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Sorghum (*Sorghum bicolor* L.) Growth, Productivity, Nitrogen Removal, N- Use Efficiencies and Economics in Relation to Genotypes and Nitrogen Nutrition in Kellem- Wollega Zone of Ethiopia, East Africa

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Abstract

Sorghum is an important cereal crop, which requires high dose of nitrogen for optimum growth and productivity, specially under rainfed farming situation in tropical regions. Field experiment was conducted at Haro Sabu Agricultural Research Center during main cropping season of 2014 with an objective to investigate Nitrogen Use Efficiency (NUE) of two improved and a local sorghum cultivar in relation to graded rates of N levels and to investigate their effect on yield, N uptake and economics. The treatments comprised factorial combination of four nitrogen rates (0, 46, 92 and 138 kg N ha^{-1}) and three sorghum genotypes (Lalo, Chemada and Local varieties) tested in a Factorial Randomized Block Design with three replications. The results revealed that there was significant effect of N rates on days to 50% flowering, days to 50% physiological maturity, Lodging percentage, leaf area at 90 and 120 DAS, leaf area index, number of green leaves plant^{-1}, biological yield, grain yield, harvest index and nitrogen use efficiency. There was significant interaction effect of N rates and sorghum genotypes on most of parameters studied. Significantly higher grain productivity was obtained in response to the application of 92 kg N ha with Lalo variety in comparison with the rest of the genotype × N-rate combinations. Genotypic variations in N uptake, partitioning and NUE in plant parts like leaves, stems and grain were noted. Increase in the rate of applied N enhanced N uptake, nitrogen utilization efficiency, and N harvest index; while higher rates decreased N use efficiency, N uptake efficiency, N recovery efficiency, and Agronomic efficiency. Economic analysis indicated higher net return with the application of 92 kg N ha^{-1} and Lalo genotype accrued the highest net return and benefit: cost ratio than Local variety.

Keywords: Productivity; Nitrogen rates; Nitrogen uptake; Partitioning; Nitrogen use efficiency; Sorghum genotypes

Introduction

Sorghum (*Sorghum bicolor* L.) is a drought tolerant and nutritious cereal crop usually cultivated for food, feed and fodder by subsistence farmers in Ethiopia. Elsewhere in the world, especially in semi- arid tropical (SAT) regions, where the production is constrained by low and erratic rainfall and low soil fertility, it is grown and consumed as staple food and is also used in the production of a variety of by-products like alcohol, edible oil, confectionary items and sugar. Cereals are the major food crops in Ethiopia, both in terms of the coverage and volume of production [1]. Sorghum is the fifth most important cereal crop worldwide. In the year 2005, sorghum was grown worldwide on 43,727,353 ha with an output of 58,884,425 metric tons [2]. Out of the total grain crop production area, 79.46% (8.1 million hectares) was under cereals. In Ethiopia Tef, maize, sorghum and wheat were raised on 22.08% (2.2 million hectares), 15.00% (1.5 million hectares), 14.43% (nearly 1.5 million hectares) and 14.35% (nearly 1.5 million hectares) of the grain crop area, respectively [1]. Cereals contributed 86.86% (more than 116.2 million quintals) of the grain production. Maize, wheat, Tef and sorghum made up 24.93% (33.4 million quintals), 16.58% (22.2 million quintals), 16.26% (21.8 million quintals) and 16.24% (21.7 million quintals) of the grain production in the same order and the Ethiopian national average yield was 14.81 q/ha [1].

Among the macro nutrients essential for crop growth, nitrogen (N) is a very mobile element in the soil, due to its susceptibility to leaching, de nitrification, and volatilization losses. Excessive use of N fertilizer can lead to pollution of water bodies and may lead to soil acidification. Balanced and efficient use of applied N is of paramount importance in the overall nutrient management system than any other plant nutrient in order to reduce its negative impact on the environment. Besides, even under the best management practices, 30%-50% of the applied nitrogen is lost through different routes [3], and hence more fertilizer needs to be applied than actually needed by the crop to compensate for the loss. The transitory loss of N not only causes loss to the farmer but also causes irreversible damage to the environment [4,5]. High rates of chemical fertilizer cause environmental pollution [6]. Increased rate of N application was reported to delay flowering, physiological maturity, and increased crop lodging across genotypes in sorghum. Thus, it warrants for a need to optimize the level of N fertilizer to be applied, with special reference to cereals like sorghum. The substantial increase in fertilizer prices many fold over the recent decade dictates that farmers need to use high nitrogen use efficient (NUE) sorghum varieties to reduce the cost incurred on N fertilizer as a major nutrient input under rain fed situations. The use of N efficient sorghum cultivars increased the production of sorghum -based cropping system in West Africa, and similar trend may be witnessed once N efficient sorghum cultivars are identified for Ethiopian conditions.

Differences exist both between and within species in terms of efficient use of mineral nutrients for growth and development. Hybrids that can exhibit superior yields at low N rates are necessary. While some genotypes are capable of performing well under nutrient stress

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conditions, others performed poorly. Genotypic differences for nutrient use, especially NUE have been recognized in many crops including sorghum. However, the mechanisms that explain how these genotypes are able to satisfy all their biosynthetic and maintenance needs, with smaller amount of nutrient than required by other genotypes is still not well studied [7]. The objectives of this study were to find out the effect of varied N rates on the productivity of sorghum genotypes; to determine the N removal of genotypes; to delineate the N use efficiency of genotypes and to compute the relative economics of genotypes and N fertilizer application in sorghum production.

Materials and Methods

Description of experimental site

The current field investigation was conducted at Kellem-Wollega zone of Ethiopia to determine the effect of graded nitrogen rates and genotypes on growth, productivity, N removal, nitrogen use efficiency and their relative economics in sorghum during the main cropping season of 2014 at Haro Sabu Agricultural Research Center (HSARC). The center is located in western Ethiopia, Oromia regional state at a distance of 550 km west of Addis Ababa. It lies at a latitude of 8° 52°51" N, longitude 35°13'18 "E and altitude of 1515 m above sea level. The center has a warm humid climate with average minimum and maximum temperature of 14°C and 30°C, respectively. The area received an average annual rainfall of 1000 mm with a uni- modal distribution pattern, most of the rain being received from April to October. The soil type of the experimental site is reddish brown, with a pH of 5.53. The area is mainly characterized by coffee- based and crop+livestock mixed farming system comprising non legumes like Coffee, maize, sorghum, finger millet; legumes such as haricot bean, soybean, besides sesame, banana, mango and sweet potato.

Description of the experimental materials

Plant materials: In the present study, Sorghum varieties Lalo and Chemada and a Local variety, which is adapted to the agro-ecology of the area, were used. Varieties Lalo and Chemada are the most promising hybrids released by Bako Agricultural Research Centre in 2006 and 2013, respectively. Both the genotypes have wider adaptability and grow well at altitudes ranging from 1500 to 1900 meters above sea level with annual rain fall of 1100 to 1200 mm. The cultivars mature in about 199 and 180 days, the seed colors are brownish-red and creamy for Lalo and Chemada, respectively. The potential yield of Lalo was 48 q/ ha^{-1} at research farm and 35 q ha^{-1} at farmer's field, and the yield of Chemada was 32 q ha^{-1} at research farm and 25 q ha^{-1} at farmer's field.

Experimental design and plot management: The experimental field was ploughed and harrowed by a tractor to get a fine seedbed and leveled manually before the field layout was made. Sowing was done on June 7, 2014 and the seeds were sown at a spacing of 75 cm between rows and 15 cm between plants. The nitrogen fertilizer source used was urea (46% N) which was applied by drilling in two splits, half at 14 days after emergence and the remaining half at knee high stage along the rows of each plot to ensure that N is uniformly distributed. The treatments comprising factorial combination of three varieties (Lalo, Chemada and Local) and four N rates (0, 46, 92 and 138 kg N ha^{-1}) were arranged in a Randomized Block Design with three replications. The plot size was 3 m long and 4.5 m wide that could accommodate 6 rows. The four rows in the net plot were set aside for data collection to eliminate any border effects. Phosphorus fertilizer in the form of triple super phosphate (TSP) at the recommended rate of 100 kg P_20_5 ha^{-1} was uniformly applied to all plots by drilling in the rows at the time of sowing. Weeds were managed by hand weeding after weed emergence and late-emerging weeds were also removed by hand hoeing to avoid competition with the sorghum plants for the N applied. Sorghum plants in the l net plot area (9 m^2) were harvested at normal physiological maturity. The ear heads in each plot were harvested manually and were separately threshed.

Soil sampling and analysis: Soil samples were collected prior to planting from a depth of 0-30 cm in a zigzag pattern randomly from the experimental field using soil auger. Composite samples were prepared for analysis to determine the soil physico-chemical properties of the experimental site at Nekemte zonal Soil Laboratory. The composited soil samples were air-dried, ground and sieved to pass through a 2 mm sieve. Total nitrogen was determined following Kjeldahl procedure [8], the soil pH (in water suspension) by a digital pH meter [9], organic carbon by wet digestion method [10], available phosphorous by Olsen method [11], Cation exchange capacity (CEC) by ammonium acetate method [8], and soil texture by Bouyoucons Hydrometer method [12].

Crop data collection

Phonological data: The days to 50% flowering was taken as the time from the date of planting until half of the plant populations in the plot started to flower. The days to 90% physiological maturity was taken as the time from date of planting until 90% of the plant leaves turned yellow and the lower most head started drying.

Crop growth parameters: The total leaf area was recorded at 60, 90 and 120 DAS, and determined by multiplying leaf length and maximum width of leaf adjusted by a correction factor of 0.75 as suggested by McKee. Number of leaves was counted from randomly selected five pre-tagged plants after plant emergence and their average was taken as the number of leaves plant^{-1}. The Leaf Area Index (LAI) was calculated from five randomly selected plants by dividing the leaf area by its respective ground area at 120 DAS. The sorghum height of five randomly selected pre-tagged plants (cm) was measured at 60, 90 and 120 DAS from the ground level up to the head/tip of the plant.

Yield and yield components: Five pre-tagged randomly selected plants were considered for determination of above ground dry biomass weight by drying in sunlight for ten days till a constant dry weight was attained. Lodging was recorded at the time of harvest from four net plot rows, and thousand seeds of sorghum was counted and weighed (g) using sensitive balance from the bulk of the seeds of sorghum and adjusted to 13.5% moisture level. Number of panicles/plant was also recorded from five pre-tagged randomly selected plants. Number of effective tillers / plant was counted at physiological maturity. Grain yield (q/ha) was recorded after harvesting from the central four rows of the net plot of 3 m × 3 m=9 m^2. Seed yield was adjusted to 13.5% moisture using moisture tester (Dickey-john) and converted to quintal ha^{-1} for statistical analysis.

Adjusted yield=Actual yield × 100-M/100-D;

where M, is the measured moisture content in grain and D is the designated moisture content (13.5%).

D is the designated moisture

Harvest index was calculated as: HI (%)=Sy/by × 100;

where HI is harvest index, SY is seed yield and BY is above ground dry biological yield.

Nitrogen use efficiency and components of N use computations

Above ground portion of plants from each plot was randomly sampled at physiological maturity as described by Vanderlip [13]. At each sampling, the leaves were separated from the stems. In addition, heads and the above ground vegetative parts were dried at 60°C in a forced air oven for 72 h. to a constant weight. The oven dry samples were ground using rotor mill and allowed to pass through a 0.5 mm sieve to prepare a sample of 10 g. The straw and grain samples were analyzed for N concentrations from each plot separately using Kjeldahl method as described by Jackson [14]. Nitrogen uptake in grain and straw were calculated by multiplying N content with the respective straw and grain yield ha^{-1}. Total N uptake, by whole biomass was obtained by summing up the N uptake by grain and straw and was expressed as kg ha^{-1}. Total N content in straw and grain samples was determined using Micro Kjeldahl's apparatus and was used to calculate N use efficiency according to Moll et al. [15] and Ortiz-Monasterio et al. [16]. The different efficiencies of nitrogen were arrived at employing the following formulae:

Nitrogen Use Efficient (NUE) (Kg Kg^{-1})=Grain weight/N supplied

Nitrogen Utilization Efficient (NUTE) (Kg Kg^{-1})=Grain weight/N total in plant

Nitrogen Uptake Efficient (NUPE) (Kg Kg^{-1})=N total in plant / N supplied

Percent N Recovery=[N uptake (fertilized plot)-N uptake (un-fertilized plot)] / [N applied] × 100

Nitrogen Harvest index (%)=Grain N content/N total in plant

N uptake of grain=N concentration of grain × grain yield (kg ha^{-1})/100

N uptake of Straw=N concentration of Straw × Straw yield (kg ha^{-1})/100

AE=[Grain yield of fertilized treatment (kg ha^{-1}) - Grain yield of unfertilized plot (kg ha^{-1})] / [Fertilizer applied (Kg/ha)

Where N supplied is the fertilizer N applied+N supplied in the soil, AE=Agronomic efficiency.

Economic analysis

Economic analysis was made following CIMMYT methodology [17]. The cost of 100 kg urea (1087 birr), 100 kg TSP (1415 birr), dry biomass in ton ha^{-1} (200 birr) and sorghum grain price of 450 birr per 100 kg were used for the benefit: cost analysis. The analysis of data in relation to different factors of production under test viz; genotypes and N fertilizer rates were computed in terms of: 1. Gross return (Birr ha^{-1}) from total economic produce and by products obtained from the crops included in the cropping system are calculated based on the local market prices at harvest, 2. Net return (Birr ha^{-1})=(Gross return – Cost of Production), 3. Cost of Production (Birr ha^{-1}), 4. Benefit: Cost ratio (Gross return/Cost of Production), 5. Per day Productivity (kg ha^{-1}), (Grain Yield/Crop duration), 6. Return/Birr Investment (Net return/ Production Cost) were determined.

Statistical analysis

All data collected were subjected to the analysis of variance (ANOVA) using SAS [18] version 9.1. Where treatment means are significant, the Tukey test at alpha=5% was adopted for mean comparison.

The model for randomized complete block design is:-

$y_{ij}=\mu+\tau_i+\beta_j+\varepsilon_{ij}$

Where:

y_{ij}=An observation in treatment i, and block j

μ=the overall mean

τ_i=the effect of treatment i

β_j=the fixed effect of block j

ε_{ij}=random error

Results and Discussion

Physicochemical properties of the soil

The results of soil analysis showed that the soil had a moderate total nitrogen content of 0.24 (%). According to Tekaligne et al. [19] soil total N availability of less than 0.05% was considered as very low, 0.05-0.12% as poor, 0.12-0.25% as moderate and more than 0.25% as high. The soil has organic matter of 5.0% which was considered as medium. According to Berhanu [20], soil organic matter content of less than 0.8% is considered as very low, 0.8-2.6 as low, 2.6-5.2% as medium and more than 5.2% as high. Thus, the soil available P content of experimental sites was 6.28 ppm, and according to Tekalign et al. [19] soils with available P <10, 11-31, 32-56, >56 ppm as low, medium, high and very high, respectively. The average CEC of the soil was 23 Cmol (+)/kg, which is rated as medium. The soil cation exchange capacity describes the potential fertility of soils and is an indicator of the soil texture, organic matter content and the dominant types of clay minerals present. In general, soils high in CEC contents are considered as agriculturally fertile. According to Landon, top soils having CEC greater than 40 Cmol (+)/kg are rated as very high and 25-40 Cmol (+)/kg as high, 15-25, 5-15 and <5 Cmol (+)/kg of soil are classified as medium, low and very low, respectively. The analytical results also indicated that the textural class of the experimental site was clay loam with a proportion of 37% sand, 25% clay and 38% silt. Thus, the textural class of the experimental soil is ideal for sorghum production and the soil reaction (pH) of the experimental site was 5.53 showing moderate acidity, but it is within the optimum range for sorghum production, i.e., 5.5 -7.0 [21].

Effect of nitrogen fertilizer rates on growth of sorghum genotypes

Plant height: Nitrogen application rates significantly influenced plant height at 90 DAS, but the effect was not significant at 60 DAS and 120 DAS. Sorghum genotypes differed significantly in plant height (Table 1) at various growth stages. Plant height increased linearly and significantly with the increase in the rate of nitrogen application from 0 through 138 kg N ha^{-1}. The increase in plant height following increased

Treatment	Plant height (cm)		
Nitrogen (N) rates	60DAS	90DAS	120DAS
0 kg N ha^{-1}	34.54b	146.82b	263.33b
46 kg N ha^{-1}	39.39ba	165.77b	275.30ba
92 kg N ha^{-1}	40.72ba	196.30a	284.88a
138 kg N ha^{-1}	41.60a	204.99a	290.90a
Sorghum varieties			
Lalo	43.86a	227.42a	299.73a
Local	38.74ba	158.01b	276.54b
Chemada	34.59b	149.98b	259.53b
CV%	18.06	11.92	7.88

DAS=Days after sowing

Table 1: Effect of nitrogen rates on plant height at different growth stages of sorghum genotypes.

N application rate indicates maximum vegetative growth of the plants under higher N availability. These results are in agreement with the results obtained by Akbar et al. [22] found that plant height in maize increased with increase in N rate. However, in contrast to the results of this study, Sadeghi and Bahrani [23] reported that increase in N rate had no significant effect on plant height. The variance in the results obtained in this study and that of Sadeghi and Bahrani [23] might be due to the difference in the range of population stand, soil fertility status, and the crop varieties used.

Number of green leaves plant^{-1}: The graded nitrogen rates did not significantly influence green leaves /plant, whereas sorghum genotypes significantly differed in the number of green leaves per plant. There was a significant interaction effect of nitrogen rates and sorghum genotypes on the number of green leaves per plant (Table 2). The highest number of green leaves (14.0) was recorded with the application of 46 kgN ha^{-1} with Local variety, while the lowest (10.67) was recorded with 92 kg N/ha in Lalo variety.

Number of effective tillers: The number of effective tillers significantly varied with sorghum genotypes, but not with the nitrogen fertilizer rates. The number of effective tillers was significantly greater (2.18) with Local variety followed by Lalo variety (1.2) (Table 3). The current result is in agreement with that of Botella et al. [24] reported that stimulation of tillers with high application rate of nitrogen might be due to its positive effect on cytokinin synthesis. In the present study the tillers tended to increase with enhanced N rates. Genene [25] also reported higher tillers and maximum survival percentage of tillers with increasing N application in bread wheat.

Table 3 indicates effect of nitrogen rates on number of effective tillers plant^{-1}, leaf area at 60 DAS, thousand seed weight (g) and panicle number per plant of sorghum genotypes.

Total leaf area: There was significant effect of nitrogen rates on leaf area at 90 DAS, but not at 60 and 120 DAS. Sorghum genotypes also significantly differed in leaf area at 60 DAS (Table 3) and 90 DAS, but the variations were nullified at 120 DAS. However, there was significant interaction effect of sorghum genotypes and nitrogen fertilizer rates on leaf area at 90 and 120 DAS. At 90DAS, the highest total leaf area per plant of 3193.3 cm^2 was obtained in Lalo variety with 46 kg N ha^{-1} while the lowest leaf area per plant of 1955.9 cm^2 was obtained in variety Chemada with 138 kgN/ha (Table 4). At 120 DAS, the highest total leaf area per plant of 3694 cm^2 was obtained from variety Lalo with 132 kgN/ha, and the lowest leaf area per plant of 2631.9 cm^2 was obtained in variety Lalo with 92 kgN/ha (Table 5). The increasing nitrogen fertilizer rates did not result in increment of leaf area at all stages of growth as observed in this study. The result of the current study is in variance with the findings of Demir et al. [26] reported that leaf area increased with increasing N levels.

Leaf Area Index (LAI): There was no main factor effect of nitrogen fertilizer rates and sorghum genotypes on leaf area index (Table 6). However, nitrogen rates and sorghum genotypes significantly interacted to influence this parameter. The highest LAI for Lalo (3.28 cm^2) was recorded with the application of 138 kg N ha^{-1}, while the lowest (2.15 cm^2) was recorded from variety Chemada with no N application. Generally, an increasing trend in LAI was observed with increased N application rates. The increase in LAI was possibly due to the improved leaf expansion in plants through application of optimum nitrogenous fertilizers. Similar to this finding, Haghighi et al. [27] reported an increasing trend in LAI in maize due to an increase in N fertilizer application rates.

Nitrogen rates	Sorghum varieties			Mean
	Lalo	Local	Chemada	
0 kg N ha^{-1}	11.67bdc	14.00a	13.67a	13.11
46 kg N ha^{-1}	11.33dc	14.00a	12.67bac	12.67
92 kg N ha^{-1}	10.67d	13.67a	14.00a	12.78
138 kg N ha^{-1}	12.00bdc	13.00ba	11.33dc	12.11
Mean	11.42	13.67	12.92	12.67
CV%	7.33			

Table 2: Interaction of nitrogen rates and sorghum genotypes^{-1} on number of green leaves/ plant.

Treatment Nitrogen rates	Number of effective tillers per plant	Leaf area(cm^2) 60DAS	Thousand seed weight(g)	Panicle number per plant
0 kg N ha^{-1}	1.36a	884.8a	26.07ba	59.67a
46 kg N ha^{-1}	1.47a	1028.5a	24.17c	61.11a
92 kg N ha^{-1}	1.54a	1092.5a	26.57a	62.89a
138 kg N ha^{-1}	1.51a	1054.5a	24.53bc	59.00a
Sorghum varieties				
Lalo	1.20b	1192.8a	32.25a	72.67a
Local	2.18a	1005.4ba	22.52b	59.25b
Chemada	1.03b	847.0b	21.24b	50.08c
CV%	22.46	25.31	3.41	9.4

Table 3: Effect of nitrogen rates on number of effective tillers plant^{-1}, leaf area at 60 DAS, thousand seed weight (g) and panicle number per plant of sorghum genotypes.

Nitrogen rates	Sorghum varieties			Mean
	Lalo	Local	Chemada	
0 kg N ha^{-1}	2869.4ba	2485.1bc	2376.1dc	2576.89
46 kg N ha^{-1}	3193.8a	2715.3bac	2361.5dc	2756.87
92 kg N ha^{-1}	2521.0bc	2728.3bac	2805.0bac	2684.77
138 kg N ha^{-1}	2799.0bac	2338.9dc	1955.9d	2364.6
Mean	2845.8	2566.9	2374.63	2595.78
CV%	11.27			

Table 4: Interaction effect of nitrogen rates on Leaf area (cm^2) at 90 DAS of sorghum genotypes.

Nitrogen rates	Sorghum varieties			Mean
	Lalo	Local	Chemada	
0 kg N ha^{-1}	3229.8ba	3169.2bac	3204.5ba	3201.17
46 kg N ha^{-1}	3092.7bc	2813.6bc	2814.2bc	2906.83
92 kg N ha^{-1}	2631.9c	2859.3bc	3229.0ba	2906.73
138 kg N ha^{-1}	3694.9a	2950.8bc	2638.2c	3094.63
Mean	3162.33	2948.23	2971.48	3027.34
CV%	10.89			

Table 5: Interaction effect of nitrogen rates on Leaf area (cm^2) at 120 DAS of sorghum genotypes.

Nitrogen rates	Sorghum varieties			Mean
	Lalo	Local	Chemada	
0 kg N ha^{-1}	2.87ba	2.82bac	2.15ba	2.85
46 kg N ha^{-1}	2.75bc	2.50bc	2.50bc	2.58
92 kg N ha^{-1}	2.34c	2.54bc	2.87ba	2.58
138 kg N ha^{-1}	3.28a	2.62bc	2.38bc	2.76
Mean	2.81	2.62	2.65	2.69
CV%	10.88			

Table 6: Interaction effect nitrogen rates and sorghum genotypes on Leaf area index.

Effects of nitrogen on yield and yield components

Biological yield: The results of the analysis of variance showed that biological yield (BY) of sorghum genotypes was not significantly influenced by the effect of nitrogen rates. However, there was significant interaction effect of nitrogen rates and sorghum genotypes on this parameter (Table 7). Biological yield (BY) is a function of photosynthetic rate and proportion of the assimilatory surface area. The increase in biological yield with increase in rate of N might be due to better crop growth rate, LAI and accumulation of photo assimilate due to maximum days to maturity by the crop, which ultimately produced more biological yield. Biomass yield generally increased significantly with the increase in the rate of nitrogen across the increasing frequency of application. The variety Lalo recorded the highest biomass yield (23443 g plot^{-1}) with the application of 92 kg N ha^{-1} and the lowest biomass yield was obtained from variety Chemada (1793 g plot^{-1}) with the application of 138 kg N ha^{-1}. The application of the highest level of N resulted in less biomass yield compared to 92 kg N ha^{-1}**.** This result however, is not in agreement with that of Haftom et al. [28].

Thousand seed weight: It is an important yield determining component and reported to be a genetic trait that is influenced least by environmental factors [29]. The analysis of variance showed that the main effect of both nitrogen rates on thousand seed weight and that of sorghum genotypes was significant. The highest 1000 seed weight (32.25 g) was obtained from variety Lalo followed by variety Local (22.52 g). However, the lowest 1000 seed weight (21.24 g) was obtained from the Chemada. On the other hand, the highest 1000 seed weight was observed with 92 kg N ha^{-1} and the lowest 1000 seed weight with 46 kg N ha^{-1} and 138 kg N ha^{-1} (Table 3). Contrary to the finding of this study; Melesse [30] reported no significant effect of the application of different rates of nitrogen fertilizer on 1000 kernel weight of bread wheat.

Panicle number/plant: Panicle number per plant is an important yield attributes of sorghum that contributes to grain yield. Crops with higher panicle number could have higher grain yield. Panicle number was significantly influenced by the main effect of the sorghum genotypes but not by the main effect of nitrogen rates as well as the interaction of the two factors (Table 3). Among the genotypes, Lalo had significantly greater number of panicles /plant than Local variety and Chemada.

Grain yield: The results showed that the sorghum grain yield was significantly influenced by the nitrogen rates, sorghum varieties and their interaction (Table 8). The highest grain yield was recorded in the variety Lalo with the application of 92 kg N ha^{-1} (47.72 q ha^{-1}) and the lowest grain yield was recorded by variety Chemada with no nitrogen application (24.27 q ha^{-1}). Thus Lalo and Local varieties showed response up to 92 kgN/ha, whereas Chemada responded up to 42 kgN/ha. The results of this study are consistent with result of Sage and Pearcy who reported that a well-balanced supply of N results in higher net assimilation rate and increased grain yield as also found by Al-Abdulsalam [31]. Corroborating the results of this study, Blankenau et al. [32] stated that proper rate and time of N application are critical for meeting crop needs, and considerable opportunities exist for yield improvement.

Nitrogen rates	Sorghum varieties			Mean
	Lalo	Local	Chemada	
0 kg N ha^{-1}	20459a	20131ba	22123a	20904.33
46 kg N ha^{-1}	21046a	20529a	20100ba	20558.33
92 kg N ha^{-1}	23443a	21784ba	21087a	22104.67
138 kg N ha^{-1}	21099ba	20237a	17934b	19756.67
Mean	21511.75	20670.25	20311	20831
CV%		10.01		

Table 7: Interaction effect of nitrogen rates and sorghum genotypes on biological yield plot^{-1} (g).

Nitrogen rates	Sorghum varieties			Mean
	Lalo	Local	Chemada	
0 kg N ha^{-1}	41.63	40.16	24.27	35.35
46 kg N ha^{-1}	45.97	41.10	31.54	39.54
92 kg N ha^{-1}	47.72	45.27	30.83	41.27
138 kg N ha^{-1}	41.87	41.08	28.93	37.29
Mean	44.3	41.9	28.89	38.36
LSD (0.05)		2.82		
CV%		4.13		

Table 8: Interaction effect of nitrogen rates on grain yield hectare^{-1} (quintal) of sorghum genotypes.

Nitrogen rates	Sorghum varieties			Mean
	Lalo	Local	Chemada	
0 kg N ha^{-1}	20.64a	17.11 cb	10.24f	15.99
46 kg N ha^{-1}	21.02a	18.12 cd	12.29ef	17.14
92 kg N ha^{-1}	22.0a	19.63ab	13.38f	18.34
138 kg N ha^{-1}	21.3a	18.97 ed	12.85e	17.71
Mean	21.24	18.46	12.19	17.3
CV%		8.54		

Table 9: Interaction effect of nitrogen rates on harvest index of sorghum genotypes.

Harvest index (HI): The physiological efficiency or translocation of assimilates from source into economic sinks is known as harvest index (HI). The effect of nitrogen rates on harvest index was not significant, but the sorghum varieties differed significantly in harvest index. The interaction effect of nitrogen rates and sorghum cultivar on harvest index was highly significant (Table 9). Lawrence [33] reported that harvest index in maize increases when nitrogen rates increased. In the present experiment, with the increase in the rate of nitrogen application, harvest index increased significantly upto 92 kgN/ha. This indicates significantly lower biomass partitioning to grain production when N was increased beyond certain level. The lower mean HI values in this experiment with the higher N application might indicate the need for the enhancement of biomass partitioning through genetic improvement. In tandem with the results of this study, Abdo [34] reported highest harvest index from treatments with the lowest rate of nitrogen application. Among the test genotypes, Lalo had greater HI followed by Local and Chemada indicating genotypic variations in partitioning efficiency.

Nitrogen uptake and nitrogen use efficiency partitioning of sorghum genotypes

The current study revealed differential quantities of nitrogen partitioned into different plant parts (grain, stem and leaves) (Figure 1). The removal of N in both grain and straw showed a distinct increasing trend with increase in N supply up to 92 kgN/ha, beyond which it showed a marginal increase (Table 10). In terms of Nitrogen use efficiency (NUE) Sorghum genotypes differed distinctly. Many studies have reported variation for NUE and components of NUE at high and low N inputs [35] as well as significant effect of genotype and N fertilization [36]. NUE and components of NUE were influenced by environments where soil test results show low residual N. Reduction in NUE with increasing N supply could result from reduction in N uptake

Parameter	Lalo variety				Local variety				Chemada variety			
	0 kg N ha^{-1}	**46 kg N ha^{-1}**	**92 kg N ha^{-1}**	**138 kg N ha^{-1}**	**0 kg N ha^{-1}**	**46 kg N ha^{-1}**	**92 kg N ha^{-1}**	**138 kg N ha^{-1}**	**0 kg N ha^{-1}**	**46 kg N ha^{-1}**	**92 kg N ha^{-1}**	**138 kg N ha^{-1}**
Nitrogen use efficiency (NUE) kg kg^{-1}	-	90.74	49.07	25.94	-	134.67	68.97	40.66	-	58.73	29.55	18.5
Nitrogen utilization efficiency (NUTE) in kg kg^{-1}	-	869.22	1010.82	695.69	-	1400.25	1691.18	1087.75	-	510.45	629.39	524.08
Nitrogen uptake efficiency (NUPE) kg kg^{-1}	-	0.104	0.05	0.037	-	0.096	0.041	0.037	-	0.12	0.047	0.035
Nitrogen uptake of grain kg ha^{-1}	23.61	77.72	94.48	93.46	67.78	98.43	105.71	107.63	15.45	52.57	41.87	58.27
Nitrogen uptake of straw kg ha^{-1}	179.84	735.95	521.64	1254.24	195.28	692.98	1061.31	759.79	198.62	633.15	713.13	516.1
Nitrogen harvest index (NHI)in %	0.29	0.39	0.47	0.51	0.25	0.36	0.44	0.37	0.29	0.37	0.36	0.49
Nitrogen recovery efficiency(NRE) %	-	117.63	79.21	50.62	-	66.63	41.23	28.88	-	80.43	28.72	31.03
Agronomic efficiency kg ha^{-1}	-	0.12	0.075	-0.26	-	0.05	0.024	-0.13	-	0.082	0.0067	-0.065

Table 10: Nitrogen up take and use efficiency and, N harvest index of sorghum genotypes as influenced by different N levels.

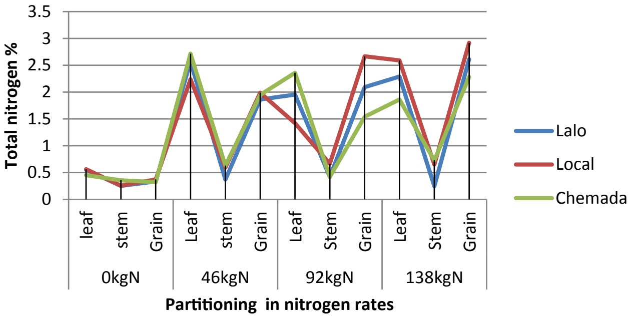

Figure 1: Nitrogen up take and partitioning in different plant parts (Leaf, stem and grain) of sorghum genotypes receiving different rates of nitrogen.

efficiency, N utilization efficiency and N retention efficiency. Nitrogen use efficiency is reported to be higher at lower N rates and decrease at higher N rates. This may indicate that plants are unable to absorb N when applied in excess quantities, because their absorption mechanism might have been saturated [37]. Under this condition, there exists the probability that more N will be subject to loss through ammonia gas, leaching or de-nitrification.

Among the genotypes, the Local variety tended to remove more N in both grain and straw than the improved genotypes Lalo and Chemada. This is in agreement with the findings of Nakamura et al. [38] reported that N absorption was regulated by root activities, higher and low–N conditions among grain sorghum genotypes. Greater N accumulation in the grain was associated with higher grain yields and NUE. Nutrient uptake by sorghum is influenced by several factors including nutrient availability, soil water availability, soil organic matter, soil chemical and physical properties, type of previous crop, plant population and the genotype. By and large, in the present study, with increase in the rate of N application there was an increase in the N removal in grain and straw, more N utilization efficiency, and greater N harvest index of sorghum genotypes, whereas, concomitantly there was a decrease in N use efficiency, N uptake efficiency, N recovery efficiency, and Agronomic efficiency (Table 10).

Nitrogen Use Efficiency (NUE): Irrespective of genotype, the NUE was maximum with 46 kgN/ha, and with every increase in N rate it decreased. Among the test genotypes, Local variety exhibited maximum NUE (134.6) followed by Lalo (90.7) and the least was with Chemada (58.7) at 46 kg N ha$^{-1.}$

Nitrogen utilization efficiency (NUTE): It increased with increased N rate up to 92 kg/ha, and there after it dwindled at high rate of N application. With respect to genotypes, the Local variety showed maximum NUTE at 9 kg N ha^{-1}(1691), followed by Lalo (1010) and Chemada (629).

Nitrogen uptake efficiency (NUPE): It decreased with every increment in the rate of applied N, and the maximum was obtained with 46 kg N ha^{-1} in all the genotypes. Among the genotypes, Chemada showed maximum efficiency (0.12) followed by Lalo (0.104) and Local variety (0.096).

Nitrogen harvest index (NHI): This parameter distinctly improved with every increment in N rate from 0 through 138 kgN/ha in all the test genotypes. The improved genotype Lalo possessed higher NHI at varied rates of applied N followed closely by Chemada, while the local variety had the least NHI.

Nitrogen recovery efficiency (NRE): It declined substantially with every increase in the rate of N applied from 46 kg N ha^{-1} to 138 kg/ha. Lalo revealed maximu NRE (117.6) followed by Chemada (80.40) and Lovcal variety (66.6) receiving 46 kg N ha$^{-1.}$

Agronomic efficiency (AE): With every increase in N application rate, the Agronomic efficiency showed diminishing trend similar to that of N uptake efficiency, and N recovery efficiency. With respect to genotypes, the improved genotype Lalo offered maximum agronomic efficiency (0.12 kg/ha) than Chemada (0.082 kg/ha) and Local variety (0.05 kg/ha) with application of 46 kg N ha^{-1}. Beyond 138 kg N ha^{-1}, the agronomic efficiency tended to be negative.

Economics of sorghum genotypes and N fertilizer

To assess the cost and benefit associated with different treatments, the partial budget technique of CIMMT was applied on yield and biomass results. Based on this technique, as clearly shown it was found that the Lalo variety with a net benefit of 13979.39 Birr ha^{-1} was found to be the most profitable (Table 11), particularly when grown with a rate of 92 kg N ha^{-1} (Table 12). The partial budget analysis also indicated that 92 kg N ha^{-1} resulted in maximum relative net return of 12434.54 Birr ha^{-1} followed by 46 kg N ha^{-1} with (12237.04) Birr ha^{-1} relative net return. The least relative net return was recorded with 138 kg N ha^{-1}.

Sorghum Varieties	Grain yield (Q ha^{-1})	Dry biomass yield of sorghum (t ha^{-1})	Gross return (Birr ha^{-1})	Cost of Production (Birr ha^{-1})	Net return (GR – PC) (Birr ha^{-1})	Benefit: cost ratio (GR/PC Eth. Birr	Per day Productivity (GY/ CD kg ha^{-1})	Return/Birr Investment (NR/PC) ETB	Total variable cost	Net return (Eth. Birr ha^{-1})
Lalo	44.3	23.74	22730	16750.61	5979.39	1.36	24.98	0.36	16750.61	13979.39
Local	41.6	24.12	31860	16750.61	15109.39	1.9	35.69	0.9	16750.61	12109.39
Chemada	29.14	23.98	16896.5	16750.61	145.89	1.01	15.73	0.01	16750.61	545.89

Table 11: Economic analysis of sorghum genotypes.

Nitrogen rates applied	Grain yield (Q ha^{-1})	Dry biomass yield of sorghum (t ha^{-1})	Gross return (Birr ha^{-1})	Cost of Production (Birr ha^{-1})	Net return (GR - PC Birr ha^{-1})	Benefit: cost ratio (GR/PC Birr)	Per day Productivity (GY/ CD kg ha^{-1})	Return/Birr Investment (NR/PC) ETB	Total variable cost	Net return (Birr ha^{-1})
0 kg N ha^{-1}	40.26	23.56	22829	10932.46	11896.54	2.08	25.4	1.09	10932.46	11896.54
46 kg N ha^{-1}	43.57	23.25	24256.5	12019.46	12237.04	2.02	26.42	1.02	12019.46	12237.04
92 kg N ha^{-1}	45.26	25.87	25541	13106.46	12434.54	1.95	26.57	0.95	13106.46	12434.54
138kg N ha^{-1}	39.15	22.99	22215.5	14193.46	8022.04	1.56	23.65	0.57	14193.46	8022.04

GR=Gross return; PC=Production cost; GY=Grain yield; CD=Crop duration; NR=Net return

Table 12: Economic analysis of N Fertilizer rates.

Conclusion

Sorghum genotypes investigated in the current study differed significantly in various growth, yield, and yield parameters, N use efficiency, N removal and economics. The maximum number of effective tillers (2.18) was recorded in response to nitrogen applied at the rate of 92 kg N ha^{-1} with the local variety followed by Lalo (1.2). The highest LAI was recorded with maximum application of N (138 kg N ha^{-1}) while Chemada variety scored the lowest LAI without fertilizer application. By and large, an increasing trend in LAI was observed with increased N application rates. Biological yield (BY) is a function of photosynthetic rate and proportion of the assimilatory surface area. The increase in biological yield with increase in rate of N might be due to better crop growth rate, LAI and accumulation of photo assimilate due to maximum days to maturity by the crop, which ultimately produced more biological yield. Biomass yield generally increased significantly with the increase in the rate of nitrogen. The Lalo variety recorded highest biomass yield when plants were supplied with 92 kg N ha$^{-1,}$ and the lowest biomass yield was scored by Chemada variety fertilized with 138 kg N ha^{-1}. The application of highest level of N resulted in less biomass yield compared to 92 kg N ha. This might be due to the effect of lodging resulted from too high amount of N fertilizer that encourage vegetative growth and height leading to lodging before the translocation of dry matter to economic yield. Thousand seed weight was significantly increased with increase in the rate of nitrogen application. Panicle number was significantly influenced by the sorghum genotypes but not by nitrogen rates and the interaction of the two factors as well.

Nitrogen rates and sorghum genotypes interacted on grain yield and harvest index, the highest grain yield was with variety Lalo fertilized with 92 kg N ha^{-1} and the lowest being Chemada variety with no N application. With increase in the rate of nitrogen application, harvest index decreased significantly. In the current study there is differential effect of nitrogen on partitioning of assimilates into grain, stem and leaves. NUE and components of NUE influenced environments where soil test results show low residual N. The results indicated that there was genotypic difference in N uptake in plant parts (leaves, stems and grain). By and large, in the present study, with increase in the rate of N application there was an increase in the N removal in grain and straw, more N utilization efficiency, and greater N harvest index of sorghum genotypes. Whereas, concomitantly there was a decrease in N use efficiency, N uptake efficiency, N recovery efficiency, and Agronomic efficiency. The economic analysis showed that variety Lalo with more net return was found to be the most profitable compared to the local variety. The partial budget analysis indicated that 92 kg N ha^{-1} resulted in maximum relative net return followed by 46 kg N ha^{-1}. Based on the genotypic difference in N uptake, partitioning and NUE in plant parts (leaves, stems and grain), and general performance of sorghum, the application of N fertilizer at the rate of 92 kg N ha^{-1} is suggested. Though these findings are zonal –specific, they can be applicable to similar agro-eco zones of Ethiopia [39]. The variables that can potentially affect these findings can be biotic and abiotic factors like rain fall, temperature, and soil which determines the moisture holding capacity and nutrient supply under rain fed farming system. In the years to come, research on sorghum should focus on relative drought tolerance of genotypes, sorghum–based cropping systems, and response to K, Ca, S and micro nutrients to alleviate soil health problems and sustainable production.

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