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Tillage System and Fertilizer Rate Effects on Sorghum Productivity in the Central Rift Valley of Oromiya, Ethiopia

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ABSTRACT

Soil moisture and soil nutrient are the most sorghum yield limiting factors in semi-arid Oromiya. Hence, to identify appropriate crop management system for sorghum productivity, the field experiment was conducted in 2004 cropping season using factorial combination of four levels of tillage systems and four rates of fertilizer in spilt plot design at two locations. It was found that the stand count and height of sorghum varied significantly between locations, and lower stand count recorded at Wolenchity (55738 plant ha^{-1}) than at Malkassa (61548 plant ha^{-1}) while greater plant height was obtained at Wolenchity. Grain yield was significantly affected by location and fertilizer rate. Significantly ($P \leq 0.05$) higher grain yield was obtained at Wolenchity (2381 kg ha^{-1}) than that at Malkassa (1747 kg ha^{-1}). Grain yield achieved at the highest fertilizer rate of 57.4-64.4 kg N-P_2O_5 ha^{-1} was significantly ($P \leq 0.01$) higher than that at the current rate of 41-46 kg N-P_2O_5 ha^{-1}. The highest grain yield was recorded from tie-ridge plot but varied with fertilizer rate for each location. Harvest Index (HI) followed the same pattern as the grain yield. However, significantly ($P \leq 0.05$) higher stover and biomass yield of sorghum were obtained at Malkassa. These findings indicated that applications of fertilizer beyond 49.2-55.2 kg N-P_2O_5 ha^{-1} could give no significant yield advantage and thus, would not be economically feasible. The tie-ridge and reduced tillage tied furrow were encouraging but need further investigation to incorporate in sorghum cropping system.

Key words: harvest index, no-tillage, soil nutrient, soil moisture, tied-ridge

INTRODUCTION

Cereal crops account for over 86% of the area planted with food crops each year in Ethiopia (CSA, 2001). Sorghum (*Sorghum bicolor*) is one of the food crops that occupy 20% of the cultivated land under cereals (CSA, 2001). It is a staple food for a significant proportion of the lowland rural population. Known as the most drought tolerant crop, sorghum is grown as one of the major multipurpose cereals in the semi-arid areas. Close to one million hectares is developed and about 1.2 million tones are produced each year (Central Statistical Authority, CSA, 2001).

Despite the importance of sorghum crop, the productivity of sorghum is far below the genetic potential of the crop; the national mean yield has been estimated at about 1.3 t ha^{-1} on peasant farms (CSA, 2003). However, research results have shown that using improved varieties

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and management practices a sorghum grain yield of 4-5 t ha^{-1} can be achieved (Kidane *et al*., 2001). Such low yields and the production shortfall of sorghum cropping system in semi-arid areas are attributable to several factors. Among these, soil moisture stress, poor soil fertility, and pests are the most limiting factors (Kidane and Abuhay, 1997). Water stress is one of the major causes for low yields and total crop failure of cereals in the semi-arid areas of the country and soil fertility is the next constraint generally faced in such regions (Kidane *et al*., 2001). Hence, moisture stress and nutrient deficiency is critical in such soils and regions. Of all nutrients, nitrogen and phosphorus are the most crop growths and yield limiting factors in the country (Kidane *et al*., 2001). The study conducted in the central rift valley of Oromiya also emphasized that the principal constraints to increase crop production in semi-arid regions were the minimal combination of technologies for water availability, soil fertility, and new genetic material (Kidane *et al*., 2001). These insist the necessity of further studies in combined technologies for soil moisture conservation and fertilizer requirements for crop production of this region. Furthermore, the studies on combined influences of conservation tillage practices and soil fertility management have been minimal particularly in the dryland central rift valley of the country. Hence, the need for in-depth research on the combination of moisture conservation techniques and fertility management is unprecedented. This experiment was, therefore, initiated to undertake comprehensive studies with the objectives to identify the appropriate tillage systems and fertilizer rates for productivity of sorghum in the semi-arid, central rift valley of Ethiopia.

MATERIAL AND METHODS

The experiment was initiated in 2004 at Melkassa Agricultural Research Center (MARC) and Wolenchity research sub-station with the hypothesis that implementation of various conservation-tillage systems with different rates of fertilizer would result in better sorghum crop yield as compared to the conventional tillage. MARC and Wolenchity are located in the semiarid central rift valley of Oromiya. The MARC is located at 8° 24'N latitude and 39° 12'E longitude of 1550 m above mean sea level and Wolenchity at 8° 40'N latitude and 39° 26'E longitude of 1450 m above mean sea level. The soil of experimental sites are loam soil with 41% sand, 37% silt, 22% clay content and a pH of 6.41 for MARC, and sandy loam with 46% sand, 34% silt and 20% clay content with a pH of 6.64 for Wolenchity.

The combined effects of tillage systems and fertilizer rates on sorghum productivity trial consisted of 16 treatments comprising the factorial combinations of four levels of tillage management, i.e., Conventional Tillage (CT), Reduced Tillage (RT), No-Tillage (NT) and Tie Ridge (TR), and four levels of fertilizer, i.e., 0-0 (F_0), 41-46 (F_1), 49.2-55.2 (F_2), 57.4-64.4 (F_3) kg N-P_2O_5 ha^{-1}. The experiment was laid out in a 4 × 4 spilt plot design with three replications at two locations. The four-tillage systems were main plots of 14m × 16.5m ($231m^2$), and fertilizer rates placed in sub plots of 14m × 3.75m ($52.5m^2$). Pathways of 0.5m, 0.75m and 1m were placed between subplots, main plots and replications, respectively. A row spacing of 0.75m was used. The conventional tillage system consisted of four plowings with traditional oxen plow 'Maresha' (farmer's practice) to a depth of first pass approximately 8 cm and the other two passes perpendicular to the previous path with a final one at 20-cm depth prior to planting. In conventional tillage the first hand weeding was done 20-29 days after crop emergence (DAE) and the second hand weeding was done 40-50 DAE. In the no-tillage treatment, no soil disturbance was made except for seeding and fertilizer application. In the reduced tillage tied furrow, it was designed to use the ridger only after one pass with the ox-plow, then furrow ties were made during planting at 5 m interval. Both no-tillage and reduced tillage tied furrow plots were sprayed with glyphosate at a rate of 3 l ha^{-1} as preplanting herbicides. In tie ridge treatments, after three plowings with traditional ox plow, 35 cm high ridges were constructed 75 cm apart and cross-tied with soil bunds across the ridges with tie ridger at about every 5 m ridge length.

The fertilizer sources were urea (46% N) and diammonium phosphate (18% N and 46% P_2O_5). All of the P fertilizer and half of the N fertilizer were banded 5 cm below and 5 cm away from the rows as a basal application during planting. The rest half of the N fertilizer was applied when crop reached a knee height.

The improved sorghum variety, Meko-1, an early maturity type (60-70 days to anthesis) was used and the seeds were placed in rows and sorghum seedlings were thinned to one plant per hill 15 days after emergence to ensure the targeted population.

Data on various crop parameters were collected throughout the cropping season. Stand count at harvesting was recorded by counting the actual numbers of plant in the subplot area and expressed on hectare basis. Plant height for a randomly selected six plants (two plants within a 36 m segment of three rows) per sub-plot was determined. Sorghum heads and stover were harvested at the base of the lowest grain branch and at the ground surface level, respectively from areas of 13.5m^2 (6m × 2.25m) 105 DAE. Then sorghum head height was determined, sun-dried and weighed. Counting 250 grains in duplicates and weighing them on two decimal electronic balances, thousand seed weight was determined. The weights thus obtained were added and multiplied by two to reach 1000-seed fresh weight. They were then oven-dried at 55-60 °C and weighed again to determine moisture contents and to obtain 1000-seed dry weight. Grain yield and above ground biomass were determined from areas of 13.5 m^2. Grain yield was adjusted to 12.5% moisture content. A total above ground biomass, which included stover and whole panicles, was used to obtain biomass yield. Harvest index (HI) values were computed as the ratio of the mass of grain yield to total biomass (grain + stover).

Soil moisture at 0-15 depth was determined gravimetrically for each plot in the central row in two replications using a core sampler. Soil water data were recorded at various growth stages from planting until the physiological maturity of sorghum crop. Gravimetric water content was converted to a volumetric basis using bulk densities of soil core taken from each depth (Lopez *et al.*, 1996).

Data were subject to General Linear Models (GLM) Procedure using SAS Statistical Software (SAS, 1989). Duncan's Multiple Range Test (DMRT) and Least Significant Differences (LSD) were used for mean separation at the 0.05 or 0.01 probability levels.

RESULTS AND DISCUSSION

Stand count, plant height, head height and 1000-grain weight

Stand count of sorghum varied significantly between locations and different tillage systems but no significant differences among fertilizer rates could be detected. The data in Table 1 revealed that an estimated mean stand count of sorghum at Wolenchity was significantly lower than that observed at Malkassa. When the data for different fertilizer rates and both locations were combined the stand counts from conventional tillage and the reduced tillage tied furrow were significantly higher than those obtained from either no-tillage or tie-ridge tillage systems.

Slight difference was observed in plant height between locations, among different rates of fertilizer application and the interaction between location and fertilizer, and between tillage and fertilizer rates. Unlike the stand count of sorghum, the greater plant height was obtained at Wolenchity as compared to that obtained at Malkassa. The unfertilized plot had significantly lower plant height those that obtained from fertilized plots (Table 2).

Almost equal head height was observed at Wolenchity and Malkassa (Table 3). It was only reduced tillage that was varying across locations and had significantly higher head height at MARC than the corresponding tillage at Wolenchity.

The 1000-grain weight of sorghum was significantly affected by location ($P \leq 0.01$), and significantly higher 1000 seed weight was obtained at Wolenchity as compared to that obtained at Malkassa (Table 4).

The highest seed weight was observed on the tied ridge treatment with the highest rate of fertilizer application at Wolenchity and no-tillage treatment of the same rate of fertilizer at Malkassa. Sorghum grain weight reflects the crop growing

Table 1 Influences of tillage system on stand count (plant ha^{-1}) with varied locations.

Tillage system	Location		
	Wolenchity	Malkassa	Mean[1]
CT	64143	70952	67548 a
RT	63214	70863	67039 a
NT	52333	57292	54813 b
TR	43262	47083	45173 c
Mean	55738 B	61548 A	

[1] Means followed by common lowercase letters within a column do not differ significantly at 5% probability level of significance, and means followed by different uppercase letters within row differ significantly at 5% probability level of significance.

Table 2 Influences of fertilizer on plant height (cm) with varied locations.

Fertilizer rate	Location		
	Wolenchity	Malkassa	Mean
F_0	148.73	137.13	142.93b
F_1	149.40	146.88	148.13a
F_2	151.08	145.55	148.31a
F_3	155.58	141.38	148.48a
Mean	151.19	142.73	

[1] Means followed by common letters within a column do not differ significantly at 5% probability level of significance.

Table 3 Influences of tillage systems on head height (cm) with varied locations.

Tillage system**	Location		
	Wolenchity	MARC	Mean
CT	23.25AB*	23.25AB	23.25
RT	20.13B	24.25A	22.19
NT	23.38AB	22.88AB	23.13
TR	23.25AB	22.25AB	22.75
Mean	22.50	23.16	

* Means followed by the same common letters are not significantly different at 5% probability; ** CT = Conventional tillage, RT = Reduced tillage, NT = No-tillage, TR = Tie ridge

conditions during the grain filling period. The greater seed weight at Wolenchity than at Malkassa might be found due to mild water deficit during grain filling at the latter location.

Grain yield and harvest index of sorghum

Grain yield of sorghum were significantly affected by locations (Table 5). The sorghum grain yield obtained at Wolenchity was significantly higher ($P<0.05$) than that obtained at Malkassa. The greater grain yield at Wolenchity could be attributed to the higher precipitation before planting in June and there after (Figure 1) and fairly distribution of rainfall at interval of ten days particularly during anthesis and head formation (Figure 2). As a consequence, a remarkably greater percentage of soil moisture content was observed in the top 0-15 cm soil layer

Table 4 Influences of location, tillage system and fertilizer rate on 1000 seed weight (gm).

Tillage system	Fertilizer Rate			
	F_0	F_1	F_2	F_3
		Wolenchity		
CT	27.55 abc[1]	27.50 abc	31.15 ab	24.70 cd
RT	27.10 abc	24.70 cd	28.60 abc	24.65 cd
NT	26.75 abc	25.25 bcd	28.80 abc	19.60 d
TR	26.20 bc	26.50 abc	25.25 bcd	32.65 a
Mean	26.90	25.99	28.45	25.40
MARC				
CT	11.40 efg	6.50 fg	11.00 efg	11.85 ef
RT	7.05 efg	5.20 g	7.05 efg	6.45 fg
NT	7.80 efg	7.05 efg	10.65 efg	13.20 e
TR	7.85 efg	10.45 efg	6.55 fg	6.30 fg
Mean	8.53	7.30	8.81	9.45

[1] Means followed by common letters do not differed significantly at 5% probability level of significance.

Table 5 Influences of location, tillage system and fertilizer rate on grain yield (kg ha^{-1}).

Tillage system	Fertilizer Rate				Mean
wolenchity	F_0	F_1	F_2	F_3	
CT	2438	2343	2533	2533	2462
RT	1714	2343	2171	2286	2129
NT	2381	2191	2476	2476	2381
TR	2381	2400	2762	2667	2553
Mean	2229	2319	2486	2491	
Malkassa					
CT	1643	1833	1857	2036	1842
RT	1476	1762	1798	2143	1795
NT	1381	1417	1679	1691	1542
TR	1667	1655	1774	2143	1810
Mean	1542	1667	1777	2003	
Grand fertilizer mean[1]	1885 c	1993 bc	2131 ab	2247 a	

[1] Means followed by the same common letters are not significantly different at 5 % probability level of significance.

at Wolenchity (Figure 3) that led to higher grain yield. The difference in mean grain yield among fertilizer rate was highly significant (P<0.01). Thus, when the data from all tillage systems and both locations were combined, the mean grain yield at the highest fertilizer rate of 57.4-64.4 kg N-P_2O_5 ha^{-1} were significantly higher than that obtained at the current recommended rate of 41-46 kg N-P_2O_5 ha^{-1} and with no fertilizer application (Table 5). Although at the highest rate of fertilizer (57.4-64.4 kg N-P_2O_5 ha^{-1}) higher grain yield was obtained, the increment of yield between this highest rate and the next immediate down rate (49.2-55.2 kg N-P_2O_5 ha^{-1}) was not significantly different. This implied that applications of fertilizer beyond 49.2-55.2 kg N-P_2O_5 ha^{-1} could give no

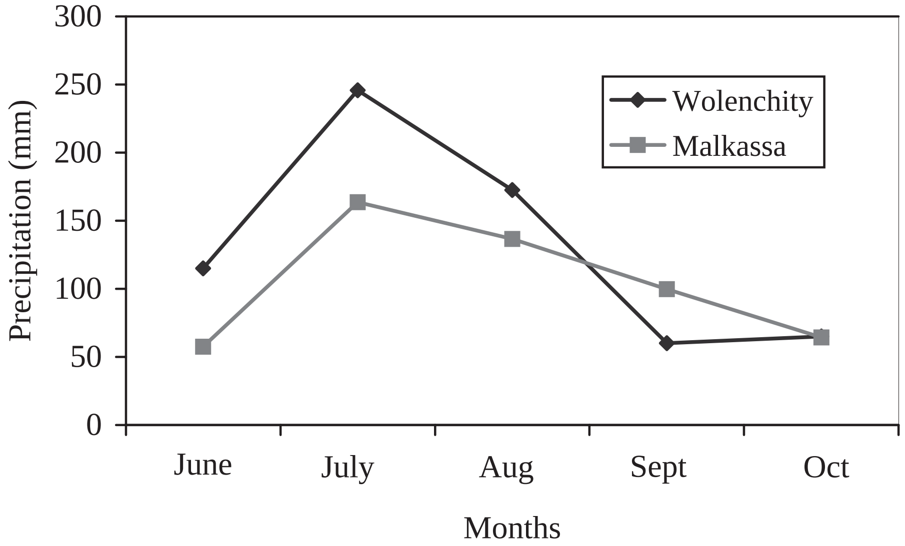

Figure 1 Precipitation per month before planting (June) and during sorghum growing season at Wolenchity and Malkassa in 2004.

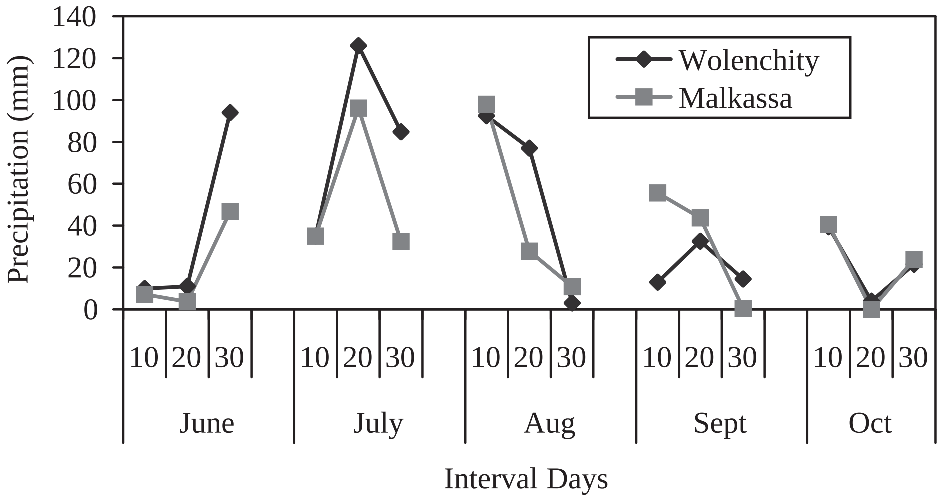

Figure 2 Rainfall distribution at 10 days interval of a month during sorghum growing season at Wolenchity and Malkassa.

significant yield advantage.

In the study, the highest sorghum grain yield was recorded due to tie-ridge tillage but varied with fertilizer rate for each location (2762 kg ha^{-1} grain at 49.2-55.2 kg N-P_2O_5 ha^{-1} for Wolenchity; and 2143 kg ha^{-1} at 57.4-64.4 kg N-P_2O_5 ha^{-1} for Malkassa). The yield obtained due to tie-ridge and reduced tillage tied furrow was equal at Malkassa. There were many other results which validated these findings, as it was evident from the extensive published data on tillage affecting crop yield that differed with soil conditions and environments (Lal, 1986; Triplett, 1986; Arnon, 1992; Dao, 1993; Radford *et al.*, 1995).

Harvest index of sorghum varied significantly with location (P<0.05) and fertilizer rates (P<0.01). The HI at Wolenchity was significantly higher than that at Malkassa and at the higher rate of fertilizer the greater HI was obtained (Table 6). The results obtained for HI followed the same pattern as the grain yield of sorghum. Thus, the attributive factors for grain yields could probably hold true for HI of sorghum. Indeed, HI is the relationship of grain yield to total above ground biomass. It measures dry matter partitioning to the grain (Huda *et al.*, 1987; Powell *et al.*, 1991). Although, harvest index was not affected by tillage and their interaction, it was greatest with tied ridging. As evident in (Figure 3) soil water content measured at the 0-15 cm depth of the soil profile during early growth stage of the crop (July 27), it was almost similar for all treatments. However, the tied ridged plots had the highest water content at the grain filling stage that could be the reason for the higher HI due to tied ridge tillage system.

Table 6 Influences of fertilizer rate on sorghum harvest index under varied locations.

	Wolenchity	MARC	Mean
F_0	0.407	0.234	0.321 b*
F_1	0.425	0.252	0.340 ab
F_2	0.442	0.256	0.349 ab
F_3	0.434	0.316	0.375 a
Mean	0.427	0.265	

* Means followed by the same common letters are not significantly different at 5% level of probability

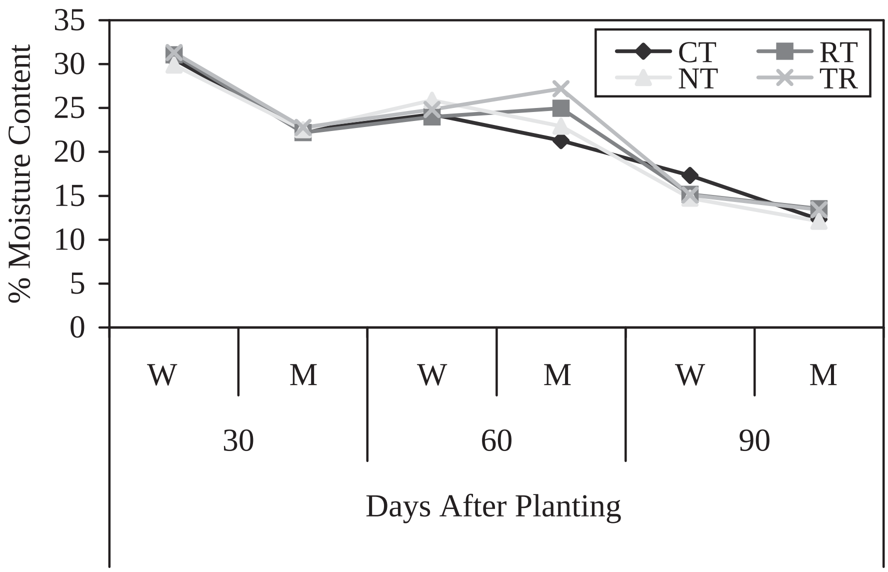

Figure 3 Soil moisture contents at 0-15 cm depth for conventional tillage (CT), reduced tillage (RT), no-tillage (NT), and Tie-ridge (TR) at Wolenchity (W) and Malkassa (M).

Stover and aboveground biomass

Contrary to the grain yield and HI, significantly higher ($P<0.05$) stover and biomass yield of sorghum were obtained at Malkassa than that obtained at Wolenchity (Table 7). Stover and aboveground biomass yield were not affected by tillage systems, fertilizer rates, and the interaction between them at the desired level of probability though the highest mean stover yields recorded in the plots received higher rate of fertilizer. The result also indicated that the above ground biomass yield of the crop generally followed the same trend as of stover yield, as most of the component which was mainly attributed by the stover of the sorghum crop.

Soil water content

During the months of July and August, the crop received about 246 and 172.5 mm of rain at Wolenchity, and 163.6 and 136.7 mm of rain at Malkassa, respectively. Generally there was good amount and distribution of rainfall for Wolenchity, therefore none of the management system brought about any difference in the soil water content except in tied ridged plots. Tied ridged was relatively better to augment more soil moisture content due to the enhanced infiltration rate of water than the other tillage treatments.

The differences in soil water content in the top 0-15 cm soil depth 30 days after emergence were related to differences in the amount of water infiltrated. The increase in soil water content stored was presumably related to the effect of tillage, which might improve bulk density and increase porosity. It was also related to furrow diking to effectively captured rainfall and prevented any possible loss of water in the form of runoff, thus, increasing the time of ponding and amount of water to be infiltrated (Krishna, 1989; Carter and Miller, 1991; Piha, 1993), despite little differences due to treatments observed. 60 days after crop emergence, the same trend of soil moisture pattern was evident, but some of the moisture had already depleted as reflected in low soil moisture content at Wolenchity while a bit higher moisture observed at Malkassa as the result of higher rainfall (56 mm) two days before the soil moisture sampling date. The soil water at this time at the depth of 0-15 cm for the tied ridge and reduced tillage tied furrow treatments were higher but were extremely low at the same depth for no-tillage and conventional tillage treatments. At the late growth stage of the crop (90 days after emergence), minimum and the same trend of soil water content was observed at both locations in the presence of small but equal amount of October rainfall (65 mm). Minimum amount of soil water was extracted at this stage of the crop growth as expected since the sorghum crop was near maturity period and did not use much of the water conserved.

Table 7 Effect of tillage systems on stover and above ground biomass of sorghum under varied locations.

Location	CT	RT	NT	TR	Mean
			Stover (kg ha^{-1})		
Wolenchity	3392.86	3166.67	2916.67	3273.81	3187.50
MARC	4997.04	4648.81	4708.33	5491.07	4961.31
Mean	4194.94	3907.74	3812.50	4382.44	
			Above ground biomass (kg ha^{-1})		
Wolenchity	5854.76	5295.24	5297.62	5826.19	5568.45
MARC	6839.29	6443.45	6250.00	7300.60	6708.33
Mean	6347.02	5869.35	5773.81	6563.39	

CONCLUSION

The stand count, plant height, grain yield, HI, stover and biomass yield of sorghum differed significantly between locations and some among fertilizer rates but no significant differences among tillage systems could be detected. Significantly greater stand count, stover and biomass yield of sorghum were obtained at Malkassa. Plant height, grain yield and harvest index of sorghum were significantly higher at Wolenchity. Grain yield and HI achieved at the highest fertilizer rate was significantly ($P<0.01$) higher than that at the current rate. The highest grain yield was recorded due to tie-ridge. The tie-ridge and reduced tillage tied furrow to conserve *in situ* soil moisture content and thereby increasing yield was found promising. Due attention for further investigation on the combined effect of conservation tillage and fertilizer rate for sustainable sorghum production system in the semi-arid of the country is suggested.

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