



Grain Yield and Economic Returns of Sesame (*Sesamum indicum* L.) Induced by *In-situ* Moisture Conservation and Sulfur Fertilization on Vertisol of Western Tigray, Ethiopia

Hailemariam Abbrha^{1,2*}

¹*Natural Resource Research Core Process, Humera Agricultural Research Center, Tigray Agricultural Research Institute, Ethiopia.*

²*Department of Land Resource Management and Environmental Protection, Mekelle University, Ethiopia.*

Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

A field experiment was conducted in 2015 and 2016 to evaluate the effects of in-situ moisture conservation using tied-ridging and conventional flatbed tillage practices combined with five sulfur fertilizer rates (0, 10, 20, 30 and 40 kg ha⁻¹). The experiment was laid out in a split plot design with three replications under rain-fed conditions. A newly released improved variety of sesame "Setit 1" was used as a test crop. Most of the agronomic data were collected at harvest. The collected data were analyzed using GenStat16 EdSP. The marginal rate of return was also estimated from the total revenue and total variable cost. Results show that there was a significant ($P < 0.05$) difference due to the combined effects of tied ridges and sulfur fertilizer rates on grain yield, days to 90% maturity, number of branches per plant, plant height, and number of capsules per plant except the days to 50% flowering in 2015. But, in 2016 there was no significant ($P > 0.05$) difference by the combined effect. The highest grain yield of 889.3 kg ha⁻¹ as well as the corresponding highest net revenue of

*Corresponding author: E-mail: hailemariamabbrha90@yahoo.com;

14,239.4 Ethiopian Birr was recorded at 40 kg S ha⁻¹ under tied ridges, but this was statistically not significant ($P > 0.05$) with the grain yield of 857.6 kg ha⁻¹ obtained using 30 kg S ha⁻¹ combined with tied ridges in 2015. However, in 2016 the significant difference resulted were due sulfur fertilizer but not due to the combined effect of tillage practices and sulfur fertilizer, hence calculating partial budget analysis is not necessary for statistically non-significant results. Therefore, sulfur fertilizer rate at 30 kg ha⁻¹ combined with tied ridges is most economically feasible technologies for the farmers to increase sesame productivity at Kafta Humera district.

Keywords: Grain yield; sulfur; sesame; tillage; Vertisol.

1. INTRODUCTION

Sesame (*Sesamum indicum* L.) is an ancient and important oilseed crop being cultivated for centuries, particularly in Asia and Africa [1]. In Ethiopia, sesame is produced by both small and large-scale farmers. In 2013, the total area under sesame was 0.30 million ha and a total of 0.22 million tons of yield was harvested. The average yield of sesame was 735 kg ha⁻¹. But compared to 2008, the total area and production have increased by 61.2% and 17.9% respectively, while the total productivity declined by 27.2% [2]. The challenges for the decrease in productivity are lack of appropriate agronomic qualities, low soil fertility, uncomfortable pH status and lack of varieties, which respond to inorganic fertilizers [3]. Among the inorganic fertilizers, sulfur is one of the important nutrients expected for increasing yield of the oilseeds.

Sesame produced in Humera is among the highest quality (color, aroma and oil content) seeds in the world [4,5]. However, sesame produced in Ethiopia in general and the Kafta humera district, in particular, is below the maximum production potential [6]. The productivity of sesame in the lowlands of western Tigray is still lower i.e. at 525 kg ha⁻¹ in a 2012/13-production season [4]. This is very low compared to the national average yield of about 757 kg ha⁻¹ during the same year [2]. Furthermore, this yield is low as compared to countries like Mozambique where productivity of sesame reaches up to 1500 kg ha⁻¹ [7]. Sulfur is the 4th major plant nutrient after nitrogen, phosphorous and potassium [8].

Oilseeds demand more sulfur than other crops, and its concentration and uptake vary with the availability of sulfur in the soil [9]. Inadequate sulfur supply can affect the yield and quality of the crop [10]. Sulfur deficiency results in reduced plant height and stunted growth weakened tillering capacity and delayed maturity [11]. Sulfur deficient plants to have less

resistance under stress conditions [12]. As oilseed crops produce seeds with a high content of protein and with relatively large quantities of sulfur-containing amino acids; they are particularly sensitive to sulfur deficiency [13]. Unluckily some Authors like [14] reported, areas of sulfur deficiency are becoming more prevalent throughout the world due to low sulfur returns with farmyard manure, cultivation of high yielding varieties and intensive agriculture, and declined use of sulfur-containing fungicides. Moreover, continuous use of N, P and K fertilizers result in sulfur deficiency along with very much deficit of organic matter that makes the situation the worst for oilseed crops. Similar studies in Ethiopia also indicated that application of N and P fertilizers without considering other nutrients such as K, S, and micro-nutrients led to the depletion of soil nutrients [15]. According to [11] sulfur application is a feasible technique to suppress the uptake of undesired toxic elements such as sodium and chlorine, because of the antagonistic relationship.

Various studies highlighted the significant increase in sesame production due to the interaction between combined inputs such as fertilizer and agronomic practices (e.g. [16]). However, previous evidence suggested that fertilizer applied in Ethiopia is not as effective as it was hoped due to low levels of soil organic matter content [17] and soil moisture stress. In Nigeria, [18] found the application of nitrogen and phosphorus fertilizers increased the productivity of sesame and gave better economic returns. Works on productivity and economic returns of sesame as influenced by in-situ moisture conservation and sulfur fertilizer rates at Kafta Humera, Ethiopia is lacking.

In addition to the effect of low soil fertility on sesame yield, drought stress had also significant effects on yield and yield components of sesame [19]. Similar findings were also reported by [20] that plant available soil moisture content as the

most limiting factor in the semi-arid Ethiopian highlands. He also put field rainwater harvesting technologies such as tied ridges as very crucial option to reduce drought risk in crop production. According to [20] research findings, such technologies achieved the goal of soil moisture content by retaining runoff within the field, thereby altering the soil water status within the root zone. In Kafta Humera district tied ridging is one of such techniques that are expected and being promoted to conserve rainwater in farmers' field.

According to [21], the practice of water conservation undoubtedly played a significant role in increasing agricultural production in arid, semi-arid and dry-humid areas where agricultural production is hampered by periodic droughts and low soil fertility status. Thus, in the study area, the problems of low soil moisture content and declining soil fertility especially low level of soil sulfur [22] needs to be addressed to increase soil quality and productivity of sesame on a sustainable basis. Low soil moisture content during the critical period of crop growth such as flowering and grain filling [23] and nutrient depletion [3] are among the most important contributors to low sesame productivity. In line with this, [22] indicated that sulfur is deficient in Kafta Humera but there is no evidence about the optimum sulfur fertilizer rate for maximum production. Soil moisture conservation using tied ridges and application of sulfur fertilizer are expected to contribute to a better productivity of sesame. However, the effect of these technologies either alone or in combination remained to be investigated. Thus, the overall objective of this study is to investigate the agronomic and economic performance of sesame as affected by in-situ moisture conservation and sulfur fertilizer rates in Kafta Humera under smallholder production system in rain-fed condition.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The study was conducted at Kafta Humera district, Northern Ethiopia during 2015 and 2016 cropping seasons. The district is found at a distance of 600 km to the west from Mekelle, the capital of the Tigray region, at 13°14' to 14°27' N and 36°27' to 37°32' E, with an elevation of 609 m a.s.l. (Fig. 1). The long-term (2007 to 2016) average annual rainfall of the area is 578 mm (Fig. 2). Most of the rainfalls ($ca=91\%$) are

concentrated during the main rainy season which extends from June to September. The rainfall fall is erratic and unpredictable in its distribution and occurrences. The area is characterized by very hot temperature. The maximum temperature ranges from 42°C in April to 33°C in August while the minimum temperature varies from 22.2°C in May to 17.5°C in July.

The dominant soil reference group of the area is Vertisol [24]. The study area is characterized by very deep soil (>150 cm) vertisol, slope gradient ranging from 0 to 5%, soils with clay texture with clay content of 40 to 60% are also common, moderately alkaline with pH of 8.5, electrical conductivity (EC) of 0.16 mmohs cm^{-1} , low organic matter (OM) content estimated at 0.98%, and Cation Exchange Capacity (CEC) of 30 meq/100 g of the soil. Kafta Humera is the most drought-prone areas of Tigray region; and the major crops grown in the area are sesame and sorghum, because of their drought tolerance compared to other crops. Limited moisture availability and dry spells limited the option for soil fertility restoration using crop rotation practices between the two dominant crops. The lack of crop rotation and increased mono-cropping of sesame further deplete soil nutrients while reducing biological nitrogen fixation that could be achieved by incorporating legumes crops in the rotation system. According to [25], the total amount of seasonal rainfall depth required for the growth and production of sesame crop ranges from 600 to 1000 mm, depending on the cultivar and the agro-climatic conditions.

The long-term (2007 to 2016) average annual rainfall (Fig. 2) of the area is 578 mm. However, the rainfall during the growing season of 2015 was only 480 mm. Besides, the low rainfall amount in the 2015 cropping season the rainfall started very late (at the end of June) while the normal starting period is at the beginning of June and extends to the end of September and ceased late (at the beginning of October) Fig. 2. This is a short rainy season with erratic rainfall is highly concentrated in August which is not enough for sesame crop to mature well as the length of growing period for sesame ranges from 90 to 105 days [26]. However, the rainfall of 2016 was 615 mm and it is well distributed during the cropping season in contrast to the rainfall in 2015. According to [25], the total amount of seasonal rainfall depth required for the growth and production of sesame crop ranges from 600 to 1000 mm, depending on the cultivar.

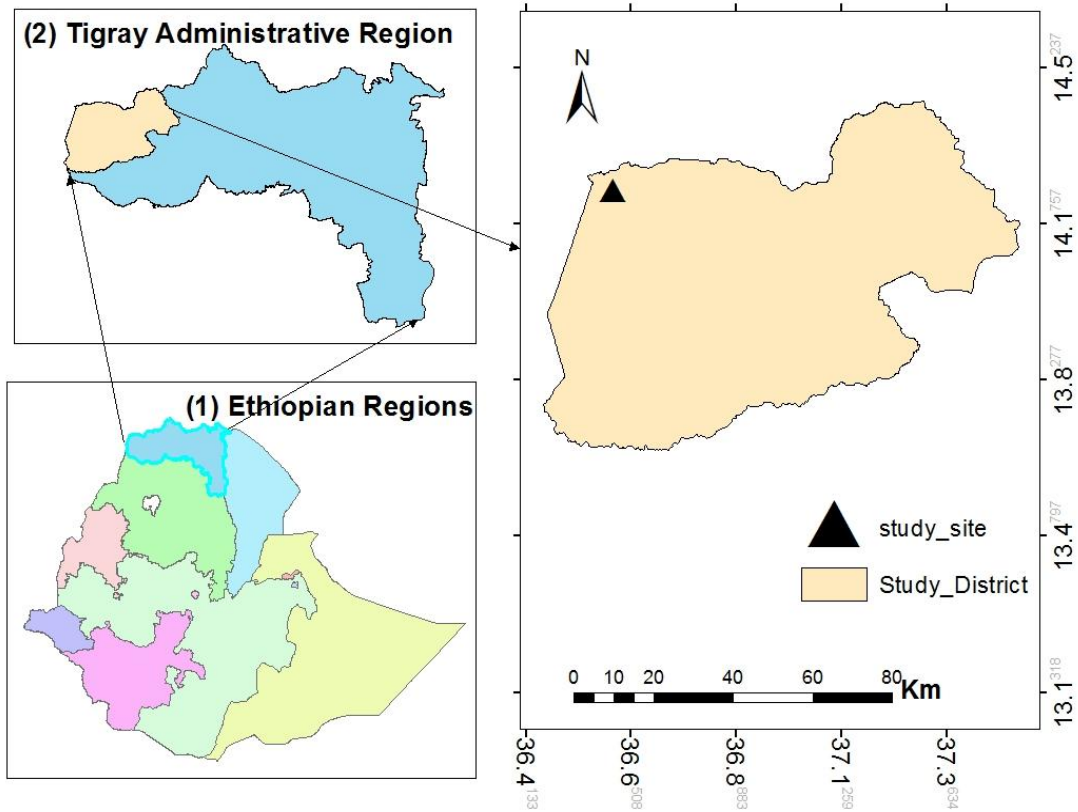


Fig.1. Map of the study area ((1) Ethiopia, (2) Tigray, and the study district is Kafta Humera)

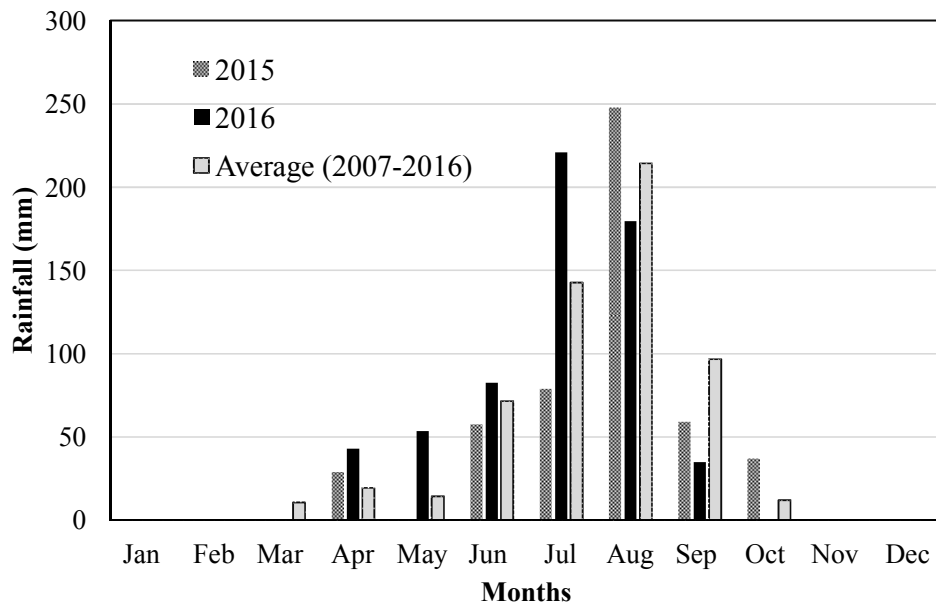


Fig. 2. Monthly rainfall depth (mm) during the experimental years in 2015 and 2016 compared to the long-term (2007 to 2016) average monthly rainfalls depth

2.2 Experimental Design

The field experimental set-up employed in this study was a split plot design with three replications under rain-fed conditions to evaluate two tillage practices i.e. closed end tied ridges (conservation tillage practice) versus conventional tillage practice i.e. flatbed and five sulfur fertilizer rates 0, 10, 20, 30 and 40 kg S ha⁻¹. The layout and experimental design had 1.5 m spacing between replications, 1 m between plots. The main plot size was 3 m × 2.8 m for each of the 5 treatments (42 m² in total), sub-plot size 2.8 m × 3 m (8.4 m² each) with 7 rows, net plot size 2 m × 3 m (6 m²) with 5 rows. The spacing between plants (after thinning) was 10 cm, between rows 40 cm, between tied ridges 40 cm and between ties was 300 cm.

Calcium sulfate (CaSO₄) was used as the source of sulfur fertilizer with 19% sulfur purity. The 46 kg N ha⁻¹ and 46 kg P₂O₅ ha⁻¹ were applied for each experimental plot as a basal application. Sources of N and P were Urea and TSP (Triple-super phosphate) respectively. Nitrogen was applied in a split dose where half of the dose was applied during planting and the remaining half 35 days after germination to simulate farmers' practices in the area. Whilst P and S were applied in full dose at planting time. The planting method was row planting for both tillage treatments i.e. with tied ridges and flatbed practices. A newly released improved variety of *Sesamum indicum* L. by Humera Agricultural Research Center (HuARC) named *Setit 1* was used as a test crop and the seeds were planted by drill at 3-5 cm depth.

2.3 Soil Sampling and Analysis

A fresh pit with 50 cm width by 100 cm length and 100 cm depth was opened and three undisturbed soil samples were collected using core samplers at depths 10 cm, 30 cm and 50 cm for analyzing soil bulk density in the root zone. A composite disturbed soil sample was also collected from each plot using soil auger from the top 20 cm soils depth before planting for characterization of selected soil physical and chemical properties. The collected samples were properly labeled, packed and transported to Mekelle Soil Research Center's laboratory.

Particle size distribution was determined using the Bouyoucos hydrometer method [27]. Bulk density was determined using core method at a known volume. Field capacity (FC), permanent wilting point (PWP), and the plant available soil water holding capacity were obtained using SPAW hydrology software, field, and pond hydrology version 6.02.74. Bulk density was calculated from the ratio of the oven-dried mass of soil and the bulk volume. Total porosity (f) of the soil sample was estimated on the basis of measured bulk density (ρ_b) and average particle density (ρ_p) assumed for mineral soils as 2.65 g cm⁻³ as:

$$f = [1 - \rho_b/\rho_p] \times 100 \quad (1)$$

The pH of the soil was measured in the supernatant suspension of a 1: 2.5 soil to water ratio using a pH meter [28]. Electrical conductivity (EC) was measured at 1:2.5 soils to water suspension according to the method described by [29]. Organic carbon was determined by the Walkley and Black method

Table 1. Description of the treatments

Main plots	Sub-plots	Treatment combinations	Treatments
Moisture conservation	Fertilizers		
Tied ridge (M1)	S0	M1S0	T1
	S1	M1S1	T2
	S2	M1S2	T3
	S3	M1S3	T4
	S4	M1S4	T5
Conventional tillage (M0)	S0	M0S0	T6
	S1	M0S1	T7
	S2	M0S2	T8
	S3	M0S3	T9
	S4	M0S4	T10

Note: (S0=0, S1=10, S2=20 S3=30and S4=40) are sulfur fertilizer rates in kg S ha⁻¹. M1= plot with tied ridges, M0= Flatbed i.e. without tied ridges

[30]. Total nitrogen was determined using the Kjeldahl method [31]. Available P was determined following the Olsen method [32]. The CEC of the soil was determined by ammonium acetate method [33] and soil available sulfur was determined by turbidity method [34].

2.4 Data Collection Techniques and Procedures

Yield and yield components were recorded from the central five rows of the net plot area. Measurements were not conducted from the borders to avoid border effect. Plant data were collected at 90% physiological maturity except days to 50% emergence (DE) and days to 50% flowering (DF). Five plants were randomly taken from each row then plant height, number of branches and number of capsule per plant were recorded. The five experimental rows of each plot were harvested, tied in bundles and were made to stand separately and dried in the sun until the capsules opened. After 15 days from harvest, the bundles were dried out fully and the capsules were opened, total aboveground biomass was measured for each bundle and then tipped out onto the plastic mat and threshed. The seeds from each net plot area were weighed for grain yield determination.

Description of the measured yield and yield components:

Days to 50% emergence (DE): This parameter of the plant was determined by counting the number of days from sowing to the time when 50% of the plants started to emerge the tip of the leaf through visual observation.

Days to 50% flowering (DF): The number of days from seedling emergence to 50% flowering of the population in each plot was recorded.

Days to 90% maturity (DM): The number of days from seedling emergence to 90% of the plants in each plot had fully matured.

A number of branches (Nb): This parameter was measured from five randomly selected plants of the 5 harvestable rows of the plot by counting the number of branches of the plant excluding the main stem at 90% maturity.

Plant height at maturity (Ph): Plant height was measured from five randomly selected plants of the 5 harvestable rows of the plot with the help of

meter tape from the ground surface to the tip of the plant.

A number of capsules (Nc): The total numbers of capsules were counted from five randomly selected plants at maturity for each plot.

Grain yield (GY): The total grain yield harvested from the net plot area was weighed using a sensitive balance after threshing and extrapolated (converted) from plot to hectare level.

For profitability of sesame production using different tillage and fertilizer technologies, marginal rate of return (MRR) was calculated as the change in net revenue (NR) divided by the change in total variable cost (TVC) of the successive net revenue and total variable cost levels [35].

$$\text{MRR}(\%) = \left(\frac{\Delta \text{NR}}{\Delta \text{TVC}} \right) * 100 \quad (2)$$

During partial budget analysis labor costs were calculated by assuming 50 ETB per day per person while revenue was calculated by assuming 18 ETB kg⁻¹ of sesame grain yield. Costs of CaSO₄ i.e., 3.60 ETB kg⁻¹ were calculated based on market price information in Humera. Common expenses (same for treated and untreated plots) such as sowing, weeding, cost of pesticides and herbicides are not included in the calculation of partial budget analysis (Table 5).

2.5 Statistical Analysis

Yield and yield components data were subjected to statistical analysis. Analysis of variance (ANOVA) was carried out using GenStat16th edition [36] statistical software programs. Statistical significant difference between and among treatment means was assessed using least significant difference (LSD) at 5% level of significance [37].

3. RESULTS

3.1 Selected Initial Soil Physical and Chemical Properties of the Experimental Site

The selected physical and chemical properties of the soil before planting are presented in Table 2. The results of the laboratory analysis for physical properties such as texture, bulk density, total

porosity and water content of the soil shows significant difference in the root zone (0-20, 20-40 and 40-60 cm) depths. Results of the chemical property of soil based on soil samples collected before planting are also presented in Table 2.

3.2 Effect of Tillage Practices and Sulfur Fertilization on Yield and Yield Components of Sesame

The results of yield and yield components of sesame crop in 2015 and 2016 years are

presented in Table 3. The results of grain yield and the different yield indicating plant parameters measured at plots with M1 is significantly ($P < 0.05$) different compared to plots with M0 (Table 3A). However, results in Table 3B have not significant ($P > 0.05$) difference in yield and yield components of sesame due to water conservation techniques. But, sulfur fertilizer levels have shown a significant effect on most of the growth parameter, yield, and yield attributing components of sesame except DE and DF in both years (Table 3A and Table 3B).

Table 2. Physical and chemical properties of the soil at the experimental site

Depth (cm)	Particle size (%)			Textural class	BD (g cm ⁻³)	TP (%)	Water content		
	Sand	Silt	Clay				FC(%)	PWP(%)	AWHC (cm/cm)
0-20 (n=3)	26	19	55	Clay	1.37	48	44.2	32.5	0.12
20-40 (n=3)	24	19	57	Clay	1.48	44	44.3	33.6	0.11
40-60 (n=3)	22	21	57	Clay	1.50	43	42.9	33.5	0.09
Soil chemical properties				Average Value	Critical level	Reference			
Soil pH 1:2.5 (H ₂ O)				8.50	6.6-7.3	[22]			
EC 1:2.5 (dS m ⁻¹)				0.16	>2	[22]			
CEC (meq/100 g of soil)				30.00	<25	[38]			
OM (%)				0.98	<2.59	[39]			
Total N (%)				0.04	<0.2	[38]			
Available P (mg kg ⁻¹)				2.78	<10	[38]			
Available S (mg kg ⁻¹)				1.35	<20	[22]			

BD= Bulk density; TP = Total porosity; FC = Field capacity; PWP = permanent wilting point; AWHC = Available water holding capacity, EC = Electrical conductivity, CEC = Cation exchange capacity, OM (%) = Percent organic matter

Table 3. The agronomic response of sesame to water conservation technique and sulfur

A. 2015

Parameter	DE (No)	DF (No)	DM (No)	Nb(plant ⁻¹)	Ph (cm)	Nc (plant ⁻¹)	GY (kg ha ⁻¹)
Water Conservation Technique (WCT)							
M1	4.4	41.0	85.5	2.9	96.2	42.6	748.2
M0	4.7	37.7	80.5	2.2	73.1	32.3	550.6
LSD	ns	3.0	4.4	0.2	14.9	3.9	107.8
CV%	1.8	2.2	1.5	1.7	5.0	3.0	4.7
Sulfur Levels [SL(kg ha⁻¹)]							
0	4.5	38.7	86.8 ^a	2.0 ^c	68.4 ^b	29.1 ^c	479.4 ^d
10	4.8	38.3	85.7 ^{ab}	2.5 ^b	85.9 ^a	36.1 ^b	598.9 ^c
20	4.6	39.2	81.0 ^{bc}	2.7 ^b	88.9 ^a	38.5 ^{ab}	683.4 ^b
30	4.3	40.0	80.7 ^c	3.0 ^a	93.2 ^a	41.8 ^a	727.3 ^a
40	4.5	40.7	80.7 ^c	2.7 ^b	86.9 ^a	42.3 ^a	758.1 ^a
LSD	ns	ns	3.1	0.3	9.69	4.8	32.80
CV%	7.5	5.4	3.1	8.4	9.4	10.5	4.1
Significance							
WCT	ns	*	*	**	*	**	*
SL	ns	ns	*	**	**	**	**
WCT x SL	*	ns	*	**	*	**	*

B. 2016

Parameter	DE (No)	DF (No)	DM (No)	Nb (plant ⁻¹)	Ph (cm)	Nc (plant ⁻¹)	GY (kg ha ⁻¹)
Water Conservation Technique (WCT)							
M1	4.3	43.6	90.	1.9	119.0	29.7	876.1
M0	4.7	43.3	89.	2.0	120.3	30.5	885.3
LSD	ns	ns	ns	ns	ns	ns	ns
CV%	9.4	1.0	1.2	5.4	1.2	2.5	6.8
Sulfur Levels [SL (kg ha⁻¹)]							
0	4.7	43.5	90	1.7 ^d	108.1 ^c	23.5 ^c	605.5 ^d
10	4.3	43.3	89	1.8 ^c	117.7 ^b	28.8 ^b	782.2 ^c
20	4.5	43.5	89	1.9 ^b	121.4 ^{ab}	31.1 ^{ab}	948.4 ^b
30	4.7	43.3	89	2.2 ^a	125.4 ^a	33.7 ^a	1031.7 ^a
40	4.5	43.5	89	2.1 ^a	125.7 ^a	33.4 ^a	1035.7 ^a
LSD	ns	ns	ns	0.10	4.4	2.8	75.3
CV%	8.5	0.9	1.2	4.1	3.0	7.5	7.0
Significance (p=0.05)							
WCT	ns	ns	ns	ns	ns	ns	ns
SL	ns	ns	ns	**	**	**	**
WCT x SL	ns	ns	ns	ns	ns	ns	ns

DE= Days to 50% emergence, DF=Days to 50% flowering, DM= Days to 90% maturity, Nb= Number of branches, Ph= Plant height, Nc= Number of capsules, GY=Grain yield, AGB= Aboveground biomass, HI= Harvest index, M1= plot with Tied ridges, M0= Flatbed or plot without tied ridges, ns = none significant, * = significant, ** = highly significant. Means with the same letter across column of the treatments are not significantly different at P < 0.05

3.3 Combination of Tillage Practices and Sulfur on Yield and Yield Components of Sesame

The results of the combined effects of tillage practices and sulfur fertilizer rates are on yield and yield components of sesame in 2015 and 2016 years are presented in Table 4. Crop

growth parameters, as well as yield and yield attributes, are significantly (P < 0.05) affected by the factorial combination of tillage and sulfur rates except for DF (Table 4A). However, the results in Table 4B shows no significant (P > 0.05) difference by the combined effects of tillage practices and different rates of sulfur fertilizer (Table 4B).

Table 4. Combined effect of tillage practices and sulfur fertilizer rates

A. 2015

Treatment combinations	DE (No)	DF (No)	DM (No)	Nb (plant ⁻¹)	Ph (cm)	Nc (plant ⁻¹)	GY (kg ha ⁻¹)
M1S0	4.0 ^c	40.0	91.3 ^a	1.9 ^{ef}	72.0 ^c	30.7 ^{ef}	528.2 ^{de}
M1S1	5.0 ^a	39.7	90.0 ^a	2.4 ^{cd}	94.3 ^b	37.9 ^{cd}	672.1 ^c
M1S2	5.0 ^a	40.0	82.7 ^b	3.0 ^b	100.5 ^{ab}	43.4 ^{bc}	793.9 ^b
M1S3	4.0 ^c	42.0	82.3 ^b	3.7 ^a	108.3 ^a	49.5 ^{ab}	857.6 ^a
M1S4	4.0 ^c	43.3	81.0 ^b	3.3 ^b	105.9 ^{ab}	51.6 ^a	889.3 ^a
M0S0	5.0 ^a	37.3	82.3 ^b	1.9 ^f	64.8 ^c	27.4 ^f	430.6 ^f
M0S1	4.7 ^{ab}	37.0	81.3 ^b	2.6 ^c	77.5 ^c	34.3 ^{de}	525.8 ^e
M0S2	4.3 ^{bc}	38.3	79.0 ^b	2.3 ^{cde}	77.3 ^c	33.6 ^{def}	572.9 ^d
M0S3	4.7 ^{ab}	38.0	79.0 ^b	2.2 ^{def}	78.1 ^c	33.3 ^{def}	597.0 ^{cd}
M0S4	5.0 ^a	38.0	80.3 ^b	2.0 ^{ef}	67.9 ^c	32.9 ^{def}	626.9 ^c
Mean	4.6	39.4	83.0	2.5	84.6	37.5	649.4
LSD	0.5	ns	4.5	0.34	14.40	6.32	82.01
CV%	7.5	5.4	3.1	8.4	9.4	10.5	4.1

B. 2016

Treatment combinations	DE (No)	DF (No)	DM (No)	Nb (plant⁻¹)	Ph (cm)	Nc (plant⁻¹)	GY (kg ha⁻¹)
M1S0	4.7	43.7	91	1.7	107.2	22.7	580.2
M1S1	4.3	43.7	89	1.8	114.5	28.9	804.8
M1S2	4.0	43.7	90	1.9	120.8	30.2	950.0
M1S3	4.3	43.3	89	2.1	125.2	33.2	1024.2
M1S4	4.3	43.7	89	2.1	127.5	33.7	1021.6
M0S0	4.7	43.3	89	1.6	108.9	24.4	630.9
M0S1	4.3	43.0	88	1.9	120.9	28.7	759.6
M0S2	5.0	43.3	89	2.0	122.1	32.0	946.9
M0S3	5.0	43.3	89	2.3	125.5	34.2	1039.3
M0S4	4.7	43.3	89	2.2	123.8	33.1	1049.9
Mean	4.5	43.4	89.	2.0	119.7	30.1	880.7
LSD	ns	ns	ns	ns	ns	ns	ns
CV%	8.5	0.9	1.2	4.1	3.0	7.5	7.0

M1=tied ridges, M0=flatbed and S=Sulfur), DE= Days to 50% emergence, DF=Days to 50% flowering, DM= Days to 90% maturity, Nb= Number of branches, Ph= Plant height, Nc= Number of capsules, GY=Grain yield, AGB=Above ground biomass, HI= Harvest index, means with the same letter are not significantly different at $P < 0.05$

3.4 Partial Budget Analysis

The results of the partial budget analysis by the combined effects of tillage practices and sulfur fertilizer rates for the year 2015 are presented in Table 5. Tied ridge tillage has a higher positive effect on sesame productivity and profit earnings of the farmers than flatbed at different sulfur fertilizer application rates. The marginal rate of return at the sulfur application rates of 10, 20, 30, and 40 kg S ha⁻¹ are all greater than 100%. As the MRR for these rates is greater than 100%, investing extra money is economical. However, high MRR was found at 20 kg S ha⁻¹ in both tied ridges and flatbed (Table 5). While the partial budget analysis for 2016 is not included in this study, because the combined use of tillage practices and sulfur fertilizer rates have no significant differences in 2016 rainy season (Table 4B) and then computing partial budget analysis for statistically none significant results is not common.

4. DISCUSSION

4.1 Effect of Tillage Practices and Sulfur Fertilization on Yield and Yield Components of Sesame

The results of the effects of tillage practices and sulfur fertilizer rates separately and in combination on yield and yield components of sesame in 2015 (Table 3) and 2016 (Table 4) years are presented from section 4.1.1 to 4.1.7.

4.1.1 Days to 50% emergence

The effects of WCT and SL on DE are presented in Table 3A Table 3B. The effect of WCT on DE has not significant ($P > 0.05$) effect. Similarly, application of different rates of sulfur fertilizer did not show significant ($P > 0.05$) difference on DE of sesame. The absence of the effect of sulfur at DE is probably attributed to the fact that during germination, seedlings depend solely on stored food than on externally applied nutrients. Because of this, the significant variation might not be observed on DE to sulfur applications. This is in agreement with the findings of [40] who reported that plants depend mostly on stored food or reserved food for their germination than external nutrients until they become autotrophic and start to demand nutrients.

The combined effect of WCT and SL have significant ($P < 0.05$) effect on sesame seed emergence Table 4A. DE generally took 4 to 5 days (Table 4A). This is in line with the range of days reported by [41] who indicated that seedling emergence for sesame started after 3 days and completed within 7 days of sowing under optimum conditions for germination. This shows the synergetic effect of tied ridges with moisture conservation and sulfur fertilizers.

4.1.2 Days to 50% flowering

DF Table 3A shows statistically significant ($P < 0.05$) difference due to WCT in the current study. The results indicated that M1 delayed DF about

Table 5. Partial budget analysis of tillage practices and sulfur fertilizer rates in 2015 growing season

S fertilizer levels (kg ha⁻¹)	Fertilizer cost (Birr)	Tillage and labor cost (Birr)	Transport and labor cost (Birr)	Total variable cost (TVC) (Birr)	Grain yield (kg ha⁻¹)	Total revenue (TR) (Grain yield*18 (Birr)	Net revenue (TR-TVC) (Birr)	Marginal rate of return (MRR)(ratio)	MRR (%)
Tied ridges (M1)									
0	0.0	1400.0	0.0	1400.0	528.2	9507.6	8107.6	-	-
10	36.0	1600.0	21.0	1657.0	672.1	12097.8	10440.8	9.08	908
20	72.0	1600.0	22.0	1694.0	793.9	14290.2	12596.2	58.25	5825
30	108.0	1600.0	23.0	1731.0	857.6	15436.8	13705.8	29.99	2999
40	144.0	1600.0	24.0	1768.0	889.3	16007.4	14239.4	14.42	1442
Flatbed (M0)									
0	0.0	1200.0	0.0	1200.0	430.6	7750.8	6550.8	-	-
10	36.0	1400.0	21.0	1457.0	525.8	9464.4	8007.4	5.67	567
20	72.0	1400.0	22.0	1494.0	572.9	10312.2	8818.2	21.91	2191
30	108.0	1400.0	23.0	1531.0	597.0	10746.0	9215.0	10.72	1072
40	144.0	1400.0	24.0	1568.0	626.9	11284.2	9716.2	13.55	1355

three days than the M0. This might be due to M1 retained moisture and then the availability of more moisture delays DF. But, Table 3B shows statistically not significant ($P > 0.05$) difference. This is because the soil moisture of 2016 is not scarce so as to bring significant difference by WCT. Although, sesame is considered as drought tolerant once established as compared to most crops [23], growth can be greatly reduced by drought, particularly at 30 to 40 days after sowing and when flowering and grain filling has been commenced. On the other hand, there was no significant ($P > 0.05$) difference on sesame at DF due to sulfur fertilizer applications both in Table 3A and Table 3B. Similarly, the combined effect of WCT and SL has no significant ($P > 0.05$) difference on DF (Table 4A and Table 4B). This implies M1 (moisture) might not delay DF if it is fertilized by sulfur fertilizer.

4.1.3 Days to 90% maturity

The results (Table 3A) showed that WCTs significantly ($P < 0.05$) affected DM. M1 resulted in a larger number of days (85.5) to mature and delayed maturity by five days than the days to maturity for sesame (80.5) grown on M0. This might be due to M1 increased the moisture content of the soil and made sesame crop to fully mature but, the M0 plots might dry before the full maturity due to the shortage of moisture. But, in Table 3B it is not significantly ($P > 0.05$) affected by WCT. Application of sulfur significantly ($P < 0.05$) affected DM in Table 3A. The highest days (86.8) taken to maturity was recorded at 0 kg S ha⁻¹ but the lowest days taken i.e. 80.7 days to maturity was recorded at 30 and 40 kg S ha⁻¹ respectively. The results showed that the control plot delayed 1 to 6 days compared to plots treated with the sulfur fertilizer. This is in agreement with the findings of [42] who reported that sulfur deficiencies in cereals can cause a delay in maturity by about 3 to 10 days. But, results in Table 3B did not show significant ($P > 0.05$) difference by SL. So, it can be concluded that sulfur deficiency may not delay DM if there is enough moisture. The combined effect of WCT with SL showed significant ($P < 0.05$) difference on DM (Table 4A). The highest number of days (91.3) taken for sesame crop to mature was recorded in the combination of M1 with zero SL i.e. (M1S0). The lowest number of days (79.0) taken to mature was recorded at both 20 and 30 kg S ha⁻¹. This shows that the area is deficient in sulfur and that is why applied sulfur fertilizer gave a high response in the sesame maturity because

of sulfur deficiency delays sesame maturity according to [42]. Similarly, moisture availability results in delaying sesame maturity. Therefore, the combined effect of M1 and sulfur fertilizer is expected to delay the DM.

4.1.4 Number of branches

Effect of WCT and SL on Nb is presented in Table 3A. Nb was highly significantly ($p < 0.01$) affected by WCT. The highest Nb (2.9) was recorded in M1. This height advantage might be due to the moisture advantage conserved by M1 than the M0 planting. This is in line with the findings of [43] who noticed that the vegetative growth attributing characteristics such as the number of branches per plant, plant height, and total dry matter production were increased appreciably with the increasing optimum moisture level for effective growth and development of the sesame crop. Results in Table 3B has not significant ($P > 0.05$) difference due to WCT because the rainfall in 2016 was comparatively optimum for sesame growth. SL showed highly significant ($P < 0.01$) difference on Nb of sesame per plant (Table 3A and Table 3B). It could be suggested that the response observed is due to the sulfur fertilizer. This is similar to the study done by [44] who reported that Nb increased significantly with increasing sulfur levels. [11] also reported sulfur deficiency weakened tillering capacity of sesame crop. The remarkable difference with this study is that he found the Nb increasing up to 40 kg S ha⁻¹, while Nb increased up to 30 kg S ha⁻¹ in this current study. This remarkable difference might be due to the difference in natural fertility status of the soil before fertilization with the sulfur chemical fertilizer and also the timing and method of fertilizer application used.

The experimental results revealed that Nb of sesame were significantly ($P < 0.01$) influenced due to the combined effect of WCT and SL (Table 4A). The highest Nb (3.7) was recorded at 30 kg S ha⁻¹ combined with M1, but the lowest Nb (1.9) was both recorded at 0 kg S ha⁻¹ combined with M1 and M0 respectively. This is in agreement with the results of the experiment done by [43] who indicated that different soil moisture tension and sulfur fertilization had a significant influence on Nb per plant at harvest on sesame crop irrigated with different moisture treatments. But, Table 4B has not significant ($P > 0.05$) difference. This might be due to the availability of optimum moisture for both M1 and M0.

4.1.5 Plant height

Ph is significantly ($P < 0.05$) affected by WCT (Table 3A). The average plant height ranged from 73.1 cm for plots with M0 to 96.2 cm for plots with M1. This shows that the maximum plant height was recorded from M1 and the lowest from M0. This is in agreement with findings of [43] who reported that the highest plant height of sesame crop on treatment with moisture than the water-stressed plots in irrigation. Sesame can continue its height if it has got enough moisture even after maturity. [45] stated two growth characteristics (indeterminate and determinate) growths of sesame reaching up to 2 m height. But, in Table 3B Ph is not affected by WCT, the reason is there was no moisture scarcity in 2016. Plant height was highly significantly ($P < 0.01$) affected by SL (Table 3A and Table 3B). For example, the highest plant height (93.2 cm) was recorded at 30 kg ha⁻¹ sulfur rate which had 36.3% increment over the control treatment (Table 3A). This is in line with the findings of [46] who reported that sulfur increased the height of sesame. Similarly, sulfur deficiency results in stunted growth of sesame [11]. The results (Table 4A and Table 4B) indicated that plant height was significantly ($P < 0.05$) affected by the combined effect of WCT and SL. Similar investigation was found by [47] who reported maintenance of proper moisture at field level along with balanced sulfur fertilization which had positive effect on growth and development of sesame in India, West Bengal humid tropical areas.

4.1.6 Number of capsules per plant

The results of the effects of WCT and SL on number of Nc are presented in Table 3A and Table 3B. Nc was highly significantly ($P < 0.01$) affected by WCT and M1 increased Nc by 32% compared to plots M0 Table 3A. This is in agreement with [43] who noticed that the vegetative growth attributing characteristics were increased appreciably with the increasing optimum moisture level effective for growth and development of the crop that is why it is not significant ($P > 0.01$) difference in Table 3B with optimum rainfall. Nc is highly significantly ($P < 0.01$) affected by SL in both years (Table 3A and Table 3B). Statistically, 40 kg S ha⁻¹ has no significant ($P > 0.05$) difference with 20 and 30 kg ha⁻¹ sulfur application. This is in agreement with the findings of [13] who reported that different sulfur rates showed highly significant ($P < 0.01$) effect on Nc. The increase in Nc might be

due to the increase in the photosynthetic activity of the plant and maximum crop growth rate.

The results indicated that Nc was highly significantly ($P < 0.01$) affected by the combined effects of WCT and SL in Table 4A. Example, the highest Nc 51.6 was recorded at 40 kg S ha⁻¹ with M1, but statistically, it has no significant ($P > 0.05$) difference with that of 30 kg S ha⁻¹ with M1. This is in line with findings of [43] and [48] who found highest Nc due to the combined effect of moisture and sulfur fertilizer rates than the moisture stressed treatments. But, results in Table 4B is not affected by the combined effect. This may be the WCT is not so much necessary in areas with enough rainfall in the growing period.

4.1.7 Grain yield

The results (Table 3A) indicated that WCT significantly ($p < 0.05$) affected the GY for sesame. But, in Table 3B GY is not affected by WCT. However, grain yield for sesame is significantly ($P < 0.01$) affected due to the effects of applied SL (Table 3A and Table 3B). GY response is significantly ($P < 0.01$) affected by the combined effect of WCT with SL (Table 4A). The highest GY i.e. 889.3 kg ha⁻¹ is recorded at 40 kg S ha⁻¹ combined with M1 but statistically it has no significant ($p < 0.05$) difference with the GY (857.6 kg ha⁻¹) recorded at 30 kg S ha⁻¹ combined with M1. The lowest GY (430.6 kg ha⁻¹) is recorded at 0 kg S ha⁻¹ combined with M0. This means the combined effect of M1 and sulfur increased by 99% at 30 kg S ha⁻¹ is the recommended one because the GY recorded at 40 kg S ha⁻¹ combined with M1 has not significant ($P > 0.05$) difference statistically. The increment is due to the synergetic effect of the tied ridges and sulfur fertilizer. This is in line with the findings of [43] who determined the interaction between water stress and sulfur fertilizers decreased grain yield than the grain yield gained from the combination of sulfur fertilizer rates with optimum moisture for sesame crop. While the results in 2016 (Table 4B) showed not significant ($P > 0.05$) difference due to the combined use of WCT and SL.

4.2 Partial Budget Analysis

M1 treatment has a higher positive effect on sesame productivity and profit earnings of the farmers than M0 at different sulfur fertilizer application rates. The marginal rate of return at the sulfur application rates of 10, 20, 30, and 40

kg S ha⁻¹ are all greater than 100%. As the MRR for these rates is greater than 100%, investing extra money is economical. However, high MRR was found at 20 kg S ha⁻¹ in both M1 and M0 (Table 5). The net benefit obtained in response to rates of sulfur fertilizer application at 40 kg S ha⁻¹ were 14,239.4 ETB for M1 and 9,716.2 ETB for M0. This shows that using M1 has more earnings than M0 treatment by 4,523.2 ETB at higher levels of sulfur fertilizer application. The marginal rate of return obtained at 40 kg S ha⁻¹ showed that further earnings could be obtained beyond the application of 40 kg S ha⁻¹ using M1 although the grain yield at 40 kg S ha⁻¹ was statistically not significant with that obtained using 30 kg S ha⁻¹ at ($P > 0.05$) level of significance (Table 4A). However, results in Table 4B shows the yield and the most of yield components are not significantly different, so it is not necessary to conduct the partial budget analysis. According to the manual for economic analysis [35], application of fertilizer with the marginal rate of return above the minimum level (100%) is economical. Thus, application of sulfur at 30 kg S ha⁻¹ rate combined with M1 was economically profitable compared to the other treatment combinations.

5. CONCLUSIONS AND RECOMMENDATIONS

Tillage practices and sulfur fertilization alone or in combination have many advantages on yield and yield components of sesame in Kafta Humera. The highest increments in yield and yield components were observed in the combination of tillage practices with sulfur fertilizer than either the use of tillage practice or sulfur fertilizer alone in 2015 rainy season. This is an indication of the synergetic effect of the tied ridges moisture conservation and sulfur fertilization. The lowest yield was recorded in the conventional (flatbed) tillage practice and zero sulfur fertilizer application, which is still practiced by the local farmers. However, in 2016 rainy season there was no significant difference due to the combination of tillage practices with sulfur fertilizer nor due to tillage practices alone but, there is a significant difference due to sulfur fertilizer. The overall yield performance of the crop was satisfactory only under tied ridges combined with sulfur fertilizer. This may be because of the sesame crop has got a chance to take the fertilizer and undertake photosynthesis. The highest grain yield obtained at 30 kg S ha⁻¹ under tied ridges was higher than the national average yield, while the highest grain yield found

under flatbed is below the national average even at 40 kg S ha⁻¹ in the rainfall scarce season in 2015. However, in 2016 the grain yield was higher than the national average even under flatbed tillage practices. This shows that tie ridger is a promising technology in increasing sesame productivity in case of rainfall scarce seasons. However, in the years of optimum to higher rainfall tillage using tied ridges is not economical, because the effective rainfall is enough for the sulfur fertilizer to be utilized by the sesame crop.

Therefore, application of sulfur fertilizer at a rate of 30 kg S ha⁻¹ combined with tied ridges is economically feasible to improve the productivity of sesame. This experiment was done on plots under small scale compared to farmers' practice then it is better to test at large scale. Micro-dosing experiment of sulfur fertilizer using sesame as a test crop would probably add to existing knowledge.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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