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Effect of Plant Densities and Nitrogen Rates on Yield and Yield Components of Sorghum Varieties (Sorghum bicolor. L Moench) in 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, yield and yield components of sorghum. 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). Biomass, head weight and grain yield (t/ha) were significantly affected by main factor effects. Moreover, interaction effect of location by variety affected almost all yield related parameters except thousand seed weight. Interaction between variety and density significantly affected biomass, head weight and grain yield with the highest results for ESH-1 at the highest density. Better grain yield, with a profitable marginal rate of return was achieved for the hybrid ESH-1 variety with application of 23 Kg N ha-1 and the highest plant density (133,333) at MARC while it was obtained with application of 69 Kg N ha-1 at the lowest density (66,667) for the same variety at Mieso.

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). Sorghum production in Ethiopia is fairly spread out covering not only a large area of production but also grown in several distinct agro-ecologies. This makes Ethiopia unique among other sorghum growing countries in East Africa as in those countries it was rather confined to the dry and semi dry areas (Gierend *et al*. 2014). They also identified that 90% of sorghum production is confined to three administrative regions of the country, 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 is widely produced more than any other crops in the areas where there is moisture stress (CSA, 2010). According to this report, the grain in these areas is used for human food like porridge, "injera", "Kitta", "Nifro", infant food, syrup, and local beverages such as "Tella" and "Areke." In addition, it serves as animal feeds, the straw is also used for construction of houses and fence, and as fuel wood. However, sorghum productivity is still far below developed countries due to several production constraints and among which lack of appropriate agronomic production packages are detrimental (EIAR, 2014). The Agronomic production packages comprises, seed rate and plant population density, soil fertility and fertilizer management, moisture availability and management and pest management among others.

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Likewise, Taffesse (2008) has indicated that the limited use of modern inputs is a major characteristic of crop production in Ethiopia and a major reason for low productivity. From the modern inputs fertilizer consumption is detrimental and shows a progressive increase with a very high variability among cereal crops, which is very low for sorghum relative to other cereals. This is partly due to the fact that sorghum is often grown in low-rainfall areas, where the return to fertilization is lower. Low yield of sorghum in semiarid areas of Ethiopia is attributed to soil moisture stress, poor soil fertility and poor pest management, which are among the most limiting factors (Kidane and Abuhay, 1997). Similarly, Kidane *et al*. (2001) have mentioned that the two most common production constraints of semiarid low land areas would be low soil moisture and poor soil fertility, 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 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. Gardener *et al*. (1990), have shown that hybrid maize favors high doses of fertilizer as compared to open pollinated varieties and this may be true for sorghum. Tsegaw (2004) have reported better yield response from a population density of 53,333 plants ha-1 at Dire Dawa. On the other hand Bayu *et al*. (2005) have indicated a possibility to extend the density of sorghum even to a double of the recommended density (88,888plants 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. In line with this Karelen and Camp (1985); Workayehu (2000) have reported that response of plant population and nitrogen fertilizer rates were positively correlated with availability of resources in a given area. 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 due to a variety of losses facing the nutrient. Though nitrogen plays a crucial role in crop production, it is also 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. It plays a pivotal role in many physiological and biochemical processes in plants. 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 (Workayehu, 2000). In line with this Masebo and Menamo (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 kgN and 30 kg P ha-1 for Derashe area of the Segen People of southern Ethiopia. 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).

In Ethiopia several research results on the response of sorghum to N and P fertilizer application in semi-arid areas of Ethiopia have indicated a non-significant yield response which is associated with limiting soil moisture conditions and lack of appropriate nitrogen management including application time (Reddy and Kidane, 1993; Woldeab and Mamo 1991). However, Burayu *et al*. (2006) reported that the highest grain yield of sorghum obtained when 49 kg N ha-1 and 55 kg P2O5 ha-1 were applied at Wolenchiti and Melkassa area of the central rift valley of Ethiopia. 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 optimum and economical yield.

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 (H.Hengsdijk and H.Jansen; 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

On-station trails were conducted to evaluate response of sorghum varieties to nitrogen rates and plant densities at Melkassa and Mieso. The experimental design was a randomized complete block with three replications. 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 spacing (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. Soil was ploughed to a depth of 0.2 m using a mould board plough after harvesting the previous crop. Prior to sowing, the land was also smoothed with a disc-plough and a spring-tooth harrow to bring the soil to a fine tilt. Subsequently, ridges spaced at 0.75m and 0.35m height was made.

Sowing and Crop Management

Sowing and Cultivation

Sorghum Seeds were drilled by hand into the furrow at a depth of 0.03 m. Manual uprooting to thin plant stands to the targeted plant density was done about two weeks after emergence. Weeds were controlled by inter-row cultivation and hand weeding as deemed necessary to maintain a weed-free environment

Fertilizer Application

Nitrogen fertilizer was applied as urea in each N treatments where, half of the dose was side-dressed after three weeks of sowing and the rest was top-dressed at booting (eight weeks after sowing). Other nutrients applied at sowing were phosphorus at 20 kg P ha-1 as triple super phosphate and potassium as potassium sulphate at 40 kg K2O ha-1 side-dressed uniformly across all plots at planting.

Crop Data Collection and Soil Sampling

Yield and Yield Components

Yield and related parameters like head weight (HW), heads of un threshed sorghum plant, grain yield(GY) measured after threshing collected heads which was sun dried and adjusted to standard moisture content(12.5%), straw weight(SW) was measured for sorghum stalk that was cut just immediately above ground and exposed to sun dried until it has got standard weight from net plot(6.75m2)in (Kg/plot) & converted to (t/ha) .Other yield related parameters were thousand seed weight(g)(weight of thousand grain seed from each plots at standard moisture content) Harvest index (%) the ratio of economic yield to total biological yield (Donald, 1962) and expressed in percentage. It was worked out as indicated below.

Harvest index (%)=(Economic yield (kg ha^(-1)))/(Biological yield (kg ha^(-1)))

Soil Sampling Procedures and Physicochemical Analysis

A total of 20 composite soil samples, from each location were collected at a depth of 0–20 cm before planting for soil characterization. Composite soil samples were also collected immediately after harvesting from each site for investigating the changes in soil chemical properties due to treatments application as per the treatment. The soil samples were air dried, grounded to pass to 2 mm sieve, and analyzed for different physical and chemical soil properties as described below (Table 1) at the soil and plant nutrition laboratory of Melkassa Agricultural Research Center.

Economic Analysis

Grain and straw yield data for the variety, fertilizer and planting density effects were subjected to economic analysis, using the CIMMYT (1988) partial budget methodology to evaluate the economic profitability of fertilizer and seed rate options for determination of the economic optimum rate. Sorghum yields were adjusted downwards by 10% to more closely approximate yields of farmers' condition. Sorghum variety, N fertilizer rates and plant densities were analyzed separately by calculating gross benefit (GB), total variable costs (TVC), net benefit (NB), and the marginal rate of return (MRR) for each treatment (that is, relative to the next lowest cost or non-dominated treatment for the N-rate and plant density analysis). Dominance analysis was used to screen treatments which have higher variable cost and lower net return and dominated treatment were removed from further consideration.

Net benefit= Gross benefit-Total variable cost (NB=GB-TVC)

Marginal rate of return MRR (%) = ((NB2-NB1)/(TVC2-TVC1))*100

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

Physicochemical Properties of the Soil

The result of soil analysis before planting have shown the soil pH was 7.55 at Mlekassa Agricultural Research Center (MARC) and 8.1 at Mieso research sub-site, which ranged from mild alkaline to alkaline soil and found to be in an optimum range for sorghum production (Espinoza and Kelley, 2005). Textural classes of the experimental sites were clay at Mieso and sandy clay loam at MARC. Similarly, Mieso soil held 2.73% organic carbon, 0.14% total nitrogen and 19.25 ppm available P, while soil of MARC held similar organic carbon, 0.13% total nitrogen and 18.74 ppm available phosphorus (Table 2). According to Tekalign *et al.* (1991) and Debele (1980) soils of the experimental sites are in a moderate range for organic carbon, total nitrogen and available phosphorus.

Yield and Yield Components

Straw Weight

Straw weight was significant ($P<0.05$) for the main effects of plant density and nitrogen rate and for interaction effects of density x location and location x density x N-rate (Appendix 2).

Interaction of location by density had indicated a linear increase in straw weight with increasing density across locations at Melkassa (Fig. 1). Accordingly, higher straw weight was recorded at the highest density at Melkassa while it was similar both at medium and highest plant densities at Mieso.. With increase in plant density from lowest to the highest plants ha-1, straw weight increased by 32 and 22% at Melkassa and Mieso, respectively.

The increase in straw weight due to increase in plant density may refer to the increase in LAI and early canopy closure that promotes maximum absorption of solar radiation and better early vegetative growth. The current study result is in agreement with the previous study done by Bayu *et al*. (2005) who reported that with increasing plant density the straw weight was increased. According to Ogulela and Okoch (1989) both straw weight and grain yield increased with increasing plant densities in Nigeria.

Biomass Yield

All main effects as well as interaction effects of location*density, variety*density, location*variety* density and location*variety *nitrogen rates were significant ($p<0.05$) for biomass (Appendix 2).

As a main effect greater biomass yield was recorded at Melkassa compared to Mieso and in a similar way variety ESH-1 had better biomass yield than Teshale variety (Table 3). Among plant densities, the denser plant stand accumulates greater biomass. This was also true for nitrogen application rate where biomass yield increase with nitrogen application rates. Hence, greater biomass was attained at the highest (69 kg N ha-1) nitrogen application rates though statistically at par with application of 46 kg N ha-1 (Table 3). The reason why the biomass yield was significant for the main effects were due to higher plant stand that led to maximum LAI and genetic difference in crop performance between the varieties as well as moisture difference across the locations.

Increasing plant density resulted in biomass yield increase at both locations (Fig. 2). Amount of biomass was similar between the lowest and medium plant densities at Melkassa and between medium and highest densities at Mieso. Biomass yield advantage of 21 and 8 % was attained due to increase in plant densities from lowest to highest at Melkass and Mieso, respectively. Hence, over all biomass yield was greater at Melkassa than Mieso, which may be attributed to overlapping of terminal stress and maximum temperature during final crop growth stage at Mieso.

The second level interaction of variety x planting density had shown an increase in biomass yield with increasing densities for both varieties (Fig 3). Variety ESH-1 had scored greater biomass yield as compared to variety Teshale at the highest plant density while it was similar both between the lower and medium plant densities (Fig 3).

Table 1: Soil Physico chemical properties and its method of analysis

No	Soil parameter	Method of measurement
1	Soil texture	Hydro meter (Bouyoucos, 1951)
2	Soil pH	1:2.5 soil water extract (Schofield and Taylor, 1955)
4	Organic carbon	Walkey & Black wet oxidation (Walkley. A & Black, 1934)
5	Total nitrogen	Micro-Kjeldahl method (Kjeldahi, J.(1883))
6	Available- P	Olsen's method (Olsen and Sommers, 1982)

Table 2: Physical and chemical properties of soil of the experimental fields

Soil Property	Measurable Values by location	
	MARC	Mieso
Soil pH	7.55	8.1
Total Nitrogen (%)	0.129	0.144
Electrical conductivity (ds/m2)	0.0163	0.0268
Soil organic Carbon (%)	2.73	2.73
Carbon to nitrogen ratio (C:N)	21.16	18.93
Available Phosphorous (ppm)	18.74	19.25
Soil texture	Clay	Sandy clay loam
Clay (%)	57.5	28
Sand (%)	17.5	57
Silt (%)	25	15

Table 3: Mean grain yield and its component as affected by main effects

Varieties	SW	BM	HW	GY	HI	TSW
ESH-1	4.8	9.7^{a}	5.0^{a}	3.5^{a}	36^{a}	107^{b}
Teshale	4.7	9.3^{b}	4.6^{b}	3.2^{b}	33^{b}	111.5^{a}
LSD(0.05)	ns	0.32	0.18	0.14	2	3.8
Plant densities(Pt ha^{-1})						
133,333	5.4^{a}	10.3^{a}	4.9	3.4	33^{bc}	106.5
88,888	4.7^{b}	9.4^{b}	4.7	3.3	35^{ab}	111
66,667	4.2^{c}	8.9^{c}	4.7	3.3	37^{a}	109.5
LSD(0.05)	0.31	0.39	ns	ns	2	ns
N-rates (Kg ha^{-1})						
0	4.3^{c}	8.4^{d}	4.1^{d}	2.8^{d}	34	112
23	4.7^{b}	9.3^{c}	4.6^{c}	3.3^{bc}	35	110.5
46	5.0^{a}	10.0^{ab}	5.0^{b}	3.5^{ab}	35	108
69	5.1^{a}	10.4^{a}	5.3^{a}	3.7^{a}	35	106.5
LSD(0.05)	0.36	0.45	0.25	0.20	ns	Ns
Locations						
Melkassa	4.9	11.0^{a}	6.1^{a}	4.2^{a}	39^{a}	122^{a}
Mieso	4.6	8.1^{b}	3.4^{b}	2.5^{b}	31^{b}	96^{b}
LSD(0.05)	ns	0.32	0.18	0.14	2	3.8
CV (%)	16.16	10.1	11.16	12.63	13.81	10.58

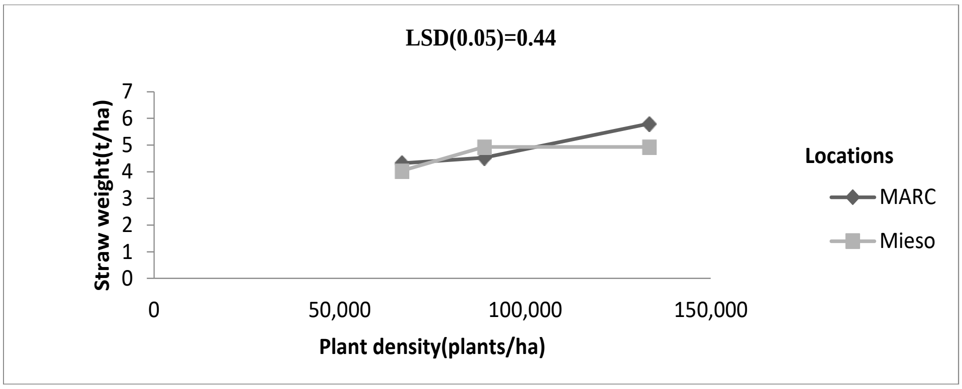

Figure 1: Straw weight (tha-1) as affected by interaction of plant densities and location

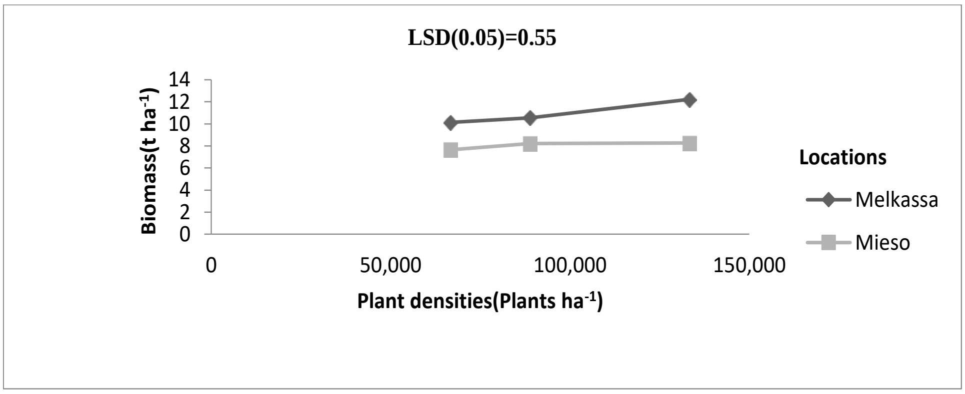

Figure 2: Biomass (t ha-1) as affected by interaction of plant densities and location

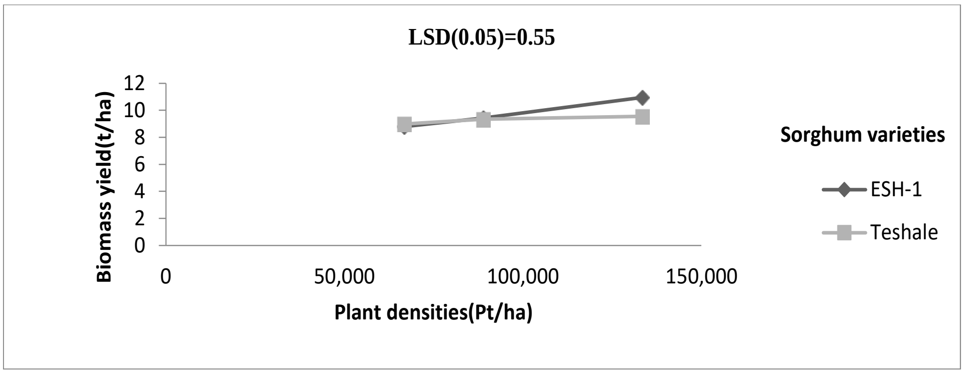

Figure 3: Biomass (t/ha) as influenced by interaction of crop varieties and plant densities

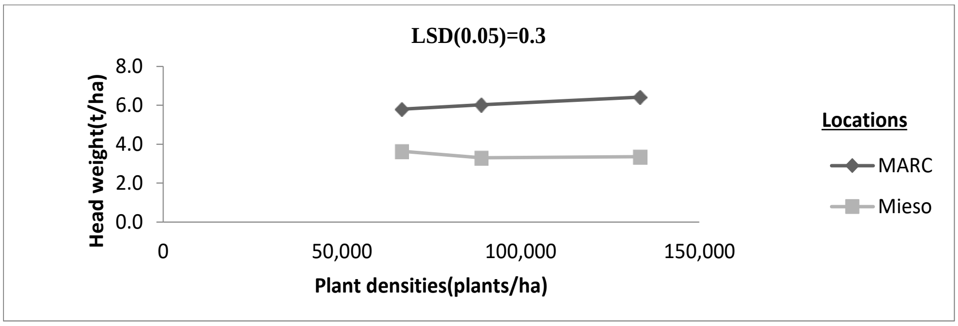

Figure 4: Head weight as affected by interaction of Location*density

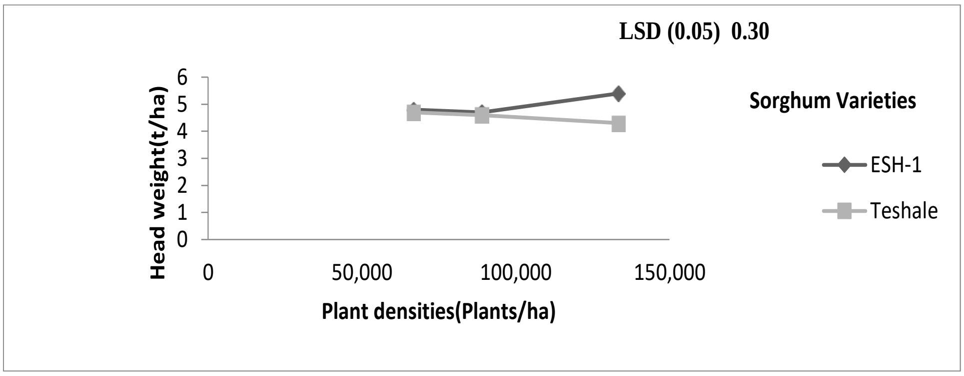

Figure 5: Head weight as affected by interaction of density *variety

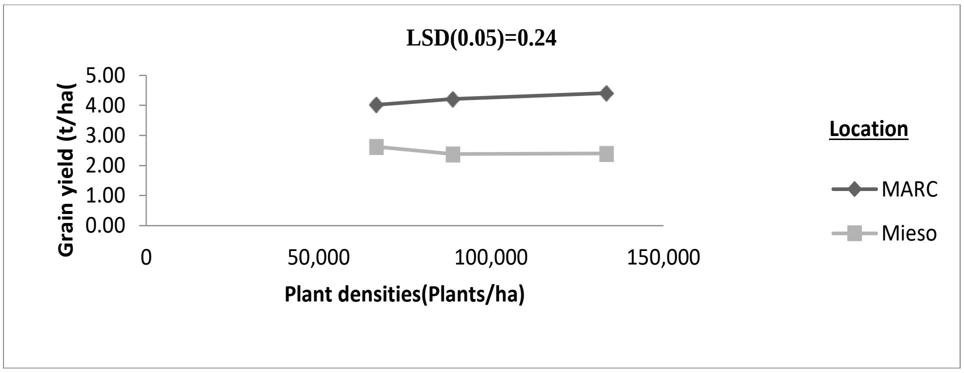

Figure 6: Grain yield as affected by interaction of Location * density

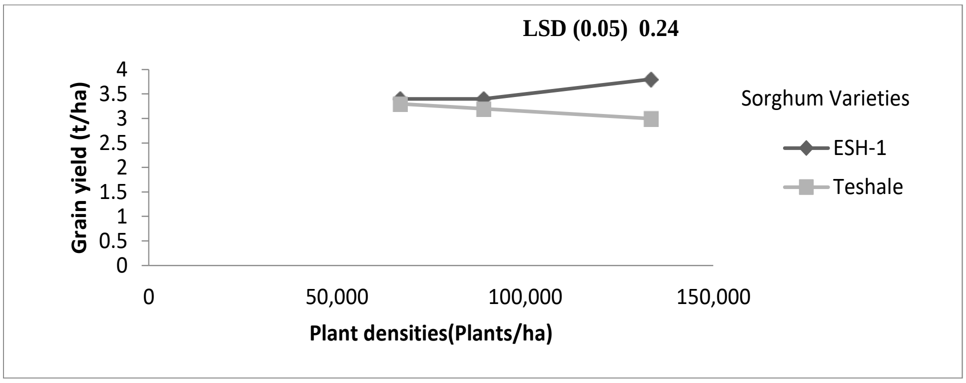

Figure 7: Grain yield as affected by interaction of density *variety

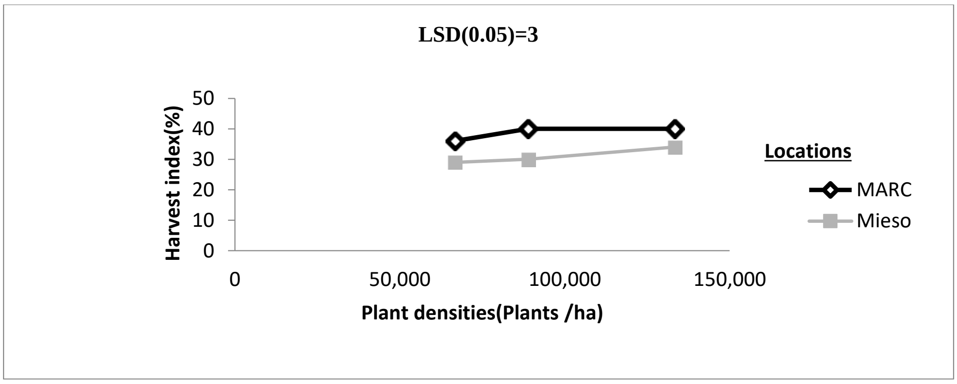

Figure 8: Mean harvest index (%) as affected by interaction of location by density

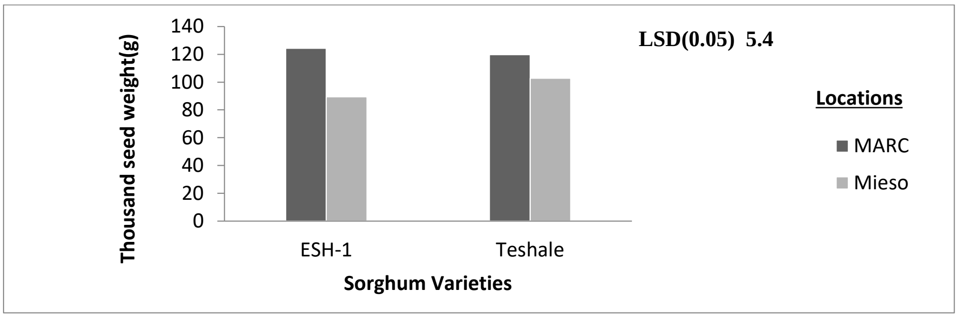

Figure 9: Thousand seed weight (g) as affected by interaction of locations and varieties.

Variety ESH-1 had given 24 and 16% more biomass yield at the highest density as compare to lowest and medium density of the same variety. Whereas, variety Teshale had given 6 and 2% biomass yield advantage at the highest density over lowest and medium densities respectively. Furthermore, variety ESH-1 had scored 14.6% biomass yield advantage at highest density as compared to variety Teshale at the same plant density. In line with the current study results Bayu et al. (2005); Abuzar et al. (2011) have concluded that increasing plant density would lead to increased biomass yield.

Head Weight (t ha-1)

Head weight (HW) was statistically significant for all the main effects except plant density and for all three-way interactions as well as for two-way interactions of location x plant density and variety x plant density (Appendix 2).As a main effect, head weight was superior for variety ESH-1 as compared to Teshale and at Melkassa as compared to Mieso. There also existed variability between the fertilized and unfertilized treatments for HW where the highest N-rate became superior to the other fertilizer rates. However, N-application rate at 69 kg N ha-1 was at par in head weight with that of 46 kg N ha-1 (Table 3).

Interaction of location * plant density had revealed higher head weight at Melkassa as compared to Mieso at all levels of plant densities (Fig. 4). Accordingly, greater head weight was recorded at Melkassa at the highest (133,333 plants ha-1) population while it was similar both at medium (88,888 plants ha-1) and lowest (66,666 plants ha-1) plant densities (Fig 4). On the other hand, though statistically at par among plant densities at Mieso better responses of density by location interaction was observed at the lowest (66,666 plants ha-1) plant density (Fig 4). Lower head weight at Mieso was due to terminal stress during later crop growth stage. In line with the current study result, Workayehu (2000): Zand and Shakiba (2013) had reported a positive response of plant density under non stress environment while a negative response under stress environment for grain yield and its component.

Variety * plant density interaction had indicated higher and significant head weight for variety ESH-1 as compared to variety Teshale at the highest plant density. However, it was similar both at the lowest and medium densities for both sorghum varieties (Fig 5).

A head weight advantage of 13 and 15 % were attained at highest density for ESH-1 variety as compared to lowest and medium densities, respectively. Teshale variety had recorded 13 and 7 % head weight advantage at lowest and medium plant densities as compared to highest plant density. Over all, head weight advantage of 26% was attained for ESH-1 variety as compared to Teshale at the highest plant density indicating that head weight increased with densities for ESH-1 while decreased for Teshale sorghum variety.

Grain Yield (t ha-1)

Variation in grain yield (GY) was statistically significant ($P<0.01$) for all the main effects (Location, Variety and N-application rate) except plant density and for all three-way interactions and two-way interactions of location * plant density and variety * plant density (Appendix 2).

As a main effect, maximum grain yield was recorded for ESH-1 sorghum variety as compared to Teshale and similarly grain yield was also higher at Melkassa as compared to Mieso. There was also variability in grain yield among fertilizer treatments where the highest N-rate become superior to the other fertilizer rates though N-application rate at 69 kg N ha-1 has no significant variation in grain yield with that of 46 kg N ha-1 (Table 3).

Interaction of location * plant density had revealed higher and significant grain yield at Melkassa as compared to Mieso irrespective of plant densities but the difference got wider as densities increased (Fig 6). Higher grain yield was recorded at the highest plant density while it was similar for medium and lowest as well as for highest and medium plant densities at Melkassa. In contrary to Melkassa, grain yield response to plant density by location interaction at Mieso had revealed better grain yield response at the lowest plant density which was significantly different from yield at medium density and at par with highest plant density (Fig 6).

Comparing grain yield at Melkassa and Mieso, Melkassa out yielded by 53,77and 84% respectively at lower, medium and higher plant densities. The reason why grain yield at Mieso was too low was partly due to terminal moisture stress and sucking insect pests at dough stage. In line with current study results Alderfasi *et al*. (2016) had reported maximum seed yield per hectare under highest plant density and better moisture supply condition.

Variety x plant density interaction had indicated higher grain yield for variety ESH-1 as compared to variety Teshale at the highest plant density. However, it was similar at both lower and medium densities for both sorghum varieties (Fig 7). Higher and significant grain yield was recorded at the highest plant density for variety ESH-1 while it was at par for lower and medium densities (Fig 7). On the other hand, though higher grain yield was attained for Teshale sorghum variety at the lowest plant density, grain yield was similar between highest density and medium density and also between medium and lowest density. Higher grain yield was attained for variety ESH-1 as compared to Teshale at consecutive plant density. ESH-1 gave a yield advantage of 3 to 26.7% as compared to Teshale with increasing plant densities from lower to higher plants per hector (Fig 7).

Overall, the variety ESH-1 responded positively to increasing planting density while Teshale failed to respond beyond medium plant density. In line with the current study results Workayehu (2000); Zand and Shakiba (2014) had reported a positive response of plant density for grain yield. On the other hand, Buah and Mwinkaara (2009) had shown that plant density had non-significant effect on grain yield.

Harvest Index (HI)

The analysis of variance (Appendix 2) revealed that harvest index was significantly varied for all the main effects except for nitrogen application rates. However, all the interaction effects except plant density * location interaction became non-significant.

Variety ESH-1 scored greater harvest index as compared to variety Teshale and similarly harvest index at Melkassa was higher than that of Mieso which might be due to relatively better rain fall at MARC as compared to Mieso. Moreover, it was higher at the lower plant density while similar at medium and higher density as well as between lower and medium densities (Table 3). The highest and lowest harvest indices of 39 and 31% were recorded at MARC and Mieso, respectively. Similarly, ESH-1 sorghum variety out yielded that of Teshale by 9% and in the same way the lowest density scored better HI as compared to the highest density with respect to HI (Table 3).

Harvest index at Melkassa was greater as compared to Mieso at all levels of plant densities (Fig 8) with greater difference at the medium density. Accordingly, the interaction of location by density had indicated that highest harvest index at highest plant density at both locations. However, similar results were attained at medium and higher densities at Melkassa while it was similar at lower and medium densities at Mieso (Fig 8). The reason why lower harvest index at lower plant density may be attributed to the fact that biological yield is favored as compared to the economical yield in response to lower plant stand.

Thousand Seed Weight

Thousand seed weight became significant (Appendix 2) only for the main effect of variety and location as well as for their interaction effect. As a main effect, heavier

TSW (g) was recorded for Teshale sorghum variety as compared to ESH-1 and similarly MARC seed was heavier than Mieso (Table 3). Heavier seed of Teshale rather than ESH-1 was due to the genetic difference of the varieties and lighter seed for Mieso was because of the problem of moisture stress during grain filling stage in the area.

Interaction of location by variety indicated highest thousand seed weight for both varieties at Melkassa as compared to Mieso (Fig 9). At Melkassa statistically no significant difference in thousand seed between the varieties. However, Teshale was superior than ESH-1 at Mieso which may be due to its early maturing character that help it to escape occurrence of terminal stress. ESH-1 had exhibited 39% weight loss while Teshale had lost only 17% due to stress at Mieso. In agreement to this study result Kimurto *et al*. (2003) had revealed that Kernel weight was affected more by moisture stress from grain filling to maturity all wheat genotypes and could have been caused by shortened grain filling periods and reduced stem reserve accumulation and remobilization for grain filling.

Economic Analysis

Marginal rate of return (MRR) analysis were done for the twenty four treatment combinations under varying costs and prices (Appendix 4 and 5) for each location. In economic analysis, it is assumed that farmers require a minimal rate of return of 100%, representing an increase in net return of at least 1 Birr for every 1 Birr invested, to be sufficiently motivated to adopt a new agricultural technology.

Under the combinations of N-fertilizer level, seed rate and variety, the highest net benefit of 38371 birr ha-1 was achieved at the highest plant density (133,333 plants ha-1) and application of 23 kg ha-1 N for ESH-1 sorghum variety with a marginal rate of return of 5341.6%). This implies that 53.42-birr gain per birr invested for inputs (variety, fertilizer and seed). It was followed by a net benefit of 2959.6-birr ha-1 and a MRR of 4934.78 % at the lowest density and nitrogen application rate of 46 kg N ha-1 for ESH-1 sorghum variety while Teshale variety had scored the highest MRR of 6208.78% under a combination of lowest plant density and application of 23 kg N ha-1at MARC (Appendix 4 and Table 4).

At Mieso the highest MRR (%) but lowest net benefit was attained for ESH-1 sorghum variety at the lowest plant density and no nitrogen application followed by the same density but for Teshale sorghum variety at lower (23 kg N ha-1) nitrogen application rate. Moreover, investing in the higher nitrogen rate (46 kg N ha-1) for ESH-1 sorghum variety was highly profitable (17147.2-birr ha-1) at the lowest density as compared to the same variety and density with no nitrogen application (control) and with variety Teshale at the same density and application of 23 kg N ha-1 at Mieso (Appendix 5 and Table 4).

Generally, at both locations the hybrid ESH-1 was economically feasible as compared to the open pollinated Teshale sorghum variety. However better return was achieved at the highest density and lower nitrogen rate at Melkassa and at lowest density and higher nitrogen application rate at Mieso. This may be due to high rain fall and low temperature at Melkassa relative to Mieso that help the plant to mobilize higher percentage of applied nutrient to maximize yield. For Mieso rain fall during the vegetative growth stage was optimum and can promote development of better leaf area and rooting depth under application of optimum amount of nitrogen. However terminal moisture stress during grain filling stage accompanied with higher temperature creates higher competition for moisture among plant densities where lower densities with better rooting depth become competent and also such stress gave rise to lower N use efficiency. For instance, agronomic use efficiency was lower by 12% at Mieso compared to Melkassa. In agreement to this study result Nielsen and Halvorson, (1991) have noted that increasing N rate would result in increased leaf area development and rooting depth thereby increased water-use efficiency. However, if there is severe moisture stress increasing N rate will increase the transpiration of the plant which may not be compensated by the increasing root volume

Table 4: Treatments with better net benefit and marginal rate of return at both locations

Locations	Varieties	Densities	N-rates	T GB	TVC	NB	MRR (%)
MARC	Teshale	88,888	0	29425	2624	26801	153
	Teshale	66,667	23	31779	2820	28959	6209
	ESH-1	66,667	46	33160	3600	29560	4935
	ESH-1	133,333	23	42361	3989	38372	5342
Mies	ESH-1	66,667	0	17364	2200	15164	4627
	Teshale	66,667	23	19008	2820	16188	2593
	ESH-1	66,667	46	20747	3600	17147	1857

Where TGB=Total Gross benefit, TVC= Total Variable cost, NB=Net benefit and MRR= Marginal rate of return.

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)

As the result revealed interaction of location and density significantly ($P < 0.05$) affected grain yield and its component. Accordingly, a significantly higher straw weight, grain yield and biomass were recorded at MARC for denser population. Similarly, interaction of variety x density was significantly ($P<0.05$) affected biomass, head weight and grain yield where better response of the interacting factors were seen at the highest density for ESH-1 sorghum variety implying that the hybrid sorghum variety can with stand crowding effect created due to intra specific competition. While the rest yield parameters (straw weight, harvest index and thousand seed weight) were not affected by this interaction.

On the other hand the main effects of location and variety were significantly affected all yield and yield components except straw weight. Plant density affected yield related parameters such as straw weight, biomass and harvest index while nitrogen application rate significantly affect grain yield, straw weight, biomass and head weight which increased with application of nitrogen rates.

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 1 Mean square for yield and yield components when combined across locations (2016)

S of variation	df	ASW	BM	HW	AGY	HI	TSW
L	1	2.64*	304.77***	252.30***	109.82***	0.204***	985.43***
Var	1	0.001	6.25**	6.42***	5.45***	0.036***	27.91*
IR	2	17.01***	22.76***	0.69	0.2	0.023***	9.37
NR	3	5.13***	28.23***	8.68***	4.92***	0.0022	9.76
Rep*L	4	1.17	1.33	0.65	0.14	0.0005	9.37
Var*IR	2	1.02	8.87***	3.84***	1.90***	0.0006	0.08
Var*NR	3	1.04	1.65	0.07	0.22	0.0019	5.24
IR*NR	1	0.45	1.01	0.22	0.31	0.0007	4.59
Var*IR*NR	2	0.55	1.06	0.63*	0.56**	0.0049	7.44
L*Var	6	0.8	1.8	0.24	0.11	0.0011	112.10***
L*IR	3	4.28**	9.34***	2.49***	1.29**	0.008*	11.61
L*NR	2	0.58	1.86	0.62	0.08	0.0021	5.14
L*Var*IR	3	0.3	3.64*	2.13***	0.60*	0.0005	7.46
L*Var*NR	6	0.98	5.25**	2.52***	0.79**	0.0016	2.02
L*IR*NR	6	2.91***	3.2	0.72*	0.66**	0.005	9.49
L*Var*IR*NR	6	0.99	1.72	0.2	0.12	0.0009	3.16
Error	91	0.58	0.93	0.28	0.18	0.0024	5.15
CV (%)		16.16	10.13	11.17	12.86	13.95	10.41

Where, df= degree of freedom, ASW= Adjusted Straw weight, BM= Bio mass, HW=Head weight, AGY= Adjusted grain yield, HI=Harvest index, TSW= Thousand seed weight.

Appendix 2 Economic analysis for Treatments at (MARC)

Varieties	Densities (Pt ha^{-1})	N-rates (Kg ha^{-1})	AGY (t ha^{-1})	GB(Gy) (Br/ha)	SW (t ha^{-1})	GB (SW)	T(GB) (Br ha^{-1})	TVC (Br ha^{-1})	NB (Br ha^{-1})	MRR (%)
Teshale	66,667	0	3.6	28732.1	5.8	2326.6	31058.7	2120	28938.7	
ESH-1	66,667	0	3.2	25903.7	5.1	2024.7	27928.4	2200	25728.4	d
Teshale	88,888	0	3.4	27185.9	5.6	2239.1	29425	2624.4	26800.5	152.598
ESH-1	88,888	0	3.2	25307.2	4.1	1629.4	26936.6	2744.4	24192.1	d
Teshale	66,667	23	3.7	29566.6	5.5	2212.2	31778.8	2820	28958.8	6208.78
ESH-1	66,667	23	2.9	23016.6	4.7	1871.8	24888.4	2900	21988.4	d
Teshale	133,333	0	3.3	26232	5.9	2365.8	28597.8	3128.9	25468.9	d
ESH-1	133,333	0	3.5	28240.1	6.3	2504.3	30744.4	3288.9	27455.5	d
Teshale	88,888	23	3.3	26174.4	5.5	2189.3	28363.7	3324.4	25039.3	d
ESH-1	88,888	23	3.7	29279.4	5.2	2071.2	31350.6	3444.4	27906.2	d
Teshale	66,667	46	3.3	26740.7	5.8	2311	29051.7	3520	25531.7	d
ESH-1	66,667	46	3.9	30859.8	5.7	2299.8	33159.6	3600	29559.6	4934.78
Teshale	133,333	23	3.8	30663.1	7.1	2830.9	33494	3828.9	29665.1	46.1283
ESH-1	133,333	23	4.9	39533.2	7.1	2827.4	42360.6	3988.9	38371.7	5341.61
Teshale	88,888	46	4.1	32506	5.8	2311.6	34817.7	4024.4	30793.2	d
ESH-1	88,888	46	4.5	36006.2	5.4	2146.9	38153.1	4144.4	34008.6	d
Teshale	66,667	69	4	32313.2	6	2387.7	34700.8	4220	30480.8	d
ESH-1	66,667	69	4.3	34517.5	5.4	2156.8	36674.3	4300	32374.3	d
Teshale	133,333	46	3.3	26590.3	6.4	2573.7	29164	4528.9	24635.1	d
ESH-1	133,333	46	4.4	35293.7	8.1	3256.9	38550.6	4688.9	33861.7	d
Teshale	88,888	69	4.3	34221.7	7.1	2824.6	37046.4	4724.4	32321.9	d
ESH-1	88,888	69	4	31676.2	7.1	2824.1	34500.3	4844.4	29655.9	d
Teshale	133,333	69	3.6	28657.3	7.3	2905.8	31563.1	5228.9	26334.2	d
ESH-1	133,333	69	4.9	38936	8	3219.5	42155.5	5388.9	36766.6	d

Where, AGY= Adjusted grain yield, SW= Straw weight, GB=Gross benefit, TVC= Total Variable cost, NB=Net benefit and MRR= Mariginal rate of return.

Appendix 3: Economic analysis for Treatments at (Mieso)

Varieties	Densities (Plants ha^{-1})	N-rates (Kg ha^{-1})	AGY (t ha^{-1})	GB(Gy) (Br/ha)	SW (t ha^{-1})	GB(SW) (Br ha^{-1})	T(GB) (Br ha^{-1})	TVC (Br ha^{-1})	NB (Br ha^{-1})	MRR (%)
Teshale	66,667	0	1.7	12179	3.3	1323.3	13502.4	2120	11382.4	
ESH-1	66,667	0	2.3	15782.8	4	1581.2	17364	2200	15164	4627.11
Teshale	88,888	0	1.4	9844.1	4.8	1927	11771.2	2624.4	9146.7	d
ESH-1	88,888	0	2.1	14698.1	5.5	2198.9	16897	2744.4	14152.6	d
Teshale	66,667	23	2.5	17171.2	4.6	1836.3	19007.5	2820	16187.5	2593.26
ESH-1	66,667	23	2.4	16688.2	4.9	1955.9	18644.1	2900	15744.1	d
Teshale	133,333	0	1.4	9946.4	4.7	1863.5	11809.9	3128.9	8681	d
ESH-1	133,333	0	2	13884.9	5.1	2055	15939.9	3288.9	12651	d
Teshale	88,888	23	2.1	14444.5	4.8	1912.4	16356.9	3324.4	13032.5	d
ESH-1	88,888	23	2.3	15949.2	4.9	1967	17916.1	3444.4	14471.7	d
Teshale	66,667	46	2.4	16952.3	5.4	2149.6	19101.9	3520	15581.9	d
ESH-1	66,667	46	2.7	19067.2	4.2	1680	20747.2	3600	17147.2	1856.62
Teshale	133,333	23	2.2	15120	4.9	1965.9	17085.9	3828.9	13257	d
ESH-1	133,333	23	2.6	17911.5	5.5	2189.8	20101.2	3988.9	16112.3	d
Teshale	88,888	46	1.8	12645.8	5.2	2092.6	14738.4	4024.4	10713.9	d
ESH-1	88,888	46	2.6	17998.2	6.7	2677.7	20676	4144.4	16531.5	d
Teshale	66,667	69	2.4	17112.7	5	2009.8	19122.6	4220	14902.6	d
ESH-1	66,667	69	2.7	18942.8	5	2011.4	20954.2	4300	16654.2	d
Teshale	133,333	46	2.3	16229	5.2	2088.9	18317.9	4528.9	13789	d
ESH-1	133,333	46	2.6	17976.2	5.8	2335.6	20311.8	4688.9	15622.9	d
Teshale	88,888	69	2.5	17451	5.7	2292.5	19743.5	4724.4	15019	d
ESH-1	88,888	69	2.7	18778.2	4.4	1771	20549.2	4844.4	15704.7	d
Teshale	133,333	69	2.3	16352.8	5.9	2348.5	18701.3	5228.9	13472.5	d
ESH-1	133,333	69	2.7	19052.1	5.8	2332	21384.1	5388.9	15995.2	d

Where AGY= Adjusted grain yield, SW= Straw weight, GB=Gross benefit, TVC= Total Variable cost, NB=Net benefit and MRR= Marignal rate of return.