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Effects of nitrogen rate on yield, yield related traits and grain quality of recently released durum wheat varieties in Bale highlands

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Shortage of improved varieties and low soil nitrogen status are some of the major constraints limiting durum wheat yield and grain quality in Bale zone, which is the major wheat producing belt in the country. An on-farm experiment was conducted at Sinana and Gololcha, districts of bale zone for three years (2016-2018), to assess the effect of nitrogen fertilizer rate on yield, yield components and grain quality of durum wheat varieties. Factorial combinations of four durum wheat varieties (Toltu, Dire, Bekelcha and Ingliz) and five rates of nitrogen (46,92,138,184 and 230 kg N ha^{-1}) were laid out in a randomized complete block design (RCBD) with three replications. The main effects of nitrogen and variety significantly ($P < 0.05$) influenced plant height, spike length, kernels per spike, bio-mass yield, grain yield, harvest index TKW,HLW and grain protein content. The grain yield for main effects of variety ranged from 3653 to 4650 kg ha^{-1}. Dire recorded the highest grain yield (4650 kg ha^{-1}) in statistical parity with Bekelcha(4563 kg ha^{-1}). Toltu produced the next highest grain yield (4477kg ha^{-1}) while the lowest yield was obtained from local variety Ingliz(3653 kg ha^{-1}). These results clearly indicated that the improved durum wheat varieties are more productive and responsive to nitrogen fertilizer than the local cultivar. Grain yield for main effects of N fertilizer rates ranged from 3815 kg ha^{-1} to 4536 kg ha^{-1}. The heghest N rate (230kg N ha^{-1}) recorded the highest grain yield(4536 kg ha^{-1}). The second was from (138 kg N ha^{-1}) in statistical parity with 184 and

92 kg N ha^{-1}, 4519, 4439 and 4370 kg ha^{-1}, respectively. The lowest yield (3815 kg ha^{-1}) was recorded by the lowest N rate (46 kg N ha^{-1}). Bekelcha gave the highest TKW(46.6g) and grain protein content(14.6%). The lowest TKW (42.9g) and grain protein content (12.9g) was recorded from lacal variety Ingliz. The highest grain protein content (15.1%) was obtained from the application of the highest N rate (230kg N ha^{-1}), the lowest (12.8%) was from the lowest N rate (46 kg N ha^{-1}).The economic analysis indicated that optimum grain yield and quality of the improved durum wheat varieties Toltu,Dire and Bekelcha were obtained at the rate of nitrogen application (92 kg N ha^{-1}). Therefore, durum wheat farmers in the study area should use 92 kg N ha^{-1} to realize maximum grain yield and quality of the crop. The results also imply that there is a need to formulate variety-specific N fertilizer recommendation rates for enhancing the productivity and grain quality of durum wheat for pasta/macaroni making.

1. Introduction

Wheat (*Triticum* spp.) is one of the most important cereal crops worldwide in total production and use (Evans, 1998). The crop is grown as bread (*Triticum aestivum* L.) and durum (*Triticum turgidum* L.var. *durum*) wheat. Durum wheat is the second most cultivated wheat species in the world next to bread wheat (Peña and Pfeiffer, 2005). Global wheat production in terms of area coverage in 2009 was estimated at 225,437,694 ha and the grain yield obtained within the same year was estimated at 681,915,838 tons (FAOSTAT, 2011).

In Ethiopia, wheat stands fourth in area coverage and third in production. Eighty-one percent of the total land cultivated to grain crops is covered by cereals out of which wheat accounts for 13.14 % of the area (CSA, 2011). There are ample opportunities in Ethiopia in general and in Bale region in particular in terms of favorable environmental conditions. Arsi and Bale highlands are regarded as highly suitable regions for wheat production in Ethiopia and 30.5% wheat production in the country comes from Arsi and Bale regions (CSA, 2008).

Durum wheat is the most important wheat species grown in the highlands of Ethiopia (Tesfaye, 1987). Ethiopian highlands are regarded as the largest wheat producer in Sub-Saharan Africa (Efrem et al., 2000). Durum wheat is traditionally grown by smallholder farmers on the heavy black clay soils (Vertisols) of the high lands at altitude ranging between 1800 and 2800 m above sea level and rainfall distribution varying from 600 to more than 1200 mm per annum (Hailu, 1991). Despite the long history of durum wheat cultivation and its importance to the Ethiopian agriculture, its average yield is still low, not exceeding 1.5 ton ha^{-1} (Efrem et al., 2000). According to Tesfaye (1986), close to 85 % of the cultivated durum wheat in Ethiopia are landraces.

The low yield of durum wheat could be mainly due to the use of low yielding landraces by farmers, weeds, diseases, insect pests, low fertility and moisture stress in the major durum wheat growing areas (Tesfaye, 1988). Soil degradation and depletion of soil nutrients are among the major factors threatening sustainable cereal production in the Ethiopian highlands. Wheat production in the country is adversely affected by low soil fertility and suboptimal use of mineral fertilizers in addition to diseases, weeds, erratic rainfall distribution in lower altitude zones, and water-logging in the Vertisols areas (Amanuel et al., 2002).

The quality of durum wheat is highly dependent on the protein content of the grain, which is largely dependent on genotype and is influenced by the environment, especially nitrogen availability of the soil. Nitrogen fertilizers are highly soluble and, once applied to the soil may be lost from the soil-plant system or made unavailable to the plants through the processes of leaching, NH_3 volatilization, denitrification, and immobilization (Bock, 1984; Stanford and Legg, 1984).

Nitrogen fertilization management, therefore, offers the opportunity for increasing wheat protein content and other related quality traits. According to Motzo et al. (2004), grain protein content is a function of total nitrogen uptake and of the partitioning of nitrogen and dry matter to the grain. Franzen and Goos (1997), also indicated that protein content consistently lower than 12% is an indication that a wheat producer needs to use more nitrogen fertilizer or better manage the nitrogen being applied for improved wheat grain quality for pasta making.

Grain protein content is considered as the main characteristic of durum wheat grain quality (Ottman et al., 2000). Protein content was associated mainly to soil nitrogen fertility status. Available soil nitrogen is often insufficient and mineral fertilizers should be supplemented. In fact, Metwally and Khamis (1998), indicated that, wheat nitrogen requirements could not be met by the separate application of any organic source. In practice, nitrogen is the most cost efficient and practical factor to manage.

Nowadays durum wheat is considered as potential crop by the government for food industry as import substitution and one means of income diversification for the farmers. With the increasing number of processing industries, the demand for durum wheat grains for pasta processing is growing-up in the country. Due to various reasons, locally produced durum wheat grains are censured to be of poor quality and do not meet the minimum quality standard of pasta production. Hence, in spite of the large volume of local production, some processing industries prefer to import durum wheat grain for pasta production. Information on yield and grain quality under different nitrogen rates for most of the recently released durum wheat varieties in Ethiopia is limited. It is, therefore, necessary to improve durum wheat productivity and grain quality through nitrogen fertilizer management and selection of genotypes with high nitrogen use efficiency to make durum wheat production rewarding to farmers, and to satisfy the demand of the processing industries. Therefore, the experiment was conducted with the following objectives:

- ✓ To determine the effect of nitrogen fertilizer rates on yield, yield related triats, and grain quality of durum wheat varieties.
- ✓ To determine economically optimum nitrogen application rate for higher yield and quality.

2. Materials and Methods

The experiment was conducted for three years (2016-2018) at three locations (Sinana on-station, Sinana on-farm and Gololcha) in main cropping season. The treatments were consist of combinations of four durum wheat varieties that includes three recently released durum wheat varieties (Toltu, Dire and Bekelcha) from Sinana Agricultural Research Center and one local check (land race variety Ingliz) and Five rates of nitrogen (46,92,138,184 and 230 kg N ha^{-1}). The experiment was laid out as Randomized Complete Block design (RCBD) in a factorial arrangement with three replications. Treatments were assigned to each plot randomly. The size of each plot was 2.4m x 2.5m=6m^2 and the distance between rows, plots and reps was 0.2, 0.5, and 1.5 m, respectively. Phosphate fertilizer in the form of TSP (46%P_2O_5) at the recommended rate of 46 P_2O_5 ha^{-1} was applied uniformly to each plot. Nitrogen was applied as split-application, $^1/_4$ at planting, $^1/_2$ at tillering and $^1/_4$ at anthesis. All the other recommended management practices to the crop were done uniformly to raise the crop.

2.1. Statistical data analysis

Analysis of variance (ANOVA) was done using Gen Stat 15th edition and means comparisons for the significantly different variables were made among treatments using least significant differences (LSD) test at 0.05 level of significance.

3. Results and Discussion

3.1. Soil analysis before planting

Selected physico-chemical properties of the soil were determined for composite surface soil (0-30 cm) samples collected before sowing (Table1). Accordingly, the texture of the soil of the experimental site is dominated by the clay fraction. The clay texture indicates the high degree of weathering that took place in geological times and the high nutrient and water holding capacity of the soil.

Soil pH values for both locations varied from 6.45 to 6.48 for soils of the experimental sites (Table 1). pH status was categorized as slightly acidic soil Jones (2003). Based on these results the pH value is optimum range for most crop production since most plant prefer the pH range 5.5 to 7.0. Soil Organic Matter values for both locations varied from 2.38 to 4.98 for soils of the experimental sites (Table 1). As the rating range established by Tekalign (1991) soil organic matter content categorized under moderate and low for Sinana on- Station and Sinana on-farm, respectively. Soil Total Nitrogen values for both locations varied from 0.22 – 0.33.As ratings suggested by Landon (1991) for soil total nitrogen soils of the experimental site were rated into moderate and low for Sinana on- station and Sinana on-farm, respectively**.** Available Phosphorous values for both locations varied from 4.5-20.58 (Table 1). According to the rating established by Cottenie (1980) the studied soils have low to high phosphorus content for Sinana on-farm and Sinanaon-station, respectively**.** Adequate phosphorus results in higher grain production, improved crop quality, greater stalk strength, increased root growth, and earlier crop maturity.

Cation exchange capacity values were ranged from 24.45 to 38.53 for soils of the experimental sites. Based on the rating established by Hazelton (2007) the soil of the study sites were moderate and high for sinana on-Farm and Sinana on-station, respectively.

Table 1
Soil physico-chemical properties of the Sinana on- station and Sinana on-farm.

Location	Textural class	pH	OM (%)	TN (%)	Available P(ppm)	CEC (cmol kg^{-1})
Sinana on-station	Clay	6.45	4.98	0.33	20.58	38.53
Sinana on-farm	Clay	6.48	2.38	0.22	4.5	24.45

3.2. Plant height

The analysis of variance showed that the varieties differed significantly ($P < 0.05$) in plant height. The local cultivar Inglizi produced significantly taller plants (122cm) than all the improved varieties. This was followed by the improved variety Bekelcha(88.9cm), which also produced significantly taller plants than Toltu and Dire. Thus, the heights of plants produced by the local cultivar Ingliz exceeded the heights of plants produced by the improved varieties Toltu, Dire and Bekelcha by about 31, 27% respectively (Table 1).

The shorter suture of the improved varieties compared to the local cultivar may be related to the pattern of modern wheat breeding which always aims at developing dwarf or semi-dwarf wheats for enhanced partitioning of carbohydrate towards the grain.

3.3. Grain yield

The ultimate goal in crop production is maximum economic yield, which is a complex function of individual yield components in response to the genetic potential of the cultivars and inputs used.

Analysis of variance indicated significant differences ($P < 0.05$) among nitrogen rate treatments and varieties for grain yield, while interaction was not significant (Table 2).

Grain yield increased as rate of nitrogen applied increased from the lowest to the highest level. Mean Grain yield ranged from 3815 kg ha^{-1} for the lowest treatment (46 kg N ha^{-1}) to 4536 kg ha^{-1} for the highest treatment (230 kg N ha^{-1}) indicating grain yield variation under the different nitrogen rate treatments. The lowest grain yield (3815 kg ha^{-1}) was recorded by the lowest nitrogen rate (46 kg N ha^{-1}). The highest grain yield (4536 kg ha^{-1}) was recorded by the highest nitrogen rate (230 kg N ha^{-1}). The remaining three nitrogen rates 92,138 and 184 kg N ha^{-1} gave statistically similar grain yield 4370, 4519 and 4439 kg/ha, respectively.

The analysis of variance also revealed that significant differences ($P < 0.05$) among tested varieties. Mean grain yield ranged from 3653 kg/ha for local variety Ingliz to 4650 kg/ha for improved variety Dire. Improved variety Bekelcha also produced statistically similar grain yield (4563 kg ha^{-1}) with Dire. Toltu also recorded statistically different grain yield (4477 kg/ha) to local check (3653 kg/ha). The three improved varieties gave statistically much higher grain yield than the Local variety. These results clearly indicated that the improved durum wheat varieties are more productive and responsive to nitrogen fertilizer than the local variety. The results are consistent with the general fact that modern wheat varieties are genetically improved through traits imparting shorter stature and higher potential to partition photo assimilate to the grains.

3.4. Bio-mass yield and harvest index

Analysis of variance indicated significant differences ($P < 0.05$) among nitrogen rate treatments for biomass yield and nitrogen rate treatments and varieties for harvest index while interaction was not significant for the two parameters (Table 2).

Table 2
Mean value of plant height and grain yield of durum wheat varieties grown under different N rates.

	N kg ha^{-1}											
	Plant height (cm)						Grain yield(kg/ha)					
Variety	**46**	**92**	**138**	**184**	**230**	**Mean**	**46**	**92**	**138**	**184**	**230**	**Mean**
Toltu	81.6	82.8	86.7	84.2	85.7	84.2c	3986	4496	4647	4574	4684	4477b
Dire	81.8	84.1	85.3	84.6	85.5	84.3c	4120	4567	4833	4791	4937	4650a
Bekelcha	86.8	88.3	89.6	89.4	90.3	88.9b	4003	4583	4769	4673	4788	4563ab
Ingliz	121.9	122.3	121.6	122.5	122.2	122.1a	3151	3834	3826	3717	3736	3653c
Mean	93.0	94.3	95.8	95.2	95.9		3815c	4370b	4519ab	4439ab	4536a	
CV (%)			7.4						12.7			
LSD(0.05)												
V			1.77						140			
N			NS						156			
VxN			NS						NS			

Means with the same letter are not significantly different at 5% level of significance; NS=Non significant; N=Nitrogen; V=Variety; CV(%)= Coefficient of variation(%).

All fertilizer nitrogen rates averaged over cultivars, gave higher biomass yield than the first two lowest treatments (Table 2). Biomass yield increased as rate of nitrogen applied increased from the lowest to the highest level. Mean biomass yield ranged from 8414 kg ha^{-1} for the lowest treatment(46 kg N ha^{-1}) to 11897 kg ha^{-1} for the highest treatment (230 kg N ha^{-1}) indicating large biomass yield variation under the different nitrogen rate treatments.

Generally, a linear increment in biomass production was observed with an increase in N rates from 46 kg ha^{-1} to 230 kg ha-1. This is in agreement with the findings of Amanuel et al. (1991) who reported a significant increase of biomass yield as a result of nitrogen rate increase in wheat.

The ability of a cultivar to partition the dry matter into economic (grain) yield is indicated by its harvest index which was significantly varied among various varieties and nitrogen rate treatments (Table 2). The highest nitrogen rate treatments significantly reduced harvest index (40%) as compared to the lowest rate. The second lowest treatment 92 kg ha^{-1} had resulted in the highest harvest index (52%), in statistical parity with the lowest nitrogen rate of 46 kg ha^{-1} with a harvest index value of 51%. There was also highly significant differences ($P < 0.05$) between the local variety and the improved varieties for harvest index across nitrogen rate treatments. This could be accounted for the enhanced above ground biomass yield in response to the incremental rates of nitrogen in contrast to grain yield during the growing season. In the case of varieties, statistically all improved varieties were at par for their harvest index ranging from 48-49% suggesting nearly an equal early assimilation and utilization of nitrogen nutrients of those varieties while lowest harvest index (42 %) was recorded for variety Ingliz.

Table 3
Mean value of bio-mass yield and harvest index of durum wheat varieties grown under different N rates.

N kg ha^{-1}	Bio-mass yield (kg ha^{-1})						Harvest index(%)					
Variety	**46**	**92**	**138**	**184**	**230**	**Mean**	**46**	**92**	**138**	**184**	**230**	**Mean**
Toltu	8090	8836	9924	10371	11697	9784	54	55	49	45	41	49a
Dire	8303	9389	9460	10931	11971	10011	53	52	53	45	42	49a
Bekelcha	8300	8649	9887	10782	11676	9859	50	55	50	44	42	48a
Ingliz	8961	9337	10996	11664	12243	10640	45	48	41	37	36	42b
Mean	8414d	9053d	10067c	10937b	11897a		51ab	52a	48b	43c	40c	
CV (%)			25.1						21.4			
LSD (5%)												
V			NS						3			
N			717						3			
VxN			NS						NS			

Means with the same letter are not significantly different at 5% level of significance; NS=Non significant; N=Nitrogen; V=Variety; CV(%)= Coefficient of variation(%).

3.5. TKW and HLW

The result showed significant differences (P < 0.05) among nitrogen rate treatments and varieties for TKW and HLW while their interaction was no significant (Table 3).

The nitrogen rate treatments caused a slight increase in TKW .The maximum TKW was observed for treatments 138 kg N ha^{-1} (45.6 g) which was statistically at par with 184 and 230 kg N ha^{-1} (Table 3). This might be attributed to a better nutritional status of the plants which resulted in good grain filling and development. The minimum TKW was achieved in the lowest treatment which was significantly different from 92 kg N ha^{-1} (41.3 g).

The result also revealed significant differences (P < 0.05) among the varieties. Improved variety Bekelcha gave the highest TKW (46.6g) while the lowest was recorded by local variety Ingliz(42.9g). Toltu and Dire were statistically identical for TKW.

A significant difference (P < 0.05) in the HLW was observed among the varieties. The highest HLW was obtained from the variety Toltu (82.3 kg hl^{-1}) in statistical parity with Dire(81.95 kg hl^{-1}). Dire and Bekelcha were statistically identical for HLW. The lowest HLW was recorded by Local variety Ingliz(81.02 kg hl^{-1}). According to this study all varieties had HLW> 81 kg hl^{-1} which most millers demand as standard for semolina milling (Sission, 2004). In general,HLW was ranged from 81.02-82.3 kg hl^{-1} for the varieties under this study. According to Atwell (2001) hectoliter weight may range from about 57.9 kg hl-1 for a poor wheat to about 82.4 kg hl-1 for a sound wheat.

Table 4
Mean value of TKW and HLW of durum wheat varieties grown under different N rates.

	N kg ha^{-1}											
	TKW (g)						HLW (kg hl^{-1})					
Variety	**46**	**92**	**138**	**184**	**230**	**Mean**	**46**	**92**	**138**	**184**	**230**	**Mean**
Toltu	41.0	42.6	45.5	45.0	45.2	43.9b	81.7	82.7	82.5	82.4	82.4	82.3a
Dire	40.5	44.1	45.2	45.5	44.9	44.1b	81.4	82.1	82.2	82.1	82.0	82ab
Bekelcha	43.6	46.3	48.1	47.3	47.6	46.6a	80.8	81.9	82.0	81.8	82.3	81.7b
Ingliz	40.3	42.6	43.5	44.0	44.0	42.9c	80.3	81	81.3	81.3	81.3	81.0c
Mean	41.3c	43.9b	45.6a	45.5a	45.5a		81.1	81.9	82.0	81.9	82.0	
CV (%)			6.9						2.9			
LSD(0.05)												
V			0.78						0.59			
N			0.87						NS			
VxN			NS						NS			

3.6. Grain protein content

Results showed significant differences (P < 0.05) among nitrogen rate treatments and varieties for grain protein content while the effect of interaction between various nitrogen rate application and varieties was non significant (Table 4).

The highest grain protein content (14.6%) was recorded for the highest nitrogen rate (230 kg N ha-1). The highest nitrogen rate resulted in 16% more grain protein content than the lowest treatment. Kirrilov and Pavlov (1989) also reported that applied nitrogen increased wheat grain protein content by 20.29 %. In general this finding was in line with Efrem et al. (2000) who reported that protein content of Ethiopian improved durum wheat cultivars released between 1966 and 1996 had ranged between 10.2% to 15.4 % using the whole mill flour. The cultivars differed significantly with respect to protein content. Grain protein content of the cultivars ranged from 12.5% (Ingliz) to 14.1% (Bekelchaa) (Table 5).

Grain protein contents of improved varieties Bekelcha, Toltu and Dire were significantly higher than the local cultivar Ingliz. This variation in grain protein content of the cultivars may be attributed to their variation in nutrient uptake and translocation capacities to the sink.

3.7. Economic analysis

The economic analysis was based on the procedures by CIMMYT (CIMMYT, 1988). Partial budget and marginal analysis were performed for nitrogen fertilizer rate and the decision for selecting the profitable treatment was made based on the highest marginal rate of return (Table 5). The Marginal analysis indicated that changing from the first treatment (46 kg N ha^{-1}) to the second treatment (92 kg N ha^{-1}) has resulted the highest marginal rate of return (212%), which means that investing 1 birr in treatment number two acquire a return of 2.12 birr. There for, the best nitrogen rate for durum wheat productivity and profitability in the high lands of bale is 92 kg N ha^{-1}.

Table 5

Mean value of grain protein content of durum wheat varieties grown under different N rates.

Grain protein content (%)						
	N kg ha^{-1}					
Variety	**46**	**92**	**138**	**184**	**230**	**Mean**
Toltu	13.0	13.8	14.5	14.4	15.3	14.2b
Dire	12.9	13.4	14.2	14.7	15.4	14.1b
Bekelcha	13.3	13.6	14.6	15.6	15.8	14.6a
Ingliz	12.1	12.7	12.9	13.5	13.7	12.9c
Mean	12.8e	13.4d	14.1c	14.5b	15.1a	
CV (%)			6.1			
LSD(0.05)						
V			0..22			
N			0.24			
VxN			NS			

Table 6

Partial budget analysis result for nitrogen rate study on durum wheat varieties.

	Treatments (Nitrogen kg ha^{-1})				
	46	**92**	**138**	**184**	**230**
Average yield(kg/ha)	3815	4370	4519	4439	4536
Adjusted yield(kg/ha)	3434	3933	4067	3995	4082
Gross field benefits(Birr/ha)	46359	53096	54905	53933	55107
Cost of Nitrogen(Birr/ha)	1500	2999	4499	5998	7498
Cost of labour to apply Nitrogen (Birr/ha)	35	70	105	140	175
Harvesting, packing and transportation (Birr/ha)	3949	4523	4678	4594	4694
Total costs that vary(Birr/ha)	5484	7592	9282	10732	12367
Net benefits (Birr/ha)	40875	45504	45623	43201	42740
MRR%		212	7		

Cost of urea 1500 Birr 100 kg^{-1}or (32.60 Birr kg^{-1} N); urea application of 46 kg N ha^{-1} one person@ 35 Birr/ person/day; 92 kg N ha^{-1} two person@ 35 Birr/ person/day; 138 three person @ 35 Birr / person/day; 184 four person@ 35 Birr / person/day; and 230 kg N ha^{-1} 5 person @ 20 Birr/ person/day; harvesting, packing and transportation 115 Birr per 100 kg; sale price of wheat grain 1350 Birr per 100 kg.

4. Conclusion and Recommendations

An experiment was conducted with the objectives of assessing the effect of nitrogen fertilizer rates on grain yield, yield components and grain protein accumulation of durum wheat varieties, in a treatment of factorial combinations of four cultivars (Toltu, Dire, Bekelcha and Ingliz) and five nitrogen application rates (46,92,138,184 and 230 kg N ha^{-1}) in RCB design with three replications. The results of the experiment revealed that nitrogen fertilizer application significantly influenced durum wheat agronomic traits and grain quality attributes.

Therefore, from the results of three years' data over locations, it was observed that *92 kg N ha^{-1}* was the most promising and economically feasible nitrogen rate for recently released durum wheat varieties in the highlands of bale. The results also imply that there is a need to formulate variety-specific fertilizer recommendation rates for enhancing the productivity and grain quality of durum wheat for pasta/macaroni making.

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