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Research Article

Improved Bread and Durum Wheat Cultivars Showed Contrasting Performances in N-Efficiency and N-Responsiveness

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Wheat productivity can be increased by applying nitrogen (N) in the form of chemical fertilizers. However, owning to the high prices, chemical fertilizers are unaffordable to resource-poor farmers in Ethiopia. The use of N-efficient cultivars rather makes an alternative option for sustainable wheat production. Six bread and six durum wheat cultivars were thus evaluated under low N ($1\,\mathrm{g{\cdot}pot^{-1}}$) and optimum N ($5\,\mathrm{g{\cdot}pot^{-1}}$) in six replications. The pot-based treatments were arranged in randomized complete block design in the lathe house at Kulumsa Agricultural Research Center. Results showed that the number of effective tillers (NET), spike length (SL), total dry biomass yield (TBY), grain yield (GY), NDVI values, total N uptake (TNUP), N utilization efficiency (NUtE), N uptake efficiency (NUpE), N use efficiency (NUE), grain, and straw N uptakes were significantly influenced by wheat cultivars and N levels. Under low N, Hidase and Kingbird gave significantly higher GY, whereas Danda'a and Hidase gave significantly higher GY under optimum N. Under low N, Hidase, Kingbird, and Lemu were identified as the most N-efficient, while Ude, Landrace, and Utuba identified as N-inefficient based on multicriterion performance (GY, TBY, SL, NET, TNUP, NHI, NUpE, NUtE, and NUE). Under optimum N, Danda'a, Shorima, Hidase, and Lemu were identified as the most responsive, while Ude, Landrace, and Kingbird identified as nonresponsive to N application. In conclusion, Kingbird is recommended for low N input, while Danda'a and Shorima are recommended for N input intensive, and Hidase and Lemu are recommended for both low and high N input intensive wheat production.

1. Introduction

Wheat is a traditional staple food crop cultivated by 95% of small-scale resource poor farmers in the highlands of Ethiopia (mainly 1800–2800 meter above sea level) under rain-fed conditions [1]. Ethiopia is the major producer of wheat in sub-Saharan African (SSA) countries [2] with total production area of 1,897,405 ha and total production of 5,780,131 tons [3]. The national average yield of wheat in Ethiopia is, however, quite low ($3.0\,\mathrm{tha^{-1}}$) [3], while other African countries such as Egypt harvest up to 6.4 $\mathrm{tha^{-1}}$ as national average [4]. The low national wheat yield in Ethiopia is mainly attributed to poor soil fertility management, especially nitrogen (N), since the crop has greater response to N [5]. In Ethiopia, in particular N is highly limiting wheat productivity [6]; hence, the application of N is one of the major inputs used by farmers to achieve the desired crop yields [5, 7].

On the other hand, the application of high amount of N to crop varieties without prior study of their responsiveness to N leads to poor N recovery efficiency and, thus, negatively affects the environment and water bodies through leaching of nitrate, runoff, product harvest, and gaseous emissions [7, 8]. Studies indicated that more than half of the N applied to soil in the entire world is currently being lost into the environment [9, 10]. Thus, N fertilizer pledges a significant cost particularly for resource-poor grower and may also have adverse environmental impacts [8]. To meet the projected demand for food while minimizing such environmental concerns, finding N use efficient cultivars among the panel of available resources and optimizing N use efficiency (NUE) through applying the N amount that is required by cultivars based on their responses to N play fundamental roles for sustainable wheat production [9, 11].

Nutrient efficiency is the ability of a cultivar to give higher yield under nutrient limiting condition [12]. Nutrient efficiency can arise from the ability of cultivar to acquire the nutrients from the soil under nutrient-limiting condition (uptake efficiency) and/or ability of the cultivar to effectively utilize the nutrient that is taken up to produce dry matter (utilization efficiency) [8, 13–15].

N use efficient cultivars are those which produce higher grain yield and/or biomass yield under N-limiting condition, while the most responsive cultivars are those which produce higher grain yield and/or biomass yield under optimum N supply. Several studies revealed that crop cultivars significantly differed in their NUE due to either higher N uptake efficiency or higher utilization efficiency [8, 14–17]. NUE of a cultivar can be enhanced by improving either N uptake efficiency (NUpE) of N utilization efficiency (NUtE) or both [11]. The first component defines a cultivar's ability to take up N from the soil, while the second refers to the ability of a cultivar to convert absorbed N into biomass or grain [18–20].

According to Gerloff [21], plant genotypes can be classified into four groups with respect to their response to nutrient deficiency: (1) efficient responders: plants producing high yield at low nutrient level and showing high response to nutrient addition; (2) inefficient responders: plants producing low yield at low nutrient level and showing high response to added nutrient; (3) efficient nonresponders: plants producing high yield at low nutrient level but not responding to nutrient addition; and (4) inefficient nonresponders: plants producing low yields at low nutrient level and also showing low response to nutrient addition.

As to the authors' knowledge, the magnitude of nationally released wheat cultivars in Ethiopia has not yet been investigated for N efficiencies and N-responsiveness. Thus, farmers have still been applying similar amounts of fertilizers to all the cultivars without considering their responsiveness to fertilizer application. Contrary to a number of studies on genetic variation in yield, NUE, and NUE components in the worlds [8, 11, 14–16], such information is scanty or unavailable to date under both low and optimum N production systems in Ethiopia in particular and in SSA in general. Thus, the aim of this study was to identify bread and durum wheat cultivars within Ethiopia that are able to maintain more yield, NUE, and NUE components under N limitation and optimum N.

The availability of information regarding the genetic variations among nationally released Ethiopian wheat cultivars for NUE is vital. Commonly, selection in wheat breeding in Ethiopia is conducted under unlimited N supply, whose excess is detrimental to the environment; thus, breeders usually screen cultivars that perform well under optimum N conditions. However, cultivars selected for high yield under optimum N conditions may not perform consistently under low N condition since cultivars and N supply do interact as reported in many works in the world (e.g., [8, 15]) indicating the necessity of selection at low N to identify cultivars with high NUE traits. Thus, wheat cultivars adapted to acquiring high quantities of N from the soil, decreasing N loss, and utilizing it to translocate more assimilates to build up more grain yield from N-deprived soil could be ideal for low-input production systems, which is a common practice among several resource-poor farmers in Ethiopia. Consequently, improving yield and NUE of wheat cultivars is crucial for the development of sustainable agriculture.

Thus, in view of the continuous nutrient mining in Ethiopia in particular and SSA in general and suboptimal fertilizer application, promoting N use efficient cultivars among resource-poor farmers, enhancing the fertilizer use efficiency and increasing yield of cultivars can be considered as better options for sustaining wheat production and productivity since increasing N fertilizer inputs may have vital economic implications on top of the detrimental environmental impacts. Thus, in such regards, identifying and availing N-efficient cultivars will be of great economic benefit, in which it contributes to minimizing the use of chemical fertilizer inputs and associated environmental impacts.

Since most farmers in Ethiopia are resource-poor, who cannot afford the higher fertilizer cost, there is a need to evaluate the nationally released bread and durum wheat cultivars for N use efficiency as well as for their responsiveness to N application. Thus, we hypothesized that the twelve bread and durum wheat cultivars included in this study show genetic diversity (variability) for NUE (NUpE and/or NUtE). Therefore, the objectives of the study were (i) to identify wheat cultivars with optimum NUE (high uptake and/or utilization efficiencies) under low N supply and (ii) to identify wheat cultivars, which are more responsive to N application and also with high NUE under optimum N supply.

2. Materials and Methods

2.1. Description of the Study Area. The pot experiment was carried out at Kulumsa Agricultural Research Center (KARC) from January to May 2021 under lathe house (prepared from mesh wire). KARC is located in southeast of Ethiopia, which is about 170 km away from the capital city, Addis Ababa. It has a bimodal rainfall pattern. Based on the data obtained from the weather station located at KARC, the mean annual precipitation was 811 mm. The mean annual maximum temperature was 23°C, and monthly values ranged between 21 and 25°C. The mean annual minimum temperature was 10°C, and monthly values ranged between 8 and 12°C. The coldest month was December, whereas March was the hottest month. The major soil type at the study area is classified as Vertic Luvisols [22].

2.2. Soil Sampling and Analysis. The soil used for this experiment was collected from compound of KARC. The soil sample was air-dried, sieved to pass through a 4-mm mesh, and filled into the experimental pots. Parts of the soil samples used for the experimental purpose were analyzed for total nitrogen (N), available phosphorous (av. P), organic carbon (OC), pH, cation exchange capacity (CEC), and textural class at the soil and plant nutrition laboratory of KARC. The pH of the composite soil samples was measured electrometrically in 1 : 2.5 soil water suspensions. OC content was determined by the wet digestion method of Walkley and Black [23] and total N by the semi-micro-Kjeldahl method [24]. The av. P content was determined by Bray-II method. CEC of the soils was determined by the neutral ammonium acetate (CH_3COONH_4) saturation method [25].

2.3. Treatments and Experimental Design. Twelve wheat cultivars (six bread and six durum) were evaluated under two nitrogen (N) levels for N use efficiency/N stress tolerance and for responsiveness to N application. The cultivars thus tested include the following: bread wheat: Danda'a, Hidase, Kingbird, Lemu, Shorima, and Wane, and durum wheat: AlemTena, Fetan, Landrace, Mangudo, Utuba, and Ude. The two N treatments were low N ($1\,g{\cdot}pot^{-1}$) and optimum N ($5\,g{\cdot}pot^{-1}$). Each wheat cultivar was evaluated under the two N levels in six replications. The pot-based treatments were arranged in randomized complete block design in the lathe house. Each cultivar was planted in a pot of 5 liters size (20 seeds in 22 cm top diameter, 16 cm bottom diameter, and 18-cm height pot were planted) filled up with 4-kg soil. The soil used for the experimental purpose was low in N. Urea and triple superphosphate (TSP) was used as sources of N and phosphorus (P), respectively. Two grams of P per pot was applied uniformly in equal amount to all the treatments. N was applied to the low N and optimum N treatments at the rate of 1 g pot^{-1} and 5 g pot^{-1}, respectively.

2.4. Experimental Procedures. Twenty seeds of each of the twelve wheat cultivars were sown in the experimental pots treated with low N and optimum N levels. After the plant emerged and well established, the seedlings were thinned out maintaining only ten plants per pot to be further grown until maturity. All the plants in each pot were uniformly watered to their field capacity.

2.5. Data Collection. The procedures followed for the measurement of the growth and yields as well as N-efficiency variables for wheat are shown below. The number of effective tillers plant kg^{-1} was counted from all the ten-plant population. The spike length was measured from ten plant samples using ruler. The data on relative chlorophyll content and normalized difference vegetation index (NDVI) were recorded using SPAD chlorophyll meter and green seeker, respectively, at booting stage of wheat development. When the plants attain full maturity, the total aboveground biomasses (g pot^{-1}) were removed, oven-dried, and weight recorded. The dried biomasses threshed, grains were later separated, and weight recorded (g pot^{-1}) using sensitive balance (0.01 g). The straw dry weight ($g{\cdot}pot^{-1}$) was determined as the difference between total aboveground weight and grain weight. The harvest index (%) was calculated by dividing the grain weight by the total biomass weight and multiplying by 100 to express it in percentage. The N-efficiency parameters were determined as described below.

Straw N uptake ($g{\cdot}pot^{-1}$) was calculated as shown in the following equation:

$$\text{Straw } N \text{ uptake} = N \text{ concentration in straw} * \text{straw yield pot}^{-1}. \tag{1}$$

Grain *N* uptake ($g{\cdot}pot^{-1}$) was calculated as shown in the following equation:

$$\text{Grain } N \text{ uptake} = N \text{ concentration in grain} * \text{grain yield pot}^{-1}. \tag{2}$$

Nitrogen use efficiency (NUE; $g{\cdot}g^{-1}$) was determined according to Gaju et al. [14] as shown in the following equation:

$$\text{NUE} = \frac{\text{Grain yield}}{N \text{ applied}}. \tag{3}$$

Nitrogen uptake efficiency (NUpE; $g\,g^{-1}$) was determined as suggested by Cormier et al. [13] and Prester et al. [26]by dividing total N taken up by the plant (grain and straw) by the amount of nitrogen fertilizer applied as shown in the following equation:

$$\text{NUpE} = \frac{\text{Total plant } N \text{ uptake}}{N \text{ applied}}. \tag{4}$$

Nitrogen utilization efficiency (NUtE; $g{\cdot}g^{-1}$) was determined according to Cormier et al. [13] and Prester et al. [26] as shown in the following equation:

$$\text{NUtE} = \frac{\text{Grain yield}}{\text{Total palnt } N \text{ uptake}}. \tag{5}$$

Thus, NUE could be summarized as shown in the following equation:

$$\text{NUE} = \text{NUpE} * \text{NUtE}. \tag{6}$$

Nitrogen harvest index (NHI; %) was determined according to Fageria [27] as shown in the following equation:

$$\text{NHI} = \frac{N \text{ uptake by grain}}{N \text{ uptake by grain + straw}}. \tag{7}$$

2.6. Plant Sampling and Analysis. Grain and straw yields of the harvested wheat were oven-dried at a temperature of 70°C for 48 hours until the samples had a constant weight. After that, they were grounded separately and the samples were analyzed for N concentration. The N contents in grain and straw were determined using Kjeldahl distillation procedure according to Sáez-Plaza et al. [28] at the soil and plant nutrition laboratory of Debrezeit Agricultural Research Center.

2.7. Screening Procedure for N-Efficiency and Responsiveness.

The procedure set by Gerloff [21] was followed to classify wheat cultivars for N-efficiency and responsiveness. The varietal performance under low-N was plotted against their performance under optimum-N, which made it possible to distinguish between N-efficient and N-inefficient cultivars on the basis of above-average and below-average performance under low-N, respectively. The responsive and nonresponsive cultivars were identified on the basis of above-average and below-average performance under optimum-N, respectively [21, 29].

2.8. Data Analysis.

The collected data were analyzed using statistical analysis software (SAS) 9.2 [30]. Analysis of variance was carried out to determine whether the crop parameters were significantly influenced by the cultivars, N level, and their interaction. Based on the presence of differences, especially if cultivar effect under each N level, LSD was used to compare means for each N level at $P < 0.05$ significance level according to Tukey's test.

3. Results

3.1. Chemical Properties of the Experimental Soil.

Data for preplanting soil sample physicochemical properties generated through laboratory analysis is presented in Table 1.

3.2. Number of Effective Tillers per Plant.

The analysis of variance (ANOVA) showed that the number of effective tillers per plant was significantly affected by the wheat cultivars, N levels, and their interaction (Table 2). The number of effective tillers per plant was higher under optimum N compared with low N. Under low N supply, the number of effective tillers per plant was significantly greater for all cultivars compared with the Landrace, which had the lowest value. On the other hand, under optimum N supply, cultivar Shorima had the highest number of effective tillers per plant compared with Mangudo, Ude, Landrace, Utuba, Fetan, and Kingbird (Table 2).

3.3. Spike Length.

The ANOVA showed that the average spike length was significantly affected by the wheat cultivars and N levels but not by their interaction (Table 2). For each cultivar, the spike was generally longer under optimum than low N. Under low N, cultivars such as Shorima, Landrace, and Lemu had significantly longer spike compared with most of the cultivars except Danda'a, Hidase, and Kingbird, all of which were at par in terms of spike length. On the other hand, under optimum N supply, cultivars such as Lemu, Shorima, Landrace, and Danda'a had significantly longer spike compared with the cultivars Ude, Utuba, Mangudo, AlemTena, Fetan, and Wane (Table 2).

3.4. Harvest Index.

The ANOVA showed that the harvest index (HI) was significantly affected by cultivars but not by N level and their interaction (Table 2). Under both low and optimum N supply, the HI was the highest for all cultivars, which did not differ from each other, but was significantly the lowest for Landrace cultivar (Table 2). Thus, the results of the current study showed that the productive efficiency (efficiency of photograph assimilate mobilization to the grain) in the case of Landrace was very poor regardless of the level of N supply, while all the other improved cultivars did not significantly differ from each other.

3.5. Relative Chlorophyll Content and Normalized Difference Vegetation Index Values.

The ANOVA showed that relative chlorophyll content (RCC) was significantly affected by N levels but not by wheat cultivars and their interaction. Both under low and optimum N supply, RCC did not significantly differ among the wheat cultivars (Figure 1). However, RCC values were higher under optimum N (Figure 1(b)) compared with low N (Figure 1(a)). On the other hand, normalized difference vegetation index (NDVI) value was significantly affected by N supply, cultivar, and their interaction. Alike to RCC, NDVI values were higher under optimum N (Figure 2(b)) compared with low N (Figure 2(a)). Although the NDVI values did not differ among wheat cultivars under low N supply, it, however, significantly differed among wheat cultivars under optimum N supply (Figure 2(b)). Under optimum N, the cultivars Lemu, Landrace, and Utuba had significantly higher NDVI values as compared to Wane. All the other cultivars except Wane were, however, at par in terms of NDVI values under the same N level (Figure 2).

3.6. Total Dry Biomass Yield.

The ANOVA showed that total dry biomass yield (TBY) was significantly affected by wheat cultivars, N levels, and their interaction. TBY was higher under optimum N (Figure 3(b)) compared with low N (Figure 3(a)). Under low N, the cultivar Hidase showed significantly higher TBY compared with AlemTena; however, the remaining cultivars did not significantly differ from each other in terms TBY under N stress (Figure 3(a)). On the other hand, under optimum N, five cultivars, namely, Danda'a, Landrace, Shorima, Hidase, and Lemu, showed significantly higher TBY compared with Kingbird, Ude, Mangudo, and Fetan (Figure 3(b)).

Based on the data presented using Figure 4, the cultivars Danda'a, Landrace, Shorima, Hidase, and Lemu were considered as N-efficient under N stress as well as responsive to N application since these same five cultivars provided the highest TBY under optimum N (Figure 3(b)). Although cultivar Fetan was N-efficient, it was not responsive to N application (Figure 4). On the other hand, the cultivars AlemTena, Utuba, Wane, Ude, Mangudo, and Kingbird were N-inefficient as well as nonresponsive since they showed lower TBY both under low and optimum N supply (Figure 4). Based on the same parameter, Hidase, with the highest TBY, was the most N efficient, while AlemTena, with the lowest TBY, was the most N-inefficient (Figure 4).

Table 1: Physicochemical properties of the experimental soil.

	Soil pH (water)	OC (%)	Total N (%)	Av. P (Bray-II) (mg kg^{-1})	CEC (meq 100g^{-1})	Texture		
						Sand (%)	Clay (%)	Silt (%)
Value	6.8	2.7	0.16	13.8	13.3	55.9	28.4	15.6
Rating	Neutral	Medium	Medium	Low	Low	Sandy clay loam		
Ref.	Jones (2003)	Berhanu (1980) and Tekalign (1991)	Berhanu (1980) and Tekalign (1991)	Berhanu (1980) and Tekalign (1991)	Landon (1991)			

OC, OM, N, Av. P, and CEC are organic carbon, organic matter, nitrogen, available phosphorous, and cation exchange capacity, respectively.

Table 2: Number of effective tillers, spike length, and harvest index of wheat cultivars under low and optimum N supply.

Genotypes	Number of effective tillers plant^{-1}		Spike length (cm)		Harvest index (%)	
	Low N	Optimum N	Low N	Optimum N	Low N	Optimum N
Danda'a	1.6^{a}	3.2^{abc}	6.1^{ab}	7.8^{ab}	38.1^{a}	37.1^{a}
Hidase	1.7^{a}	3.6^{ab}	6.0^{ab}	5.9^{bcd}	37.4^{a}	34.4^{a}
Shorima	2.1^{a}	4.3^{a}	6.6^{a}	8.0^{ab}	30.2^{a}	31.1^{a}
Kingbird	2.0^{a}	3.0^{bc}	5.6^{ab}	7.4^{abc}	43.7^{a}	34.5^{a}
Lemu	2.1^{a}	3.5^{ab}	6.2^{a}	8.3^{a}	30.3^{a}	30.1^{a}
Wane	2.0^{a}	3.5^{ab}	5.1^{bc}	6.2^{cd}	33.1^{a}	38.5^{a}
AlemTena	1.7^{a}	3.3^{abc}	4.1^{cd}	5.2^{d}	37.7^{a}	28.2^{a}
Fetan	1.8^{a}	3.0^{bc}	4.3^{cd}	5.5^{cd}	34.8^{a}	28.7^{a}
Landrace	0.8^{b}	2.6^{bc}	6.3^{a}	7.9^{ab}	6.4^{b}	4.7^{b}
Mangudo	1.7^{a}	2.1^{c}	4.2^{cd}	5.2^{d}	27.9^{a}	28.2^{a}
Utuba	1.5^{a}	2.7^{bc}	3.9^{d}	4.6^{d}	26.6^{a}	30.9^{a}
Ude	1.6^{a}	2.5^{bc}	3.4^{d}	4.5^{d}	30.2^{a}	31.2^{a}
LSD (5%)	0.73	1.1	1.04	1.9	28.98	20.02
CV (%)	21.6	18.7	10.3	15.1	12.9	19.1

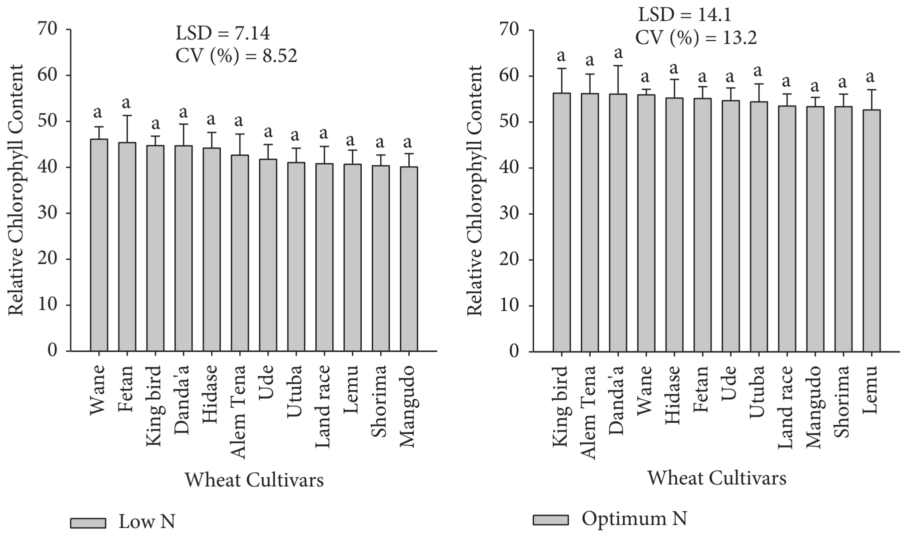
Mean followed by similar letters in a column is not significantly different from each other at 5% probability level.

3.7. Grain Yield. The ANOVA showed that grain yield was significantly affected by N levels, wheat cultivars, and their interaction (Figure 5). Generally, grain yield was significantly higher under optimum N (Figure 5(b)) compared with low N supply (Figure 5(a)). Under low N, the cultivars Hidase and Kingbird gave significantly higher grain yield than Landrace and Ude (Figure 5(a)). On the other hand, under optimum N supply, the cultivars Danda'a and Hidase gave significantly higher grain yield compared with the cultivars Landrace, Mangudo, and Ude (Figure 5(b)).

According to the classification of crop cultivars for nutrient efficiency stated by Gerloff [21], the wheat cultivars Danda'a, Hidase, Shorima, Lemu, and Wane were considered as N-efficient under N stress as well as responsive to N application based on their grain yield performance (Figure 6). Shorima, Lemu, and Wane were, however, close to the border line of N-efficiency. Thus, Danda'a and Hidase gave significantly higher grain yield compared with cultivars such as Landrace, Mangudo, and Ude, implying that the former cultivars are the most responsive to N supply. On the other hand, the cultivars Landrace, Mangudo, Ude, AlemTena, and Utuba were clearly N-inefficient as well as nonresponsive to N application. Utuba was on the borderline in terms of N-responsiveness and hence can be classified as neither N responsive nor nonefficient. However, it is among the N-inefficient cultivars (Figure 6). Under low N, the cultivars Fetan and Kingbird gave higher grain yield; thus, they were N-efficient. However, they provided lower grain yield under optimum N supply, implying that they were not N-responsive (Figure 6).

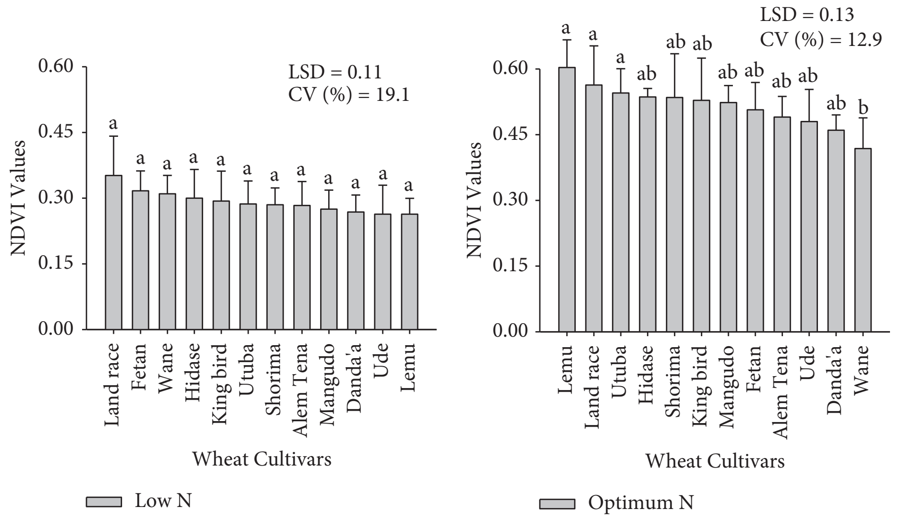
3.8. Grain and Straw N Concentration and N Uptake. Results showed that there was no pronounced difference between low and optimum N in terms of grain as well as straw N concentration although for low N, the value was slightly lower (data not shown). However, due to the remarkable differences in grain and straw yields among wheat cultivars, remarkable differences between low and optimum N levels could be observed in terms of grain and straw N uptake (Table 3). Results further revealed that the relative proportions of grain to straw N uptakes also highly differed among the studied wheat cultivars (Figure 7).

The ANOVA further revealed that total plant N uptake was also significantly affected by cultivars, N level, and their interaction. Total N uptake was higher under optimum N compared with low N (Table 3). Under low N, total plant N uptake pot^{-1} was significantly higher for Wane compared especially to the Landrace and Ude. All the other cultivars, however, did not significantly differ in total plant N uptake pot^{-1} under low N (Table 3). Under optimum N, the total plant N uptake was significantly higher for Lemu and Danda'a compared with most of the cultivars (Kingbird, Ude, and few others) (Table 3).



(a) (b)

Figure 1: Relative chlorophyll content of wheat cultivars under low and optimum N supply. Bars followed by similar letters under similar N level are not significantly different from each other at 5% probability level.

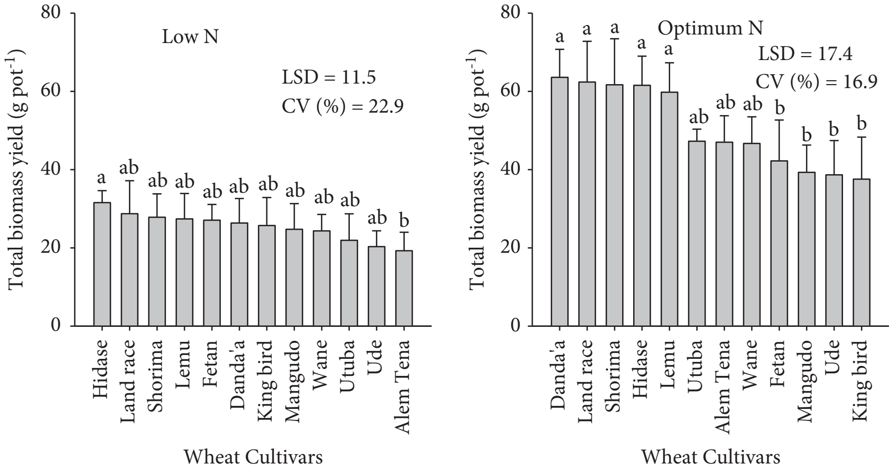


(a) (b)

Figure 2: NDVI values of wheat cultivars under low and optimum N supply. Bars followed by similar letters under similar N level are not significantly different from each other at 5% probability level.

3.9. N Harvest Index, N-Utilization, N-Uptake, and N-Use Efficiencies. The ANOVA revealed that all N harvest index (NHI), N utilization, uptake, and use efficiencies were significantly affected by cultivars, N level, and their interaction except for NHI, which was not significantly affected by N level (Table 4). N uptake efficiency (NUpE) and N use efficiency (NUE) were higher under low N compared with optimum N. There is no clear trend of N-level effect on NHI and N utilization efficiency (NUtE) (Table 4).

Data presented in Table 4 show that under low N, the NHI was significantly higher for Hidase followed by Kingbird, but was very low for Landrace, Ude, and Utuba. Under optimum N, Shorima showed the highest NHI, while Landrace showed the lowest NHI. Cultivar Hidase had the highest NUtE followed by Shorima, Fetan, and Kingbird, while Landrace followed by Utuba showed the lowest NUtE under low N. However, under optimum N, Shorima had the highest NUtE, while Landrace followed by Fetan and Lemu showed the lowest NUtE. All the other cultivars showed intermediate NUtE under the same N level (Table 4). Under low N, most cultivars (Wane, King bird, Lemu, Hidase, and Danda'a) showed significantly higher NUpE compared especially to the Landrace and Ude. Under optimum N, Lemu closely followed by Danda'a and Hidase showed significantly higher NUpE, while Mangudo closely followed by Kingbird and Ude showed the lowest NUpE (Table 4). Cultivar Hidase



(a)

(b)

Figure 3: Total biomass yield of wheat cultivars under low and optimum N supply. Bars followed by similar letters under similar N level are not significantly different from each other at 5% probability level.

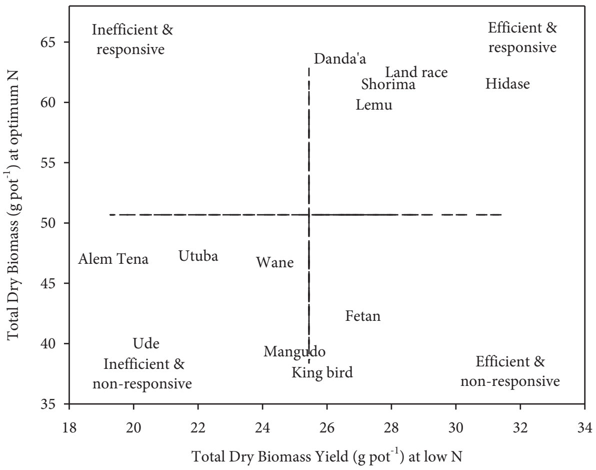


Figure 4: Categorization of wheat cultivars to N efficiency and N responsive using total dry biomass yield. Vertical and horizontal broken lines show average TBY under low and optimum N, respectively.

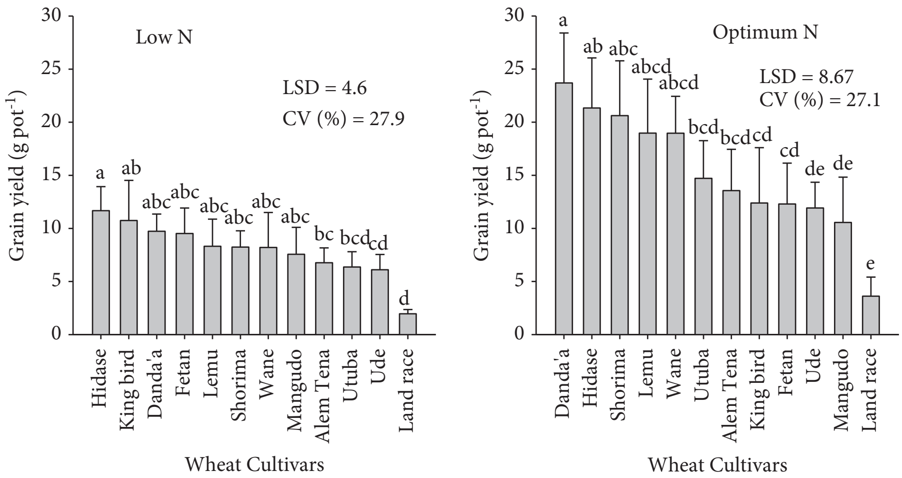
followed by Kingbird had the highest NUE under low N, while Landrace followed by Ude showed the lowest NUE under the same N level. Under optimum N, however, cultivars Danda'a and Hidase had the highest NUE, while Landrace closely followed by Mangudo, Ude, Kingbird, and Fetan showed the lowest NUE (Table 4).

The selection procedure of N-efficient and N-responsive wheat cultivars in the current study is summarized in supplementary Tables 1 and 2. Results presented in these tables clearly showed that the use of multiple criteria is highly reliable in selecting N-efficient and N-responsive wheat cultivars rather than using single criteria.

4. Discussion

The studied bread and durum wheat varieties greatly varied in their tillering capacities. The major reason behind the difference in tillering capacities among wheat varieties could be ascribed to their genetic difference. The increased tiller number under optimum N is associated with increased cytokinin production as a result of higher nitrate ion uptake under optimum N supply by the plant, which further induces tiller formation as suggested by Bauer et al. [31]. Cultivars with a greater number of effective tillers plant kg^{-1} use the supplied N more efficiently resulted in higher net assimilation rate, more productive tillers, and greater spike population and consequently contributing to higher biological and grain yields of wheat [16]. In agreement with the results of the current study, Astawus et al. [32] also reported that wheat varieties nationally released in Ethiopia have contrasting tillering capacities. Results of the current study further showed significant positive correlation between number of tiller plant kg^{-1} and grain yield under optimum N (data not shown). This parameter can therefore be considered to screen cultivars for N-efficiency.

Similarly, the studied wheat varieties varied significantly in spike length under a different N management (Table 2). Under low N, spike length did not significantly correlate with grain yield (data not presented). The reason for the weak correlation of spike length with grain yield under low N could probably be attributed to the absence of grains in some parts of the spike due to the N stress. However, under optimum N supply, significant positive correlation between spike length and grain yield was observed (data not presented). The cultivars with longer spikes under optimum N such as Lemu, Shorima, Danda'a, and Landrace can be considered as N-responsiveness. Supporting the current finding, Knezevic et al. [33] also found variability in spike length among wheat cultivars under optimum N. In close agreement with the present results (Table 2), Luo et al. [34] also reported that spike length of wheat progressively increased with an increase in N levels. Similarly, Nourldin et al. [35] also observed increased spike length with an increase in N level as well as difference in spike length among the wheat cultivars, which supports the present finding. Thus, the



(a)

(b)

Figure 5: Grain yield of wheat cultivars under low and optimum N supply. Bars followed by similar letters under similar N level are not significantly different from each other at 5% probability level.

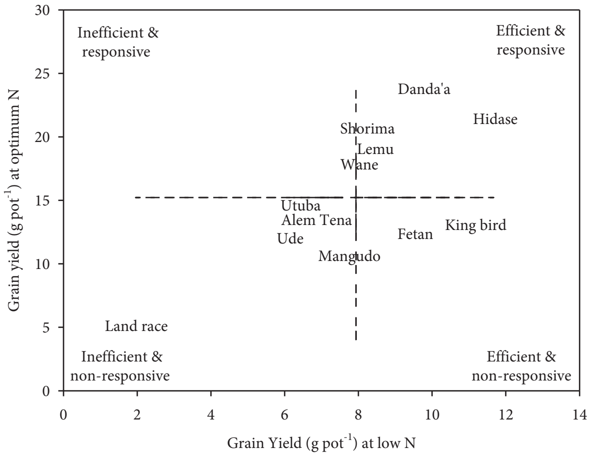


Figure 6: Categorization of wheat cultivars to N-efficiency and N-responsive groups using grain yield. Vertical and horizontal broken lines show average grain yield under low N and optimum N, respectively.

current results suggest that wheat cultivars cannot be categorized for N efficiency, but can be considered for N-responsiveness based on spike length.

The studied wheat cultivars differed significantly in their harvest indices (Table 2), which could be attributed to their genetics. The exceptionally lowest HI for Landrace compared with the contemporary cultivars in this study could be due to the fact that the selection of these improved cultivars for final release seriously considered the presence of higher HI as one of important traits. In agreement with the current results, Kobata et al. [36] reported smaller harvest indices of emmer wheat compared with other types of tetraploid and hexaploid wheat cultivars under Mediterranean conditions of Turkey and Syria. Our results are also in line with Gaju et al. [14], who reported higher HI (49%) for modern cultivars compared with the Landraces (40%) with insignificant N by genotype interaction. Gaju et al. [14] also reported great variations among wheat genotypes ranging from 36% for “W300” to 53% for “Cordiale,” and higher HI under low N (46%) compared with optimum N (43%), which support the present findings. Corroborating the current observation, Zhang et al. [37] also reported that HI did not differ between N fertilized and unfertilized treatments but significantly varied among wheat cultivars that contrasted in N efficiency. In this study, HI showed weak correlation with grain yield under both low and optimum N (data not shown) as contrasted to Gaju et al. [14], who attained positive linear relationships among genotypes between HI and grain yield under high N and low N conditions. Thus, our results depicted that HI may neither be considered for N efficiency nor N responsiveness.

As differed from most of the measured variables, the studied wheat cultivars did not vary in terms of RCC, however, contrasted under low and optimum N (Figure 1). In agreement with the current results, Kizilgeci et al. [38] stated that N fertilization significantly influenced the RCC, where durum wheat cultivar “Sena” recorded the highest values (53.5 in 2016/17 and 50.2 in 2017/18). In contrast to our results, Gaju et al. [14] observed that flag-leaf RCC was significantly influenced by wheat genotypes, which differed in the range of 40.1 for “W300” to 56.6 for “Oakley” SPAD units. Gaju et al. [14] additionally reported higher SPAD values (52.7) with the modern cultivars than the Landraces (44.2), which was also not in agreement with the current result since wheat cultivars in this study did not significantly differ in RCC under both low and optimum N. Results of current study showed no clear relationship between RCC and grain yield of wheat cultivars (data not presented) unlike Kizilgeci et al. [38], who obtained highly significant correlation of RCC with grain yield of durum wheat cultivars. Our results, thus, indicated that RCC can reflect neither N efficiency nor N-responsiveness.

Wheat cultivars included in this study contrasted each other in terms of NDVI values under optimum N supply

Table 3: Grain and straw N concentration and N uptake of wheat cultivars.

Cultivars	Grain N uptake (g pot^{-1})		Straw N uptake (g pot^{-1})		Total plant N uptake (g pot^{-1})	
	Low N	Optimum N	Low N	Optimum N	Low N	Optimum N
Danda'a	0.36^{abc}	0.90^{a}	0.29	0.62^{bc}	0.65^{ab}	1.52^{a}
Hidase	0.43^{a}	0.88^{ab}	0.22	0.56^{bcd}	0.65^{ab}	1.44^{ab}
Shorima	0.26^{bcd}	0.89^{ab}	0.24	0.38^{de}	0.50^{abc}	1.35^{abc}
King bird	0.43^{ab}	0.50^{cdef}	0.24	0.42^{de}	0.67^{ab}	0.89^{d}
Lemu	0.32^{abc}	0.85^{abc}	0.32	0.68^{b}	0.66^{ab}	1.53^{a}
Wane	0.34^{abc}	0.84^{abcd}	0.28	0.40^{de}	0.69^{a}	1.24^{abcd}
AlemTena	0.24^{cd}	0.63^{abcde}	0.22	0.40^{de}	0.45^{abc}	1.04^{bcd}
Fetan	0.36^{abc}	0.52^{bcde}	0.21	0.51^{bcde}	0.56^{ab}	1.03^{bcd}
Landrace	0.07^{d}	0.19^{f}	0.25	1.00^{a}	0.30^{c}	1.14^{bcd}
Mangudo	0.29^{abc}	0.43^{ef}	0.28	0.35^{e}	0.56^{ab}	0.84^{abcd}
Utuba	0.25^{cd}	0.64^{abcde}	0.29	0.40^{de}	0.50^{abc}	1.06^{bcd}
Ude	0.22^{cd}	0.47^{def}	0.22	0.48^{cde}	0.43^{bc}	0.97^{cd}
CV (%)	28.7	27.1	20.48	17.9	20.2	17.5
LSD (5%)	0.179	0.36	NS	0.19	0.25	0.45

Mean followed by similar letters in a column is not significantly different from each other at 5% probability level.

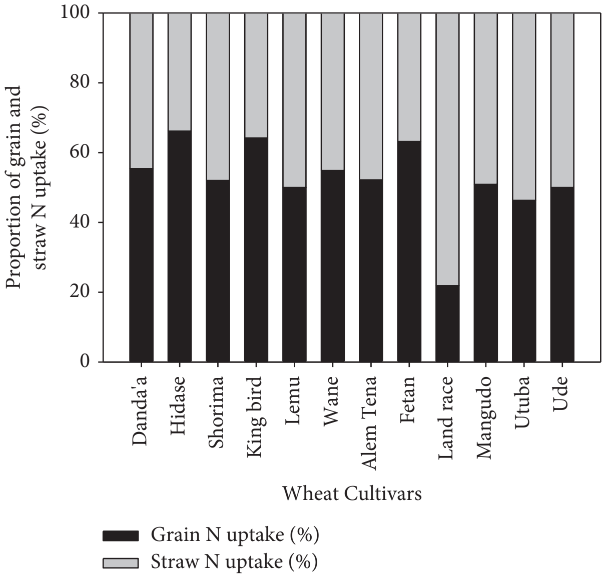


Figure 7: Relative proportion of grain and straw N uptake by wheat cultivars.

(Figure 2). In line with the current results, Kizilgeci et al. [38] also reported that N fertilization significantly influenced the NDVI values in durum wheat, where the cultivar "Svevo" had the highest NDVI values at all growth stages. Current results indicated that NDVI values significantly correlated with grain yield under optimum N (data not presented), unlike under N stress, where NDVI did not show any positive correlation with grain yield (Figure 2). Kizilgeci et al. [38] also observed highly significant relationship of NDVI with the grain yield of durum wheat cultivars suggesting their reliability as indicators for determining N efficiency. Therefore, the parameter NDVI under optimum level can be used to determine N-responsiveness of the wheat cultivars.

Total biological yield (TBY) significantly varied among the studied wheat cultivars and was markedly influenced by N supply (Figure 3). The increase in TBY with N supply could be ascribed to enhanced photosynthesis via chlorophyll synthesis and increased RuBisCO activities under optimum N, thus resulting in higher photosynthate availability that promotes growth and higher dry matter accumulation [14, 39]. Our results showed that TBY had strong positive linear relationships among wheat genotypes with grain yield under both low and optimum N (data not presented). Thus, the wheat cultivars can also be evaluated using TBY performance under low N for N efficiency and under optimum N for responsiveness to N.

In agreement with the current study, many studies including Gaju et al. [14], Fatholahi et al. [15], and Mansour et al. [16] reported that dry matter of improved durum and bread wheat cultivars was increased with increase in the N supply. Similar results were also stated in the works of Fatholahi et al. [15], where the ancient "emmer," "spelt," and "macha" wheat cultivars tended to produce greater TBY compared to improved durum and bread wheat cultivars under both low and moderate N supplies. Gaju et al. [14], on the other hand, reported that cultivars ranged from 1373 ("W081") to 2132 ("Paragon") g·m^{-2} under high N and 1198 ("Cordiale") to 2037 ("SD 24") g·m^{-2} under LN conditions, which was also in consistent with the current results. They also stated that aboveground biomass yield of wheat was increased overall from 1471 g·m^{-2} under low N to 1728 g·m^{-2} under high N conditions (+14.9%). A significant increase in dry matter with increasing N level averaged across all genotypes between 5164.6 and 19904.6 kg·ha^{-1} was also documented in Mansour et al. [16]. Mansour et al. [16] also reported that "Line 6052" presented the highest aboveground dry matter of 7454 kg·ha^{-1} at no N, and 19387 kg·ha^{-1} when N level was increased to 280 kg·ha^{-1} followed by "Gemmiza 10 and 11" cultivars. Ullah et al. [40] reported that biological yield of wheat was significantly influenced by N levels, where maximum and minimum biological yields (16134 and 10044 g·m^{-2}, respectively) were harvested with the applications of 203 kg·N·ha^{-1} and no N, respectively.

Table 4: N harvest index, N utilization, N uptake, and N use efficiencies of wheat cultivars.

Cultivars	N harvest index (%)		N utilization efficiency (g grain DM per g·N taken up)		N uptake efficiency (g N taken up per g·N applied)		N use efficiency (g grain DM per g nitrogen applied)	
	Low N	Optimum N	Low N	Optimum N	Low N	Optimum N	Low N	*N*
Danda'a	55.3^{abcd}	58.7^{abc}	14.8^{abc}	15.4^{ab}	65^{ab}	30^{ab}	9.7^{abc}	4.7^{a}
Hidase	65.9^{a}	60.5^{abc}	17.8^{a}	14.7^{abc}	65^{ab}	29abc	11.7^{a}	4.3^{ab}
Shorima	51.6^{bcd}	70.3^{a}	16.4^{ab}	16.3^{a}	50^{abc}	27^{abcd}	8.2^{abc}	4.1^{abc}
King bird	62.6^{ab}	54.3^{bc}	15.7^{ab}	13.5^{abc}	67^{ab}	18^{e}	10.7^{ab}	2.5^{cd}
Lemu	51.5^{bcd}	53.1^{c}	13.4^{bc}	11.9^{c}	66^{ab}	31^{a}	8.3^{abc}	3.8^{abcd}
Wane	59.0^{abcd}	67.4^{ab}	14.3^{bc}	15.3^{ab}	69^{a}	25^{abcde}	8.2^{abc}	3.8^{abcd}
AlemTena	51.3^{bcd}	61.8^{abc}	14.3^{bc}	13.3^{abc}	45^{abc}	21^{cde}	6.8^{bc}	2.7^{bcd}
Fetan	61.6^{abc}	49.5^{c}	16.1^{ab}	11.7^{c}	56^{ab}	21^{cde}	9.5^{abc}	2.5^{cd}
Landrace	25.5^{e}	17.0^{d}	6.7^{d}	3.2^{d}	30^{c}	23^{abcde}	2.0^{d}	0.7^{e}
Mangudo	50.8^{bcd}	58.2^{abc}	13.4^{bc}	14.2^{abc}	56^{ab}	17^{e}	7.6^{abc}	2.1^{de}
Utuba	48.1^{d}	59.6^{abc}	12.3^{c}	13.7^{abc}	50^{abc}	21^{bcde}	6.4^{bcd}	2.9^{bcd}
Ude	49.4^{cd}	50.4^{c}	14.0^{bc}	12.7^{bc}	43^{bc}	19^{de}	6.1^{cd}	2.4^{de}
CV (%)	10.4	11.35	10.36	11.11	20.2	17.5	27.9	27.02
LSD (5%)	12.4	13.7	3.3	3.18	0.25	0.09	4.64	1.73

Mean followed by similar letters in a column is not significantly different from each other at 5% probability level.

Wheat cultivars varied significantly in their grain yield potentials and responses to applied N (Figure 5) indicating wider differences in their genetic background. The great increase in grain yield of wheat cultivars when N is added was due to the lower N content of the soil (see section 3.1). The differences in the grain yields of the tested wheat cultivars under similar environment could be also ascribed to their diverse capacities to recover more N; use this recovered N to progress tillering, resulting in greater spike population; and consequently accumulate more dry matter and grain yield as well as extensive N concentration in grain and straw parameters, which is economically and environmentally vital [16]. This is because enhancing N uptake and utilization diminishes N loss, particularly under higher rates, which reduces pollution risks posed to environmental [16]. Thus, it is vitally important to identify wheat cultivars with the highest N uptake and utilization efficiencies to meeting the highest yield goal. Our results, generally, indicated the need for the application of N fertilizers owing to the depleted nutrient status of the experimental soil.

Similar to the present findings, an overall positive relationship between grain yield and N levels among wheat cultivars was reported by Nehe et al. [8], Gaju et al. [14], Mansour et al. [16], and Ivić et al. [41]. Nehe et al. [8] stated that the growth in grain yield under high N compared with low N conditions was $1.49\,\text{t·ha}^{-1}$ (+29.6%) and $1.43\,\text{t·ha}^{-1}$(+26.7%) in 2014 and 2016, respectively, with an average rise across years of $1.46\,\text{t·ha}^{-1}$ (+28.1%). Similarly, Gaju et al. [14] also reported an overall 10.1% increase in grain yield among the 15 wheat cultivars under high N ($743.6\,\text{g·m}^{-2}$) compared with low N ($665.6\,\text{g·m}^{-2}$) conditions. A similar 10% increase in grain yield under high compared with low N conditions in southeastern European environments was also reported in a panel of 48 winter wheat cultivars by Ivić et al. [41]. Belete et al. [5] and Tyagi et al. [42] also observed significant grain yield difference among wheat cultivars and N condition, showing that the cultivars also contrasted in terms of responsiveness to N supply, which is similar to the results of the current study. Mansour et al. [16] also reported that grain yield of wheat was doubled from $2794\,\text{kg·ha}^{-1}$ at no N to $7245\,\text{kg·ha}^{-1}$ at $208\,\text{kg·N·ha}^{-1}$ when averaged across all genotypes. They further stated that the highest grain yields at no N ($3348\,\text{kg·ha}^{-1}$) and $280\,\text{kg·N·ha}^{-1}$ ($6094\,\text{kg·ha}^{-1}$) were observed in "Sids 12" and "Line 6052" cultivars, respectively. Corroborating the current results, Kobata et al. [36] reported smaller grain yields with Landraces compared with other types of tetraploid and hexaploid wheat cultivars under Mediterranean conditions of Turkey and Syria. Similarly, Gaju et al. [14] also stated that the modern wheat cultivars had higher yield ($880\,\text{g·m}^{-2}$) than the Landraces ($548\,\text{g·m}^{-2}$) in the high N treatment, but larger grain yield reduction with N limitation for the modern cultivars than the Landraces, which agrees well with our current results.

The current results indicated the need to consider both TBY and grain yield for classifying wheat cultivars for nutrient efficiency as stated by Gerloff [21], but with due emphasis given to grain yield. This was because some cultivars characterized as N efficient in terms of TBY did not perform similarly in grain yield parameter. For example, the cultivar Landrace was in the category of N efficient and responsive to N supply using TBY. However, this could not hold true when grain yield was considered since its harvest index (proportion of grain to total biomass) was very low (see section 3.4). Thus, for cultivars that are very low in harvest index, the use of TBY to categorize cultivars for N efficiency and/or responsiveness could be misleading. On the other hand, under optimum N supply, Shorima, Wane, and Lemu were among the N-efficient and responsive cultivars in terms of TBY; however, they fall on the border line when grain yield was considered. Therefore, it is necessary to rely on grain than biomass yield as the main criterion for the categorization of wheat varieties for N efficiency and/or N-responsiveness.

Grain, straw, and total plant N uptakes accounted for a greater proportion of the variations in grain and biomass yields among wheat cultivars under low and optimum N supply (Table 3). As average of all cultivars, the grain and straw N uptakes for optimum N were 2.2- and 2.0-folds, respectively, higher than that of the low N. Cultivars such as Hidase, Kingbird, and Fetan accumulated more N (>60% of total uptake) in the grain than the straw, while Landrace accumulated more N (>80% of total uptake) in the straw than in the grain (Figure 7). The differences in N uptake among the tested wheat cultivars could partly be attributed to variations in root traits [8]. Direct links between root density and/or deeper root system and enhanced N uptake among wheat cultivars have been demonstrated in ranges of pots and field investigations (e.g., [8, 14]). In agreement with the finding of the present study, Nehe et al. [8] reported that total N uptake was higher under optimum N ($162\,\mathrm{kg{\cdot}N{\cdot}ha^{-1}}$) compared with low N ($85\,\mathrm{kg{\cdot}N{\cdot}ha^{-1}}$) in wheat. Similarly, Gaju et al. [14] also reported that N uptake was increased in high N ($283\,\mathrm{kg{\cdot}N{\cdot}ha^{-1}}$) compared with low N conditions ($200\,\mathrm{kg{\cdot}N{\cdot}ha^{-1}}$). Nehe et al. [8] also additionally reported that aboveground total N uptake among wheat cultivars varied from 64 (“Kharchia-65”) to $101\,\mathrm{kg{\cdot}N{\cdot}ha^{-1}}$(“HD-2932”) under low N conditions and 122 (“DBW-16”) to 196 (“MACS-6222”) $\mathrm{kg\,N{\cdot}ha^{-1}}$ under high N conditions. Similarly, Gaju et al. [14] also stated that N uptake ranged among genotypes from 224 to $368\,\mathrm{kg{\cdot}N{\cdot}ha^{-1}}$ under high N and $164–270\,\mathrm{kg{\cdot}N{\cdot}ha^{-1}}$ under low N conditions, which is in agreement with the results of the current study. Kassie and Fantaye [43] reported that grain and total N uptake were greater in Miscal-21, while straw N uptake was greater in Holker. They also reported that as N rates increased, malting barley grain and straw yields, and total N uptakes increased. Gaju et al. [14] reported that wheat cultivar with a high total N uptake at physiological maturity under low-N condition was the most N efficient, which also supports the current finding, in which cultivars Hidase, Kingbird, Danda’a, and Lemu, with higher grain yield under low N, also had higher total N uptake and were among the N efficient. Results further exhibited total plant N uptake highly correlated with grain yield (data not shown). Thus, this parameter can be considered to categories wheat cultivars for N efficiency and responsiveness.

The studied bread and durum wheat cultivars significantly differed in their N harvest indices (NHI) (Table 4). For instance, the NHI of Shorima was 4-fold higher under optimum N and 2-fold higher under low N when compared to that of the Landrace (Table 4). Agreeing with these results, Fatholahi et al. [15] also observed the smallest values of NHI with the ancient “spelt-macha” (34–44%), “einkorn” (36–44%), and “emmer” (47–61%) cultivars of wheat, which were lower relative to improved durum and bread wheat cultivars (within 52–70% range). The generally lower NHI of the ancient wheat cultivars relative to the improved ones demonstrated that the older wheat cultivars are not efficient in transforming the absorbed N into biomass and/or grain. Nehe et al. [8] also reported that wheat cultivars differed in NHI in the range 0.81 (“KRL-210”) to 0.86 (“NW-1067”) under low N and 0.72 (“Kharchia-65”) to 0.86 (“WH-1021”) under high N conditions. The significant influence of N rate and wheat variety on NHI was also reported by Belete et al. [5], where the maximum NHI (90.74%) was recorded from variety Menze for the control treatment than for the higher N rate. Greater NHI in Miscal-21 for the malt barley cultivars was also reported by Kassie and Fantaye [43]. They further reported that NHI decreased as N rates increased. Results indicated that NHI positively correlated with grain yield (data not shown); hence, it can function as another indicator of N efficiency by which cultivars transform the absorbed N in to biomasses and grains.

Comparing the nitrogen use efficiency (NUE) components, N uptake efficiency (NUpE) explained a larger proportion of the genetic variations in grain yield and NUE than N utilization efficiency (NUtE) of the tested wheat cultivars under both low and optimum N (Table 4). NUpE explained 92% and 82% of the variation in NUE of the wheat cultivars under low and optimum N, respectively (Table 4). According to Nehe et al. [8], Ranjan et al. [11], and Gaju et al. [14], and consistent with our data, genetic variations in NUE among wheat cultivars was more strongly linked to NUpE than NUtE under both high N and low N conditions. The significant effects of genotype, N, and their interaction on NUpE were reported in a number of works (e.g., [11, 14, 15, 41]). In agreement with the current results, Fatholahi et al. [15] reported that NUpE of all types of wheat, which ranged from 1.72 to $7.14\,\mathrm{kg{\cdot}N}$ in plant $\mathrm{kg^{-1}}$ N applied, was decreased with increase in the N supply. They also reported that NUpE of most of the ancient wheat types was greater or comparable to those of the improved durum and bread wheat cultivars when grown under low N supply; however, the reverse was true when the cultivars were grown under high N supply. Ranjan et al. [11] also stated that NUpE of wheat was comparatively higher under low than high N conditions. Similarly, Mansour et al. [16] also documented total NUpE of wheat ranged from 1·07 to $1{\cdot}66\,\mathrm{kg{\cdot}kg^{-1}}$ and from 0·73 to $1{\cdot}21\,\mathrm{kg{\cdot}kg^{-1}}$ at 0 and $280\,\mathrm{kg{\cdot}N{\cdot}ha^{-1}}$, respectively, which agreed well with the present results. NUpE are correlated with grain yield in the present study; thus, it can be taken as one of the most important criteria to evaluate wheat cultivars for N efficiency and responsiveness.

Several factors may regulate plant N uptake rate. As stated in Xu et al. [18], N uptake rate by plants is largely governed by root morphology, architecture, and ammonium and nitrate transporters that reside in cell membranes for available forms of N in the rhizosphere. The overall root morphology and architecture, in turn, could be influenced by nutritional status of plants and external nutrient availability [44]. Considering the greater NUpE of the tested wheat cultivars under low N conditions, it can be inferred that existence of extensive and deep rooting strategy and a high-affinity N-transport might have helped the cultivars to be efficient in N uptake under N deficiency [15]. Upon N supplement, on the other hand, down-regulation of the genes encoding nitrate and ammonium transporters may pledge an enhanced nitrate and ammonium efflux from the root into the soil and lead to reduction in net N uptake by the plant [45]. The functionality of such process can be justified by the observation of the substantial decrease in NUpE with increase in N supply of all wheat cultivars in the present study (Table 4). Since most of the current wheat cultivars have been screened under optimum N condition, genes from the ancient relatives adapted to low N conditions may initiate useful sources for improving N uptake and, consequently, NUE under nutrient-deficient conditions.

The findings of the present study also indicated that wheat cultivars significantly contrasted in their N utilization efficiencies (NUtE). Significant effects of genotypes, N, and interaction of genotype by N on NUtE were also reported by Nehe et al. [8] and Fatholahi et al. [15], which partly agreed with the result of the current study, since N effect was insignificant in the present study (Table 4). In agreement with the present study, Fatholahi et al. [15] stated that NUtE of majority of the wheat cultivars did not indicate a particular trend. A number of studies (e.g., [8, 11, 14, 16, 41]) documented a significant and positive linear relationship between NUtE and grain yield of wheat cultivars at low N and high N, which shows the importance of these traits in varietal response to N fertilization recommendations. Overall increased NUtE of wheat under low N (33.9 and 44.6 kg $\mathrm{DM{\cdot}kg^{-1}\,N}$) compared with high N (26.3 and 44.6 kg DM $\mathrm{kg{\cdot}N^{-1}}$) conditions were reported by Nehe et al. [8] and Gaju et al. [14], respectively. Similarly, Mansour et al. [16] also documented that grain-NUtE ranged from 39.3 to 65.8 $\mathrm{kg{\cdot}kg^{-1}}$ and from 16.0 to 23.2 $\mathrm{kg{\cdot}kg^{-1}}$ at 0 and 280 $\mathrm{kg{\cdot}N{\cdot}ha^{-1}}$, respectively. Comparatively higher NUtE of wheat under low than high N conditions were also reported by Ranjan et al. [11] and Ivić et al. [41]. Fatholahi et al. [15] also reported that NUtE tended to be greater in the improved durum and bread wheat cultivars relative to the emmer (ancient) wheat cultivars, which agreed well with the results of the present study. Moreover, the genetic variation in NUtE was mainly associated with grain N% [8,11]. An enhanced ability to produce viable grains at a low grain N% may therefore be a trait associated with high NUtE under low N conditions [8]. NUtE are correlated with grain yield and, hence, are a matter of interest to the agronomists and plant breeders for improving NUE. Thus, NUtE can also be used to classify wheat varieties for N efficiency and responsiveness.

Generally, the current results indicated that it is vitally important and highly reliable to employ multiple criteria than a single criterion for the selection of N-efficient and N-responsive wheat cultivars (Supplementary tables 1 and 2). This idea also draws support from reports of Tyagi et al. [42], who also used four common selection indices to identify low N-tolerant wheat cultivars. Similar to the criteria used in the present study for low N tolerance/N-efficiency, Chen et al. [46] also reliably used total N uptake and NUE to assess the ability of low N tolerance during screening tea cultivars. Kassie and Fantaye [43] also reported that grain yield was positively correlated with N efficiency traits. Thus, it is useful to identify and use traits that are directly correlated with grain yield for categorizing wheat cultivars for N efficiency and responsiveness.

5. Conclusion

Yield attributes, yield, nitrogen use efficiency, and its components of nitrogen uptake and utilization efficiencies varied significantly among wheat cultivars and nitrogen levels. Results of the present study demonstrated that multicriterion-based performance evaluation has been found the most useful tool to identify bread and durum wheat cultivars for N-efficiency and/or N-responsiveness than relying on a single criterion. Results of the current study further clearly illustrated that a panel of the tested twelve bread and durum wheat cultivars varied largely in their yield and nitrogen use efficiencies under both low and optimum conditions. These contrasting performances of wheat cultivars under different environments enable to make specific recommendations based on the farmers' capacities to invest on nitrogen fertilizer. Reliant on the findings of this study, it can be concluded that cultivar Kingbird was the most N-efficient under low N-input wheat production system, potentially becoming the preference of resource-poor farmers. Similarly, cultivars Danda'a and Shorima were the most N responsive under optimum N supply, which can be recommended to resourceful farmers who aspire to attain the highest yield goals under intensive input management. It can also be concluded that cultivars Hidase and Lemu can serve the dual purposes of both high N-efficiency and N-responsiveness; thus, it can be recommended to any wheat growers regardless of resource base.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declared that they have no conflicts of interest regarding the publication of this paper.

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Supplementary Materials

The use of multiple criteria is highly reliable in selecting N-efficient and N-responsive genotypes rather than using single criteria. This idea also draws support from reports of Tyagi et al. (2020) who also used four common selections, which induces to identify low N-tolerant wheat cultivars. Thus, results presented in supplementary Tables 1 and 2 clearly summarized, the selection procedure of N-efficient and N-responsive wheat cultivars in the current study. Based on multicriterion performance (GY, TBY, number of seeds per pot, spike length, number of effective tillers, total N uptake, N harvest index, N uptake efficiency, N utilization efficiency, and N use efficiency) under low N condition, three cultivars such as Hidase, King bird, and Lemu were identified as the most N-efficient in this study, while three cultivars, namely, Ude, Landrace, and Utuba, were identified as the most N inefficient (Supplementary Table 1). Based on the same multicriterion performance listed above under high N supply, four cultivars such as Danda'a, Shorima, Hidase, and Lemu were the most responsive to N application, while three cultivars such as Ude, Landrace, and King bird were the most nonresponsive to N application (Supplementary Table 2). (*Supplementary Materials*)

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