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Influence of Nitrogen Fertilizer Levels on Growth and Development of Bread Wheat (*Triticum aestivum L.*) Varieties at Kulumsa, South-Eastern Ethiopia

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Abstract: In the Ethiopian highlands low soil fertility, notably nitrogen deficiency, is one of the main constraints limiting wheat production and productivity. For this purpose, an experiment on the effect of different nitrogen fertilizer levels on the growth and developments of bread wheat varieties was conducted at Kulumsa, south-eastern Ethiopia, during the 2017/18 cropping season. The experiment consisted of factorial combinations of two bread wheat varieties (Lemu and Wane) and five N rates (0, 46, 92, 138 and 184 kg N ha^{-1}) performed in a three replicate randomized complete block design. The result revealed that, the interaction effects of variety and N fertilizer rate showed less effect than their main effects and only days to grain filling period and the spike length were significantly influenced by the interaction effects of variety and the N rate. It was indicated that, the Wane variety was shorter days to heading, maturity and grain filling period than Lemu variety whereas Lemu was taller variety, more effective tillers, number of grains per spike and gave better aboveground biological yield than Wane variety at the study site. Conversely, significantly the longest days to heading and maturity were recorded at the highest N rate (184 kg ha^{-1}). The days to grain filling period was increased with rising N rate for both varieties. The peak spike length was recorded at N rate of 92 and 138 kg ha^{-1} for Lemu and Wane varieties, respectively. The maximum aboveground biological yield recorded at the top N rate 184 kg ha^{-1} and significantly at par with that of 92 and 138 Kg N ha^{-1}. Therefore, it was concluded that the response of growth and development of Lemu and wane varieties were different for N fertilizer rate.

Keywords: Bread Wheat, Varieties, Nitrogen, Growth, Phenology, Development, Yield Components

1. Introduction

Ethiopia is the second largest wheat producer in sub-Saharan Africa, after South Africa [1]. Despite the long history of wheat cultivation and its importance for the Ethiopian agriculture, its average productivity at national level is 3.1 t ha^{-1} [2]. This is definitely far below the world average yield (3.52 t ha^{-1}) [3]. The research showed that acute crop cultivation, complete removal of crop residues and high nutrient deficiency all contribute to low wheat productivity [4].

Wheat is one of the most important cereals cultivated in Ethiopia and ranks fourth after sorghum, maize and teff in area coverage, while third in total production after teff [2]. Despite the large area under wheat, the national average yield of wheat in Ethiopia is well below the experimental yield of above 5 t ha^{-1} [5]. This is attributed to the low use of chemical fertilizers, limited knowledge of the time and amount of fertilizer application, the complete removal of crop residues from agricultural land, the unbalanced use of mineral fertilizers and the inappropriate method of their application, which led to low efficiency [6].

Both bread and durum wheat are produced in the country, but bread wheat is the major crop varieties grown in Ethiopia though farmers grow both varieties [7]. Wheat consumption is higher in urban areas than in rural areas due to high population growth, lifestyle changes and rising prices for tef [8]. Poor agronomic management and soil management, insufficient technology generation and dissemination are the main obstacles to increased wheat production in the highlands and mid-highlands of Ethiopia [9]. Wheat is mainly grown in the highlands of Ethiopia, lying between 6°N and 16°N and between 35°E and 42°E, at elevations of 1,500 to 2,800m above sea level and with mean minimum temperatures of 6°C to 11°C [10]. About 75% of the total wheat acreage is in the Arsi, Bale and Shewa wheat belts [10]. The wheat productivity of these areas in terms of yield per unit area of land is very low due to poor agronomic and soil management practices. As a result of this, the Ethiopian government is forced to import wheat every year as the demand is higher than the supply [11]. In order to increase and maintain wheat production and reduce the gap between supply and demand, the implementation of proper soil fertility management is paramount. Low soil fertility, especially nitrogen (N) deficiency, is one of the main constraints limiting wheat production in the Ethiopian highlands [12]. However, less than 45% of farmers, on about 40% of the utilized agricultural area, are most likely applying fertilizers below the optimal dosage [13]. Nitrogen is often the most deficient of all plant nutrients. Wheat is very sensitive to nitrogen deficiency and responds very well to nitrogen fertilization [14]. The global increase in agricultural food production over the past four decades has been associated with a 7-fold increase in N-fertilizer use [15]. Hence, applying nitrogen fertilizers in the right amount and at the right time is essential to improve soil fertility and crop productivity. Therefore, the experiment was conducted to evaluate the effect of nitrogen fertilizer rates on the phenogy, growth and yield components of bread wheat varieties Lemu and Wane in Kulumsa, Arsi Zone highlands, south-eastern Ethiopia.

2. Materials and Methods

2.1. Description of the Study Area

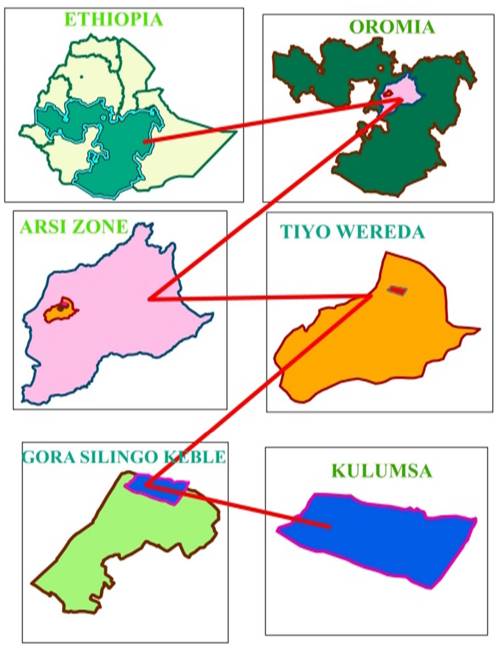

Figure 1. *Location map of the study area.*

A field experiment was conducted during the 2017/18 peak growing season at Kulumsa Agricultural Research Center (KARC) farm in Tiyo District, East Arsi Zone, Oromia Regional State, Ethiopia (Figure 1). Tiyo District is 175 km south-east of Addis Ababa. The geographic location of the test field is found at longitude of 8 01' N and latitude of 39 09' E. The altitude of the test site is 2200 m above sea level.

2.2. Soil Analysis

Fifteen pre-planting surface soil samples (0-20 cm) were randomly collected from the test site in a zigzag walk and compacted into one representative composite soil sample. Three undisturbed soil samples were also taken with a core sampler to determine bulk density. Soil texture, pH, organic carbon, total nitrogen and available phosphorus and bulk density analyzes were performed according to standard procedures.

2.3. Experimental Methods

The experiment consisted of 10 treatments as a factorial combination of two improved bread wheat varieties Lemu and Wane and five N rates (0, 46, 92, 138 and 184 kg ha^{-1}) arranged in a three replicate randomized complete block design. Farm that were covered with wheat or barley in the previous year were selected for planting in order to avoid after-effects of legumes. The gross plot size of the experiment was 4 m long and 2.6 m wide with row spacing of 0.2 m. The harvestable net plot size of the experiment was 3.20 m long and 2 m wide with 16 middle rows. The spacing between plots and blocks was 1 and 1.5 m, respectively. Lemu and Wane were released from KARC in 2016 to improve productivity and adaptation in the agro-ecology of the highlands of south-eastern Ethiopia. Wane has shorter days to head, grain filling and maturity than the Lemu variety. Both varieties were planted in rows using a manual row marker at the recommended seed rate of 125 kg ha^{-1}. Urea (46% N) was used as N source in triple application form (1/3 at planting, 1/3 at tillering and 1/3 at flowering) as top dressing according to the treatments. As a source of phosphorus (P), a basal application of triple superphosphate at a rate of 100 kg ha^{-1} was used at the time of sowing on all experimental units. Other agronomic practices were properly carried out according to the recommendations of the areas.

2.4. Data Collection and Analysis

The data collected were as follows: days to heading, grain filling period, days to maturity, plant height, number of fertile tillers, spike length, number of grains per spike, and aboveground biological yield.

The collected data were subjected to analysis of variance using the General Linear Model procedure of R computer software version 4.0.1 [16]. Whenever treatment effects were significant, the mean differences were separated using the least significant difference (LSD) at 5% level of significance [17].

3. Results and Discussion

Soil and agro-climatic conditions of the experimental area

The result of the pre planting soil physic-chemical analysis at the study site is presented in (Table 1). The result indicated that the soil had a clayey texture, low levels of organic carbon and total N, slightly acidic reaction, high levels of available phosphorus and low bulk density as shown in Table 1. The soil texture delivery of the experimental site was clayey. Soils with high clay content may have higher soil organic matter (SOM) content, due to slower decomposition of organic matter. In agreement with this result it was reported that soil texture influence the rate of SOM decomposition [18]. According to [19] rating, the soil reaction of the experimental site is moderately acidic. This indicates that the soil of experimental site is suitable for optimum growth and yield of most crops. It was found that, plant nutrients are most available at pH varying from 5.5 to 7 [20]. Organic carbon (2.5%) and total nitrogen contents (0.16%) were low in this study site, while available P level (11.4 mg kg^{-1} of soil) was high [21]. The low availability of total N at experimental site indicates maximizing N-application at the study area is very critical to maximize wheat production. The bulk density of the soils of the experimental site was (1.3 g cm^{-3}) which is found in moderate range as [22] rating.

Table 1. *Selected soil physical and chemical properties of the experimental site before planting.*

Soil parameters	Value	Rating	Reference
pH (1:2.5 Water)	5.8	Moderately acidic	[19]
Available Phosphorus (mg kg^{-1})	11.4	High	[21]
Organic carbon (%)	2.5	Low	[21]
Total Nitrogen (%)	0.16	Low	[21]
Sand (%)	6.3		
Silt (%)	22.5	Clayey	Textural Class
Clay (%)	71.2		
Bulk Density (g cm^{-3})	1.3	Low	[22]

Weather data recorded during the 2017/18 harvest season showed that the area received a total annual precipitation of 718.8 mm, unimodally extending from February to October. However, the main rainy season was from July to September (Figure 2). The average annual minimum and maximum temperatures were 12.1 and 24.1°C, respectively (Figure 2).

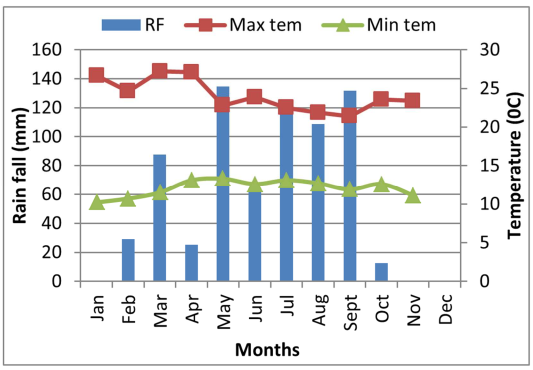

Figure 2. *Mean monthly rain fall, maximum and minimum T^0 of the study area in the year 2017.*

3.1. Phonological Parameters

3.1.1. Days to Heading

Days to 50% heading was significantly (P<0.001) affected by the main effects of variety and N-rate while their interactions didn't show significant (Table 2). The variety Wane was 5 days earlier in days to heading than variety Lemu. This difference could be attributed to the genetic makeup. In line with this result, bread wheat varietal differences with respect to heading were reported by [23]. Increasing N fertilizer rates from 0 to 184 kg ha^{-1} extended the number of days to 50% heading from 55 to 81 days (Table 2). Days to heading showed an increasing tendency with rising N rates (Table 2). The use of low N fertilizer rate in wheat shortens the intervals between the growth phases by facilitating the physiological activities of crops due to the accessibility of inadequate resource. Short number of days to heading was recorded from plots without nitrogen fertilization while the longest days to heading was recorded for plots that received 184 kg N ha^{-1}. In line with the result, [24] reported that days to heading were significantly delayed when N fertilizer was applied at the highest rate for wheat and barley production compared to the lowest rate. This could be due to the fact that higher N rates enhance more vegetative growth and larger photosynthesis than reproductive parts. Consistent with this result, [25] indicated that rate of N-fertilizer application had significantly affected days to heading of wheat.

3.1.2. Days to Maturity

The results showed that the main effects of varieties and N fertilizer rate were highly significant (p<0.001) on days to 90% physiological maturity. Conversely, the interaction effects of N-fertilizer rate and varieties did not show any significant effect on days to 90% physiological maturity (Table 2). Variety Wane took shorter time to maturity compared to variety Lemu (Tables 2). It is also important to note that the differences in maturity can be caused by the combined effect of genetic and environmental factors during the growth stage of the crops. Days to maturity consistently increased with increasing N rate. The shortest and longest days to maturity was recorded from 0 and 184 kg ha^{-1} N rates, respectively. This might be attributed to the role of N, which increases vegetative growth of crops whereby it delays maturity time. The result was confirmed with that of [26] who stated days to maturity linearly increased with increasing N rates. This result was in line with [25] who reported that, N fertilizer rate significantly affected days to maturity on wheat.

3.1.3. Grain Filling Period

Days to grain filling period was significantly (p < 0.001) influenced by the main effects of N rates, varieties and their interaction (Figure 3). Variety Wane took shorter time to grain filling compared to variety Lemu (Figure 3). The differences in grain filling can be caused by the combined effect of days to heading and days to maturity during the growth stage of the crops. The longest days to grain filling period was at higher N rates, 138 and 184 kg ha^{-1} for variety Lemu than Wane (Figure 3). Despite small variability, both varieties showed a consistent increasing trend in days to grain filling with increasing nitrogen fertilizer rates. About seven more days was required for the 184 kg N ha^{-1} treatment, which took 77 days to grain filling for Lemu variety; while five days difference was noted for Wane variety with similar treatment compared to the control (Figure 3). The result was in line with that of [27] who stated that a steady increasing trend in grain filling period with rates of N in wheat was observed. Wakene *et al.* [28] also reported that application of N significantly prolonged number of days to heading and maturity and grain filling period in barley.

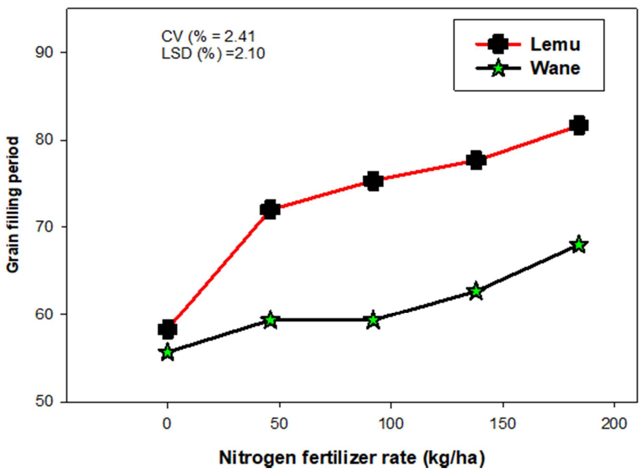

Figure 3. *Interaction effect of Nitrogen and Variety on days to grain filling.*

3.2. Growth and Yield Components

3.2.1. Plant Height

Plant height was highly significantly (P<0.001) affected by N-rate and variety, but their interaction was non-significant (Table 2). This result was similar with that of [29] who reported interactions among the four bread wheat cultivars and the five nitrogen doses were showed non-significant. Variety Lemu had higher plant height (98.6 cm) than Wane (96.7 and 94.7 cm) variety (Table 2). This variation could be related to the inherent character of the variety. The plant height consistently increased with increasing N rates. In line with this result [29] also revealed that plant height increased, with increasing nitrogen level from the control level to the highest nitrogen level. The highest plant heights were recorded from the treatment with the highest N rate of 184 kg ha^{-1}, while the shortest plant height was recorded on plots without N application. Tayebeh *et al.* [30, 27] also reported significant increments in plant height due to application of high nitrogen rate.

3.2.2. Spike Length

Spike length was significantly affected by N, variety and their interactions (Figure 4). Results of N rates and variety interaction effects indicated that the longest spike length (9.33cm) was obtained from 92 kg N ha $^{-1}$ for Lemu variety whereas at 138 kg N ha^{-1} for Wane (7.13 cm) variety. The spike length of Lemu increased with increasing N from 0 to 92 kg ha^{-1} and then decreased from 138 to 184 kg N ha^{-1} while for Wane variety it increased from 0 to 138 kg ha^{-1} N rates. But no statistical difference was observed between 92 and 138 kg ha^{-1} N rates for Lemu variety (Figure 4). These findings justified that N fertilizer application beyond optimum does not have significant effect on spike length of wheat. In line with these results, [25] reported that optimum amount of fertilizer application has significant effect on spike length growth. Similarly, [31] reported that excessive application of N fertilizer has toxic effect on wheat growth and results in stunted growth and reduced spike length.

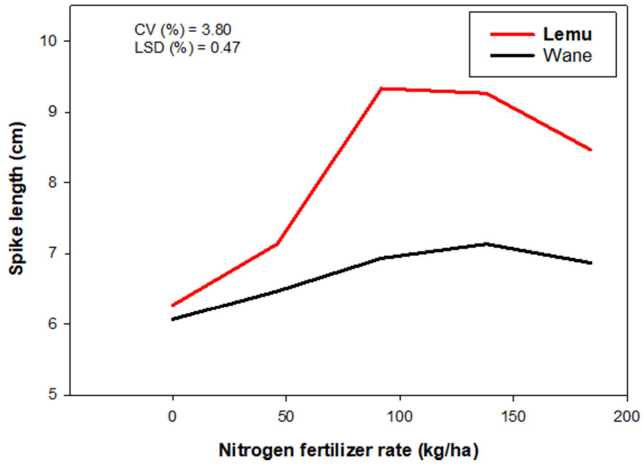

Figure 4. *Interaction effect of Nitrogen and Variety on spike length.*

3.2.3. Number of Effective Tillers

Number of effective tillers were highly (p<0.001) significantly influenced by N rate and variety, but their interactions were non- significant (Table 2). Corresponding to this growth parameter, variety Lemu had better performance than variety Wane (Tables 2). The response of the crop in terms of number of effective tillers was higher at 92 kg N ha^{-1}, but the trend was inconsistent for the remaining N rates (Table 2). The lowest numbers of effective tillers were recorded from the control plots; which might be due to the role of N in accelerating vegetative growth of plants. The result was in agreement with that of [32] who reported that increasing in the number of effective tillers with nitrogen fertilization. Bereket *et al.* [33, 34] also stated that nitrogen fertilization have significant effect on effective number of tillers of wheat.

3.2.4. Number of Grains Per Spike

Number of grains per spike was significantly affected due to the main effects of variety and rate of N, but not by their interactions (Table 2). Higher number of grains per spike (54.6) was recorded from variety Lemu than Wane (53.4) (Table 2). This might be, suggesting that variety Lemu is genetically superior to Wane for this parameter character. It was evident from the results that the spike length of Lemu variety was markedly higher than variety Wane. Similar with this result, it was informed that the length of spike plays a vital role in wheat towards the grains spike^{-1} and finally the yield [35]. Nitrogen rates of 92 and 138 kg ha^{-1} were similar with each other while they were significantly different from the rest treatments (Table 2). Lower number of grains spike^{-1} was recorded in control plot than fertilized plots. Number of grain spike^{-1} increased from 0 to 92 kg N ha^{-1} and then decreased from 138 to 184 kg N ha^{-1}. Despite this difference, the highest grain spike^{-1} (57.4) obtained from the plots fertilized with 92 kg N ha^{-1} (Table 2). The results were in conformity with that of [36] who stated that increasing N rates up to optimum level significantly increased number of grain spike^{-1}.

Table 2. *Main effect of variety and N- rate on days to heading, days to maturity, plant height, fertile tillers plant^{-1} and aboveground biological.*

Treatment	Days to heading	Days to maturity	Plant height (cm)	Fertile tillers plant^{-1}	Grains spike^{-1}	Aboveground biological yield (t ha^{-1})
Variety						
Lemu	146.0^{a}	146.0^{a}	98.6^{a}	5.1^{a}	54.6^{a}	19.7a
Wane	134.7^{b}	134.7^{b}	96.7^{b}	4.8^{b}	53.4^{b}	18.8b
LSD (%)	0.7	0.7	0.6	0.1	0.8	0.5
N rates (kg ha^{-1})						
0	132.8^{e}	132.8^{e}	95.0^{d}	4.3^{d}	48.5^{d}	15.9c
46	136.7^{d}	136.7^{d}	96.8^{c}	4.7^{c}	52.6^{c}	18.7b
92	140.2^{c}	140.2^{c}	98.2^{b}	5.7^{a}	57.4^{a}	20.3a
138	144.0^{b}	144.0^{b}	99.0^{ab}	5.1^{b}	56.5^{a}	20.4a
184	148.2^{a}	148.20^{a}	99.3^{a}	4.8^{c}	55.0b	21.1a
LSD (5%)	1.1	1.1	1	0.2	1.3	0.8
CV (%)	0.7	0.7	1.1	3.1	1.9	3.6

Means followed by the same letter(s) within a column are not significantly different from each other at 5% level of significance.

3.2.5. Aboveground Biological Yield

Both the main effect of nitrogen and variety significantly influenced aboveground biological yield (AGBY), but their interaction effects were not significant (Table 2). The AGBY was increased with increasing N rate, whereby the lowest and highest values were obtained from control plots (15.9 t ha^{-1}) and from plots that received 184 kg N ha^{-1} (21.1 t ha^{-1}), respectively (Table 2). The maximum AGBY recorded at the treatment which received 184 kg N ha^{-1} and did not show significant different to the AGBY obtained from 138 and 92 Kg N ha^{-1} (Table 2). Even though, the increment of AGBY was consistent with increasing N rate, addition of N above 92 kg N ha^{-1} didn‘t give response. At higher doses N increases vegetative growth of plants and parameters such as plant height, spike length, number of seeds per spike, number of fertile tillers and grain yield which contributed for the increase in AGBM. This result was in line with the findings of [37] who stated that increased nitrogen level increased total dry matter irrespective of cultivars. Nitrogen application rates notably improved aboveground biological of wheat [38]. On the other hand, Lemu variety gave 8.5% more AGBM advantage than Wane variety. This difference might be attributed to the higher productivity of growth and yield components of Lemu variety. Consistent with this result of [12] who reported that bread wheat was found to be superior in growth and yield performance as compared to each other which might be associated with its better genetic yield potential and higher N uptake efficiency.

4. Conclusions

The results of the experiment showed that the days to heading, days to maturity, plant height, number of effective tillers, and number of grains per spike and aboveground biological yield were significantly influenced by the main effects of the variety and the level of N fertilization. Whereas; days to grain filling period and the spike length was significantly influenced by the main effects of the variety, the N-rate and their interactions. According to this study result, the Wane variety was shorter days to heading, maturity and grain filling period than Lemu variety whereas Lemu was taller variety, more effective tillers, number of grains per spike and gave better aboveground biological yield than Wane variety at the test site. On the other hand, significantly the longest days to heading and maturity were recorded at the highest N rate (184 kg ha^{-1}). The days to grain filling period was increased with rising N rate for both varieties. The peak spike length was recorded at N rate of 92 and 138 kg ha^{-1} for Lemu and Wane varieties, respectively. The extreme aboveground biological yield recorded at the peak N rate 184 kg ha^{-1} and significantly at par with that 92 and 138 Kg N ha^{-1}.

In general, based on the studied agronomic parameters, it was concluded that different varieties responded differently to the unlike nitrogen application levels.

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