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Response of Plant Densities and Nitrogen Rates on Sorghum (Sorghum bicolor. L Moench) Growth and Nutrient use Efficiency in the Central Rift Valley of Ethiopia

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ABSTRACT

Plant density (PD) and nitrogen (N) fertilizer are considered the most important crop management practices in improving sorghum grain yield. In line with this a field experiments was conducted at Melkassa Agricultural Research Center (MARC) and Mieso research sites in the central Rift Valley (CRV) areas of Ethiopia during the main rainy season of 2016 to study the effects of PD and N fertilizer rates on growth and nutrient use efficiency and uptake. The experiment was laid out in a randomized complete block design in factorial arrangement with three replications. Two Sorghum Varieties, a hybrid (ESH-1) and an open pollinated variety (Teshale) were used with three plant densities (66,666, 88,888 and 133,333 plantsha-1) and four N rates (0, 23, 46 and 69 kg ha-1). Growth parameters (LAI, crop growth rate and net assimilation rate) were significantly affected by all main factors and their interaction effects. Nutrient concentration and uptake were variable across main effects; it increased with nitrogen rate while decreased with plant density and was higher for Mieso than MARC as well as for ESH-1 than Teshale.

Key words: Location, N-rates, N-uptake, Plant densities and Sorghum Varieties.

INTRODUCTION

Sorghum (Sorghum bicolor L. Moench) is the fifth most important cereal crop worldwide. In the year 2016, sorghum was grown worldwide on 42,201,000 ha with an output of 63,090,000 metric tons (FAO, 2016). The world average yield is 1.49t ha-1 and yield of developed countries is 4t ha-1 and that of developing countries is 1.1t ha-1. Despite the low productivity in the developing countries, they accounted for 90% of the area and 77% of the total output produced (FAO, 2016). In Ethiopia sorghum has become the third major grain cereal in area of production (1,831,600.45ha) and amount produced (4,339,134.3 tons) with a productivity of 2.37 t ha-1 (CSA, 2015). Ethiopia is unique among other sorghum growing countries in East Africa as in those countries its production was rather confined to the dry and semi dry areas while produced in all agro ecologies in Ethiopia (Gierend *et al*., 2014). 90% of sorghum production is confined to three administrative regions, Oromiya, Amahara and Tigray while 10% goes to other regions. Sorghum production acreage in Harareghe zone accounts for one third of sorghum production area in Oromiya region and is greater or equals to area under sorghum production in Tigray region (CSA, 2015).

Sorghum productivity is still far below developed countries due to several production constraints, among which lack of appropriate agronomic production packages are detrimental (EIAR, 2014) which comprises, seed rate and plant population density, soil fertility and fertilizer management, moisture availability, management of pest and disease among others. Likewise, Taffesse (2008) has indicated that the limited use of modern inputs like fertilizer is a major reason for low productivity of sorghum. This is partly due to the fact that sorghum is often grown in low-rainfall areas, where the return to fertilization is lower (Kidane and Abuhay, 1997: Kidane *et al*., 2001)). Hence matching Soil fertility and planting density with availability of soil moisture resource is crucial in order to improve land productivity and nutrient use efficiency.

In Ethiopia sorghum is sown by broadcasting with a seed rate of 15-20 kgha-1 for local sorghum varieties and about 8 kg ha-1 for improved sorghum varieties. To improve productivity of sorghum it is important to adjust the plant population densities with respect to crop varieties

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under production. This should take into consideration factors such as the nutrient requirement of each variety, morphological and physiological growth of the crop and resource availability of the target area. Plant density can affect productivity through its effect on tillering ability, light interception, nutrient and moisture mobilization efficiency of the crop (Mahesh *et al*., 2015). Altering row spacing influences interception of solar radiation and weed control (Teasdale, 1995). Moreover, crop varieties have different response to plant population densities with hybrids having different resource requirement as compared to the open pollinated sorghum varieties. Tsegaw (2004) reported better yield response from a population density of 53,333 plants ha-1 at Dire Dawa. While. Bayu *et al*. (2005) have indicated a possibility to extend the density of sorghum more than 88,888 plants ha-1 in northern Ethiopia. This implies that population density may differ with respect to the variety to be used, soil fertility status of the area, moisture availability, weed density and morphology. Response of plant population and nitrogen fertilizer rates were positively correlated with availability of resources in a given area (Karelen and Camp 1985; Tenaw 2000). They obtained better yield and nutrient use efficiencies with higher density in less stressed agro ecological zone and with lower density in stressed agricultural areas.

Beside plant population density and row spacing, fertilizer management specifically nitrogen is also a concern in developing countries like Ethiopia as it is highly exposed to loss that makes the nitrogen use efficiency management to be very challenging (Fageria and Baligar, 2005a and b). It has greater influence on growth and yield of crop plants than any other essential plant nutrient. Nitrogen deficiency also decreases leaf area index (LAI), lowers radiation use efficiency and lowers photosynthesis activity in plants (Fageria and Baligar, 2005a and b).

There has been variation in N and P fertilizer recommendation rates for sorghum across different locations and agro ecologies of the country which is due to the fact that different agro-ecologies have different moisture gradient, soil fertility and vegetation coverage that may enhance or depress the nutrient use efficiency of the crop (Tenaw. 2000). In line with this Nebyou and Muluneh (2016) have revealed that grain yield and its components such as biomass and others such as plant height and sorghum heads were tended to be highest under 92 kg N and 30 kg P ha-1 for Derashe area of the Segen People of southern Ethiopia. Similarly, Gebrelibanos and Dereje (2015) have indicated that 100 kg ha-1 N has given the highest plant height, panicle length, leaf area index (LAI) and grain yield in striga infested areas in northern Ethiopia as compared to the blanket recommendation of 41kg ha-1 N. Likewise, Habtamu *et al*. (2015) have shown integrated application of organic and inorganic fertilizers of 120 kg ha-1 N,10 t ha-1compost and 15 kg ha-1 slulpher has increased maize grain yield, total above ground dry biomass, plant height, grain number per cob, cob weight, thousand seed weight, N and S concentration of leaves and grains. Ogunlela and Okoh (1989) indicated that there was significant interaction effect between sorghum varieties and N-rate as well as plant density and N-rates in Nigeria. Furthermore, they reported that there was varietal difference with respect to response of the sorghum varieties to plant density. Similarly, Miko and Manga (2008) have shown that both intra-row spacing and nitrogen rates had a significant influence on plant height, number of leaves per plant, dry matter, and grain yield. Increasing N fertilizer rates from 40 kg N ha-1 to 120 kg N ha-1and plant densities from 8,000 to 20,000 plants ha-1 m-2 led to a raise in biomass production and grain yield of sorghum (Zand *et al*., 2014). The recommended N and P rate and plant density for sorghum production in central rift valley of Ethiopia is 41 kg N ha-1 and 46 Kg P2O5 ha-1 respectively with a plant density of 88,888 plants ha-1

Sorghum research in the country has been started before three decades and several sorghum varieties were released to the national agricultural production system, most of which are open pollinated. Recently hybrid sorghum production was launched with the release of sorghum hybrid varieties, which are more productive than the existing open pollinated sorghum varieties. However, key agronomic management strategies such as planting density and nitrogen fertilizer rate recommendation are lacking in the proposed study areas and currently the same plant density and fertilizer rates were used for all existing sorghum varieties of different growth habit and morphology. Thus, this research work was conducted to adjust the plant density and nitrogen fertilizer rate for sorghum varieties with better nutrient use efficiency and growth attributes in semi-arid central rift valley areas of Ethiopia.

MATERIALS AND METHODS

Description of the Study Area

The field experiments were conducted at Melkassa and Meiso in the Central Rift Valley (CRV) area of Ethiopia. Melkassa is located at 8º30’ N, 39º21’ E, 1550 meter above sea level (m.a.s), while Meiso is loacated at 9º13’ N, 40º45’ E, 1400 meter above sea level (m.a.s) .The climate of the CRV region is tropical and dry semi-arid (Meshesha *et al*., 2012). Melkassa and Meiso have a mono-modal and bi-modal rainfall pattern with average annual rainfall of 763 mm and 470 mm, and average annual temperature of 21.3oC and 22.8oC, respectively. Melkassa soil is a well-drained typical sandy loam with an average pH of 7-8.2, mainly classified as Andosols and Meiso soil is well-drained clay with an average pH of 7-8.6 (Meshesha *et al*., 2012).

Experimental Design and Treatment Set up

The experimental design was a randomized complete block with three replicates. The treatments consisted of a factorial combination of two sorghum varieties (a hybrid, ESH-1 and an improved open pollinated variety, Teshale); three plant densities of (D1=133,333, D2=88,888 and D3=66,666 plants ha-1) obtained by using three intra-row plant spacings (10, 15 and 20 cm) and four rates of Nitrogen (N) fertilizer (0, 23, 46 and 69 kg N ha-1). The plot size was 3 x 3.75 m with five rows of 0.75 m width and 3m length.

Data Collection and Analysis

Data recorded were plant height, panicle length, leaf area index (LAI), crop growth rate (CGR), Net assimilation rate (NAR), Nitrogen concentration (NC), Nitrogen uptake in grain, Stover and total nutrient uptake (NUTK) and Agronomic use efficiency.

Leaf area index is defined as leaf area per unit land area. It was calculated by dividing the leaf area by the land area as described by Diwaker and Oswat, (1992).

Crop growth rate (CGR) is the rate of dry matter production per unit ground area per unit time (Watson (1952). CGR= ((W2-W1))/((t2-t1)) X 1/A.

Net assimilation rate (NAR) is the rate of increase in dry weight per unit leaf area per unit time (Gregory (1926). NAR= ((W2-W1) (ln⁡L2-ln⁡L1))/((L2-L1)(t2-t1)).

Analysis of total nitrogen was done both for the straw and grain sampled per treatment with Kjeldahl method of nitrogen determination (Kjeldahi,J.(1883)).

Nitrogen uptake (kg ha-1) = ((% N in grain or straw) (grain yield or straw weight (kg ha-1))/100 Cassman *et al*. (2003).

Nutrient use efficiency/Agronomic use efficiency: calculated as per the formula derived by Cassman *et al*. (2003) AE= GY (f)-GY (u)/N (a)

Plant Tissue Analysis

For the analysis of N concentrations in sorghum plant tissue, samples of straw and grain were taken from all experimental plots at physiological maturity. Samples of similar treatments over replications were combined to make composite samples. Each sample was partitioned into grain and straw for the analysis of their total N contents. Nitrogen content in plant tissues (straw and grain) were analyzed by Micro-Kjeldahl method (Kjeldahi,J.(1883)) and then the nitrogen uptake and N use efficiencies of the treatments were estimated.

Statistical Analysis

Prior to combined analysis of variance, separate analysis of each location was carried out using general linear model following the procedures given by Gomez and Gomez (1984). The level of significance used for F and t-test was P = 0.05. SAS statistical software program package (9.1), 2003 was used for data analysis. The data were tested for homogeneity of error variance using ratio of larger mean square to smaller mean square for locations and had identified two parameters (dry matter yield at vegetative and flowering) with heterogeneous variance and then transformed using log transformation.

RESULTS AND DISCUSSION

Plant Height, Panicle Length and Width

The main plot effects of location and variety as well as the interaction effects of location x variety and location x N-rate significantly affected plant height (Appendix 2). Teshale had longer plant height at both locations though height differences were wider at Mieso (Table 1). Longer plant for Teshale variety was attributed to its genetic performance while locations difference may be attributed to limitation of growth resources (moisture) at Mieso during the growth period. Plant height was not responsive for plant densities which were in agreement with Gebremedhin (2015) who reported a non -significant plant height in response to plant density for haricot bean at Mizan Tepi district. However, Mohmoud *et al*. (2013) had reported plant height increase with increasing plant density and nitrogen application rates for sweet sorghum grown in Egypt. Conversely, Tajul *et al*. (2013) reported longest plant for sparsely populated sorghum at an optimum N-application rates.

On the other hand, panicle width (PW) became significantly influenced by the main effects of variety and plant density and by interaction effect of location x variety (Appendix 2). Hence both wider and narrower panicles were recorded at MARC for Teshale and ESH-1 respectively (Table 1). Moreover, Teshale variety exhibited similar panicle width at both locations while ESH-1 had scored different panicle width across locations where wider panicle was attained at MARC (Table 1). Plants with longer panicle were recorded for ESH-1 at MARC followed by the same variety at Mieso (Table 1).

Panicle length (PL) was significantly influenced by all the main effects except for nitrogen application rate and for the interaction effects of plant density x N-rate and location x Variety (Appendix 2). As a main plot effect Teshale sorghum variety was better in plant height, panicle length and panicle width as compared to ESH-1 and similarly longer and wider panicle was recorded at the lowest plant density. Sorghum planted at MARC was longer in height and panicle as compared to those planted at Mieso (Table 2).

On the other hand, location x N-application rate had revealed that plant height was not responsive to nitrogen application rates at Melkassa while significant difference in plant height existed between the highest (69 kg ha-1) and the check unfertilized plot at Mieso (Table 3). However, application of nitrogen fertilizer at a rate of 23 to 69 Kg ha-1 did not show significant difference in plant height at Mieso. The reason why no variation existed between fertilizer rates at Melkassa may be attributed to enough moisture that help mobilize the existing nutrients. In agreement with this study results Miko and Manga (2008) and Selassie (2015) had revealed that nitrogen application rate was not significant for plant height for sorghum in Iran and for maize in Tigray in Ethiopia, respectively.

Similarly, longer panicle was attained for ESH-1 Variety at the lowest (66,666 plants ha-1) plant density followed by the same variety at a plant density of 88,888 plants ha-1 while shortest panicle was recorded at the highest (133,333 plants ha-1) plant density for Teshale sorghum variety (Table 4). However, no statistically significant variation in panicle length between a plant density of 66,666 and 88,888 plants ha-1 existed irrespective of locations (Table 4). Decrease in panicle length due to increase in plant density was attributed to more intra specific competition for growth resource at the highest density.

Table 1: Mean plant height, Panicle length (cm) and width (mm) as affected by location * variety

	Plant height(cm)		Panicle length(cm)		Panicle width(mm)	
Locations	ESH-1	Teshale	ESH-1	Teshale	ESH-1	Teshale
Melkassa	152.5c	180.7a	27.94a	18.92c	38.17c	43.3a
Mieso	121.9d	171.3b	22.64b	19.14c	40.69b	41.75ab
LSD (0.05)	3.42		0.83		2.48	
CV (%)	4.66		8.03		12.94	

Columns with same letter are not significant at P<0.05.

Table 2: Plant height, panicle width and length as affected by main factor effects

Varieties	Plant height(cm)	Panicle length(cm)	Panicle width(mm)
ESH-1	137.2[b]	25.3[a]	39.4[b]
Teshale	176.0[a]	19.0[b]	42.5[a]
LSD (0.05)	2.42	0.59	1.75
Plant densities (Pt ha^{-1})			
133,333	155.9	21.3bc	38.5[bc]
88,888	157.2	22.4ab	41.3[ab]
66,667	156.7	22.8a	43.2a
LSD(0.05)	ns	0.72	2.15
Locations			
Melkassa	166.6[a]	23.4[a]	40.8
Mieso	146.6[b]	20.9[b]	41.2
LSD (0.05)	2.42	0.59	ns
CV (%)	4.66	8.03	12.94

Columns with same letter are not significant at P<0.05.

Table 3: Plant height (cm) as affected by location* N-rate interaction

	Locations	
N-rates (kg ha^{-1})	Melkassa	Mieso
0	163.[3a]	142.7[c]
23	168.1[a]	146.3[bc]
46	167.3[a]	146.9[bc]
69	167.6[a]	150.3[b]
LSD (0.05)	4.83	
CV (%)	4.66	

Column with same letter are not significant at P<0.05.

Table 4: Panicle length (cm) as affected by plant density* Variety interaction

Plant densities (Plants ha^{-1})	Sorghum Varieties	
	ESH-1	Teshale
66,666	25.88[a]	19.79[c]
88,888	25.54[a]	19.21[c]
133,333	24.46[b]	18.08[d]
LSD	1.02	
CV (%)	8.03	

Column with same letter are not significant at P<0.05.

Leaf Area Index (LAI) at Vegetative and Flowering

Application of different levels of nitrogen, plant density and crop variety under both locations and their interactions significantly (P<0.01) affected the leaf area index irrespective of crop growth stages (Appendix 2). Variety ESH-1 had greater LAI at Mieso compared to Melkasa while variety Teshale had similar leaf area indices at both locations (Table 5) at flowering stage. Both varieties developed larger leaf area indices at Mieso though differences between the locations were more remarkable for ESH-1 at vegetative stage. Overall, variety ESH-1 was found to be more responsive to changes in growth environment.

Variety Teshale had scored 29 and 13% more in leaf area index at Melkassa over variety ESH-1 at flowering and vegetative growth stages, respectively while Variety ESH-1 was greater at Mieso by 8 and 6% over variety Teshale at flowering and vegetative growth stages, respectively.

Leaf area index at flowering increased linearly and consistently with increasing plant density for both varieties. Teshale variety had scored greater LAI as compared to ESH-1 at the lowest (66,667 plants ha-1) and highest (133,333 plants ha-1) plant densities while no difference in LAI existed between the varieties at medium plant density (88,888 plants ha-1) (Fig 1). LAI at the highest plant density out yielded the lowest and medium plant densities, respectively, by 98 and 58% for Teshale sorghum variety. On the other hand, LAI at highest plant density exhibited 93.3 and 38.8% advantage respectively over lowest and medium plant densities for ESH-1 variety. Location by plant density interaction revealed that LAI at flowering and vegetative stages increased linearly and consistently with density at both locations.

Accordingly larger LAI was recorded at Mieso as compared to Melkasa irrespective of plant densities and crop growth stages (Fig 2A & B). Increasing plant density from the lowest to the highest plants ha-1 caused an increased in LAI at flowering from 25 to 87(%) at Melkasa and from 38 to 105 (%) at Mieso (Fig 2A). The increase in LAI at vegetative stage was from 26 to 89(%) at MARC and 27 to 91(%) at Mieso for the same plant density (Fig 2B).

Increase in LAI at flowering was observed with increasing of both plant density and nitrogen application rates. However, the increase was more remarkable for plant density than nitrogen application rates (Fig.3). Accordingly, the largest LAI at flowering was recorded at the highest plant density and highest nitrogen application rate, while the smallest LAI recorded at the lowest N-rate and plant density. Greater LAI in response to plant density and nitrogen application rates was attributed to the effect of nitrogen on leaf expansion and the additive effect of more plants to leaf area.

In line with this result Mohmoud et al. (2013) revealed that increasing N rate up to 120 kg ha-1 significantly increased growth traits like LA, LAI, straw diameter and straw length for sweet sorghum in Egypt and in a similar way Bayu et al. (2005) have indicated that better LAI with increasing plant density and nitrogen rate for sorghum in Northern Ethiopia.

Crop Growth Rate (CGR) and Net Assimilation Rate (NAR) (gm-2 day-1)

Crop growth rate was significantly affected (P<0.01) by main factor effects of variety and plant density and by all the interaction effects except location *variety (Appendix 2).

Variety Teshale had scored greater (CGR) and NAR as compared to variety ESH-1 across all N-levels (Table 6). Variety Teshale had scored a 39, 61, 25 and 79% advantage in crop growth rate at 0, 23, 46 and 69 Kg N ha-1, respectively over the other variety.

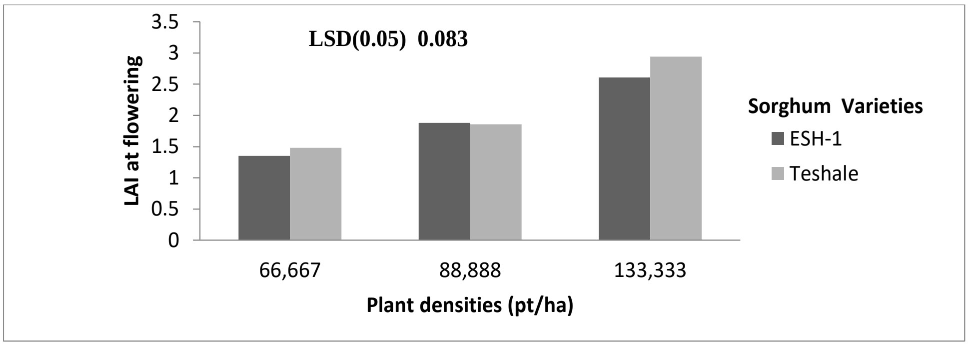

Fig. 1: Leaf area index at flowering as affected by variety * density interaction.

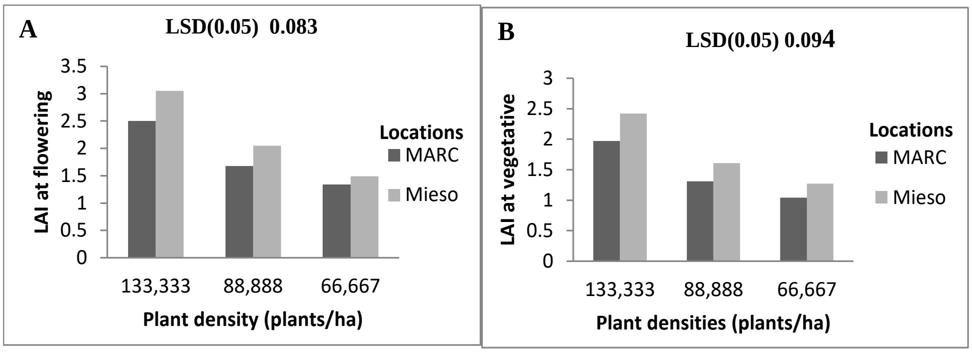

Fig. 2: LAI at vegetative (B) & flowering (A) as affected by Location *density interaction.

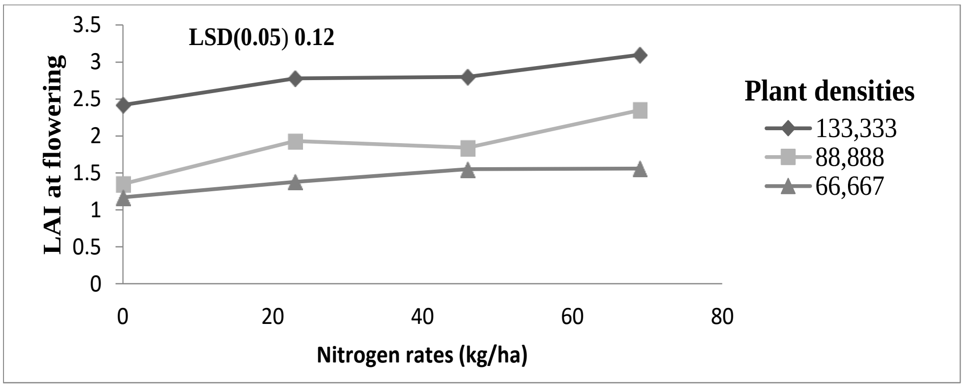

Fig. 3: LAI at flowering as affected by interaction of nitrogen rate and plant density.

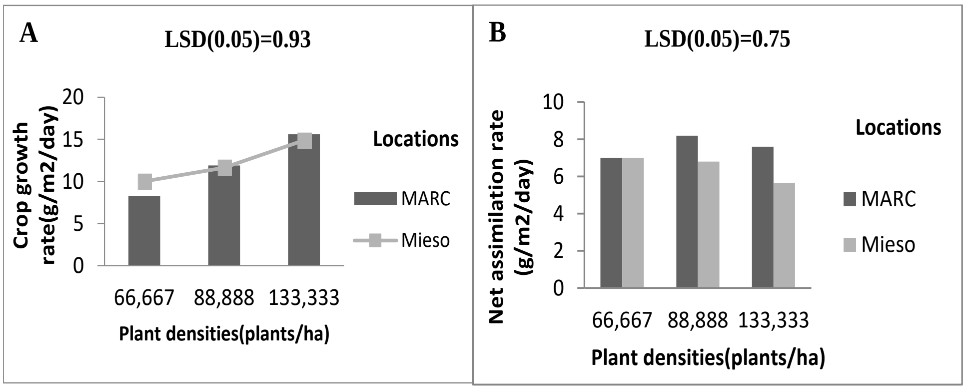

Fig. 4: CGR (A) and NAR (B) (gm-2 day-1) as affected by interaction of plant density and location.

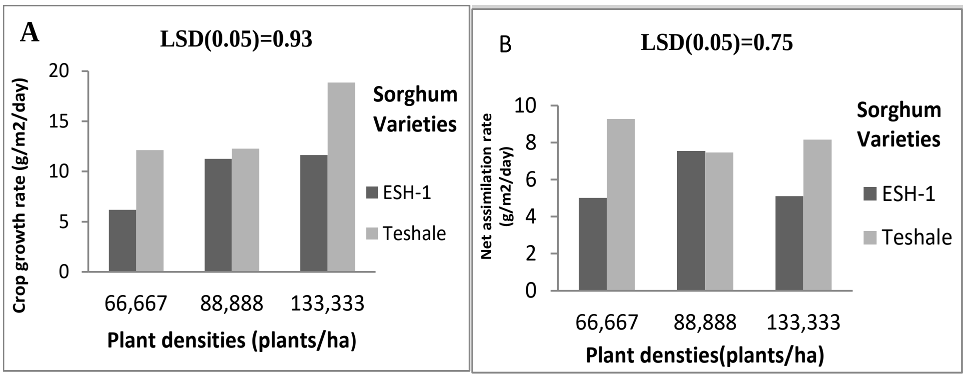

Fig. 5: CGR (A) and NAR (B) ($gm^{-2}day^{-1}$) as affected by interaction of varieties & densities.

Table 4: Leaf area index as affected by interaction of variety * location

	LAI at vegetative		LAI at flowering	
	Sorghum Varieties			
Location	ESH-1	Teshale	ESH-1	Teshale
Melkassa	1.35[d]	1.53[c]	1.61[c]	2.07[b]
Mieso	1.82[a]	1.71[b]	2.28[a]	2.11[b]
LSD (0.05)	0.076		0.08	
CV (%)	10.02		6.85	

Columns with same letter are not significant at P<0.05.

Table 5: Mean CGR & NAR ($gm^{-2}day^{-1}$) as affected by Variety by NR interaction

NR (kgha-1)	CGR		NAR	
	ESH-1	Teshale	ESH-1	Teshale
0	9.76d	13.50b	7.41b	8.97a
23	8.60e	13.83b	5.17d	8.16ab
46	11.17c	14.01b	6.15c	7.86b
69	9.25de	16.36a	4.84d	8.21ab
LSD (0.05)	1.08		0.86	
CV (%)	13.44		18.18	

Columns with same letter are not significant at P<0.05.

Table 6: CGR and NAR (g/m2/day) as affected by Location by N-rate interaction

	CGR		NAR	
NR(kgha-1)	Melkassa	Mieso	Melkassa	Mieso
0	10.33b	10.35b	7.63b	8.74a
23	12.08a	12.93a	7.63b	5.70c
46	12.24a	12.94a	7.75b	6.26c
69	13.11a	12.5a	7.16b	5.89c
LSD (0.05)	1.08		0.86	
CV (%)	13.44		18.18	

Column with same letter are not significant at P<0.05.

Variety Teshale had greater net assimilation rate as compared to variety ESH-1 at all levels of nitrogen application rates. Net assimilation rate was similar among nitrogen application rates of 23, 46 and 69 kg N ha-1 for variety Teshale and between nitrogen application rates of 23 and 69 kg N ha-1 for variety ESH-1(Table 6). Though it was at par with N-application rate of 23 and 69 kg ha-1 a remarkably higher NAR was recorded at 0 kg N ha-1 for both sorghum variety. Accordingly, application of nitrogen fertilizer at a rate of 23, 46 and 69 kg ha-1 reduce NAR by 43, 20 and 53% for ESH-1 and 10, 14.1 and 9.3 for Teshale var in comparison to the check unfertilized treatment. which may be due to the fact that applications of nitrogen fertilizer promote LAI which become inversely related to NAR (Table 6).

Application of nitrogen fertilizer rates resulted in similar CGR across both locations except for the check unfertilized plots. NAR was highest and significant at Mieso with no N-applied while similar for consecutive nitrogen application rates. On the other hand, no variation in NAR at Melkassa with consecutive nitrogen application rates (Table 7). Variability in NAR with N-rate at Mieso might be attributed to the fact that more leaf area development due to nitrogen application between the two-sampling period.

Location by density interaction (Fig 4A) had revealed that crop growth rate (CGR) was remarkably higher at the highest plant density than consecutive lower densities across both locations. Planting sorghum at the highest density (133,333 plants ha-1) resulted in 88 and 31% CGR advantage over the lowest (66,667 plants ha-1) and medium (88,888 plants ha-1) densities at Melkassa while the increase in CGR for higher plant density was 49 and 28% over lower and medium plant densities at Mieso, respectively. Location * density interaction (Fig. 4B) indicated that NAR decreased with increasing plant density at Mieso while increased up to the medium density at Melkassa. Hence, maximum and minimum NAR was attained at MARC and Mieso when planted with a density of 88,888 and 133,333 plants ha-1, respectively. In comparing net assimilation rate at the lowest density, an advantage of 3 and 24% was attained respectively over medium and highest densities at Mieso. However, NAR at the lowest density was decreased by 17 and 9 % as compared to medium and highest plant densities at Melkassa. In contrast to Melkassa and in line with Mieso, Sudha and Pandey (1998) had reported a declining trend of net assimilation rate with increasing plant density.

Interaction of plant density * variety indicated remarkably greater crop growth rate values for variety Teshale as compared to ESH-1 at all levels of plant densities (Fig 5A). It was increased with plant density for both varieties though similar CGR was attained at medium and higher plant densities for variety ESH-1 while lower and medium densities had similar CGR for variety Teshale. Medium and highest plant densities had scored 82 and 88% more in CGR as compared to lower plant density for variety ESH-1. Similarly highest density scored 56 and 54% CGR advantage over lower and medium plant densities for variety Teshale. Comparing the two varieties across respective densities, variety Teshale had scored 96 and 62% more crop growth rate over variety ESH-1 respectively at the lowest and highest plant densities (Fig 5A). Interaction of plant density * variety indicated higher and significant NAR for Teshale sorghum variety at the lowest density while it was at par between medium and higher plant densities. However, it was increasing with density until medium and then declined for ESH-1 sorghum variety (Fig 5B).

Highest plant density had scored higher crop growth rate as compared to both lowest and medium plant density irrespective of nitrogen application rate. Accordingly, the highest crop growth rate was attained at the highest plant between medium and higher plant densities. However, it was increasing with density until medium and then declined for ESH-1 sorghum variety (Fig 5B).density in combination with a nitrogen rate of 46 kg N ha 1, and no difference in CGR for highest plant density at nitrogen application rates of 46 and 69 kg N ha-1 however no difference existed among nitrogen application rates at lowest density (Table 8).

In general, crop growth rate was higher with increased densities and nitrogen application rates for variety Teshale. In line with current study result Tajul et al. (2013) had concluded that application of N-rate and plant density increase crop growth rate as maximum dry matter yield is achieved due to both increased density and nitrogen application rates. Higher and significant net assimilation rate was also achieved when lower plant density was combined with lower N-application rate (Table 8). Accordingly, though it was at par a remarkably higher NAR was attained at medium and lowest plant densities under no fertilizer application rate. NAR was decreased

Table 7: CGR and NAR (g m-2 day-1) as affected by N- rate by density interaction

	Crop growth rate (CGR)			Net assimilation rate (NAR)		
	Plant densities (Plants ha-1)			Plant densities (Plants ha-1)		
NR(Kg ha-1)	133,333	88,888	66,667	133,333	88,888	66,667
0	15.48b	10.71e	8.70f	7.20bd	9.20a	8.17ab
23	12.03cd	12.25cd	9.37f	4.98d	7.44bc	7.57bc
46	17.24a	11.15de	9.37f	7.63bc	6.79cd	6.60cd
69	16.22ab	12.97c	9.27f	6.72cd	6.58cd	6.28e
LSD	1.32			1.06		
CV (%)	13.44			18.18		

Column with same letters are not significant at (P<0.05).

with increasing nitrogen application rate under lowest and medium plant densities though inconsistent under highest plant density.

Nitrogen Concentration, up take and use efficiency in Sorghum Plant Tissue

Nitrogen Concentration

Nitrogen concentration both in straw and grain was higher at Mieso than att MARC which was 55.9% more in grain and 34.1% more in straw at Mieso (Table 9). Moreover, nitrogen concentration in grain was 16.6% higher for ESH-1 as compared to Teshale sorghum variety (Table 9). Increased application of N rates slightly increased both grain and straw nitrogen concentration. Accordingly, the straw and grain N content recorded at 46 and 69 kg N ha-1 was higher than that obtained at zero and 23 kg N ha-1 and the percentage of nitrogen in the grain was increased by 20.9 and14.1% over control at the highest fertilizer rates (46 kg N ha-1and 69 kg N ha-1), respectively (Table 9). Similar report had shown that increase in the level of nutrients application caused a corresponding increase in nutrient concentration in both grain and straw (Sujathamma *et al*., 2015). On the other hand, both nitrogen concentration in grain and straw was decreased with increasing density where it was declined by about 18% in grain and by 6% in straw at the highest plant density as compared to the lowest density. In general, nitrogen concentration in grain was higher and significant as compared to that found in straw which may be associated to higher nutrient translocation from source to the sink during the last crop growth stage.

In line with the current study results Aklilu *et al*. (2010) had reported higher nutrient concentration and up take in grain as compared to straw for forage oat at Mieso. The reason why the hybrid sorghum responds well to nutrient concentration and uptake in grain may attribute to their genetic makeup (stay green character) and their performance to withstand moisture stress and hence facilitate better nutrient translocation.

Nitrogen Uptake

Total nitrogen uptake (straw and grain) increased consistently with increasing nitrogen application rates and hence the lowest and highest nutrient uptake of 35.98 and 51.87 kg ha-1 was attained at application of 0 (control) and 46 kg N ha-1 respectively, which was an increment of 44% over the control (Table 9). It was observed that nutrient uptake was 5% higher at Mieso than at MARC and 21% higher for ESH-1 as compared to Teshale sorghum variety. In agreement with the current study results Sujathamma *et al*. (2015) reported a significant NPK uptake among varieties and NPK rates in India. Similarly, Aklilu *et al*. (2010) had reported that nitrogen uptake was increased with increasing application of nitrogen rates for forage oat. The higher uptake with increased dose of N level might be due to increased availability of nitrogen in soils & better root development.

In response to increased plant density, total and grain nitrogen uptake decrease consistently while uptake in straw increased with plant density. On the other hand though the concentration was lower in grain at MARC uptake in grain was higher due to higher yield at MARC than Mieso, while uptake in straw and over all uptake was higher for Mieso which may be due to higher nitrogen concentration in straw at Mieso and comparable straw yield with that of Melkassa (Table 9).

The higher uptake with increased dose of N level might be due to increased availability of nitrogen in soils & better root development.

In response to increased plant density, total and grain nitrogen uptake decrease consistently while uptake in straw increased with plant density. On the other hand though the concentration was lower in grain at MARC uptake in grain was higher due to higher yield at MARC than Mieso, while uptake in straw and over all uptake was higher for Mieso which may be due to higher nitrogen concentration in straw at Mieso and comparable straw yield with that of Melkassa (Table 9).

Agronomic Nutrient use Efficiency

Agronomic use efficiency is defined as the nutrient use efficiency of a crop where a kilogram of applied nutrient would cause a kilogram of yield increment (Mosier *et al*., 2004). Accordingly, the highest agronomic use efficiency was attained with the lowest nitrogen application rate and decrease linearly with increasing the nitrogen rates. Hence application of 23 kg N ha-1 resulted in 55.8% more agronomic use efficiency as compared to 69 kg N ha-1 (Table 9). In a similar trend agronomic use efficiency increased linearly and consistently with increasing plant density where denser plants became 19% more efficient than sparse population. Also, ESH-1 sorghum variety became superior in agronomic use efficiency than Teshale sorghum variety (Table 9). In agreement with this result De-yang *et al*. (2016) reported that increasing plant density could improve NUE significantly, and the NUE was higher at a lower N rate at any plant density.

Agronomic use efficiency was also higher at Melkassa than Mieso which was 12% more at Melkassa. The differences in nutrient use efficiency between locations may be attributed to limitation of other growth resource specifically moisture during the critical crop growth stage

Table 9: Nitrogen concentration, up take &AUE as influenced by main effects

	N-concentration(g/Kg)			N-uptake(kg/ha)			AUE (Kg/Kg)
Locations	Grain	Straw	Total	Grain	Straw	Total	
Melkassa	6.6	3.34	9.94	27.92	16.28	44.2	18.92
Mieso	10.29	4.48	14.77	25.74	20.79	46.55	16.93
SEM±	0.24	0.11	0.35	1.05	0.71	1.27	0.97
Varieties							
ESH-1	9.1	3.96	13.06	30.87	18.78	49.65	19.22
Teshale	7.8	3.85	11.65	22.8	18.3	41.11	16.63
SEM±	0.24	0.11	0.35	1.05	0.71	1.27	0.97
NR(kg/ha)							
0	7.72	3.63	11.35	20.79	15.2	35.98	
23	7.93	3.88	11.81	24.17	18.23	42.4	21.72
46	9.33	4.06	13.39	31.7	20.15	51.87	18.12
69	8.81	4.07	12.88	30.67	20.58	51.26	13.94
SEM±	0.34	0.15	0.49	1.48	1.01	1.8	1.18
PD(pt/ha)							
133,333	7.61	3.83	11.44	24.24	20.29	44.55	20.53
88,888	8.73	3.97	12.7	27.34	18.99	46.33	15.92
66,667	9	4.06	13.06	28.92	16.33	45.25	17.33
SEM±	0.29	0.13	0.42	1.28	0.87	1.56	1.18

at Mieso that hinder nutrient translocation from source (leaf and straw) to sink (grain). In accordance to the current study result Wortmann *et al*. (2007) reported lower agronomic N use efficiency (6 kg grain/ kg N ha-1) at sites with maximum yields of 6 Mg ha-1 indicating presence of severe constraints other than nitrogen.

In general, crop management other than nutrients may improve crop performance and thereby enhance all resource use efficiencies of a crop. Fertilizer use efficiency can be optimized by fertilizer best management practices that apply nutrients at the right rate, time, and place and accompanied by the right agronomic practices (Ghosh *et al*., 2015).

Summary and Conclusions

To improve productivity of sorghum it is important to manipulate agronomic crop management through adjusting plant densities taking in to consideration factors such as the nutrient requirement of each variety, morphological and physiological growth of the crop and resource availability of the target area. In line with this the national sorghum research coordination has released hybrid sorghum varieties which have used the same plant densities and nitrogen rate with those already under production. Hence this research work was proposed to address the gap using a factorial arrangement of two sorghum varieties (ESH-1 and Teshale), three plant densities (D1=133,333, D2=88,888 and D3=66,666 plants ha-1) and four nitrogen application rates (0, 23, 46 and 69 Kg N ha-1).

Growth parameters including leaf area index, crop growth rate (CGR) and net assimilation rate (NAR) were significantly affected by all main and interaction effects except for interaction of variety x nitrogen application rates for crop growth rate.

Nitrogen concentration and over all uptake was higher at Mieso than Melkassa which was also higher for ESH-1 than Teshale. Similarly, concentration and uptake of nitrogen increased with increasing N-application rates while it was decreased with increasing plant density both for nutrient concentration and uptake. Better agronomic efficiency was attained for ESH-1 sorghum variety at higher density and application of 23 kg N ha-1.

Economic analysis conducted among the treatments indicated that acceptable marginal rate of return was obtained for ESH-1 hybrid variety with application of 23 kg N ha-1 at the highest density at MARC while lowest density (66,667) and application of 46 kg N ha-1 was profitable at Mieso for the same variety. Thus, the recommendations for increasing sorghum productivity in the Central Rift Valley need to be area specific as observed in the current experiment in terms of density and fertilization rate. It is better to recommended for user after being tested over location and season to accommodate seasonal weather variability.

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Appendix 2 Mean square for growth parameters when combined across locations (2016)

S of variation	df	PH	PL	PW	CGR	NAR	LIF	LIV
L	1	14465.79**	230.28***	6.76	2.03	28.90***	4.66***	3.92***
Var	1	53901.68***	1396.78***	352.84***	805.42***	208.54***	0.77***	0.05
IR	2	16.63	30.91***	261.18***	447.25***	9.25**	23.03***	13.64***
NR	3	30.88	4.98	22.02	20.74	20.56***	2.91***	2.25***
Rep*L	4	295.77***	4.47	18.09	1.96	1.90	0.07**	0.04
Var*IR	2	22.6	0.29	36.61	20.26***	22.87***	0.49***	0.15**
Var*NR	3	208.10*	5.99	14.27	31.35***	16.73***	0.05	0.32***
IR*NR	1	99.23	8.42*	16.12	0.11	7.24*	3.52***	0.77***
Var*IR*NR	2	23.13	1.57	33.18	129.64***	60.65***	0.36***	0.04
L*Var	6	4084.83***	272.29***	145.17*	27.21***	10.92***	0.23***	0.04
L*IR	3	59.5	0.99	5.05	31.34***	7.39**	0.21***	0.08*
L*NR	2	235.00**	7.74	68.35	14.31**	23.43***	0.12**	0.003
L*Var*IR	3	115.95	7.4	14.65	17.08**	1.17	0.21***	0.03
L*Var*NR	6	26.86	14.31	52.59	23.68***	9.04***	0.17***	0.09**
L*IR*NR	6	79.71	3.08	26.89	21.89***	15.04***	0.24***	0.03
L*Var*IR*NR	6	72.65	5.63	46.63	23.45***	4.41*	0.16***	0.13***
Error	91	53.51	3.18	28.46	2.63	1.66	0.02	0.03
CV (%)		4.67	8.06	13.03	13.44	18.18	6.85	10.02

Where, df= degree of freedom, PH=Plant height, PL=Panicle length, PW= Panicle width, CGR=Crop growth rate, NAR=assimilation rate.