the leaf to the highest point of the arch of the topmost leaf, which tip-point is down [5]. At the harvest, the plant height was measured from soil level to the tip of the collar leaf. No. of leaf plant$^{-1}$ was all the leaves of the plant leaving un-fold one [33]. Stem diameter (cm) of the plant was measured at the ground level. The measurement was taken by using digital slide calipers [26, 59]. Chlorophyll content (SPAD value) was estimated [60] by taking an average of four results from the apparatus (SPAD 502 plus chlorophyll meter). The data were taken from the indicator leaf of the plant during the morning from the four different places of the leaf. Ear height (cm) of the corn plant was estimated by taking measurements at the ground level to the cob-initiated nod. Ear length (cm) was estimated by taking measurements between the bottoms to the top of the cob. Maturity duration (days) was the duration from seed germination to the cob harvest. Total produced biomass (g) or stover was estimated during harvesting without any moisture loss. Dry weight was done by following the drying protocol [39]. Fresh weight of cob (g) was estimated during harvesting without any moisture loss. The number of kernel row cob$^{-1}$ and number of grains row$^{-1}$ were estimated without unhusking and made average for each cob. Husk weight and 100-grain weight were estimated after air drying and de-husking from the cob [57]. Yield of grain (kg ha$^{-1}$) was taken after air drying and husking from the cob [60]. Then it was converted into kg ha$^{-1}$.

The total N content (kg ha$^{-1}$) in the plant was calculated [8] by multiplying the grain and stover dry yield (kg ha$^{-1}$) with the N content (mg kg$^{-1}$).

$$Total\ N\ content\left(kg\ ha^{-1}\right) = \frac{N\ content\left(mg\ kg^{--1}\right) \times Yield\left\{grain\ and\ stover\left(kg\ ha^{--1}\right)\right\}}{1000000}$$

$$NUE(\%) = 100 \times \frac{Total\ N\ uptake\ -\ Total\ N\ uptake\ by\ the\ control\ plant}{Amount\ of\ urea\ applied}$$

### 2.5 Statistical analysis

The recorded data were subjected to analysis of variance (ANOVA) for a factorial experimental design using Statistical Analysis Software (SAS) [46] and mean comparisons were analyzed using the least significance difference test (LSD) at 5% level of significance.

## 3 Results

### 3.1 Plant growth parameters and N content at 50 DAS

The plant growth parameters of grain corn receiving LU and GU urea treatments at 50 DAS are shown in Table 3.

There was no significant difference in plant height among the fertilized plants, but they were significantly higher than the U0 (control) treatment. There was also no significant difference in stem diameter among all the treatments. The SPAD value of the control plant differed significantly from the fertilizer treated plant, where the highest SPAD value was recorded from the LU100 (54.35), it was not significantly different from GU100 (52.55) treatment. On the other hand, LU50 (47.93) was not significantly different from the GU100 (52.55) treatment, but LU33 was lower than GU100. The lowest SPAD value was recorded from U0 (39.73), but it was not significantly different from LU33 (44.10) treatment. There was a significant difference among treatments in the fresh biomass of corn at 50 DAS. The highest fresh biomass production was recorded in LU100 (394.50 g), which was 13.86% higher than GU100 (346.47 g) treatment. On the other hand, the fresh biomass production in GU100 and LU50 treatments was statistically similar. The lowest fresh biomass was recorded from U0 (181.49 g), followed by LU33 (321.41 g) treatment.

The results on the dry matter, %N content, total N content in plant and NUE of grain corn at 50 DAS have shown in Table 4.

**Table 3** Plant height (cm), Stem diameter (cm), Chlorophyll content (SPAD value) and Fresh biomass (g) of grain corn at 50 DAS (mean ± SE)

| Treatment | Plant height (cm) | Stem diameter (cm) | Chlorophyll content (SPAD value) | Fresh biomass (g) |
|---|---|---|---|---|
| U0 | 186.80 ± 2.02 b* | 1.60 ± 0.02 | 39.73 ± 0.59 d | 181.49 ± 4.85 d |
| GU100 | 206.99 ± 1.65 a | 1.79 ± 0.02 | 52.55 ± 0.45 ab | 346.47 ± 9.47 b |
| LU100 | 216.92 ± 1.61 a | 1.84 ± 0.19 | 54.35 ± 0.46 a | 394.50 ± 9.04 a |
| LU50 | 214.61 ± 2.29 a | 1.79 ± 0.14 | 47.93 ± 0.35 bc | 355.45 ± 8.46 b |
| LU33 | 212.38 ± 1.48 a | 1.76 ± 0.09 | 44.10 ± 0.39 cd | 321.41 ± 7.71 c |
| $LSD_{0.05}$ | 11.2 | NS | 4.7311 | 24.009 |
| CV (%) | 1.77 | 13.33 | 1.80 | 4.98 |

*Different letters within the column indicate significant differences between means using the least significant difference test (LSD) at 5% significant level ($p \le 0.05$)

**Table 4** Dry matter (g plant$^{-1}$), % N content plant$^{-1}$, Total N content (%) and NUE (%) of grain corn at 50 DAS (mean ± SE)

| Treatment | Dry matter (g plant$^{-1}$) | % N content plant$^{-1}$ | Total N content (g plant$^{-1}$) | NUE (%) |
|---|---|---|---|---|
| U0 | 28.44 ± 0.94 b* | 1.24 ± 0.04 c | 0.352 ± 0.02 c | – |
| GU100 | 54.24 ± 1.43 a | 1.56 ± 0.04 b | 0.847 ± 0.04 b | 8.69 ± 1.01 c |
| LU100 | 55.54 ± 1.19 a | 1.73 ± 0.05 a | 0.960 ± 0.04 a | 10.67 ± 0.82 c |
| LU50 | 55.24 ± 1.61 a | 1.57 ± 0.03 b | 0.864 ± 0.04 ab | 18.04 ± 3.61 b |
| LU33 | 53.05 ± 1.31 a | 1.56 ± 0.04 b | 0.828 ± 0.03 b | 25.05 ± 2.96 a |
| $LSD_{0.05}$ | 3.9627 | 0.1168 | 0.0994 | 0.7257 |
| CV (%) | 5.33 | 5.07 | 8.56 | 15.52 |

*Different letters within the column indicate significant differences between means using the least significant difference test (LSD) at 5% significant level ($p \le 0.05$)

**Table 5** Plant height (cm), No. of leaf plant$^{-1}$, stem diameter (cm) and ear height (cm) of grain corn at the mature stage (mean ± SE)

| Treatment | Plant height (cm) | No. of leaf plant$^{-1}$ | Stem diameter (cm) | Ear height (cm) |
|---|---|---|---|---|
| U0 | 197.00 ± 3.35 b* | 7.25 ± 0.48 c | 1.63 ± 0.05 | 85.75 ± 2.90 |
| GU100 | 229.75 ± 4.36 a | 9.25 ± 0.25 b | 1.78 ± 0.03 | 88.13 ± 4.05 |
| LU100 | 232.50 ± 3.91 a | 10.50 ± 0.29 a | 1.87 ± 0.19 | 88.63 ± 4.12 |
| LU50 | 226.25 ± 3.67 a | 10.25 ± 0.25 a | 1.86 ± 0.14 | 86.00 ± 3.67 |
| LU33 | 214.25 ± 3.47 b | 7.50 ± 0.28 c | 1.64 ± 0.09 | 85.88 ± 2.68 |
| $LSD_{0.05}$ | 10.824 | 0.9435 | NS | NS |
| CV (%) | 4.85 | 7.21 | 13.37 | 8.16 |

*Different letters within the column indicate significant differences between means using the least significant difference test (LSD) at 5% significant level ($p \le 0.05$)

There was no significant difference in dry matter production among the fertilized plants, but all of them differed significantly from the control treatment. The dry matter production in the LU100 treatment was 55.53 g plant$^{-1}$, and the lowest (28.44 g plant$^{-1}$) dry matter was recorded from the U0 (control) treatment. The highest %N content was recorded in LU100 (1.73%) followed by the other treatment, but they were significantly different from the other fertilized treatments. The lowest %N content was recorded from the U0 (1.24%) treatment. Similarly, the highest total N content in the plant was recorded in LU100 (0.960 g), but it was significantly different from LU50 (0.864 g) treatment. In addition, total N content in GU100, LU50 and LU33 were as par as they were not significantly different. The NUE was the highest in the LU33 (25.05%) treatment, followed by LU50 (18.04%) treatment. The NUE values in GU100 and LU100 were not significantly different, the LU50 treatment recorded 107.59% higher NUE than GU100.

## 3.2 Growth parameters at maturity

The results of plant growth parameters at the mature stage of the corn are shown in Table 5.

**Table 6** Ear length (cm), days of maturity and fresh cob weight (kg ha$^{-1}$) of grain corn at the mature stage (Mean ± SE)

| Treatment | Ear length (cm) | Days of maturity (days) | Fresh cob weight (kg ha$^{-1}$) |
|---|---|---|---|
| U0 | 14.75 ± 0.72 c* | 84.50 ± 1.50 b | 5079.97 ± 121.96 |
| GU100 | 22.25 ± 0.27 a | 88.75 ± 2.63 a | 10,866.60 ± 185.23 |
| LU100 | 22.88 ± 1.13 a | 89.00 ± 3.02 a | 10,946.60 ± 181.35 |
| LU50 | 21.75 ± 0.25 a | 86.75 ± 2.25 ab | 10,927.93 ± 290.05 |
| LU33 | 18.25 ± 0.25 b | 86.50 ± 2.50 ab | 7519.96 ± 367.57 |
| $LSD_{0.05}$ | 1.899 | 3.7024 | 739.97 |
| CV (%) | 6.31 | 2.51 | 5.41 |

*Different letters within the column indicate significant differences between means using the least significant difference test (LSD) at 5% significant level ($p \le 0.05$)

**Table 7** Fresh stover weight (g plant$^{-1}$), dry stover weight (kg ha$^{-1}$), grain weight (g plant$^{-1}$) and husk weight (kg ha$^{-1}$) of grain corn at the mature stage (mean ± SE)

| Treatment | Fresh stover weight (g plant$^{-1}$) | Dry stover weight (kg ha$^{-1}$) | Grin weight (g plant$^{-1}$) | Husk weight (kg ha$^{-1}$) |
|---|---|---|---|---|
| U0 | 185.51 ± 4.65 d* | 3824.11 ± 210.74 d | 39.50 ± 1.94 d | 613.06 ± 30.26 c |
| GU100 | 230.63 ± 5.85 b | 5208.10 ± 216.71 b | 94.89 ± 1.52 b | 1093.33 ± 63.48 b |
| LU100 | 281.48 ± 7.88 a | 5663.43 ± 157.43 a | 102.17 ± 2.18 a | 1346.66 ± 59.13 a |
| LU50 | 213.46 ± 4.34 c | 4735.44 ± 200.27 c | 92.75 ± 1.93 b | 1093.33 ± 63.48 b |
| LU33 | 198.41 ± 4.39 cd | 4506.77 ± 153.76 c | 65.10 ± 1.48 c | 720.00 ± 55.51 c |
| $LSD_{0.05}$ | 16.84 | 417.95 | 5.5138 | 168.12 |
| CV (%) | 5.03 | 5.79 | 4.64 | 11.46 |

*Different letters within the column indicate significant difference between means using the least significant difference test (LSD) at 5% significant level ($p \le 0.05$)

There was no significant difference in GU100 (229.75 cm), LU100 (232.50 cm) and LU50 (226.25 cm) treatments in terms of plant height, but they were significantly higher than LU33 and U0 (control) treatment. The lowest plant height was recorded from the U0 treatment. On the other hand, the U0 (197.00 cm) treatment was not significantly different from LU33 (214.25 cm) treatment. The highest leaf number was recorded from the LU100 (10.50) and the LU50 (10.25) treatments, while the lowest leaf number was recorded from the U0 (7.25) and LU33 (7.50) treatments. There were not significantly different in stem diameter and ear height among the treatments.

### 3.3 Yield and yield contributing parameters at maturity

The results of ear length, days of maturity and fresh cob weight are tabulated in Table 6.

The ear lengths in GU100 (22.25 cm), LU100 (22.88 cm), and LU50 (21.75 cm) treatments were not significantly different, and they were significantly higher than in LU33 (18.25 cm) treatment. Furthermore, the LU33 treatment was higher than the U0 (control) treatment in terms of ear length. There was no significant difference among the fertilized plant in the duration of maturity, but LU100 and GU100 were significantly higher than the U0 (control) treatment. The fresh cob weight of GU100 (10,866.60 kg ha$^{-1}$), LU100 (10,946.60 kg ha$^{-1}$), and LU50 (10,927.93 kg ha$^{-1}$) were not significantly different, but they were significantly higher than LU33 (7519.96 kg ha$^{-1}$) treatment. On the other hand, the fresh cob weight of the LU33 treatment was significantly higher than the U0 (5079.97 kg ha$^{-1}$) treatment.

The results of fresh stover weight, dry stover weight, grain weight and husk weight of grain corn at the mature stage are listed in Table 7.

The highest fresh stover weight plant$^{-1}$ was recorded from LU100 (281.48 g) treatment which was 22.08% higher than GU100 (230.63 g) treatment. The fresh stover weight in LU50 (213.46 g) and LU33 (198.41 g) were not significantly different. The lowest fresh stover weight was recorded in the U0 (185.51 g) treatment which was as par with the LU33 (198.41 g) treatment as they were not significantly different. The dry stover weight ha$^{-1}$ was also a similar trend to fresh stover production. The dry stover weight ha$^{-1}$ was the highest in the LU100 (5663.40 kg) treatment which was 8.74% higher than GU100 (5208.10 kg) treatment. Dry stover weight in LU50 (4735.44 kg) and LU33 (4506.77 kg) were not significantly different, but they were significantly higher than in U0 (3824.10 kg) treatment. The highest grain weight plant$^{-1}$

**Table 8** Kernel rows (No.), no. of grain row$^{-1}$, 100-grain weigh (g) and grain yield (kg ha$^{-1}$) of grain corn at the mature stage (mean ± SE)

| Treatment | Kernel rows (no.) | No. of grain row$^{-1}$ | 100-grain weight (g) | Grain yield (kg ha$^{-1}$) |
|---|---|---|---|---|
| U0 | 12.50 ± 1.26 | 19.25 ± 1.44 c* | 14.75 ± 0.95 c | 2906.65 ± 228.87 d |
| GU100 | 14.00 ± 0.82 | 32.25 ± 1.55 ab | 20.51 ± 0.96 ab | 5746.64 ± 102.99 b |
| LU100 | 14.00 ± 0.50 | 34.50 ± 1.85 a | 22.50 ± 0.96 a | 6249.03 ± 41.60 a |
| LU50 | 13.25 ± 0.50 | 33.75 ± 2.50 ab | 21.39 ± 0.37 a | 5666.50 ± 59.22 b |
| LU33 | 13.25 ± 0.63 | 28.75 ± 0.95 b | 18.50 ± 0.96 b | 4271.98 ± 78.69 c |
| $LSD_{0.05}$ | NS | 5.22 | 2.62 | 367.75 |
| CV (%) | 11.71 | 11.66 | 8.90 | 4.91 |

*Different letters within the column indicate significant difference between means using the least significant difference test (LSD) at 5% significant level ($p \le 0.05$). NS = Not significant

**Table 9** %N in stover, %N in grain, total N content in plant (kg ha$^{-1}$) and NUE (%) of grain corn at the mature stage (mean ± SE)

| Treatment | % N in stover | % N in grain | Total N content in plant (kg ha$^{-1}$) | NUE (%) |
|---|---|---|---|---|
| U0 | 0.345 ± 0.019 c* | 0.917 ± 0.03 d | 30.78 ± 1.92 d | – |
| GU100 | 0.659 ± 0.010 a | 1.159 ± 0.04 c | 82.84 ± 2.87 b | 37.19 ± 1.93 c |
| LU100 | 0.655 ± 0.004 a | 1.489 ± 0.04 a | 102.83 ± 1.93 a | 51.47 ± 0.82 b |
| LU50 | 0.492 ± 0.0178 b | 1.274 ± 0.03 b | 77.62 ± 1.07 b | 66.92 ± 2.47 a |
| LU33 | 0.358 ± 0.005 c | 0.966 ± 0.02 d | 46.83 ± 1.05 c | 34.40 ± 2.94 c |
| $LSD_{0.05}$ | 0.031 | 0.095 | 5.704 | 6.756 |
| CV (%) | 4.15 | 5.44 | 5.55 | 9.23 |

*Different letters within the column indicate significant difference between means using the least significant difference test (LSD) at 5% significant level ($p \le 0.05$)

was recorded from LU100 (102.17 g), followed by GU100 (94.89 g) and LU50 (92.75 g) treatments. However, GU100 and LU50 were not significantly different. The grain weight plant$^{-1}$ in LU100 was 7.67% higher than in GU 100 treatment. The lowest grain weight plant$^{-1}$ was recorded in U0 (39.50 g), followed by LU33 (65.10 g) treatment. The highest husk weight ha$^{-1}$ was recorded in the LU100 (1346.66 kg), which was 22.83% higher than GU100 (1096.33 kg) treatment. Husk weight ha$^{-1}$ in GU100 (1096.33 kg) and LU50 (1093.33 kg) treatments were not significantly different, while the lowest husk weight ha$^{-1}$ were recorded in LU33 (720.00 kg) and U0 (613.06 kg) treatments.

The results of kernel rows, number of grainrow$^{-1}$, 100-grain weight, and grain yield are presented in Table 8.

The number of kernel rows was not significantly different among the treatments. The highest number of grains row$^{-1}$ was recorded in LU100 (34.50) treatment which was not significantly different from GU100 (32.25) and LU50 (33.75). On the other hand, GU100, LU50 and LU 33 were not significantly different, but they were significantly higher than the U0 (control) treatment. The lowest number of grains per row was recorded from the U0 (19.25) treatment. The 100-grain weight in the fertilized plant was significantly higher than the U0 (control) treatment. 100-grain weight in the LU100 (22.50 g), LU50 (21.39 g), and GU100 (20.51 g) treatments were not significantly different. On the other hand, the 100-grain weight of the treatment GU100 and LU33 were not significantly different. The lowest 100-grain weight resulted from U0 (14.75 g) treatment followed by LU33 (18.50 g) treatment. The grain yield was the highest in the LU100 (6249.03 kg ha$^{-1}$) treatment which was 8.70% and 10.22% higher than GU100 and LU50 treatments. Nonetheless, the grain yield in GU100 (5746.64 kg ha$^{-1}$) was not significantly different from the LU50 (5666.50 kg ha$^{-1}$) treatment.

### 3.4 N content and NUE of grain corn at maturity

The %N in stover, grain, total N content in plant and NUE are stated in Table 9.

The %N content in the stover in the LU100 (0.655%) and GU100 (0.659%) treatments were not significantly different, but they were significantly higher than LU50 (0.492%) treatment. The highest %N content in the grain was recorded from LU100 (1.489%) among the treatments, followed by LU50 (1.274%). The %N content by the grain in LU50 (1.274%) was even higher than in GU100 (1.159%) treatments. The %N content grain in LU100 and LU50 was 28.47% and 9.92% higher than GU100 treatment, respectively. The highest total N content in the plant was recorded in LU100 treatment

(102.83 kg ha$^{-1}$), followed by GU100 (82.84 kg ha$^{-1}$) and LU50 (77.62 kg ha$^{-1}$) treatments. In addition, the total N content in the LU100 treatment was 24.15% higher than in the GU100 treatment. The total N content in GU100 and LU50 was not significantly different, but they were higher than LU33 (46.83 kg ha$^{-1}$) treatment. The lowest total N content was recorded in U0 (30.78 kg ha$^{-1}$) treatment, followed by LU33. The NUE was highest in LU50 treatment (66.92%), followed by LU100 (51.47%). The NUE in the LU50 treatment was 79.94% higher than in GU100 treatment.

### 3.5 Total N (%) content of post-harvest soil

The nitrogen content (%) of post-harvest soil is presented in Table 10.

The N content in LU100 (0.073%), GU100 (0.073%) and LU50 (0.067%) treatments were not significantly different though they were significantly higher than in U0 (control) and LU33 treatments. The lowest N content of post-harvest soil was found in U0 (0.052%) and LU33 (0.055%) treatments.

## 4 Discussion

The results of the study revealed that the yield contributing parameters and yield of grain corn were significantly different between the application of LU and GU. The SPAD value, fresh biomass and N content were highest in the LU100 treatment while harvested at 50 DAS among all the treatments. Besides, LU50 treatment was not significantly different from GU100, even when half of the recommended dose was used. Possibly, the LU treatments provided more available N for the plant for uptake and fewer N losses than GU, which promoted the corn plant to take up a greater amount of N than GU applications; meanwhile, GU had higher N loss, as it was reported about 10 – 80% N loss from applied urea remain unexplained [28]. The higher N uptake promoted higher growth and development, and the higher growth enabled higher biomass production. The higher growth also increased the yield contributing parameters and finally increased the yield of the crop. The LU-treated plant might have received more available N, which increased the N uptake by the corn plant and increased the N content in the plant. Biomass production is positively associated with growth and N uptake rate by the plant [28, 29, 35].

At the mature stage, the yield components such as ear length and fresh cob weight in LU50 were as par with GU100 as they were not significantly different even when only half of the recommended urea dose was applied. Due to the higher availability of N and lower N loss, the plant in LU50 treatment could take up a higher amount of N. The increased N content in the plant led to increased yield ultimately [1, 2]. Other researchers reported that less biomass production was recorded (260.86 g plant$^{-1}$ and 266.59 g plant$^{-1}$) when N was applied at a lower rate (70 kg ha$^{-1}$ and 140 kg ha$^{-1}$) due to lower N availability and uptake (2.12 g N plant$^{-1}$ and 2.58 g N plant$^{-1}$) against plant demand [43]. However, this was not observed for LU applied at 50% of the recommended dosage due to higher N availability and loss minimization.

The LU100 treatment produced the highest grain yield as the growth and development of the corn plant was higher. The balanced N concentration in plants promotes greater protein synthesis, which can be stored in the grain [6, 31]. In addition, grain yield in LU50 was not significantly different from the GU100 application, which indicates that most of the N in GU100 was lost. There is a directly proportional relationship between N source and corn development [36]. Liquid urea was reported to increase plant N uptake potential, which significantly affected the grain yield of corn [3, 10, 28].

**Table 10** Total N content (%) of post-harvest soil

| Treatment | Total N content (%) (mean ± SE) |
|---|---|
| U0 | 0.052 ± 0.003 b* |
| GU100 | 0.073 ± 0.002 a |
| LU100 | 0.073 ± 0.002 a |
| LU50 | 0.067 ± 0.003 a |
| LU33 | 0.055 ± 0.003 b |
| $LSD_{0.05}$ | 0.0075 |
| CV (%) | 7.69 |

*Different letters within the column indicate significant differences between means using the least significant deference test (LSD) at 5% significant level ($p \leq 0.05$)

Liquid urea application has also been reported to increase grain yield by 15–20% due to higher N availability than GU [19, 29, 49]. The higher plant N uptake by the LU-treated crops was due to the higher urea mineralization and adsorption of N by the soil particles, which increases N availability and reduces N losses (e.g., gaseous and leaching), where, the gaseous ($NH_3$ and $N_2O$) losses and leaching loss were significantly lower in LU-treated soil than that of GU at same application rate [27, 30].

Nitrogen content in the plant directly relates to biomass production and N concentration in the plant. In this study, the highest total N content in the plant was recorded in the LU100 treatment. On the other hand, the N content in GU100 and LU50 was significantly similar, as the LU treated plant received more available N for uptake and lower N losses than the GU treated plant. Singh et al. [49] recorded a higher N uptake in LU applied crops compared to GU because of higher N availability. Moreover, Mueller and Vyn [31] obtained higher biomass production in the surface-banded UAN (a liquid N fertilizer) than in the surface application of urea, as urea had experienced greater gaseous loss.

Nitrogen use efficiency will be higher if N is more available, while N losses are lower because of the higher N uptake potential of the crop. It is directly proportional to total biomass production and its N content. In LU50, NUE was the highest (66.92%) as a lower N rate (50% of recommendation) was used, but the yield (5666.50 kg $ha^{-1}$) was statistically similar to GU100 (5746.64 kg $ha^{-1}$. Granular urea application increased the N loss and reduced the N availability to the plant [28, 41, 49]. Liquid urea application improves NUE by decreasing N losses as LU can be dispersed throughout the rhizosphere and reduces the risk of N loss increasing the N availability and uptake potential of the crops [38, 58]. Corn is a crop with high nutrient demand, and N is the most significant nutrient that influences crop productivity [9]; therefore, the soil cannot maintain optimum N in the soil applied with a lower N application rate or when applied in areas prone to N losses.

The plant N content and N uptake by the plants depend on the demand and availability of N in the soil. The N demand in corn depends on its growing stages, and N availability depends on its soil adsorption and loss minimization processes. The fast mineralization of N reduces N losses and rapidly supplies N to plants, which will increase NUE and reduce the risk of environmental contamination. Optimum N management increases farm income by lowering fertilizer input cost, plant protection cost, and increasing grain quality.

## 5 Conclusion

The grain yield in GU100 and LU50 treatments were not significantly different, though; the grain yield was the highest in the LU100 treatment. The highest total N content (N uptake) was recorded in the LU100 treatment. The total N content in GU100 and LU50 were not significantly different. The NUE was highest in LU50 treatment, followed by LU100 treatment. Therefore, the LU100 treatment might be yield effective and LU50 treatment cost effective. In conclusion, the efficiency of LU was higher than GU in terms of the growth and development of grain corn. Further field assessment is necessary to conform to the findings.

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## Declarations

**Competing interests** The authors declare no competing interests.

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