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Response of Tef *(Eragrostis tef [Zucc.] Trotter)* to Rates of Nitrogen from Urea and Urea ^{Stabil} on Vertisols in the Central Highlands of Ethiopia

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Abstract

Nitrogen loss through leaching, volatilization, and denitrification poses significant challenges with highly soluble fertilizers like urea, leading to decreased crop yields and nitrogen use efficiency. To address this issue, field experiments were conducted from 2017 to 2019 at Becho district of the southwest Shewa zone in Oromia Region with the objectives of evaluating the efficiency of Urea ^{Stabil} as a slow-release nitrogen source; and determining optimum rate of nitrogen application for tef production on Vertisols in the central highlands of Ethiopia. The experimental design used was a randomized complete block design with three replications. Four levels of Urea ^{Stabil} fertilizer, applied once at sowing and in two splits, were compared to conventional urea at recommended and one-third more than recommended rates, resulting in a total of nine treatments. Nine treatments, including four levels of Urea ^{Stabil} and conventional urea at recommended and higher rates, were compared across six farmers' fields. Results revealed significant effects of nitrogen levels on various tef growth parameters. While the highest biomass and grain yields were obtained with 92 kg ha^{-1} N from Urea ^{Stabil} applied in two splits, comparable yields were achieved when the same nitrogen rates were applied from Urea ^{Stabil} once at sowing or from urea in splits. The timing and source of nitrogen did not significantly affect tef yields, certain similar nitrogen rates. Moreover, increasing nitrogen levels beyond existing recommendations improved both biomass and grain yields, indicating the insufficiency of current recommendations for optimizing tef yield in the study area. Generally, applying 92 kg ha^{-1} N in splits using Urea Stabil enhanced tef productivity more effectively than the previously recommended nitrogen rates.

Keywords: Grain Yield, Urea ^{stabile}, Nutrient Use Efficiency, Vertisol

Introduction

Tef *(Eragrostis tef [Zucc.] Trotter)* is a cereal crop of dominant importance in Ethiopia, valued for its nutritional richness, adaptability to diverse agro-ecological conditions, and integral role in the country's culture and cuisine (Gebremariam et al., 2019). As Ethiopia's most widely cultivated cereal, tef plays a crucial role in ensuring food security and sustaining livelihoods, particularly in rural areas where it serves as a staple food for millions of people (Assefa & Cannarozzi, 2015; Girma et al ;2022).

However, the sustainable production of tef faces several challenges, mainly including soil fertility depletion, which is particularly obvious in regions dominated by Vertisols, prevalent in the central highlands of Ethiopia (Gebremariam et al., 2019). Vertisols are characterized by high clay content and low organic matter, making them prone to soil moisture fluctuations and nutrient leaching, thereby posing constraints to crop productivity (Majid Rahimizadeh et al., 2010; Haile et al., 2012; Bereket et al., 2014).

Among the essential nutrients vital for tef growth and development, nitrogen (N) is of paramount importance. Nitrogen fertilization significantly influences tef yield and quality; however, traditional urea fertilizers, commonly used for N supplementation, are susceptible to N losses through volatilization, leaching, and denitrification, especially in Vertisols-dominated regions (Assefa & Cannarozzi, 2015; Hailu & Demelash, 2017).

In response to the challenges associated with traditional nitrogen (N) fertilizers, alternative sources such as Urea Stabil have gained attention for their potential to enhance nitrogen use efficiency and reduce environmental impacts (Tadesse & Mohammed, 2018). Urea Stabil fertilizers are formulated to inhibit urease and nitrification enzymes, which helps to minimize N losses and increase N availability to crops. This can potentially lead to improved yields and reduced environmental pollution (Tadesse & Mohammed, 2018).

Despite these promising attributes, the effectiveness of Urea Stabil fertilizers for tef production on Vertisols in the central highlands of Ethiopia remains underexplored. Comprehensive evaluations are needed to assess their performance and suitability for tef cultivation in these conditions. The optimal application rate of slow-release N fertilizers for maintaining tef productivity in this region has yet to be determined (Zeleke & Nega, 2016; Abebe & Chali, 2020).

The objectives of this study were to: (1) evaluate the effectiveness of Urea Stabil compared to conventional urea (referred to as urea) and (2) determine the optimal rate of Urea Stabil nitrogen fertilizer for balanced fertilization in tef production in the central highlands of Ethiopia. Through a systematic assessment, the study aims to provide valuable understandings into the potential of Urea Stabil fertilizers as a sustainable solution for improving tef productivity in Vertisol-dominated areas.

Materials and Methods

Description of the study area

The experiment was conducted during 2017 to 2019 across a total of six farmers' fields in Becho district of the southwest Shewa zone in Oromia Region, located in the central highlands of Ethiopia. The experimental site is positioned between 09°03'N and 38°30'E, and at an altitude of approximately 2200 meters above sea level. This area experiences a bimodal pattern of precipitation, with an average annual rainfall of 1100 mm. around 85% of the rainfall occurs from June to September, while the remaining occurs from January to May. The average minimum and maximum air temperatures are 7.2°C and 22.4°C, respectively. The predominant soil type at the trial site is Vertisol (IUSS Working Group WRB, 2014), and the major crops cultivated in the area include tef and chickpea (ESS, 2022).

Treatments and Experimental Design

Four levels of Urea ^{Stabil} fertilizer, applied once at sowing and in two splits, were compared to conventional urea at recommended and one-third more than recommended rates, resulting in a total of nine treatments. The experimental design used was a randomized complete block design with three replications. The recommended amounts of phosphorus (20 kg ha^{-1}) and sulfur (30 kg ha^{-1}) were applied to all plots using triple super phosphate (TSP) and calcium sulfate ($CaSO_4$), respectively. Phosphorus and sulfur fertilizers were applied once at sowing whereas Urea and Urea ^{Stabil} were applied either once during sowing or in two splits, with half at sowing and the remaining half at the tillering stage of the test crop. Tef (variety: kuncho) seeds were manually drilled in rows spaced 20 cm apart on a 12 m^2 (4m x 3m) plot at a seed rate of 15 kg ha^{-1} at the end of June. All other cultural practices were performed according to the recommended practices for tef cultivation.

Table 1. Description of Treatments

No	Treatments Description	N rate (kg ha^{-1})
1	No input (negative control)	0
2	Recommended nitrogen (RN) from urea (positive control)	69
3	RN from Urea ^{Stabil} applied once at sowing	69
4	RN from Urea ^{Stabil} applied in splits	69
5	Half RN from Urea ^{Stabil} applied once at sowing	34.5
6	Half RN from Urea ^{Stabil} applied in splits	34.5
7	One-third more than RN from Urea ^{Stabil} applied splits	92
8	One-third than RN from Urea applied in splits	92
9	One-third more than RN from Urea ^{Stabil} applied once at sowing	92

Note: ***RN- recommended Nitrogen***

Soil and Agronomic Data Collection

Composite surface soil samples from each treatment (0-20 cm depth) were collected from the experimental fields. These samples underwent analysis for pH, organic carbon (OC), total nitrogen (N), and available phosphorus (P). Soil pH was determined using a pH electrode at a soil: water ratio of 1:1 (w/v) (Carter, 1993). Organic carbon was determined using the wet digestion method outlined by Walkley and Black (1934). Total nitrogen content was analyzed using the Kjeldahl method (Jackson, 1958). Available phosphorus was determined following the procedures outlined by Bray and Kurtz (1945).

Additionally, soil texture was assessed using the hydrometer method (Gee & Bauder, 1986), while soil moisture content was measured by gravimetric analysis (Blake & Hartge, 1986). Cation exchange capacity (CEC) was determined using the ammonium acetate method (Soil Survey Staff, 1996). Electrical conductivity (EC) was measured in a saturated paste extract using a conductivity meter (Rhoades, 1982).

Agronomic data collected included grain yield, above-ground total biomass yield, harvest index, plant height, panicle length, and days to maturity. Plant height was measured from ground level to the tip of the panicle at physiological maturity from ten representative plant samples. Panicle length was measured from the base to the top of the panicle, from ten randomly chosen plant samples. The entire plot was harvested at physiological maturity and its biomass yield was determined. Harvested were air-dried to constant moisture content, threshed, cleaned, and weighed to determine grain yields. Total biomass (on a dry matter basis) and grain yields recorded on a per-plot basis were converted to kg ha^{-1} for statistical analysis. Agronomic efficiency was calculated by dividing the grain yield to the applied nitrogen (Cleemput *et al.*, 2008).

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

Where, AE is Agronomic efficiency; Yn and Yo are the grain yield with and without N applied, respectively, and Fn is the amount of nitrogen fertilizer applied.

Data Analysis

The collected soil and agronomic data underwent analysis of variance (ANOVA) using SAS program version 9.1.3 (SAS, 2002). Prior to analysis, outliers were removed, and normality of residuals was tested using the same tool. Significant differences among treatment means were evaluated using the least significant difference test (LSD) at the 0.05 level of probability (Gomez and Gomez, 1984).

Results and Discussion

Soil Properties

Table 2 presents the chemical properties of the surface soil (0-20cm depth) at the experimental sites collected from each treatment after harvesting (Table 2).

Table 2. Soil Chemical properties of the experimental sites after harvest

Treatments	pH	Available P (mg kg^{-1})	Total N (%)	Organic carbon (%)
No N	6.2	10.86	0.26	1.56
34.5 N from Urea ^{Stabil} applied once	6.11	9.75	0.26	1.48
34.5 N from Urea ^{Stabil} applied in splits	6.08	11.02	0.28	1.58
69 N from urea	6.13	12.96	0.24	1.46
69 N from Urea ^{Stabil} applied once	6.22	11.72	0.22	1.42
69 N from Urea ^{Stabil} applied in splits	6.06	10.37	0.26	1.52
92 N from Urea ^{Stabil} applied in splits	6.15	12.38	0.24	1.56
92 N from Urea applied in splits	6.12	10.79	0.26	1.6
92 N Urea ^{Stabil} applied once	6.18	12..77	0.22	1.53
Mean	**6.14**	**11.23**	**0.25**	**1.52**

The average soil pH (H_2O) of 6.14 indicates a slightly acidic soil reaction, which is generally suitable for tef production (Tekalign, 1991). However, tef has specific soil pH preferences, so adjustments may be necessary based on local recommendations. Similar variations in soil pH in response to different fertilization practices have been observed in previous studies (Carter, 1993).

The mean values for organic carbon (OC) at 1.52% and total nitrogen (N) at 0.25% fall into the low to medium categories, respectively, according to Tekalign (1991). These results highlight the need for soil management practices that promote organic matter accumulation and enhance nitrogen availability to improve soil fertility and crop productivity. Variations in nitrogen content among treatments suggest differences in the efficiency of nitrogen uptake and utilization by the soil and crops (Jackson, 1958). These findings reflect the impact of nitrogen fertilization practices on soil organic matter dynamics, with implications for soil fertility and carbon sequestration (Walkley and Black, 1934).

The average available phosphorus (P) content of 11.23 mg kg^{-1} categorizes the soil as low in phosphorus (Jones, 2003). Adequate phosphorus availability is crucial for various physiological processes in plants, including energy transfer and root development. Therefore, strategies to improve phosphorus availability, such as targeted fertilizer applications or soil amendments, may be acceptable.

In general, the soil analysis results emphasize the importance of implementing appropriate soil management practices to address deficiencies in organic matter, nitrogen, and phosphorus levels. Strategies such as incorporating organic amendments, balanced fertilization, and soil conservation measures can contribute to improving soil health and supporting sustainable tef production systems.

Effects of UREA Stabil and Conventional Urea on Tef Growth Parameters

The analysis of variance revealed significant effects ($p<0.05$) of applying different levels of nitrogen (N) from urea and urea Stabil fertilizer sources on the plant height and panicle length of tef (Table 3). Application of 92 kg ha^{-1} N from Urea Stabil once at sowing resulted in the tallest plant (107.9 cm) and longest panicle (38.8 cm). Interestingly, applying the same N amount (92 kg ha^{-1}) from Urea Stabil in two splits also resulted in comparable panicle length (37 cm) with once application, suggesting that the of Urea Stabil application does not significantly influence this parameter. Likewise, using 92 kg ha^{-1} N from urea in two splits provided a similar panicle length (36.5 cm), indicating that the nitrogen source has no significant effect as long as the amount of N available to plants is consistent (Table 3).

Mostly, the results indicated that both plant height and panicle length increased with higher nitrogen levels. Conversely, untreated plots exhibited the lowest plant height (72.8 cm) and panicle length (29.3 cm) (Table 3).

These findings are consistent with previous studies demonstrating the positive impact of nitrogen fertilization on the growth and development of tef (Smith et al., 2020; Bekalu and Arega 2016). The observed increase in plant height and panicle length with higher N levels emphasizes the importance of optimizing nitrogen application rates for maximizing tef yield potential.

Table 3. Mean of growth parameters and phenology of tef as affected by UREA ^{Stabil} and Conventional Urea

Treatments(kg/ha)	Day to physiological maturity	Plant height (cm)	Panicle length (cm)
No N	166.9^{a}	72.8^{f}	29.3^{d}
34.5 N from Urea ^{Stabil} applied once	152.7^{d}	92.2^{cd}	36.1^{b}
34.5 N from Urea ^{Stabil} applied in splits	151.3^{de}	97.0^{bc}	36.4^{ab}
69 N from urea	150.3^{e}	97.4^{bc}	35.9^{b}
69 N from Urea ^{Stabil} applied once	161.6^{b}	84.7^{e}	33.1^{c}
69 N from Urea ^{Stabil} applied in splits	161.7^{b}	86.9^{de}	34.7^{bc}
92 N from Urea ^{Stabil} applied in splits	157.3^{c}	100.4^{b}	37.0^{ab}
92 N from Urea applied in splits	157.2^{c}	99.9^{b}	36.5^{ab}
92 N Urea ^{Stabil} applied once	157.7^{c}	107.9^{a}	38.7^{b}
Mean	**157.4**	**93.2**	**35.3**
LSD (0.05)	1.88	5.58	2.36
CV (5%)	1.48	7.39	8.26

The application of different levels of nitrogen from urea sources seems to have an impact on the days to physiological maturity of tef. Ordinarily, higher levels of nitrogen result in a decrease in the number of days to maturity. This finding is consistent with previous research by Chala et al (2022), who observed a similar trend in the days to maturity of teff when different nitrogen levels were applied.

The plant height also shows variability with different nitrogen levels. Higher nitrogen levels tend to result in taller plants. This finding aligns with the findings of Abebe, & Tefera, (2015), who reported increased plant height with increased nitrogen application in tef cultivation. Similarly, panicle length shows variation with nitrogen application, with higher nitrogen levels generally resulting in longer panicles. This observation is in line with the results of Gebremariam, & Tefera, (2017), who found a positive correlation between nitrogen levels and panicle length in teff production.

The results of this study validate several other studies that have investigated the effect of nitrogen fertilization on growth parameters and days to maturity in various crops. For instance, Belay, & Tadele, (2014) conducted a study on tef and found similar trends in plant height and panicle length with varying nitrogen levels. Additionally, Getachew, & Haileselassie, (2019) conducted a meta-analysis on the effect of nitrogen fertilization on crop growth and maturity across different regions, further supporting the findings of this study. Therefore, the results of this study indicate that nitrogen fertilization significantly influences the growth parameters and days to physiological maturity of tef. Higher nitrogen levels generally lead to shorter days to maturity, increased plant height, and longer panicle length.

Effects of UREA Stabil and Conventional Urea on Yield and Yield Components of Tef

The comprehensive analysis of three years data demonstrated that the application of nitrogen at different rates from both urea and urea Stabil fertilizers resulted in a highly significant ($p<0.01$) higher biomass and grain yields of tef compared to the negative control (Table 4). The highest biomass (6112 kg ha^{-1}) and grain yields (2446 kg ha^{-1}) were achieved when 92 kg ha^{-1} N was applied from Urea Stabil fertilizer in two splits. Remarkably, this result was statistically comparable to the biomass (5751 kg ha^{-1}) and grain yields (2222 kg ha^{-1}) obtained from plots treated with the same amount of N from the same fertilizer, applied once at sowing. This suggests that the splitting of nitrogen application for urea Stabil did not significantly influence tef yields.

Similarly, plots treated with 92 kg ha^{-1} N from urea, applied in two splits, gave statistically equal biomass (5601 kg ha^{-1}) and grain (2200 kg ha^{-1}) yields with yields obtained from application of the same amount of nitrogen from Urea Stabil fertilizer applied in two splits and once at sowing indicating that the source of N fertilizer did not significantly impact yields provided the N quantity was consistent.

In general, the findings indicate a positive correlation between nitrogen levels and both biomass and grain yields of tef. These results suggest that the current recommendation of 69 kg ha^{-1} N may be insufficient to optimize tef yields in the study area. Conversely, untreated plots exhibited the lowest biomass (2356 kg ha^{-1}) and grain (931 kg ha^{-1}) yields, emphasizing the necessity of nitrogen fertilization for enhancing tef productivity.

Table 4. Tef Mean yield and yield components as affected by UREA Stabil and Conventional Urea

Treatments	Biomass yield (kg ha^{-1})	Grain yield (kg ha^{-1})	Harvest Index (%)
0N	2356^{g}	931^{f}	42.1
69N (Conventional urea)	4827^{cde}	1782^{cd}	37.5
69N Urea Stabil at planting	5127^{bcd}	1957^{bc}	38.1
69N Urea Stabil in split form	4735de	1841^{bcd}	38.7
34.5N Urea Stabil at once application	3583^{f}	1319^{ef}	38.2
34.5N Urea Stabil in split form	4014^{ef}	1422de	37.0
92N Urea Stabil split application	6112^{a}	2446^{a}	40.6
92N Normal Urea in split application	5601^{abc}	2200^{abc}	39.8
92N Urea Stabil at once application	5751^{ab}	2222^{ab}	38.0
Mean	4679	1791	39.0
LSD (0.05)	835.13	427	Ns
CV (5%)	22.03	29.4	23.06

Comparing these findings with existing research, studies by Bekalu and Arega 2016; Tadesse and Mohammed (2018) similarly observed significant increases in tef yields with higher nitrogen levels.

Additionally, a study by Assefa and Cannarozzi (2015) found that nitrogen application significantly increased tef yields, supporting the importance of nitrogen fertilizer application in tef crop production.

However, further investigations into optimal nitrogen management practices, including timing and sources of fertilizer application, are practical to maximize tef productivity while ensuring sustainability and resource efficiency.

Generally, the results presented in Table 4 prove the significant impact of nitrogen fertilization, both from conventional urea and urea ^{Stabil} sources, on biomass and grain yields of tef. Higher nitrogen levels generally correspond to increased yields, with the most substantial yields observed with the application of 92N from urea ^{Stabil} in split form. This suggests that optimized nitrogen management practices, particularly utilizing urea ^{Stabil} fertilizers and applying them in split form at higher rates, can effectively enhance tef productivity.

Effect of UREA Stabil and Conventional Urea on NUE of Tef

The agronomic nitrogen use efficiency (NUE) of tef, as depicted in Figure 1, reveals significant variability across different rates of urea and urea Stabil fertilizers. This variability emphasizes the importance of nitrogen management practices in optimizing crop productivity while minimizing environmental impacts.

Comparing these findings with existing research, a study by Gebremariam et al. (2018) investigated the influence of nitrogen fertilizer types and application rates on NUE in tef cultivation. Their results indicated that urea Stabil fertilizers improved NUE compared to conventional urea application methods. This aligns with the trend observed in Figure 1, where the use of urea Stabil appears to enhance NUE in tef. Supporting this effectiveness, further studies by Gebremariam et al. (2019) and Tadesse and Mohammed (2018) provide additional evidence for the benefits of optimized nitrogen management practices in tef cultivation.

Additionally, a study by Hailu and Demelash (2017) emphasized the impact of various nitrogen management practices on tef productivity, emphasizing the advantages of using slow-release fertilizers. Furthermore, a meta-analysis conducted by Getachew and Haileselassie (2020) synthesized findings from multiple studies on nitrogen fertilizer management in tef production. Their analysis revealed that optimal application rates of urea and urea Stabil fertilizers significantly contributed to higher NUE and improved tef yields. These findings underscore the importance of considering both fertilizer types and application rates in maximizing NUE in tef crop production.

Moreover, research by Abebe and Chali (2020) supports the idea that enhancing nitrogen use efficiency can lead to sustainable agricultural practices, which is crucial for the long-term productivity of tef in Ethiopia. Additional studies by Fekadu et al. (2021) demonstrated that integrated nutrient management practices further improve NUE and overall crop health in various regions of Ethiopia, highlighting the potential for holistic approaches in tef cultivation.

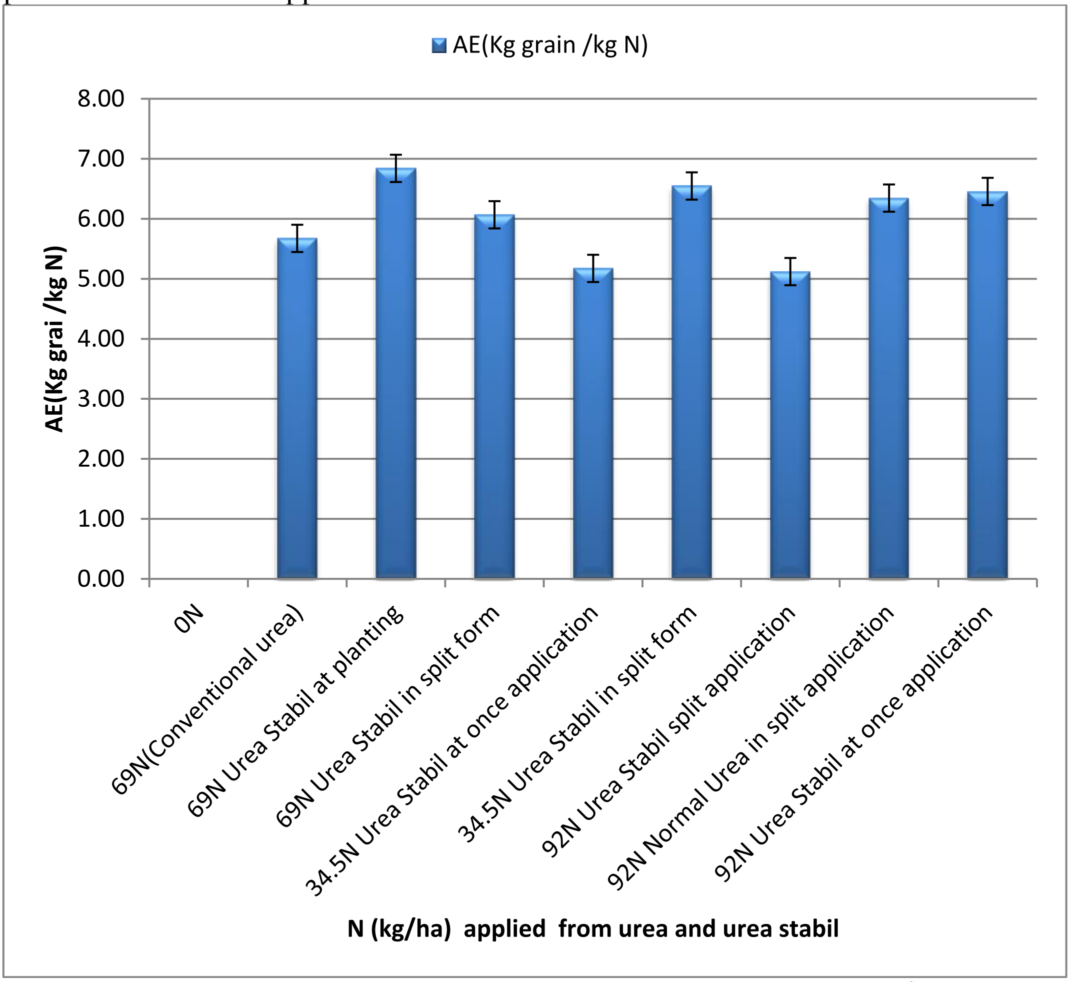

Figure 1. Agronomic nitrogen use efficiency of tef as influenced by applying conventional urea and urea Stabil fertilizers

However, it's essential to note that NUE can be influenced by various factors, including soil properties, climatic conditions, and agronomic practices. For instance, a study by Assefa and Cannarozzi (2015) demonstrated that soil nitrogen availability and moisture levels can affect the efficiency of nitrogen uptake by tef plants, ultimately influencing NUE outcomes.

Finally, the findings depicted in Figure (1) underline the significance of optimizing nitrogen fertilizer management practices to enhance agronomic nitrogen use efficiency in teff crop production. The use of urea ^{Stabil} fertilizers, along with appropriate application rates, can contribute to improved NUE and comprehensive crop productivity.

Conclusion

In conclusion, this study reveals the significant impact of nitrogen fertilization, sourced from both Urea ^{Stabil} and conventional urea fertilizers, on various growth parameters and yield components of tef. These findings reveal that higher nitrogen levels positively influence plant height, panicle length, grain, and biomass yield of tef. Notably, the application of 92 kg ha^{-1} N from Urea ^{Stabil} fertilizer, either in two splits or as a single application, resulted in the highest biomass and grain yields.

The timing of nitrogen application for Urea Stabil did not affect yields significantly; similar results were obtained regardless of when the nitrogen was applied. Likewise, the source of nitrogen (Urea Stabil vs. conventional urea) did not affect yields on condition that the nitrogen rate was the same, with both split applications showing similar results. The study suggests that the currently recommended nitrogen rate of 69 kg ha^{-1} is insufficient for maximizing tef yields in this area. Instead, applying 92 kg ha^{-1} of nitrogen, especially in split applications, appears to be more effective in enhancing tef productivity.

Therefore, this study suggests that the application of 92 kg ha^{-1} N in splits, whether from Urea ^{Stabil} or conventional urea, holds promise for maximizing tef yields. However, further assessments of nitrogen use efficiencies and economic benefits associated with different nitrogen fertilizer types and rates are necessary to formulate final recommendations for optimal tef production practices. A limitation of this study is the lack of data on nitrogen uptake, which is essential for understanding nutrient use efficiency and response variability. Further research is needed to assess nitrogen use efficiency and the economic benefits of different nitrogen fertilizers and application rates to finalize recommendations for optimal tef production.

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