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Influence of Nitrogen Fertilizer Application on Grain Yield, Nitrogen Uptake Efficiency, and Nitrogen Use Efficiency of Bread Wheat (*Triticum aestivum* L.) Cultivars in Eastern Ethiopia

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Abstract

The study was conducted in Eastern Ethiopia, namely Meta and Tullo districts, during the 2015 cropping season to determine the effect of N fertilizer levels on N uptake, N use efficiency (NUE) and grain yield on bread wheat cultivars. Factorial combinations of five N levels (0, 30, 60, 90, and 120 kg N ha^{-1}) and four bread wheat cultivars (Danda'a, Digalu, Kakaba and local cultivar) were laid out as a randomized complete block design (RCBD) with three replications. The interactions of sites, N levels, and cultivars significantly ($p \leq 0.01$) affected grain yield (GY), nitrogen uptake by grains, total nitrogen uptake, nitrogen uptake efficiency (NUpE) and nitrigen use efficiency for grain yield (NUEGY). Main effects of sites, N levels and cultivars had significant ($p < 0.01$) effect on grain and straw N contents, straw N uptake, N biomass production efficiency, N utilization efficiency (NUtE) and nitrogen harvest index (NHI). The cultivar Kakaba at rate of 90 kg N ha^{-1} produced the highest grain yield (4880 kg ha^{-1}) in Tullo, which was statistically similar with the grain yield (4816 kg ha^{-1}) obtained from the cultivar Digalu with 120 kg N ha^{-1} in Meta district. The NUEGY was higher with values of 24.2 and 24.1 kg grain kg^{-1} N in Tullo and Meta districts, respectively, for Digalu cultivar at 30 kg N ha^{-1} application rate than the remaining N levels and variety interactions at both sites. Cultivars variations in NUEGY under low N application levels were mainly due to higher variations in NUpE than in NUtE. Therefore, there is a need for exploration of the effectiveness of various combinations of N rates with time of applications for improvements of N-use efficiency traits and cost effectiveness in improved wheat cultivars production.

Keywords: cultivar, grain yield, harvest index, nitrogen, nitrogen uptake, nitrogen use efficiency

1. Introduction

Bread wheat (*Triticum aestivum* L.), which is used both as a source of food and income, is one of the most important cereal crops in Ethiopia. It is the fourth most widely grown crop after tef, maize, and sorghum (FAO, 2015). Wheat grows mostly in the range between 1500-3000 m above sea level in Ethiopia, where the need for chilling temperature is satisfied. According to USDA (2015), Ethiopia produces 3.8 million tons of wheat per year, making it the second largest wheat producer country in the Sub-Saharan Africa (SSA) next to South Africa. However, the amount of wheat produced is insufficient to meet the domestic needs, which is compelling the country to import about 25 to 35% of the annual wheat grain required for consumption (CSA, 2014).

Tropical smallholder farming systems lack sustainability, due mainly to nutrient losses by soil erosion, lack of soil fertility restoring inputs, nutrient mining, lack of nutrient efficient crop cultivars (Gooding et al., 1997; Ajayi et al., 2007; Hirpha et al., 2009). Declining of soil fertility is a major constraint for wheat production (Fageria, 2007); hence supply of adequate and balanced nutrients is one way of achieving high bread wheat grain yield (Kassahun, 2004).

Due to the fact that nitrogen (N) is the most limiting nutrient for wheat production and the possible environmental problems related to its use, nitrogen use efficiency (NUE) of crops plays a fundamental role in sustainable grain production (Pan et al., 2006; Asplund et al., 2014). NUE is given by the ratio between grain yield (GY) and the amount of nutrient provided by the fertilizer (Moll et al., 1982; Cormier et al., 2013). The variability among modern wheat cultivars NUE has been attributed to nitrogen uptake efficiency (NUpE) and nitrogen utilization efficiency (NUtE) (Barraclough et al., 2010). LeGouis et al. (2010) reported various contributions of NUpE and NUtE to wheat genetic variation in NUE. However, Barraclough et al. (2010) found that NUtE explained more of the variation in grain yield than NUpE in an examination of 39 wheat varieties at 5 N application rates. Gaju et al. (2011) also reported genetic variability in NUE under low N application rate due largely to differences in NUtE rather than NUpE. Studies indicate that the development and use of wheat cultivars with higher NUE can contribute to a reducing the amount of nitrogen to be applied without decreasing grain yield (Barraclough et al., 2014; Gaju et al., 2014). Therefore, understanding the physiological basis of variations among wheat cultivars in NUtE may offer avenues to increase NUE for enhancing whaet yield in Ethiopia.

Wheat yield depends on the choice of appropriate cultivars, inputs of inorganic N fertilizer, appropriate management of N fertilizer and suitable agro-ecological conditions (Khattari, 1984; Gooding et al., 1997). Recently, various studies have been conducted in Eastern Ethiopia to assess the optimum level of N that improves N uptake, N use efficiency and grain yield by bread wheat cultivars. However, there is paucity of information on performances of bread wheat cultivars grown in the region in terms of yield and nitrogen and nitrogen use efficiency (NUE). Therefore, the present experiment was conducted to elucidate effect of nitrogen application on nitrogen uptake, nitrogen use efficiency, and grain yield on bread wheat cultivars in Meta and Tullo districts of eastern Ethiopia.

2. Materials and Methods

2.1 Description of the Experimental Sites

The experiment was conducted both in Meta district (9°24′N latitude, 41°35′E longitude, with altitude of 2227 meters above sea level) on a farmer's field in easter Hararghe Zone and in Tullo district (09°15′N latitude, 41°06′E longitude, and altitude of 1870 meters above sea level) at the experimental stations of Haramaya University in western Hararghe Zone of eastern Ethiopia during the 2015 main cropping season. Total seasonal (July to November) rainfall of 624.7 and 688.6 mm were recorded for Meta and Tullo districts, respectively. Average minimum temperatures of 10.5 and 13.8 ºC, and maximum temperatures of 24.3 and 26.54 ºC were recorded for Meta and Tullo districts, respectively.

2.2 Treatments and Experimental Design

The treatments consisted of five nitrogen levels (0, 30, 60, 90 and 120 kg N ha^{-1}) and four bread wheat cultivars [Dana'a (Danphe #1), Digalu (HAR 3116), Kakaba (Picaflor #1) and a local cultivar]. The experiment was laid out as a randomized Complete Block Design (RCBD) in a factorial arrangement and replicated three times per treatment.

2.3 Experimental Procedures

The experimental areas were ploughed three times using oxen and leveled manually before planting. Planting was done manually both in Meta and Tullo districts on 10 and 13 July 2015 cropping season, respectively.Twenty treatments were randomly assigned to the experimental units within replications. The gross and net harvestable plot areas were 3 m by 2.2 m (6.6 m^2) and 2.5 m by 1.8 m (4.5 m^2), respectively. The spacing between rows, plots and blocks were 0.2, 0.5 and 1.0 m, respectively. One-third of the nitrogen fertilizer as per the treatment and a uniform dose of phosphorus at the rate of 46 kg P_2O_5 ha^{-1} in the form of triple super phosphate were applied within the rows at sowing and the remaining nitrogen in the form of urea was side-dressed in two equal splits at tillering and panicle initiation stages. All broad-leafed and grassy weeds were removed by hand weeding. The fungicide propiconazole (Tilt 250 EC) was applied at the rate of 0.5 L ha^{-1} immediately at the start of disease appearance to avoid damage and variability due to outbreak of rust diseases, which frequently occur in the areas.

2.4 Soil Sampling and Analyses

Soil samples were taken five times using a zigzag pattern technique from the depth of 0-30 cm before planting in each replication for both experimental sites and one composite sample was formed. The samples were air-dried, ground using a pestle and a mortar and allowed to pass through a 2 mm sieve. The samples were analyzed at Haramaya University Analytical Service Laboratory for selected physico-chemical properties, namely organic carbon, total nitrogen (N), soil pH, available phosphorus (P), cation exchange capacity (CEC) and textural analysis. Organic carbon content was determined by the volumetric method (Walkley & Black, 1934) as described in Food and Agriculture Organization (FAO) guide to laboratory establishment for plant nutrient analysis (FAO, 2008) using 1.0 g of the prepared soil sample. Total soil N was analyzed by Micro-Kjeldahl digestion method with sulphuric acid (Jackson, 1962). The pH of the soil was determined according to FAO (2008) using 1:2 (weight/volume) soil sample to $CaCl_2$ solution (0.01 M) ratio using a glass electrode attached to a digital pH meter. CEC was measured after saturating the soil with 1 M ammonium acetate (NH_4OAc) and displacing it with 1 M NaOAc (Chapman, 1965). Available P was extracted by the Olsen method, and P analyzed with a spectrophotometer (Olsen et al., 1954). Particle size distribution was done by hydrometer method according to FAO (2008).

2.5 Plant Sampling for N Analysis

Plant samples collected at physiological maturity were partitioned into grain and straw (stems, leaves and chaff) to determine N contents in the grain and straw. The plant samples were washed with distilled water and oven dried at 70 °C for over 24 hrs to a constant dry weight measured using an electronic balance (FAO, 2008). The straw and grain samples were ground with rotary mill and allowed to pass through a 2 mm sieve for straw and a 0.5 mm sieve for grain. The N content of the grain and straw samples were determined using the wet digestion method, which involved the decomposition of the plant tissues using various combinations of HNO_3, H_2SO_4 and $HClO_4$ by using Kjeldahl procedure described by the American Association of Cereal Chemists (AACC, 2000).

2.6 Data Measurenments

2.6.1 Grain yield (kg ha^{-1})

Grain yield was determined after threshing the sun-dried plants harvested from each net plot area and the yield was adjusted at 12.5% moisture content.

2.6.2 Nitrogen Uptake Traits

Grain nitrogen (kg ha^{-1}) uptake was computed as grain yield multiplied by percent N content of the grain for each plot. Straw nitrogen (kg ha^{-1}) uptake was calculated as straw yield multiplied by percent N content of the straw in each plot. Total nitrogen (kg ha^{-1}) uptake was obtained as the sum of grain nitrogen uptake and straw nitrogen uptake.

2.6.3 Nitrogen Use Efficiency Traits

Total N in the straw and grain samples were used to analyze the N use efficiency and its component traits according to an expanded model of Moll et al. (1982) and Ortiz-Monasterio et al. (1997).

$$\text{N Uptake Efficiency (\%)} = \frac{\text{Ntf}\left(\frac{\text{kg}}{\text{ha}}\right) - \text{Ntc}\left(\frac{\text{kg}}{\text{ha}}\right)}{\text{Ns}\left(\frac{\text{kg}}{\text{ha}}\right)} \times 100 \tag{1}$$

Where, Ntf = total aboveground N content at maturity of fertilized treatment Ntc = total aboveground N content at maturity of control treatment; Ns = N supplied.

$$\text{N Biomass Production Efficiency}\left(\frac{\text{kg}}{\text{kg}}\text{N}\right) = \frac{\text{TDWf}\left(\frac{\text{kg}}{\text{ha}}\right) - \text{TDWc}\left(\frac{\text{kg}}{\text{ha}}\right)}{\text{Ntf}\left(\frac{\text{kg}}{\text{ha}}\right) - \text{Ntc}\left(\frac{\text{kg}}{\text{ha}}\right)} \tag{2}$$

Where, TDWf = total dry weight of fertilized treatment; TDWc = total dry weight of control treatment.

$$\text{N Utilization Efficiency}\left(\frac{\text{kg}}{\text{kg}}\text{N}\right) = \text{Harvest Index} \times \text{N biomass Production Efficiency} \tag{3}$$

$$\text{N Use Efficiency}_{\text{grain yield}}\left(\frac{\text{kg}}{\text{kg}}\text{N}\right) = \frac{\text{GDWf}\left(\frac{\text{kg}}{\text{ha}}\right) - \text{GDWc}\left(\frac{\text{kg}}{\text{ha}}\right)}{\text{Ns}\left(\frac{\text{kg}}{\text{ha}}\right)} \tag{4}$$

Where, GDWf = grain dry weight of fertilized treatment; GDWc = grain dry weight of control treatment.

Agronomic Efficiency (AE) and Physiological Efficiencies (PE) of N fertilizer were calculated using the procedures described by Craswell and Godwin (1984) as:

$$\text{AE}\left(\frac{\text{kg}}{\text{kg}}\text{N}\right) = \frac{\text{GNYf (kg)} - \text{GNYU (kg)}}{\text{Na (kg)}} \tag{5}$$

$$\text{PE}\left(\frac{\text{kg}}{\text{kg}}\text{N}\right) = \frac{\text{GNYf}\left(\frac{\text{kg}}{\text{ha}}\right) - \text{GNYu}\left(\frac{\text{kg}}{\text{ha}}\right)}{\text{Nf}\left(\frac{\text{kg}}{\text{ha}}\right) - \text{Nu}\left(\frac{\text{kg}}{\text{ha}}\right)} \tag{6}$$

Where, GNYf = grain yield of fertilized plots, GNYU = grain yield of the unfertilized plot, Nf = total N uptake of the fertilized plots, Na = quantity of N applied, Nu = total N uptake of unfertilized plot. Nitrogen harvest index was calculted as follows.

$$\text{Nitrogen Harvest Index (\%)} = \text{GNY}\left(\frac{\text{kg}}{\text{ha}}\right)/\text{Nt}\left(\frac{\text{kg}}{\text{ha}}\right) \tag{7}$$

2.7 Data Analyses

Analyses of the contributions of component traits to the resultant NUE traits were carried out as presented by Moll et al. (1982) and Dhugga and Waines (1989). If Y_n is the log of a resultant trait and X_{1n}, X_{2n}, X_{3n} and X_{4n} the logs of component traits at the n^{th} N level, then taking logarithms of these expressions yields the following identities:

$$Y_1 = X_1 + X_2 + X_3 \quad (8)$$

$$Y_2 = X_2 + X_3 + X_4 \quad (9)$$

Where, Y_1 = log (NUEGY), Y_2 = log (NUEPY), X_1 = log (GDW/TDW), X_2 = log (NBPE), X_3 = log (NUpE), X_4 = log (GNY/TDW).

The sum of cross products divided by the sum of squares of Y_1 and Y_2 at n^{th} N level, *i.e.*, $\Sigma X_{in} Y_n / \Sigma Y_n^2$ represent the net contributions of each component trait to the dependent trait both directly and indirectly through the other variables. This can also be expressed as: $\Sigma X_{in} Y_n / \Sigma Y_n^2 = (r_{xin} Y_n)(S_{Xin}/S_{Yn})$, where $r_{Xin} Y_n$ is a correlation coefficient between X_{in} and Y_n, and S_{Xin} and S_{Yn} are the standard deviations for X_{in} and Y_n, respectively. This analysis describes the net contribution of each component variable, both directly and indirectly through the other variables.

The data were subjected to analysis of variance (GLM procedure) using SAS software program version 9.1 (SAS Institute, 2003). Homogeneity of variances was evaluated using the F-test as described by Gomez and Gomez (1984) and since the F-test showed homogeneity of the variances of the two sites, combined analysis of variance was used. From the analysis of variance, treatment means were compared using the least significant difference (LSD) at p = 0.05 significance level following the procedure described by K. A. Gomez and A. A. Gomez (1984).

3. Results and Discussion

3.1 Soil Physical and Chemical Properties

Selected physico-chemical properties of the soils were analyzed for composite surface soil (0-30 cm) samples collected from each replication in both sites before planting. According to the soil textural class determination triangle, the soil samples from both Meta and Tullo districts experimental sites were found to be clay (sand 16, silt 37 and clay 47%) and silty clay (sand 12.5, silt 43.3 and clay 44.2%), respectively (Table 1). The texture indicates the degree of weathering, nutrient- and water-holding capacity of the soil. High clay content implies better nutrient- and water-holding capacity of the soil in the specific experimental site. The soils of Meta and Tullo districts had available P contents of 11.21 and 13.14 mg kg^{-1}, respectively, which were at medium level at both sites according to the rating of Landon (1991). The soil reaction of the experimental sites were nearly neutral where the pH in 1:2.5 (weight $volume^{-1}$) soil samples to $CaCl_2$ solution were 8.2 and 6.8 in Meta and Tullo, respectively. According to FAO (2008), suitable pH range for most crops is between 6.5 and 7.5, which confirms N availability is optimum. This indicates the more suitability of the soil pH for optimum crop growth and grain yield in Tullo experimental site than in Meta district.

The organic carbon contents of the soils in Meta and Tullo districts were 1.65 and 1.88%, respectively (Table 1). According to Roy et al. (2006), the soils of both sites had medium organic carbon contents. The CEC values in the two sites are 20.7 and 26.3 cmol kg^{-1} soil in Meta and Tullo districts, respectively, thereby indicating the high capacity to retain cations. Analysis of soil samples indicated low level of total N with values of 0.06 and 0.16% in Meta and Tullo districts, respectively, indicating that the particular nutrient was a more limiting factor for optimum crop growth in Meta than in Tullo district.

Table 1. Physico-chemical properties of the experimental soils before sowing in Meta and Tullo districts during 2015 main cropping season

Soil properties	Measured parameter values	
	Meta	**Tullo**
pH	8.2	6.8
Total N (%)	0.06	0.16
Organic carbon (%)	1.65	1.88
Available P (ppm)	11.21	13.14
Cation exchange capacity [cmol(+)kg^{-1}]	20.7	26.3
Sand (%)	16	12.5
Silt (%)	37	43.3
Clay (%)	47	44.2
Soil textural class	Clay	Silty clay

3.2 Effects of Nitrogen Levels on Grain Yield of Bread Wheat Cultivars

The interaction effect of sites, nitrogen levels, and cultivars was significant ($p \leq 0.01$) on grain yield (Table 2). The cultivar Kakaba grown on soil treated with 90 kg N ha^{-1} in Tullo district had the highest grain yield (4880 kg ha^{-1}), which was in statistical parity with the grain yield (4816 kg ha^{-1}) obtained from the cultivar Digalu grown on soil treated with 120 kg N ha^{-1} in Meta district (Table 3). The means of grain yield obtained from the cultivar Kakaba at 90 kg N ha^{-1} in Tullo and the cultivar Digalu grown on soil treated with 120 kg N ha^{-1} in Meta district were 49.42 and 58.94% higher than the mean of grain yield obtained from local cultivar (check), with their corresponding N application levels and sites, respectively. This indicates the existence of significant differences in the genetic background of the two cultivars for yield potential under different agro-ecological conditions.

On the other hand, the lowest grain yield was obtained from the local cultivar with no nitrogen application in Meta district. This could be probably due to low level of total N available in the soil in Meta before planting (Table 1). The interaction effects between site, cultivar, and N application level showed a progressive increase in grain yields of the wheat cultivars with increase in N levels in both sites. The maximum yields for all cultivars were obtained at the highest (120 kg N ha^{-1}) N level and at 90 kg N ha^{-1} applications in Meta and Tullo, respectively (Table 3). Further, the maximum yields of Danda'a, Digalu and Kakaba each under the highest level of N application was higher by 7.46%, 58.94%, and 21.32% respectively than the maximum yield of the local cultivar under same level of N application in Meta. In Tullo, however, the maximum yields of these three improved cultivars (Danda'a, Digalu and Kakaba) was higher by 21.43%, 33.99% and 49.43%, respectively, than the maximum yield of the local cultivar grown on soil treated at 90 kg ha^{-1} N application. This is indicating the genetic differences in yield potential among the cultivars across environments.

For the cultivar Digalu, a highest mean grain yield was obtained when N level was increased up to 120 and 90 kg N ha^{-1} in Meta and Tullo, respectively (Table 3). On the other hand, grain yields of the cultivars Danda'a and Kakaba were significantly influenced when the N level of N was changed between the two lower N levels (*i.e.* 0 and 30 kg N ha^{-1}) and the two medium N levels (*i.e.* 60 and 90 kg N ha^{-1}) at both sites. However, Danda'a was not affected when the level was changed from 30 and 60 kg N ha^{-1} in Meta. A similar trend was observed for the cultivar Kakaba when the N level was changed from 60 and 90, and from 90 and 120 kg N ha^{-1} in Meta. Grain yield of Digalu in Meta, and Digalu and Kakaba in Tullo, each with 60 kg N ha^{-1} application, were significantly higher than the yield of the local cultivar at the highest N level (at 120 kg N ha^{-1}) in both sites (Table 3).

Generally, the cultivars Kakaba and Digalu showed better grain yield performance at 90 kg N ha^{-1} in Tullo than the other cultivars and at the highest (120 kg N ha^{-1}) nitrogen application rate in Meta, respectively. This might be due to the high responses to N use efficiency by these cultivars under the respective N levels in both experimental sites. All cultivars exhibited lower grain yield performance under no-N application plots in Meta than in Tullo district. This might be due to the genetic potential variation of the cultivars, better soil fertility and other environmental conditions in Tullo than in Meta. Cultivars variations in wheat grain yield at different nitrogen levels applications were also reported by (Hassan et al., 1998; Genene, 2003; Alam et al., 2007; Haile et al., 2012).

3.3 Nitrogen Concentration in Grain and Straw

The grain and straw N contents were significantly ($p \leq 0.01$) influenced by the main effect of sites, nitrogen rates and cultivars. However, their interaction effects did not significantly affect the nitrogen concentration in grain and straw (Table 2).

The grain and straw N contents were higher by 3.37 and 5.41%, respectively, in Tullo than in Meta district. Nitrogen concentrations in grain and straw exhibited progressive increases in response to the increasing N levels from 0 to 120 kg N ha^{-1} application. However, it had no statistically significant difference between 90 and 120 kg N ha^{-1} application in case of N concentration in straw. On the other hand, significant increase in N content in grain yield was exhibited at the highest N level application (Table 4). Moreover, the concentration of N in straw at 120 kg N ha^{-1} was statistically on a par with the concentration of N in straw at 90 kg N ha^{-1}. The N content in grain and straw of wheat cultivars under the application of 0 to 120 kg N ha^{-1} ranged from 1.54 to 2.0% and 0.28 to 0.46%, respectively. The highest (2.0%) grain and (0.46%) straw N contents were estimated at the highest level of N (120 kg N ha^{-1}) application, implying a positive response of the cultivars to N fertilizer application. A similar finding was also reported by Sheoran et al. (2015). On the other hand, the low grain (1.53%) and straw (0.28%) N contents were recorded from no-N application plots. Hence, the maximum grain and straw nitrogen contents exceeded the minimum grain and the straw nitrogen contents by about 29.87 and 60.78% respectively (Table 4). This result implies a positive response of grain and straw N concentration to the increased N level, and is consistent with the results reported by Tamado Tana et al. (2015) who reported decreases in grain N content of wheat with increasing levels of nitrogen application.

Table 2. Mean squares of combined analysis of variance for the effects of site, cultivar and nitrogen level on nitrogen uptake, use efficiency and grain yield of bread wheat in Meta and Tullo districts in 2015 main cropping season

Parameters	Mean squares for sources of variation with respective degrees of freedom in parenthesis								
	S(1)	**R in S(4)**	**C(3)**	**N(4)**	**S×C(3)**	**S×N(4)**	**C×N(12)**	**S×C×N(19)**	**Pooled error(76)**
Grain yield	4948734.68**	354025**	4570858.01**	16279159.59**	1106782.90**	219576.8**	245143.9**	151667.5**	50889.74
Grain N content	0.0957**	0.0287**	0.34448**	0.8528**	0.0283**	0.011**	0.0091**	0.00372^{ns}	0.00231
Straw N content	0.02054**	0.004798**	0.004518**	0.121394**	0.00738**	0.00194ns	0.00056ns	0.00076ns	0.00064
Grain N uptake	2328.196**	105.58**	3479.748**	9720.20**	668.05**	156.31**	207.5**	112.09**	23.7737
Straw N uptake	101.79**	37.016**	65.33**	693.8**	23.01**	11.47*	2.141ns	3.247ns	2.3095
Total N uptake	1456.3**	224.45**	4487.99**	15599.1**	889.56**	247.26**	230.29**	143.95**	31.277
NHI	0.00062*	0.000959**	0.0006**	0.0038**	0.0007**	0.00021ns	0.00015ns	0.00008ns	0.0001031
Parameters	**S(1)**	**R in S(4)**	**C(3)**	**N(3)**	**S×C(3)**	**S×N(3)**	**C×N(9)**	**S×C×N(15)**	**Pooled error(60)**
NUpE	59.90^{ns}	45.69^{ns}	944.45**	2458.78**	551.1**	1324.6**	48.71^{ns}	103.5**	26.83
NBPE	726.48**	152.65*	846.52**	2156.81**	465.6**	1101.2**	18.77^{ns}	37.147^{ns}	46.677
NUtE	84.257**	46.796**	239.33**	139.82**	151.5**	73.3**	5.712^{ns}	16.56^{ns}	8.21
NUEGY	59.88**	27.969**	229.71**	377.91**	141.8**	199.6**	4.82^{ns}	17.760**	3.983
NAE	41.69^{ns}	209.7**	567.36**	1185.38**	364.57**	607.99**	12.73^{ns}	42.81^{ns}	31.364
NPE	42.82^{ns}	74.614**	10.16^{ns}	242.20**	11.64^{ns}	122.09**	4.24^{ns}	5.299^{ns}	18.35

Note. S = Site, R in S = Replication within site, C = Cultivar, N = Nitrogen level, S×C = Site and cultivar interaction, S×N = Site and nitrogen level interaction, C×N = Cultivar and nitrogen level interaction, S×C×N = Site, cultivar and nitrogen level interaction; *, ** = Significant at p = 0.05 and p = 0.05, respectively, and ^{ns} = Non-significant, NHI = Nitrogen harvest index, NUpE = Nitrogen uptake efficiency, NBPE = Nitrogen biomass production efficiency, NUtE = Nitrogen utilazation efficiency, NUEGY = Nitrogen use efficiency of grain yield, NAE = Nitrogen agronomic efficiency, NPE = Nitrogen physiological efficiency.

Among the wheat cultivars, Digelu and Kakaba were found to be superior for grain and straw N contents, which were in statistical parity were. The grain and straw N contents of the bread wheat cultivars ranged from 1.69 to 1.91%, and from 0.37 to 0.40%, respectively, where the highest and lowest grain and straw N contents were obtained from the cultivar Kakaba and the local cultivar, in the order mentioned here. The grain and straw N contents by Kakaba and Digelu cultivars increased by 13 and 8%, and 12 and 6%, respectively, due to the highest (120 kg N ha^{-1}) N application rate over the local cultivar (Table 4). The results further revealed no significant differences between Digalu and Kakaba in grain N contents and between Danada'a and Digalu, and Digalu and Kakaba in straw N contents (Table 4). However, all the improved cultivars had significantly higher grain and straw N contents than the local cultivar in both parameters.

Table 3. Interaction effects of site, nitrogen level and cultivar on grain yield (kg ha^{-1}) of bread wheat in Meta and Tullo districts during 2015 main cropping season

Cultivar	Nitrogen rate (kg N ha^{-1}) in Meta					Nitrogen rate (kg N ha^{-1}) in Tullo				
	0	30	60	90	120	0	30	60	90	120
Danda'a	1590^{pq}	2413^{klmn}	2726^{jkl}	3183^{fghi}	3256^{fgh}	2073no	2970^{hijk}	3400^{efg}	3966^{c}	3780^{cd}
Digalu	1676^{pq}	3016^{hij}	3813^{cd}	4396^{b}	4816^{a}	2106no	3160^{fghi}	3760^{cde}	4376^{b}	3766^{cde}
Kakaba	1620^{pq}	2683^{jklm}	3283^{fgh}	3526^{def}	3676^{cde}	2203^{n}	3180^{fghi}	3986^{c}	4880^{a}	4406^{b}
Local	1413^{q}	2330^{mn}	2606^{klm}	2886^{ijk}	3030^{hij}	1833^{op}	2683^{jklm}	3033^{ghij}	3266^{fgh}	3236^{fghi}
LSD (0.05) = 366.85; CV (%) = 7.3										

Note. Means followed by the same letter within the same column are not significantly different from each other at p = 0.05 level of significance; CV = Coefficient of variation; LSD = Least significant difference.

3.4 Effects of Nitrogen Levels on Nitrogen Uptake of Bread Wheat Cultivars

3.4.1 Nitrogen Uptake by Grains

The nitrogen uptake by the wheat grain was significantly ($P \leq 0.01$) affected by the sites, nitrogen rates, cultivars and by their interactions (Table 2). With increasing N application rates from 0 to 120 kg N ha^{-1}, there was a gradual increase in the uptake of N by wheat grain (Table 5). The highest amount of nitrogen uptake (104.9 kg ha^{-1}) by grain was recorded for the cultivar Digelu at 120 kg N ha^{-1} in Meta, which was statistically similar with the interaction of Kakaba at 90 kg N ha^{-1} in Tullo (Table 5). However, the lowest (nitrogen uptake 20.4 kg ha^{-1}) by grain was estimated for the local cultivar with no-N application in Meta district. The highest nitrogen uptake by grain at 120 and 90 kg N ha^{-1} application in Meta and Tullo, respectively, might be due to adequate amount of nitrogen to the crop for the respective site compared to the rest of N levels.

Table 4. Grain N content, straw N content, straw N uptake and nitrogen harvest index of bread wheat as influenced by main effects of cultivar and N levels in Meta and Tullo districts during 2015 main cropping season

Factors	Grain nitrogen content (%)	Straw nitrogen content (%)	Straw nitrogen uptake (kg ha^{-1})	Nitrogen harvest index (%)
Site				
Meta	1.78^{b}	0.37^{b}	20.67^{a}	82.8^{a}
Tullo	1.84^{a}	0.39^{a}	18.82^{b}	82.3^{b}
LSD (0.05)	0.018	0.009	0.55	0.4
N level (kg ha^{-1})				
0	1.54^{e}	0.283^{d}	11.97^{d}	84.5^{a}
30	1.71^{d}	0.344^{c}	16.95^{c}	83.2^{b}
60	1.84^{c}	0.395^{b}	20.71^{b}	82.3^{c}
90	1.96^{b}	0.442^{a}	24.13^{a}	81.6^{d}
120	2.00^{a}	0.455^{a}	24.97^{a}	81.4^{d}
LSD (0.05)	0.0277	0.0146	0.87	0.6
Cultivar				
Danada'a	1.75^{b}	0.383^{b}	19.17^{b}	82.1^{b}
Digalu	1.89^{a}	0.388^{ab}	21.30^{a}	83.0^{a}
Kakaba	1.91^{a}	0.397^{a}	20.54^{a}	82.9^{a}
Local	1.69^{c}	0.367^{c}	17.97^{c}	82.3^{b}
LSD (0.05)	0.025	0.013	0.78	0.52
CV (%)	2.66	6.61	7.69	1.22

Note. Parameter means followed by the same letter within a column are not significantly different from each other at 5% level of LSD = Least significant difference; CV = coefficient of variantion.

The result also showed significantly higher N uptake by grains for the cultivars Digalu and Kakaba grown on soils treated with 60, 90 and 120 kg N ha^{-1} than the interactions of the local cultivar grown on soils under equivalent N application rates at both sites. In Meta, the N uptakes by grains of bread wheat cultivars increased with increase in N application rates up to 120 kg N ha^{-1}. A similar trend was observed in Tullo when the N rate was extended up to 90 kg N ha^{-1} but the N uptake by grain significantly decreased for the cultivars Digalu and Kakaba beyond this level (Table 5). This might be due to higher grain yield and grain N concentration in these treatments that resulted in increased N uptake by grain than in similar treatment combinations, including the local cultivar. In conformity with the current result, Dhugga and Waines (1989) reported that increase in grain N uptake by wheat depends on the potentials of cultivars to absorb N efficiently from the soil. Similarly, Gholamereza et al. (2011) reported high nitrogen uptake by the grain from high (131 kg ha^{-1}) nitrogen rate application due to enhanced N absorption in winter wheat.

3.4.2 Nitrogen Uptake by Straw

Analysis of variance (ANOVA) for the straw nitrogen uptake showed a highly significant ($p \leq 0.01$) difference due to sites, N levels and cultivars, but their interactions had no significant effect on the trait (Table 2). Comparing the two sites, higher (20.67 kg ha^{-1}) straw nitrogen uptake was recorded in Meta than in Tullo, whereas lower (18.82 kg ha^{-1}) was obtained in Tullo than in Meta. A perusal of the field data indicated that application of N significantly increased the uptake of N by straw up to 90 kg N ha^{-1} and beyond this level, however, the uptake of N by straw did not significantly increase (Table 4). The extent of increase was from 11.97 to 24.97 kg ha^{-1} over no-N applied treatment. The data further revealed that the uptake of N by straw of wheat cultivars ranged from 17.97 to 21.3 kg ha^{-1} and the highest (21.3 kg ha^{-1}) was recorded from the cultivar Digalu, which was statistically similar with Kakaba (20.54 kg ha^{-1}), while the lowest (17.97 kg ha^{-1}) was recorded from the local cultivar (Table 4). Similar results were reported by Gouis et al. (2000) and Sreenivash *et al.* (2000). Though a highly significant difference was observed among the wheat cultivars in uptake of N by straw, no significant difference was obtained between the two cultivars Digalu and Kakaba in uptake of N by straw. The current data indicated that the N uptake by straw exceeded by 101.6 and 108.6% over the control (no-nitrogen application) due to application of N at 90 and 120 kg ha^{-1}, respectively (Table 4). On the other hand, the N uptake by straw increased by 18.53 and 14.30% for the cultivars Digalu and Kakaba, respectively, over the corresponding local cultivar.

3.4.3 Total Nitrogen Uptake

The current research data revealed that the main effects of N levels, cultivars and their interactions significantly ($p \leq 0.05$) affected the total N uptakes (Tables 2 and 5). The N uptake of the crop exhibited an increasing trend with the increase in N level up to application rates of 120 kg ha^{-1} in Meta district, whereas in Tullo, a similar trend was observed for this trait when N was applied up to 90 kg ha^{-1} level and, beyond this level, the total N uptakes by wheat crop significantly declined for the cultivar Digalu (Table 5). The total nitrogen uptake by wheat was significantly higher (135.3 kg N ha^{-1}) in the interaction of Digalu with 120 kg N ha^{-1} in Meta than other treatment combination interactions. This was followed by the interaction of the cultivar Kakaba with 90 kg N ha^{-1} in Tullo, which did not differ significantly from 120 kg N ha^{-1} rate application at the same site (Table 5).

The data also showed that, with the increase in N application levels from 30 to 120 kg N ha^{-1}, there was a significant increase in nitrogen uptake by the cultivar Digalu over the rest bread wheat cultivars in Meta and over the control cultivar in Tullo (Table 5). A similar trend was also observed for the cultivar Kakaba over the local cultivar in both sites. Application of some extra N through increased levels increased the concentration of N in soil and led to greater absorption of nutrients by plants than in soil with no-N application, which ultimately resulted in vigorous growth of bread wheat in higher dry matter accumulation and enhanced the total uptake of nitrogen. The high total N uptake by the wheat cultivars under high nitrogen application might be due to the congenial growth environment for development of wheat root hairs and growth might have led to enhanced N uptake by the roots of the plant, resulting in enhanced uptake of the nutrient and its concentration in the grain and straw tissues. The current finding is in consistent with the investigation of Kumbhar et al. (2007) who reported the highest plant N uptake of 131.2 kg N ha^{-1} in wheat on soil treated with the application rate of 100 kg N ha^{-1}.

The lowest total N uptake (31.7 kg ha^{-1}) by bread wheat was recorded from the local cultivar with no-N application in Meta district, which was statistically on a parity with the cultivars Danda'a and Kakaba at the same site and local cultivar in Tullo, all under the no-N application (Table 5). Similar observations were also reported by several researchers (Azad, 1997; Bharat & Kachroo, 2010).

3.5 Effects of Nitrogen Levels on Nitrogen Use Efficiency by Bread Wheat Cultivars

3.5.1 Nitrogen Uptake Efficiency

Nitrogen uptake efficiency (NUpE) was highly and significantly ($p \leq 0.01$) affected by the interaction of sites, N levels, and cultivars (Tables 2 and 6). The interaction mean values of NUpE ranged from 39.2% for Digalu with 120 kg N ha^{-1} in Tullo to 82.2%, with 30 kg N ha^{-1} for the same cultivar at same site (Table 6). The current data indicated that NUpE of all cultivars declined with increasing N levels in both sites (Table 6). Comparing the NUpE of cultivars at both sites, all improved cultivars (Danada'a, Digalu and Kakaba) had higher NUpE than the local cultivar under all N levels (Table 6). The highest NUpE (82.2%) was recorded for the cultivar Digelu with 30 kg N ha^{-1} application, which was in statistical parity with NUpE of the cultivars Kakaba and Danda'a under the same N levels in both sites, and with Digalu at 30 kg N ha^{-1} application in Meta, while the lowest (39.2%) NUpE was recorded for the cultivar Digalu with the highest (120 kg N ha^{-1}) N level in Tullo. The data further revealed that all bread wheat cultivars showed a highly significant decline in NUpE as N level increased from 90 to 120 kg ha^{-1} in Tullo, whereas no significant difference was exhibited in Meta for similar treatment combinations (Table 6).

Comparing the interaction values of cultivars grown on soil treated with N application levels across both sites, the cultivars Digalu and Kakaba were superior in NUpE at all the nitrogen application rates in Meta and between 30 to 90 kg ha^{-1} N applied in Tullo over both Danda'a and the control cultivar (Table 6). However, statistically significant superiority was observed at application rates of 60, 90 and 120 kg N ha^{-1} in Meta for both cultivars Digalu and Kakaba over Danda'a and the control cultivar. A related trend was observed for Kakaba with 60 and 90 kg N ha^{-1} application in Tullo. Similarly, Dobbermann (2005) reported the variation in NUpE of wheat which were ascribed to differences in climate, cultivar and nitrogen rates.

3.5.2 Nitrogen Biomass Production Efficiency

Nitrogen biomass production efficiency (NBPE) was significantly ($p \leq 0.01$) affected by the sites, N levels and cultivars. However, their interaction effects did not affect NBPE significantly (Tables 2 and 7). The highest (63.26 kg N kg^{-1}) NBPE obtained in Meta was superior by 9.52% to the lowest (57.76 kg kg^{-1}N) NBPE obtained in Tullo district. The NBPE at different N levels ranged from 51.09 to 73.24 kg kg^{-1} N at the application rates of 30 and 120 kg N ha^{-1}, respectively. Furthermore, the data revealed that as the level of N increased from 30 to 120 kg N ha^{-1}, NBPE decreased sharply and significantly (Table 7). Among the cultivars, the highest (68.71 kg kg^{-1} N) NBPE was recorded for the cultivar Digalu, followed by Danda'a and Kakaba, while the lowest (55.26 kg kg^{-1} N) NBPE was obtained from the local cultivar (Table 7). The variations in NBPE among cultivars might result from the genetic structures of variety, root morphology; absorption of ion, ecological factors, agricultural practices (Barbottin et al., 2005).

3.5.3 Nitrogen Utilization Efficiency

Similar to NBPE, nitrogen utilization efficiency (NUtE) was also highly and significantly ($p \leq 0.01$) affected by the sites, N levels and cultivars. However, the interaction effect of site, N rates and cultivars did not affect the trait significantly (Tables 2 and 7). Thus, significantly higher (24.44 kg kg^{-1} N) NUtE was obtained in Tullo than in Meta district (Table 7). The NUtE obtained in Tullo exceeded by 8.33% over that obtained in Meta. This might be due to better growing conditions in Tullo than in Meta.

The highest (26.54 kg kg^{-1} N) and the lowest (20.67 kg kg^{-1} N) NUtE values were obtained from the application of 30 and 120 kg N ha^{-1}, respectively. This indicates that the plant produced about 21 kg wheat grain yield per 1 kg of total plant N and about 27 kg wheat grain yield for every kg N it had in the total biomass, respectively. The efficiency significantly dropped when N application level changed from 30 to 120 kg N ha^{-1}. However, mean comparisons showed statistically similar NUtE between 60 and 90 kg N ha^{-1} as well as between 90 and 120 kg N ha^{-1}. The decrease in N utilization efficiency was by 12.03, 2.6 and 11.71%, in that order, when fertilizer application levels increased from 30 to 60, from 60 to 90 and from 90 to 120 kg N ha^{-1}, respectively.

Table 5. Interaction effects of sites, nitrogen application levels and cultivars on nitrogen uptake by grain and total nitrogen uptake in Meta and Tullo districts during 2015 main cropping season

Cultivar	Nitrogen level (kg N ha^{-1}) in Meta					Nitrogen level (kg N ha^{-1}) in Tullo				
	0	30	60	90	120	0	30	60	90	120
Nitrogen uptake of grain ($kgha^{-1}$)										
Danda'a	22.9^{s}	38.9^{mnop}	46.2^{jklm}	58.1^{fghi}	60.9^{fgh}	32.2^{pqr}	51.5^{ijk}	62.5^{fg}	75.6^{de}	73.9^{de}
Digalu	26.7^{qrs}	53.8^{hij}	74.1^{de}	90.9^{c}	104.9^{a}	34.0^{pq}	57.1^{fghi}	73.5^{de}	90.3^{c}	74.1^{de}
Kakaba	25.1^{rs}	46.5^{jklm}	62.6^{f}	71.5^{e}	79.7^{d}	35.9^{op}	57.1^{fghi}	78.4^{de}	103.8^{ab}	96.2^{bc}
Local	20.4^{s}	36.6^{nop}	42.9^{lmno}	50.7^{ijkl}	55.1^{fghi}	27.2^{qrs}	44.3^{klmn}	54.6^{ghi}	61.9^{fg}	60.5^{fgh}
LSD (0.05) = 7.93; CV (%) = 8.4										
Total nitrogen uptake (kg ha^{-1})										
Danda'a	34.9^{wx}	56.3^{qrs}	68.2^{mno}	81.848^{hij}	88.2^{gh}	42.5^{uvw}	66.1^{mnop}	81.2^{hijk}	98.3^{ef}	97.1^{fg}
Digalu	41.4^{uvw}	73.4^{jklm}	97.8^{ef}	118.4^{c}	135.3^{a}	46.3^{tuv}	74.5^{jklm}	94.3^{fg}	115.2^{cd}	95.7^{fg}
Kakaba	37.9^{vwx}	63.9^{nopq}	83.8^{hi}	95.2^{fg}	106.3^{de}	47.9^{stu}	74.5^{jklm}	100.1^{ef}	130.4^{ab}	122.2^{bc}
Local	31.7^{x}	54.0^{rst}	62.9^{opqr}	72.3^{klmn}	78.3^{ijkl}	37.9^{vwx}	58.6^{pqr}	72.1^{lmn}	84.3^{hi}	82.0^{hij}
LSD (0.05) = 9.09; CV (%) = 7.2										

Note. Means followed by the same letter within the column are not significantly different from each other at p = 0.05 level of significance; CV = Coefficient of variation; LSD = Least significant difference.

Table 6. Interaction effects of sites, nitrogen levels and cultivars on N uptake and grain N use efficiency of bread wheat in Meta and Tullo districts during 2015 main cropping season

Cultivar	Nitrogen level (kg N ha^{-1}) in Meta				Nitrogen level (kg N ha^{-1}) in Tullo			
	30	60	90	120	30	60	90	120
Nitrogen uptake efficiency (%)								
Danda'a	74.4^{abcde}	61.1^{ijk}	58.1^{jkl}	50.8^{lm}	$76.7a^{bc}$	67.8^{defghi}	60.4^{ijk}	49.7^{lm}
Digalu	78.9^{abc}	73.3^{bcde}	68.1^{defghi}	63.0^{hijk}	82.2^{a}	72.8^{bcdef}	66.3^{efghij}	39.2^{n}
Kakaba	78.9^{abc}	76.1^{abcd}	67.0^{efghi}	64.2^{ghij}	80.0^{ab}	79.448^{abc}	76.7^{abc}	63.6^{hij}
Local	72.2^{bcdefg}	55.0^{kl}	51.1^{lm}	45.3^{mn}	71.1^{cdefgh}	67.228^{efghi}	64.4^{fghij}	45.5^{mn}
LSD (0.05) = 8.46; CV (%) = 7.9								
Grain N use efficiency (kg grain kg^{-1} N)								
Danda'a	17.6^{efg}	12.9^{jk}	11.4^{klm}	9.4^{mn}	22.5^{ab}	16.5^{fgh}	15.5^{ghij}	10.7^{klmn}
Digalu	24.1^{a}	21.3^{abcd}	18.9^{cdef}	16.8^{fgh}	24.2^{a}	19.3^{bcdef}	18.1^{defg}	9.5^{mn}
Kakaba	19.4^{bcdef}	16.5^{fghi}	13.2^{ijk}	11.3^{klmn}	22.1^{abc}	20.4^{bcde}	21.7^{abc}	12.8^{jkl}
Local	16.4^{fghi}	11.4^{klm}	9.61^{mn}	8.1^{n}	17.2^{efg}	13.6^{hijk}	11.2^{klmn}	8.1^{n}
LSD (0.05) = 3.26; CV (%) = 12.72								

Note. Means followed by the same letter within the same column are not significantly different from each other at p = 0.05 level of significance; CV = Coefficient of variation; LSD = Least significant difference.

In agreement with this result, other researchers also reported significant influence of N application rate on NUtE in which the highest efficiencies were measured at the lowest application rate (Ortiz-Monasterio et al., 1997; Singh & Arora, 2001).

Among the bread wheat cultivars, Digalu resulted in the highest (27.69 kg kg^{-1} N) NUtE as compared to the rest bread wheat cultivars. The lowest (20.03 kg kg^{-1} N) NUtE was recorded from the local cultivar. Nitrogen utilization efficiency of Digalu was higher by 20.03, 19.30 and 38.24% than that of efficiencies obtained from

Danda'a, Kakaba and the local cultivar, respectively (Table 7). Therefore, the result indicated higher dry matter partitioning to the grain per unit of total plant N for Digalu cultivar than the rest of the cultivars. According to Kanampiu et al. (1997), wheat cultivars with a high harvest index and low aboveground biomass yield have low plant N loss and increased nitrogen use efficiency. In contrast to this, Karrou and Maranville (1993) suggest that wheat cultivars that produce more seedling dry matter with greater N accumulation are not necessarily the ones that use N more efficiently than the other cultivars.

3.5.4 Agronomic and Physiological Efficiencies

No significant effects of site and the interaction effects of sites × cultivars × N levels were observed on agronomic efficiency (AE); however, the main effects of N levels and cultivars highly and significantly ($p \leq 0.01$) influenced the trait (Tables 2 and 7).

The agronomic efficiency of applied N exhibited a decreasing trend in response to higher N application level. Accordingly, the highest (33.00 kg kg^{-1}) NAE was obtained at the lowest (30 kg N ha^{-1}) N level (Table 7). The results showed a significant difference but decreased response to N fertilizer at higher application rates, which indicated efficient use of nitrogen at lower rate of application (30 kg N ha^{-1}), which is in agreement with previous results reported by other investigators (Alcoz et al., 1993; Campbell et al., 1993; Genene, 2003). On the other hand, the decrease in agronomic efficiency with increasing levels of N applied is remarkably different from the report of Gebreyes (2008), who reported higher NAE under the application of higher levels of nitrogen. In all the N application rates the agronomic efficiency of applied nitrogen deceased significantly at 120 kg N ha^{-1} compared to the rest of N application rates. However, under 60 and 90 kg N ha^{-1}, the agronomic efficiency was almost the same. Nano et al. (2012) also reported a decreasing trend in NAE with increasing N levels. Comparing the cultivars, the cultivar Digalu had higher (29.79 kg kg^{-1}) agronomic efficiency than the rest, followed by the cultivar Kakaba (26.4979 kg kg^{-1}). On the other hand, the local and Danda'a cultivars had a significantly lower agronomic efficiency of nitrogen than the other cultivars (Table 7). This indicated that differences in genetic backgrounds for the trait adversely affected the agronomic nitrogen efficiency. Nevertheless, statistically significant difference was not exhibited between the cultivar Danda'a and the local cultivar.

Physiological efficiency (PE) did not exhibit a significant response to site, cultivar and the interaction of sites × N levels × cultivars (Tables 2 and 7). However, the main effect of N levels significantly ($p \leq 0.01$) influenced the trait. The physiological efficiency under different N application rates ranged from 31.94 to 39.32 kg kg^{-1} (Table 7). Furthermore, physiological efficiency decreased with increasing N application levels, which might be due to the less efficient utilization of nitrogen for biomass and grain production as incraesing N application levels. However, there were no significant differences in physiological efficiency at N levels of 60 to 90 and 90 to 120 kg ha^{-1} application.

The maximum (39.32 kg kg^{-1}) physiological efficiency of N was recorded with the application of N at 30 kg ha^{-1}, whereas the lowest (31.94 kg kg^{-1}) was recorded at 120 kg N ha^{-1} application (Table 7). Like the agronomic efficiency of applied nitrogen, the physiological efficiency also decreased at higher rates than at lower rates of nitrogen application. Although, the cultivars had no significant ($p \geq 0.05$) influence on physiological efficiency, the maximum (35.73 kg kg^{-1}) physiological efficiency was recorded from the cultivar Digalu, whereas the lowest (34.4 kg kg^{-1}) was calculated for the cultivar Danda'a (Table 7). The non-significant differences among cultivars in this study for NPE are in contrast to the findings of other researchers who reported significant cultivar differences on NPE (Dhugga & Waines, 1989; Singh & Arora, 2001).

3.5.5 Nitrogen Use Efficiency for Grain Yields

Interaction of sites, nitrogen levels and cultivars showed highly significant ($p \leq 0.01$) effect on N use efficiency for grain yield (NUEGY) (Table 2). The highest (24.2 kg grain kg^{-1} N) NUEGY was calculated for the cultivar Digalu under 30 kg N ha^{-1} treatment in Tullo, followed by the same combination of treatments in Meta. However, the lowest (8.1 kg grain kg^{-1} N) NUEGY was obtained for the local cultivar with 120 kg N ha^{-1} at both sites (Tables 2 and 6). It was also found that the NUEGY by wheat decreased with the increase in the nitrogen application levels for all cultivars in both sites. However, for all cultivars, except for the local cultivar, significantly decreases in NUEGY when N application level increased from 90 to 120 kg N ha^{-1} in Tullo district. The two improved cultivars Digalu, Danda'a and the local cultivar showed a similar trend when N application level increased from 30 to 60 kg N ha^{-1} in Tullo. On the other hand, the cultivars Kakaba, Danda'a and local cultivar exhibited significant decreases in NUEGY in Meta when N application rates increased from 30 to 60 kg N ha^{-1} (Table 6).

The results clearly showed that there was no significant differences among all wheat cultivars in the NUEGY with increasing level of N from 90 to 120 kg N ha^{-1} in Meta district. Nevertheless, in Tullo it had a significant difference for all except for the local cultivar, which had no significant difference in NUEGY when N was applied at 90 and 120 kg ha^{-1}. The cultivar Digalu exhibited higher NUEGY under lower N application rate in both sites, where the efficiency was statistically at par with each other. Thus, the results clearly indicated efficient N use for grain yield when the crop was supplied with smaller amounts of N in which the overall efficiency of the improved cultivars were higher than that of the local cultivar in both experimental sites. This current finding is in agreement with previous observations by several investigators (Dhugga & Waines, 1989; Ortiz-Monasterio et al., 1997; Roberts, 2008; Haile et al., 2012) who reported that NUEGY decreased significantly in responses to increasing N application rates.

3.6 Nitrogen Harvest Index (%)

Main effects of sites, N levels and cultivars significantly ($p \leq 0.05$) affected the nitrogen harvest index (NHI), while their interaction had no significant effect (Table 2). The maximum (82.8%) NHI was recorded in Meta district, whereas the lowest (82.3%) NHI was recorded in Tullo district.

Table 7. Nitrogen biomass production,N utilization, agronomic and physiological efficiencies of bread wheat as influenced by cultivar and N level in Meta and Tullo districts during 2015 main cropping season

Factors	NBPE (kg kg^{-1} N)	NUtE (kg kg^{-1} N)	NAE (kg kg^{-1})	NPE (kg kg^{-1})
Site				
Meta	63.26^{a}	22.56^{b}	24.77^{a}	35.76^{a}
Tullo	57.76^{b}	24.44^{a}	23.45^{a}	34.42^{a}
LSD (0.05)	2.83	1.197	NS	NS
N level (kg ha^{-1})				
30	73.24^{a}	26.54^{a}	33.00^{a}	39.32^{a}
60	61.42^{b}	23.69^{b}	25.19^{b}	35.53^{b}
90	56.28^{c}	23.09^{b}	22.17^{b}	33.59^{bc}
120	51.09^{d}	20.67^{c}	16.09^{c}	31.94^{c}
LSD (0.05)	3.94	1.65	3.23	2.47
Cultivar				
Danada'a	60.87^{b}	23.07^{b}	20.65^{c}	34.40
Digalu	68.71^{a}	27.69^{a}	29.79^{a}	35.73
Kakaba	57.20^{bc}	23.21^{b}	26.49^{b}	34.67
Local	55.26^{c}	20.03^{c}	19.53^{c}	35.56
LSD (0.05)	3.94	1.65	3.23	NS
CV (%)	11.29	12.19	23.22	12.20

Note. Means followed by the same letter are not significantly different from each other at p = 0.05 level of significance; CV = Coefficient of variation; LSD = Least significant difference, NPE = Nitrogen physiological efficiency, NUtE = Nitrogen utilization efficiency, NBPE = Nitrogen biomass production efficiency, NAE = Nitrogen agronomic efficiency.

The highest (84.5%) NHI was recorded for the lowest N level, whereas the lowest (81.4%) NHI was recorded for the highest N level, which did not differ significantly from the NHI calculated from plots treated with 90 kg N ha^{-1} application rate (Table 4). This could be due to partitioning of the total nitrogen content more to the vegetative part of the crop than to the grain and increased the total aboveground biomass yield. The present investigation is consistent with the observation by Tamado et al. (2015) who reported the decline in NHI at the highest N rate. Also, Mohammad et al. (2010) found the highest (81%) NHI in wheat at the application rate of 100 kg N ha^{-1}.

4. Conclusions

This study has demonstrated that grain yields of the two improved bread wheat cultivars, Kakaba and Digelu, were maximized significantly with N application rates of 90 and 120 kg ha^{-1} in Tullo and Meta districts, respectively, compared to the other lower nitrogen treatment combinations. Therefore, application of N at 90 kg ha^{-1} proved to be the optimum for production of Kakaba in Tullo, while application of N at 120 kg ha^{-1} seems also adequate to increase the grain yield of the cultivar Digelu in Meta district.

The current research result also suggests that increased N application rates from 30 to 120 kg N ha^{-1} in Meta and from 30 to 90 kg N ha^{-1} in Tullo districts significantly decreased NUpE and NUEGY. Therefore, it can be concluded that grain yields, nitrogen uptake and use efficiencies of bread wheat cultivars were distinctly influenced by N application rates that improved the overall performances of the tested cultivars. In future, there is a need to explore the effectiveness of various combinations of N application rates with time of applications for improvements of N-use efficiency traits and cost effectiveness in improved wheat cultivars production.

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