Nitrogen use efficiency, yield and yield traits of wheat response to slow-releasing N fertilizer under balanced fertilization in Vertisols and Cambisols of Tigray, Ethiopia

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Abstract: The study was initiated to investigate the effects of slow nitrogen-releasing fertilizer (UREA\textsuperscript{Stabil}) on yield, yield components and nitrogen use efficiency indices of bread wheat at Emba Alaje and Hawzien Districts in Tigray, Ethiopia in 2015 at six farmers’ field and arranged in a randomized complete block design with three replications. Treatments were four levels of nitrogen (0, 32, 64 and 96) kg ha\textsuperscript{-1}. The nitrogen source was UREA\textsuperscript{Stabil}, which is slow N-releasing fertilizer. Conventional urea at the recommended rate (64 kg N ha\textsuperscript{-1}) was included as a positive control at both sites. A full dose of UREA\textsuperscript{Stabil} were applied at planting while prilled urea (conventional urea) was applied in two splits 1/3 at planting and 2/3 at tillering. Application of UREA\textsuperscript{Stabil} significantly influenced yield and yield components at both soil types. The highest grain yield was obtained on plots treated with 64 kg N ha\textsuperscript{-1} in the form of UREA\textsuperscript{Stabil} and prilled urea (conventional urea) in Hawzien and Emba Alaje districts, respectively. The highest nitrogen uptake was recorded on plots treated with 64 kg N ha\textsuperscript{-1} in the form of UREA\textsuperscript{Stabil} and prilled urea (conventional urea) in Hawzien and Emba Alaje, respectively. Nitrogen uptake, agronomic, physiological and apparent recovery efficiency were significantly influenced by the application of slow-releasing and conventional nitrogen fertilizers at both sites. In Hawzien, the application of slow-releasing N fertilizer in the form of UREA\textsuperscript{Stabil} reduces the amount of N used and application time. Hence, it could be concluded application of slow-releasing fertilizer could be used as an alternative source of nitrogen for wheat production in the study site.

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PUBLIC INTEREST STATEMENT
Nitrogen fertilizer is one of the main inputs for cereal production systems. Highly soluble N fertilizers like urea may be lost from the soil-plant system through leaching, volatilization and denitrification thereby reduce yields and NUE of arable crops. There are different mechanisms to improve the nitrogen fertilizer use efficiency. The use of appropriate N fertilizer, application rate and time are among the main management options to increase N fertilizer use efficiency. In addition, the use of slow N-releasing fertilizers like UREA\textsuperscript{Stabil} is an option to alleviate the problem.
1. Introduction
Nitrogen (N) transformation in soils, climate and sub-optimal fertilizer management practices have led to reduce N use efficiency (NUE) in many instances (i.e. up to 30–50%) (Sutton et al., 2013). These factors have contributed to an increase in N losses such as ammonia (NH₃) volatilization, nitrate (NO₃⁻) leaching and nitrous oxide (N₂O) emissions (IPCC, 2007), which are of economic and environmental concern. There are different mechanisms to improve the nitrogen fertilizer use efficiency. Cropping system, soil and water management, use of appropriate N fertilizer and application rate are the main management options to increase N fertilizer use efficiency (Fageria, 2009). Enhanced-efficiency fertilizers such as those containing nitrification inhibitors (NIs) and urease inhibitors (UIs) have been developed to increase NUE and reduce N losses by increasing the congruence between N supply and crop N demand. This effect is achieved by delaying the bacterial oxidation of ammonium (NIs) or the hydrolysis of urea (UIs). However, the use of these technologies is under debate because there are studies in which yield increases are not observed despite the additional costs (Akiyama et al., 2010).

UREA<sub>Stabil</sub> is one form of slow nitrogen-releasing urea. The nitrogenous fertilizer UREA<sub>Stabil</sub> is urea enriched with the inhibitor of urease enzyme NBPT (N-(n-butyl)-thiophosphoric triamide). It is a new fertilizer that was registered in the Czech Republic in 2006. UREA<sub>Stabil</sub> reduces losses due to volatilization, leaching and denitrification (Mraz, 2007). In Hawzien and Emba Alaje districts, application of N as Urea fertilizer and P as Diammonium Phosphate (DAP) at the rate of 100 kg urea and 100 kg DAP ha⁻¹ is a recommended rate to boost up wheat production and productivity. Nevertheless, wheat production and productivity are not as such satisfactory from year to year. At Hawzien and Emba Alaje districts, N losses from applied urea fertilizer might be through volatilization, denitrification and leaching. Therefore, an appropriate source of N fertilizer, rate and time of application may improve N fertilizer use efficiency of the wheat. However, the effects of slow nitrogen-releasing fertilizer on yield and yield components of wheat at Hawzien and Emba Alaje districts were not investigated. Therefore, this study was initiated to investigate the effects of slow nitrogen-releasing fertilizer (UREA<sub>Stabil</sub>) on yield and yield components of bread wheat and to quantify nitrogen use efficiency of wheat in Hawzien and Emba Alaje.

2. Materials and methods

2.1. Description of the study areas
The studies were conducted in Eastern Zone of Tigray Region, on Cambisols of Hawzien district and on Vertisols of Emba Alaje in 2015 main cropping season (Dargie et al., 2018). Soils of Hawzien District are one of the most degraded soils in the Tigray Region (Northern Ethiopia), which are very low in soil organic matter content and macro-nutrients such as N, P and K (EthioSIS, 2014). The dominant soil type in the district is Cambisols and the dominant soil type in Emba Alaje is Vertisols (Tigray finance and economic bureau [TFEB], 1995). The main soil properties of the six experimental sites are presented in Table 1.

2.2. Soil properties

2.3. Experimental design, treatments and procedures
The experimental design was a randomized complete block design (RCBD) with three replications. In all sites, the preceding crop was wheat or barley. Plot sizes were 4 m x 3 m. The spacing between plots and blocks was 50 and 100 cm, respectively. The spacing between wheat plant rows was 20 cm. A disease-resistant, early maturing and relatively high yielding varieties called Pica flor (kakaba) and kingbird were chosen for Hawzien and Emba Alaje, respectively.
Table 1. Selected physical and chemical properties of the soils of experimental sites sampled at 0–20 cm depth

| Soil parameters          | Experimental sites |
|-------------------------|--------------------|
|                         | Cambisols (Hawzien) | Vertisols (Emba Alaje) |
|                         | Field 1 | Field 2 | Field 3 | Field 1 | Field 2 | Field 3 |
| Sand (%)                | 71      | 65      | 63      | 25      | 27      | 19      |
| Silt (%)                | 13      | 15      | 19      | 29      | 35      | 25      |
| Clay (%)                | 16      | 20      | 18      | 46      | 38      | 56      |
| Textural Class          | SL      | SL      | SL      | C       | CL      | C       |
| pH(1:2.5 H2O)           | 6.2     | 6.1     | 6.2     | 6.7     | 6.4     | 6.6     |
| Organic Matter (%)      | 1.38    | 0.89    | 1.18    | 1.667   | 2.972   | 2.61    |
| Total Nitrogen (%)      | 0.082   | 0.051   | 0.073   | 0.157   | 0.211   | 0.204   |
| Available Phosphorous (mg kg⁻¹) | 5.04   | 6.34     | 5.54     | 9.7   | 16.74   | 11.86   |
| Available K (ppm)       | 122     | 127     | 228     | 144     | 191     | 162     |
| Cation Exchange Capacity (cmol (+) kg⁻¹) | 19.4 | 21.4     | 18.8     | 38   | 57.4    | 48.2    |

Adapted from Dargie et al. (2018).

Four levels (0, 32, 64 and 96) kg ha⁻¹ of nitrogen were tested. The nitrogen source was UREA⁷b⁶l which is slow N-releasing fertilizer. Treatments were applied at planting (sowing). Positive control of prilled urea (conventional urea) was included with a split application of 1/3 of 64 kg N ha⁻¹ at planting and 2/3 of N was applied at the tillering stage in the form of urea. Phosphorus in the form of triple superphosphate (TSP) was applied at the rate of 46 kg ha⁻¹ as (P₂O₅). Potassium in the form of chlorite potash (KCl) was applied at the rate of 100 kg ha⁻¹. Sulfur in the form of CaSO₄ was applied at the rate of 30 kg S ha⁻¹. P, K and S fertilizers were applied as a basal application at planting to all plots.

2.4. Data collection and data analysis

Agronomic data were collected following the standard procedures. Plant samples were collected at maturity for tissue analysis. Analysis of variance (ANOVA) and correlation were carried out using the SAS software program using SAS version 9.1.3 (SAS, 2002). A significant difference among treatment means, agronomic, physiological and apparent recovery efficiency were assessed using the least significant difference (LSD) at 0.05 level of probability (Gomez & Gomez, 1984). Normality and homogeneity of variance were checked using Anderson–Darling and Bartlett test, respectively, using SAS software (SAS, 2002).

3. Result and discussion

3.1. Growth parameters

3.1.1. Plant height

Results revealed that plant height was significantly (P < 0.001) affected by rates of nitrogen at all sites (Table 2). Plant height increased with increasing rates of nitrogen at all sites. At Suluh site, differences in plant height were significant, but at Atsela and Ayba sites, differences in plant height were significant only between the control and the other treatments. This may be due to the sufficient nitrogen in the soil (Table 1) and an abundant amount of rainfall. At Suluh site, the differences in plant height were significant on plots received the same rates of N (64 N kg ha⁻¹), but from different sources (conventional Urea and UREA⁷b⁶l) and it was higher for plots received N as UREA⁷b⁶l. At all sites, 32 kg N ha⁻¹ had also no statistically significant difference with recommended conventional urea (64 N kg ha⁻¹). This indicates
Table 2. Effect of conventional urea and UREAStabil on plant height, spike length and number of effective tillers of wheat

| Nitrogen levels (kg ha⁻¹) | Experimental sites |
|---------------------------|-------------------|
|                           | Cambisos (Hawzien) | Vertisols (Emba Alaje) |
|                           | PH (cm) | SL(cm) | NET | PH (cm) | SL(cm) | NET |
| 0 N                       | 61.8 c   | 6.24d  | 3.27 c | 86.09b | 7.08 c | 8.73 c |
| 32 N (UREA₃₈₃⁰)           | 67.73b  | 6.95bc | 5.44a  | 91.48a | 7.47b | 9.36bc |
| 64 N (UREA₆₆₈₈)           | 70.91a  | 7.18ab | 5.11ab | 92.09a | 8.04a | 11.3a |
| 96 N (UREA₇₇₈₉)           | 68.82ab | 7.37a  | 5.36a  | 91.2a  | 7.9a  | 10.53a |
| 64 N (Conventional Urea)   | 66.42b  | 6.82 c | 4.69b  | 92.72a | 7.88a | 10.29ab |
| Mean                      | 67.14   | 6.915  | 4.77   | 90.717 | 7.673 | 10.045 |
| LSD (0.05)                | 2.981   | 0.285  | 0.5965 | 2.9498 | 0.3624 | 1.1308 |
| CV (%)                    | 4.644   | 4.309  | 13.058 | 3.401  | 4.94  | 11.774 |

PH – plant height; NET – number of tillers; SL – spike length. Means with the same letter are not significantly different.

UREAStabil is superior to conventional urea in increasing plant height at Suluh site which might be due to the slow release of N that could accessible to plant throughout the growing period. The shortest plant height was recorded on plots that received 0 kg N ha⁻¹ at all sites.

The results obtained from Suluh site in Hawzien were in line with the finding of Khan et al. (2013) stated that plant height of wheat was high on plots received urea treated with urease and nitrification inhibitors than the conventional urea only. The results obtained from Atsela and Ayba sites in Emba Alaje were in line with the findings of Espindula et al., (2014) who stated that there was no significant difference at (P < 0.05) between wheat plant heights on plots treated with different rates of urea and urea + NBPT. Mengel and Kirkby (2001) reported significant increments in plant height due to the application of high nitrogen rate.

3.1.2. Spike length

Spike length is one of the yield attributes of wheat that contributes to grain yield. Crops with higher spike length could have higher grain yield. Spike length was significantly (P < 0.01) influenced by the rate and source of nitrogen fertilizer at all sites. At Suluh site in Hawzien district, there was an increasing trend in spike length with N rates. The highest and lowest spike length were recorded on plots treated with 96 kg N ha⁻¹ as UREAStabil (7.38 cm) and on control plots, 0 kg N ha⁻¹ (6.24 cm), respectively (Table 2). At Atsela and Ayba sites in Emba Alaje district, the highest and lowest spike length were recorded on plots treated with 64 kg N ha⁻¹ as UREAStabil (8.04 cm) and 0 kg N ha⁻¹ (7.08 cm), respectively. The differences were higher for plots treated with N as UREAStabil than plots treated with conventional urea at the same rates (64 kg N ha⁻¹). Plots received 32 kg N ha⁻¹ had higher spike length than 64 kg N ha⁻¹ in the form of conventional urea.

3.1.3. Number of effective tillers

Number of effective tillers contributes a lot to the total biomass gain and other yield attributes. The analysis of variance showed there was a highly significant difference (P < 0.01) due to the difference in nitrogen rates. The highest numbers of effective tillers were recorded for plots treated at 32 kg N ha⁻¹ and at 64 kg N ha⁻¹ of UREAStabil at Suluh in Hawzien and at Atsela and Ayba site in Emba Alaje, respectively (Table 3). The lowest numbers of effective tillers were recorded for plots received zero nitrogen at all sites and this might be due to the role of N in accelerating vegetative growth of plants. The results were in agreement with Abdullatif et al. (2010) reported shows increasing in the number of effective tillers with nitrogen fertilization. Haileselassie et al. (2014) and Abdollahi Gharekand et al. (2012) also reported that nitrogen fertilization has a significant effect on the effective number of tillers of wheat.
Table 3. Mean of number of seeds per spike, thousand seed weight of wheat as affected by Conventional urea and UREAStabil fertilizers

| Nitrogen level (kg ha⁻¹) | Experimental sites |          |          |
|--------------------------|--------------------|----------|----------|
|                          | Cambisos (Hawzien) | Vertisol (Emba Alaje) |
|                          | NSPS   | TSW (gm) | NSPS   | TSW (gm) |
| 0 N                      | 32.75c | 30.07b   | 40.98b | 47.93   |
| 32 N (UREAStabil)        | 36.98ab| 31.37ab  | 42.67ab| 48.9    |
| 64 N(UREAStabil)         | 38.18a | 33.65a   | 44.48a | 49.66   |
| 96 N(UREAStabil)         | 38.76a | 32.8ab   | 45.84a | 49.27   |
| 64 N(Conventional Urea)  | 35.84b | 33.82a   | 44.6a  | 51.63   |
| Mean                     | 36.50222| 32.344  | 43.64  | 49.44   |
| LSD (0.05)               | 1.8033 | 3.2703   | 2.938  | NS      |
| CV (%)                   | 5.167  | 10.575   | 7.041  | 8.581   |

NSPS – number of seed per spike, TSW – thousand seed weight (gm). Means with the same letter are not significantly different.

3.1.4. Number of seeds per spike
The analysis of variance showed a significant difference (P < 0.01) on the number of seeds per spike due to the effects of sources and rates of nitrogen. There was an increasing trend in the number of seeds per spike across UREAStabil treatments at all sites. The lowest and highest value were recorded at zero nitrogen treatment and 96 kg N ha⁻¹ as UREAStabil respectively at both sites (Table 3). At Suluh site differences in the number of seeds per spike was significant for the same rates of nitrogen (64 kg N ha⁻¹) but from different sources (UREAStabil and conventional urea) (Table 3). The values were higher for plots treated with UREAStabil than plots treated with conventional urea at equal rates. Number of seeds per spike for plots treated with 32 kg N ha⁻¹ UREAStabil was statistically significant on plots received 64 kg N ha⁻¹ as conventional urea at Hawzien. This might be due to the existence of NBPT in UREAStabil which has the capacity to inhibit or slow down the nitrification process and made N to be accessible for the rest of the growing period. Similar results have been reported for the influence of urease and nitrification inhibitors on yield and yield components including the number of seed per spike, plant height, spike length, number of tillers, TSW of wheat by Zaman et al. (2009).

3.1.5. Thousand seed weight
Analysis of variance showed that nitrogen rates and sources significantly influence the thousand seed weight. The highest thousand seed weight was recorded for plots treated at 64 kg N ha⁻¹ UREAStabil and the lowest was at zero nitrogen at Suluh in Hawzien. The thousand seed weight obtained at plots treated with 32 kg N ha⁻¹ UREAStabil was statistically the same with plots received 64 kg N ha⁻¹ as conventional urea at Hawzien. On the contrary, N rates and sources had no significance effect on the thousand seed weight at Atsela and Ayba in Emba Alaje. Numerically, thousand seed weight was higher in Emba Alaje than in Hawzien. This may be due to the genetic potential of the wheat variety used, the environmental stress especially rainfall and differences in grain filling period. The results recorded from Suluh site in Hawzien district were in line with Abdollahi Gharekand et al. (2012), Khan et al. (2013) and Xu et al. (2002) reported that urease and nitrification inhibitors influenced the thousand seed weight of wheat. Espindula et al. (2013) also reported that plants received urea had lower thousand grain mass than those which received urea with inhibitors.

3.1.6. Grain yield
At Suluh site in Hawzien, there was an inconsistent increment in the amount of grain yield with rates of N. The highest grain yield was recorded from plots treated with 64 kg N ha⁻¹ as UREAStabil...
(1708.33 kg ha⁻¹) and the lowest was recorded from plots that received 0 kg N ha⁻¹ (1102.73 kg ha⁻¹) (Table 5). Grain yield obtained from plots treated with 64 kg N ha⁻¹ in the form of conventional urea was significantly different (P < 0.05) from grain yield obtained from plots treated with the same rates of N as UREAStabil. Higher grain yield was obtained from plots treated with N as UREAStabil. In addition to this, grain yield obtained from plots treated with 32 kg N ha⁻¹ as UREAStabil was not significantly different from 64 kg N ha⁻¹ in the form of conventional urea. This might be due to the slow-releasing effect and low volatilization of N when applied as UREAStabil which could contribute to the higher grain yield. Khan et al. (2013) reported a higher grain yield of wheat when N was applied as super urea (urease plus nitrification inhibitor-treated urea).

At Atsela and Ayba sites in Emba Alaje, there was an increasing trend in grain yield with N application rates. Haileselassie et al. (2014) also reported that an increasing rate of nitrogen fertilization increased grain yield of wheat. The highest grain yield was recorded for plots that received 64 kg N ha⁻¹ (5467.9 kg ha⁻¹) as conventional urea. This might be due to the application of UREAStabil only at planting while N as conventional urea was applied through the split application. Therefore, split application of conventional urea (1/3 at planting and 2/3 at tillering stage) has an advantage to obtain higher grain yield at Atsela and Ayba sites in Emba Alaje district. Nelson et al. (2014) reported that split-N applications as urea, Urea+NBPT generally resulted in greater wheat yields than the application of N at planting. Hirzel et al. (2010) also reported that the highest grain yield of durum wheat was recorded for plots treated with a split application of urea. From these and results in Table 4, it is possible to predict that split application of N as UREAStabil could result in higher grain yield than conventional urea at Atsela and Ayba sites in Emba Alaje. Application of full dose of UREAStabil at planting may increase the loss due to denitrification and leaching at Emba Alaje district. This was in line with Picone et al. (2014) reported that the denitrification rate in wheat crop was observed when N fertilizer was applied and the rain was more frequent and intensive.

The mean grain yield at Suluh site in Hawzien was lower compared with that of Atsela and Ayba sites in Emba Alaje. This could be due to differences in wheat variety used, soil fertility status and amount of rainfall received. The fertility status of soils of Atsela and Ayba sites in Emba Alaje is better than that of Suluh site in Hawzien (Table 1). The amount of rainfall was also higher at Emba Alaje (960.4 mm) than that received at Hawzien (371.9 mm) during the cropping season (Dargie et al., 2018). As a result of these, grain yield was not as such satisfactory at the Suluh site in Hawzien.

Table 4. Mean of grain yield, straw yield, and harvest index as affected by Conventional Urea and UREAStabil fertilizers on wheat

| Nitrogen levels (kg ha⁻¹) | Cambisols (Hawzien) | Experimental sites | Vertisols (Emba Alaje) |
|--------------------------|---------------------|--------------------|----------------------|
|                          | Grain Yield kg ha⁻¹ | Straw Yield kg ha⁻¹ | Harvest Index (%) | Grain Yield kg ha⁻¹ | Straw Yield kg ha⁻¹ | Harvest Index (%) |
| 0 N                      | 1102.73d            | 2259.3c            | 32.5               | 4043.5c             | 5906.0d             | 41.1               |
| 32 N (UREAStabil)        | 1393.22c            | 2850.0b            | 33.3               | 4313.9c             | 6277.6c             | 41.0               |
| 64 N (UREAStabil)        | 1708.33a            | 3400.0a            | 33.7               | 4812.2b             | 6718.2bc            | 42.5               |
| 96 N (UREAStabil)        | 1633.91b            | 3127.8ab           | 35.4               | 4909.1b             | 7064.0b             | 41.4               |
| 64 N (Conventional Urea) | 1543.19bc           | 3168.5a            | 32.9               | 5467.9a             | 7810.1a             | 41.4               |
| Mean                     | 1476.279            | 2961.11            | 33.515             | 4769.306            | 6755.207            | 41.49              |
| LSD (0.05)               | 151.89              | 311.09             | NS                 | 486.13              | 548.13              | NS                 |
| CV (%)                   | 10.761              | 10.988             | 9.351              | 10.797              | 8.487              | 7.20               |

Means with the same letter are not significantly different.
3.1.7. Straw yield
At Suluh site in Hawzien, straw yield showed an increasing trend even though there are some inconsistencies. The lowest and highest straw yield were obtained from control plots with no nitrogen treatment (2259.3 kg ha⁻¹) and from plots received 64 kg N ha⁻¹ (3400.0 kg N ha⁻¹) in the form of UREAStabil, respectively. There were no statistically significant differences in straw yield between plots treated with the same rates of N as conventional urea and UREAStabil (Table 4). Espindula et al. (2013) reported that Urea+NBPT had significant effect on straw yield of wheat. Khan et al. (2013) also reported that maximum straw yield was obtained from plots treated with super urea (urease plus nitrification inhibitor-treated urea).

At Atsela and Ayba sites in Emba Alaje, straw yield showed consistently increasing trend with N rates that applied as UREAStabil (Table 4). The highest and lowest straw yields were recorded from plots treated with 64 kg N ha⁻¹ as conventional urea (7810.1 kg ha⁻¹) and from zero nitrogen, respectively. Abebe (2012) and Haileselassie et al. (2014) reported that wheat straw yield increased with N rates. For the same rates of N (64 kg N ha⁻¹) applied as UREAStabil and conventional urea, higher straw yield was obtained from plots to which conventional urea was applied with split application. This clearly shows the importance of split application of N at Atsela and Ayba sites in Emba Alaje district.

3.1.8. Harvest index
Harvest index was computed as the ratio of grain yield to the total above-ground dry biomass yield. The analysis of variance revealed that rates and sources of N did not significantly affect (P > 0.05) harvest index of wheat at all sites. A similar result was reported by Espindula et al. (2013). The results found in contrary to Espindula et al., (2014) reported that Urea+NBPT had a significant effect on the harvest index of wheat than urea.

3.1.9. Nitrogen uptake and nitrogen use efficiency indices
Application of N significantly influenced uptake, agronomic, physiological and apparent recovery efficiency of wheat at both sites. Nitrogen uptake was increased with a rate of up to 64 kg N ha⁻¹ then starts to decline in Hawzien (Figure 1). On contrary in Emba Alaje grain, straw and total uptake of wheat increased with rate. The highest uptake of wheat was retrieved on plots that received UREAStabil than conventional urea at the same rate (64 kg N ha⁻¹). The highest agronomic efficiency of 9.08 kg⁻¹ (32 kg N ha⁻¹) and apparent recovery of 55% was obtained at 64 kg N ha⁻¹ as UREAStabil and physiological efficiency of 60.28 kg⁻¹ was obtained at 64 kg N ha⁻¹ as conventional urea at Hawzien district. The highest agronomic efficiency of 22.2 kg⁻¹, physiological efficiency of 93.7 kg⁻¹, apparent recovery of nitrogen 59.7% was obtained at 64 kg N ha⁻¹ as conventional urea at Atsela and Ayba sites in Emba Alaje district.

3.1.10. Correlation among agronomic parameters of wheat
Correlation analysis among growth parameters, yield-related traits and grain yield from all sites is presented in Tables 6 and 7. The correlation analysis revealed that there was a significant and positive

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Table 5. Nitrogen use efficiency indices in Cambisols of Hawzien and Vertisols of Emba Alaje

| Nitrogen levels (kg ha⁻¹) | Experimental sites | Cambisols (Hawzien) | Vertisols (Emba Alaje) |
|--------------------------|--------------------|---------------------|-----------------------|
|                          | AE (kg kg⁻¹) | PE (kg ha⁻¹) | ARE (kg kg⁻¹) | AE (kg kg⁻¹) | PE (kg ha⁻¹) | ARE (kg kg⁻¹) |
| 0 N                      | 0          | 0              | 0              | 0          | 0              | 0              |
| 32 N (UREAStabil)       | 9.08       | 52.55          | 0.52           | 8.44       | 45.33          | 0.46           |
| 64 N (UREAStabil)       | 8.97       | 55.44          | 0.49           | 12.01      | 85.62          | 0.33           |
| 96 N (UREAStabil)       | 4.53       | 53.46          | 0.27           | 10.35      | 83.83          | 0.30           |
| 64 N (Conventional Urea)| 6.45       | 84.59          | 0.34           | 22.25      | 93.7           | 0.59           |

AE = agronomic efficiency, PE = physiological efficiency, ARE = apparent recovery efficiency.
correlation between grain yield and yield-related agronomic parameters of wheat at all sites. At Suluh site in Hawzien district, grain yield was significantly correlated with plant height ($r = 0.625$), number of effective tillers ($r = 0.456$), thousand seed weight ($r = 0.365$), straw yield ($r = 0.513$), harvest index ($r = 0.688$) (Table 6). Correlation between grain yield and spike length ($r = 0.289$), and number of seed per spike ($r = 0.203$) were not significant. Straw yield was positively correlated with almost all agronomic parameters except thousand seed weight ($r = 0.152$), grain filling period ($r = 0.129$) and harvest index ($r = -0.244$) at Suluh site in Hawzien. At Ayba and Atsela sites in Emba Alaje district grain yield was significantly correlated with plant height (0.771), spike length ($r = 0.732$), number of effective tillers ($r = 0.751$), number of seed per spike ($r = 0.661$), straw yield ($r = 0.891$) and thousand seed weight ($r = 0.636$) (Table 7). Applying higher rates of nitrogen delays heading and maturity which ultimately increase grain yield. Under normal condition plants need more time to efficiently utilize the
Dargie et al., Cogent Environmental Science (2020), 6: 1778996
https://doi.org/10.1080/23311843.2020.1778996

resource which is available in the soil and this may ultimately affect grain and straw yield. Thousand seed weight, effective tillers, number of seed per spike also affected significantly and positively grain yield. Grain yield was negatively correlated with harvest index (r = −0.140). Straw yield was positively correlated with all phenological, growth and yield traits of wheat at Ayba and Atsela sites in Emba Alaje district (Table 7).

Joglan et al. (1997) and Abebe (2012) reported that grain yield was significantly and positively correlated with plant height, straw yield, thousand seed weight and biomass of wheat.

PH – plant height (cm), SL – spike length (cm), NSPS – number of seed per spike, NET – number of effective tillers, DY – grain yield (kg ha⁻¹), TSW – thousand seed weight (gm), SY – straw yield (kg ha⁻¹), HI – harvest index (%).

4. Conclusion
Application of different rates of UREAStab and conventional urea significantly affected most of the crop parameters tested, such as growth parameters, yield and yield components at Hawzien and Emba Alaje. Straw yield showed an increasing trend even though there were some inconsistencies. The lowest and highest straw yield were obtained from control plots with no nitrogen treatment (2259.3 kg ha⁻¹) and from plots received 64 kg N ha⁻¹ (3400.0 kg N ha⁻¹) in the form of UREAStab, respectively, at Suluh site in Hawzien. At Suluh site in Hawzien, the highest grain yield was obtained from plots treated with 64 kg N ha⁻¹ as UREAStab and the lowest was recorded from plots received 0 kg N ha⁻¹. Grain and straw nitrogen uptake of wheat were increased with N rate in Emba Alaje, but not in Hawzien. Nitrogen use efficiency indices were influenced by nitrogen rates and sources at both sites. Grain and straw yields had a positive correlation with most of the parameters tested. Slow-releasing nitrogen fertilizer UREAStab could be used as an alternative source of nitrogen fertilizer for wheat production at Hawzien. Further study should be done on solubility, time of application and placement of slow-releasing nitrogen fertilizer which is UREAStab.

Funding
The authors received no direct funding for this research.

Competing Interests
The authors declare no competing interests.

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Citation information
Cite this article as: Nitrogen use efficiency, yield and yield traits of wheat response to slow-releasing N fertilizer under balanced fertilization in Vertisols and Cambisols of Tigray, Ethiopia, Sofonays Dargie, Lemma Wogi & Selamnyhun Kidanu, Cogent Environmental Science (2020), 6:1778996.

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