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Response of Wheat on Uptake, Protein and Nitrogen Use Efficiency to Application of Slow Releasing Nitrogen Fertilizer in Northern Ethiopia

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Authors' contributions

This work was carried out in collaboration between all authors. Author SD designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors LW and SK reviewed the experimental design and all drafts of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

The N recovery by crops from the soluble N fertilizers such as urea is often as low as 30–40%, with a potentially high environmental cost associated with N losses via NH_3 volatilization, NO_3^- leaching and N_2O emission to the atmosphere. This study was initiated to evaluate the effects of slow releasing nitrogen fertilizer in nitrogen uptake, nitrogen use efficiency and grain protein content of wheat. A field experiment was carried out in 2015 main cropping season at Hawzien district in Tigray Regional State, Ethiopia. The experiment were arranged in a randomized complete block design with three replications at three farmer's field. Treatments were four levels of nitrogen (0, 32, 64 and 96) kg ha^{-1}. The nitrogen source was $UREA^{Stabil}$, which is slow N releasing fertilizer. Conventional urea at recommended rate (64 kg N ha^{-1}) was included as positive control at both sites. The highest grain and straw N uptake, and total uptake (41.81 kg ha^{-1}, 24.28 kg ha^{-1}, and 66.09 kg ha^{-1}, respectively) were recorded for grain and straw harvested from plots treated with 64

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kg N ha^{-1} in the form of $UREA^{Stabil}$. The highest agronomic efficiency of 9.46 kg $kg^{-1}$and apparent recovery of nitrogen 55% was obtained at 64 kg N ha^{-1} as $UREA^{Stabil}$ and physiological efficiency of 60.28 kg kg^{-1} was obtained at 64 kg N ha^{-1} as conventional urea. The highest and lowest grain protein content were recorded for grain harvested from plots fertilized with 96 kg N ha^{-1} (14.151%) in the form of $UREA^{Stabil}$ and 0 kg N ha^{-1} (10.62%), respectively. It can be concluded that the highest uptake and nitrogen use efficiency was obtained on plots treated with $UREA^{Stabil}$ than conventional urea.

Keywords: Protein content; nitrogen use efficiency; uptake; nitrogen.

1. INTRODUCTION

Wheat is one of the major cereal crop in Ethiopia next to teff (*Eragrostis tef*), maize (*Zea mays*) and sorghum (*Sorghum bicolor*). In Tigray region, wheat is a priority cereal crop for food security. It covers over 0.1 million ha with total production of more than 0.19 million tons per year [1]. Nitrogen fertilizers plays a vital role in improving wheat production and productivity. Fertilizers application rate particularly, N significantly influenced grain yield, protein content, N uptake efficiency, N biomass production efficiency, N utilization efficiency of wheat [2]. The N recovery by crops from the soluble N fertilizers such as urea is often as low as 30–40%, with a potentially high environmental cost associated with N losses via NH_3 volatilization, NO_3^- leaching and N_2O emission to the atmosphere [3]. Then, nitrogen fertilizer use efficiency of crops becomes low. The use of slow releasing fertilizers can be a solution to alleviate problem. Slow nitrogen release urea fertilizers can increase nitrogen use efficiency through either slowing the release rate or by altering reactions that lead to losses [4]. $UREA^{Stabil}$ is another form of slow releasing fertilizer which contain *substance NBPT (N-(n-butyl)-thiophosphoric triamid), which functions as a urease enzyme inhibitor.* Urease inhibitors are substances that reduce the rate of hydrolysis of urea - $CO(NH_2)_2$, which allows for greater percolation of urea in the soil profile, reducing the concentration of NH_3 on the soil surface which therefore reduces the NH_3 volatilization [5]. Adding NBPT to urea resulted in better N utilization by wheat plants provided the best N use efficiency by wheat plants than applying only urea [6].

In Hawzien district application of N as urea fertilizer and P as DAP at the rate of 100 kg urea and 100 kg DAP ha^{-1} are the recommended rate to boost up wheat production and productivity. Nevertheless, wheat production and productivity is not as such satisfactory from year to year. At Hawzien district, N losses from applied urea fertilizer is expected, which might be through volatilization and leaching because of sandy texture of soil. Therefore, appropriate source of N fertilizer, rate and time of application may improve wheat productivity, nitrogen uptake and N fertilizer use efficiency of the crop. However, alternative nitrogen fertilizers were not investigated for the improvement of wheat production and productivity in Hawzien district. The use of slow releasing nitrogen fertilizer like $UREA^{Stabil}$ is not a common practice in the study area. This study was initiated to investigate the effect of slow releasing fertilizer on uptake, nitrogen use efficiency and grain protein content of wheat in Cambisols of Hawzien District.

2. MATERIALS AND METHODS

2.1 Description of the Study Areas

The study was conducted in Eastern Zone of Tigray Region, at Hawzien district on three farmers' field in 2015 main cropping season. Hawzien district is located at 78 km away from Mekelle, the capital of the region to east direction and 861 km from Addis Ababa to south direction. Its altitude ranges from 1500 to 2300 masl. Agro ecological zone of the district is tepid to cool sub moist mountains plateau [7]. The experiments were carried out at Suluh Kebele in Hawzien district on three farmers' field. The geographical location of experimental fields are 39^0 27' 43.11'' E, and 13^0 59' 37.416'' N, and 2263 masl (Field1), 39^0 27' 21.911'' E, and 13^0 59' 20.299'' N and 2270 masl, (Field 2) and 39^0 27' 33.747'' E and 13^0 59' 11.801''N, and 2273 masl (Field 3). 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, K, [8]. The dominant soil type in the district is Cambisols [9]. Wheat, ground nut and grass pea are the most common crops cultivated in the district. The area is characterized by bimodal rainfall distribution pattern and in the cropping season receives annual rainfall of 371.9 mm. The

average annual maximum and minimum temperatures were 27.6 and 9.83℃, respectively.

2.2 Experimental Design, Treatments and Procedures

The experimental design was randomized complete block design (RCBD) with three replications. The full experiments were conducted in Hawzien district at Suluh Kebele on three farmers' field. Following the history of preceding production season, farm lands which were covered with wheat and barley last year were selected. The bread wheat variety used for the experiment was Pica flor (*kakaba*) at Suluh kebele in Hawzien district. This wheat variety is disease resistance, early maturing, relatively high yielding.

Treatments were four levels of nitrogen (0, 32, 64 and 96) kg ha^{-1}. The nitrogen source was $UREA^{Stabil}$ which is slow N releasing fertilizer. Treatments were applied at planting (sowing). Positive control of conventional urea was included with split application of 1/3 of 64 kg N ha^{-1} at planting. The remaining N was applied at tillering stage in the form of urea. Phosphorus in the form of triple super phosphate (TSP) was applied at the rate of 46 kg ha^{-1} as (P_2O_5). Potassium in the form of murite potash (KCl) was applied at the rate of 80 kg ha^{-1} as (K_2O). Sulfur in the form of $CaSO_4$ was applied at the rate of 30 kg S ha^{-1}. P, K and S fertilizers were applied as basal application at planting to all plots. Plot sizes were 4 m by 3 m. The spacing between plots and blocks were 50 and 100 cm, respectively.

2.3 Plant Tissue Sampling and Analysis for Nitrogen Content

At maturity, five non-boarder wheat plant samples was randomly collected from each plot and partitioned into grain and straw. The straw samples were washed with distilled water to clean the samples from contaminants such as dust. The grain and straw samples were oven dried at 70^0C to constant weight. After drying, the samples were ground and passed through 0.5 mm sieve.

The samples were analyzed for nitrogen following wet digestion method. The nitrogen use efficiencies of wheat such as agronomic efficiency, physiological efficiency and apparent recovery efficiency of N were calculated as describe by [10].

1) The total uptake of nitrogen was calculated by multiplying the grain and straw yield (kg ha^{-1}) with the nitrogen concentration in (%) of each treatment as follows:
   a) N uptake of grain or straw (kg ha^{-1}) = Yield of grain or straw (kg ha^{-1}) x N concentration of grain or straw (%) x 10^{-2}
   b) Total N uptake = N uptake of grain + N uptake of straw

2) Agronomic Efficiency of Nitrogen:

$$\text{Agronomic N use efficiency } (\text{kg kg}^{-1}) = \left(\frac{\text{Gf} - \text{GU}}{\text{Na}}\right)$$

Where;

Gf is the grain yield in the fertilized plot (kg)
Gu is the grain yield in the unfertilized plot (kg)
Na is the quantity of N applied (kg)

3) Physiological Efficiency of Nitrogen:

$$\text{Physiologcal N use efficiency } (\text{kg kg}^{-1}) = \left(\frac{\text{Yf} - \text{Yu}}{\text{Nf - Nu}}\right)$$

Where;

Yf is the total biological yield (grain plus straw) of the fertilized plot (kg),
Yu is the total biological yield in the unfertilized plot (kg),
Nf is the N accumulation in the fertilized plot (kg),
Nu is the N accumulation in the unfertilized plot (kg).

4) Apparent Recovery Efficiency of Nitrogen:

$$\text{ApparentN recovery}(\text{kgkg}^{-1}) = \left(\frac{\text{Nf} - \text{Nu}}{\text{Na}}\right)$$

Where;

Nf is the N accumulation by the total biological yield (straw plus grain) in the fertilized plot (kg),
Nu is the N accumulation by the total biological yield (straw plus grain) in the unfertilized plot (kg),

Na is the quantity of N applied (kg).

5) Grain protein:

Grain protein content was calculated as:

% protein = % N in grain × 5.7 [11].

2.4 Data Analysis

The collected data were subjected to statistical analysis. Analysis of variance (ANOVA) was carried out using SAS software program using SAS version 9.1.3 [12]. Normality and homogeneity of variance were checked using Anderson darling and Bartilet test, respectively and Combined analysis for the three sites were done using SAS soft ware [12]. Marginal rate of return (MRR) was calculated as the change in net revenue (NR) divided by the change in total variable cost (TVC) of the successive net revenue and total variable cost levels [13]. Daily labor costs were calculated by assuming 60 ETB per person and revenue was calculated by considering the prevailing market price which is 9ETB kg^{-1} of wheat grain yield for Hawzien district. Urea (1125.57 ETB 100 kg^{-1}), $UREA^{Stabil}$ (1193.1042 ETB 100 kg^{-1}) were calculated based on Enderta union blended fertilizer factory and the cost of $UREA^{Stabil}$ was 6% more than the cost of conventional urea [14].

3. RESULTS AND DISCUSSION

3.1 Nitrogen Uptake of Wheat

3.1.1 Grain, straw and total nitrogen uptake

Mean grain and straw nitrogen uptake of wheat increased with rates of N up to 64 kg N ha^{-1} at Suluh site in Hawzien. [15,16] reported that N uptake of wheat increased with N rates. The highest grain and straw N uptake, and total uptake (41.81 kg ha^{-1}, 24.28 kg ha^{-1}, and 66.09 kg ha^{-1}, respectively) were recorded for grain and straw harvested from plots treated with 64 kg N ha^{-1} in the form of $UREA^{Stabil}$. For the same rates of N (64 kg N ha^{-1}) applied as $UREA^{Stabil}$ and conventional urea, higher grain and straw N uptake were recorded on plots treated by $UREA^{Stabil}$. This implies that accessibility of N to plant from $UREA^{Stabil}$ is higher than from conventional urea, which might be due to the slow N releasing ability of $UREA^{Stabil}$. [6] reported higher total N accumulation in shoot and uptake for wheat plants, which was fertilized with urea+NBPT relative to wheat plants fertilized with urea only.

3.2 Nitrogen Use Efficiency Indices

3.2.1 Agronomic and physiological efficiencies

Agronomic efficiency is the amount of additional yield obtained for each additional kg of nutrient applied, whereas physiological efficiency is the biological yield obtained per unit of nutrient uptake [10]. Agronomic efficiency showed inconsistent trend at all sites. The highest and lowest agronomic efficiency were recorded for plots treated with 64 kg N ha^{-1} as $UREA^{Stabil}$ and 96 kg N ha^{-1} as $UREA^{Stabil}$, respectively at Suluh site in Hawzien. Even though there were some inconsistent trends, physiological efficiency decreased with N rates at all sites. The highest PE was recorded for plots fertilized with 64 kg N ha^{-1} as conventional urea.

According to [17] agronomic and physiological efficiency have 10 to 30 and 30 to 60 common values respectively. If the obtained results are above these common values, it could be concluded that the farm was under well managed system and reverse is true, if the results obtained are below the common values. Agronomic efficiency at Suluh site was below the common values. Physiological efficiency at Suluh site was in range of common values. The result from Suluh site in Hawzien was nearly in line with [18,16] reports, AE and PE of wheat decreases with N rates. [19] asserted that high agronomic efficiency could be obtained if the yield increment per unit N applied is high because of reduced losses and increased N uptake.

3.2.2 Apparent nitrogen recovery efficiency

Apparent nitrogen recovery efficiency is a measure of the ability of the crop to extract N from the soil [10]. Both nitrogen fertilizer sources and rates of application influenced apparent nitrogen recovery. There was nearly a decreasing trend with N rates at all sites. The highest N recovery was obtained from plots received 64 kg N ha^{-1} as $UREA^{Stabil}$ (55%) at Suluh in Hawzien. Thus slow releasing of N from $UREA^{Stabil}$ had increased apparent N recovery of wheat at Suluh site. [6] reported that wheat plants fertilized with urea+NBPT had higher apparent nitrogen recovery, total shoot N accumulation, and NUE than plants that fertilized only with urea. [20] also reported that the use of urease and nitrification inhibitors reduced N

losses and increased N use efficiency by various crops.

According to [17], apparent N recovery efficiency of wheat at Suluh site fall within the common range 0.3 to 0.5 values or (30% to 50%), inclusive. Based on the same author, at Suluh site in Hawzien plots treated with 32 kg N ha^{-1} (53%) and 64 kg N ha^{-1} (55%) in the form of $UREA^{Stabil}$ showed the experiment was under well managed system. ARE for plots treated with 32 kg N ha^{-1} (53%) was higher than plots received 64 kg N ha^{-1} (35%) as conventional urea at Suluh site in Hawzien. This may be due to the slow nitrification process of $UREA^{Stabil}$.

3.3 Grain Protein Content

Grain protein content of wheat was affected by N application rates. At Suluh site in Hawzien, the highest and lowest grain protein content were recorded for grain harvested from plots fertilized with 96 kg N ha^{-1} (14.151%) in the form of $UREA^{Stabil}$ and 0 kg N ha^{-1} (10.62%), respectively. In general grain protein content showed nearly increasing trend with nitrogen rates. The result obtained are in line with [15] reported that grain protein content of wheat increased with nitrogen rates. Grain protein content of $UREA^{Stabil}$ was greater than that of conventional urea. This may be due to the slow releasing effect of $UREA^{Stabil}$. $UREA^{Stabil}$ contains NBPT and this minimizes NH_3 volatilization [19]. In contrary [6] reported that plants fertilized with urea+NBPT had similar grain N content and protein content with plants received urea. Grain protein content of wheat increases with increasing grain yield.

3.4 Partial Budget Analysis of Nitrogen Rates and Sources

The results of MRR of the Hawzien district is presented in Table 3. The highest net revenue was obtained from plots fertilized with $UREA^{Stabil}$ at a rate of 64 kg N ha^{-1} at Suluh site in Hawzien. At Suluh site in Hawzien the highest marginal rate of return was obtained from plots treated with 64 kg N ha^{-1} (3838.85%) as $UREA^{Stabil}$. As indicated in the table plots treated with 96 kg N ha^{-1} at Suluh site in Hawzien was found dominated treatments, negative MRR. The negative marginal rate of return values obtained at both sites were rejected. According to the manual for economic analysis of [13] the recommendation is not necessarily based on the treatment with the highest marginal rate of return compared to that of neither next lowest cost, the treatment with the highest net benefit, and nor the treatment with the highest yield. The identification of a recommendation is based on a change from one treatment to another if the marginal rate of return of that change is greater than the minimum rate of return (100%). According to the marginal rate of return at Suluh site in Hawzien 64 kg N ha^{-1} as $UREA^{Stabil}$ was found economically profitable compared to other treatments.

Table 1. Grain, straw, and total uptake of wheat at Suluh site in Hawzien district

Nitrogen levels (kg N ha^{-1})	Grain N uptake (kg ha^{-1})	Straw N uptake (kg ha^{-1})	Total N uptake (kg ha^{-1})
0 N	20.56	10.45	31.01
32N($UREA^{Stabil}$)	30.98	16.86	47.84
64N($UREA^{Stabil}$)	41.81	24.28	66.09
96N($UREA^{Stabil}$)	40.56	21.45	62.02
64N(Conventional Urea)	33.34	20.06	53.4

Table 2. Agronomic, physiological and apparent recovery efficiency as affected by Urea and $UREA^{Stabil}$ fertilizers on wheat at both sites

Levels of N (kg/ha)	Suluh (Hawzien)		
	AE (kg kg^{-1})	PE (kg kg^{-1})	ARE (%)
0 N	-	-	-
32 N ($UREA^{Stabil}$)	9.08	52.35	53
64 N ($UREA^{Stabil}$)	9.46	49.78	55
96 N ($UREA^{Stabil}$)	5.53	45.14	32
64N (Conventional Urea)	6.88	60.28	35

AE- Agronomic Efficiency, PE- Physiological Efficiency, ARE- Apparent Recovery efficiency

Table 3. Partial budget analysis for wheat at Suluh site in Hawzien District

Nitrogen levels (kg ha^{-1})	Fertilizer cost (Birr)	Fertilizer application and transport cost [Birr]	Total variable cost (TVC) [Birr]	Grain Yield (kg ha^{-1})	Adjusted Grain yield (10%)down (kg ha^{-1})	Total revenue (TR) [Grain yield*9ETB]	Net revenue [TR-TVC]	Marginal rate of return (ratio)	Marginal rate of return (%)
0 N	0	0	0	1102.73	992.457	8932.113	8932.113	0	0
32N(UREA^{Stabil})	829.98	240	1069.98	1393.22	1253.898	11285.08	10215.1	1.199	119.9
64 N(Conventional Urea)	1566	480	2046	1543.19	1388.871	12499.84	10453.84	0.2446	24.46
64N(UREA^{Stabil})	1659.96	420	2079.96	1708.33	1537.497	13837.47	11757.51	38.388	3838.85
96N(UREA^{Stabil})	2489.94	480	2969.94	1633.91	1470.519	13234.67	10264.73	-1.677^{D}	-16.77^{D}

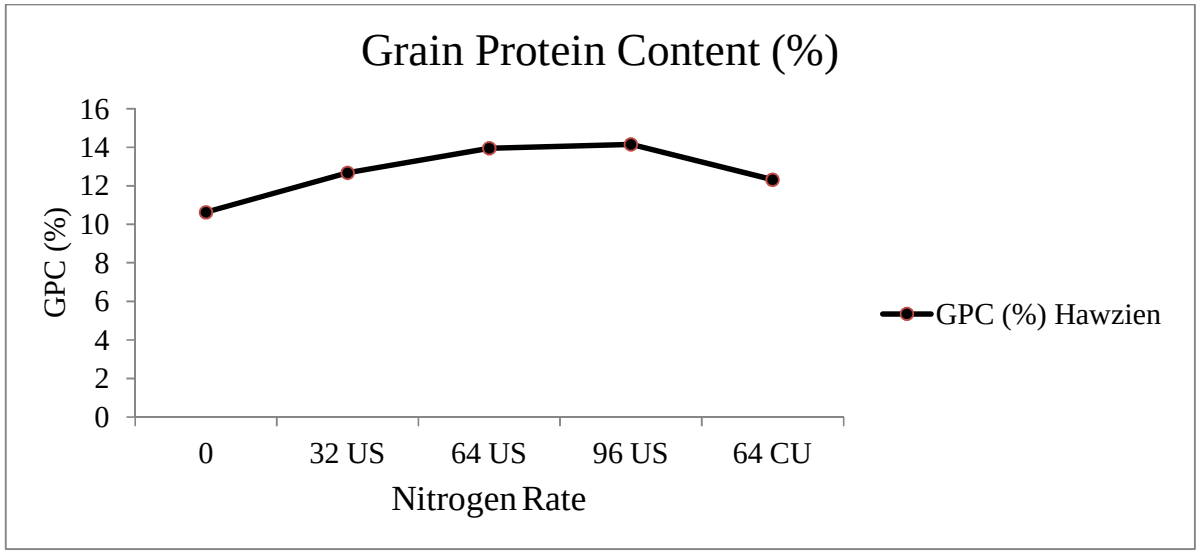

Fig. 1. Grain protein content as affected by Urea and UREA^{Stabil} at Suluh site in Hawzien
CU- Conventional Urea, US - UREA^{Stabil}, GPC (%)= Grain protein content

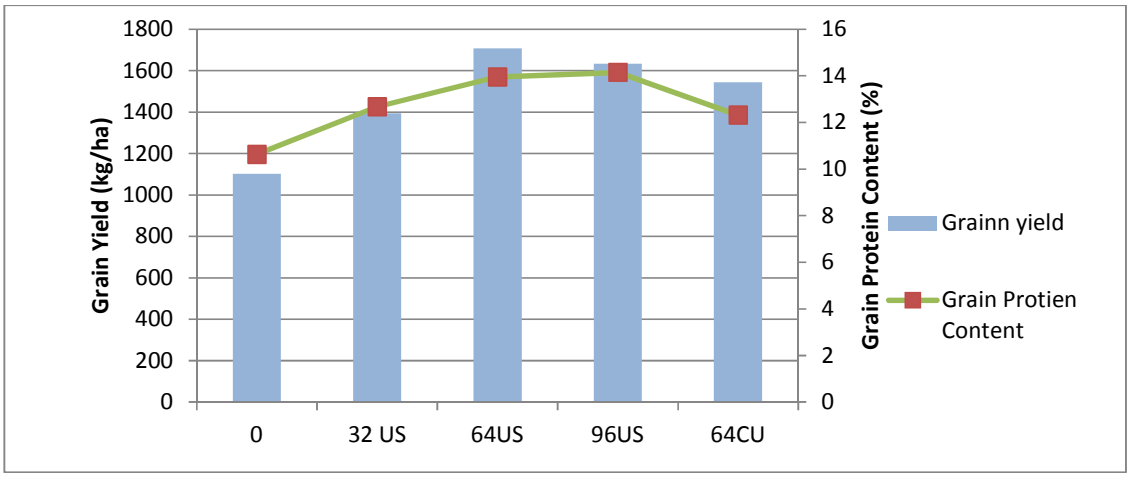

Fig. 2. The relation between grain protein content and grain yield of wheat

4. CONCLUSION

The use of soluble nitrogen fertilizer significantly decreases uptake, nitrogen use efficiency and grain protein content of wheat. This may be due to soluble fertilizer like urea is liable to different means of losses like volatilization, denitrification, and leaching, ultimately nitrogen use efficiency becomes lower. The use of slow releasing fertilizers like UREA^{Stabil} may be a solution for such problem. The use of UREA^{Stabil} increases nitrogen uptake, agronomic use efficiency, physiological and apparent recovery than use of conventional urea on wheat. Grain protein content also was higher in plots treated with slow releasing nitrogen fertilizer (UREA^{Stabil}) than conventional urea on wheat in the study area. further study should be done on the effect of split application of slow releasing fertilizer and appropriate placement of slow releasing nitrogen fertilizer on improving nitrogen use efficiency and grain protein content of wheat.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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