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Research Article

Productivity and Water use Efficiency of Sorghum (*Sorghum bicolor* [L.] Moench) Under Some Soil and Water Management Practices in Eritrea

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Abstract

High rainfall intensities, steep slopes, shallow soils and poor ground cover result in runoff and soil loss; moreover non implementation of soil and water conservation techniques and use of animal dung for energy needs, come in the way to achieve food security in Eritrea. To address these factors the present experiment was conducted in model integrated watershed at Hamelmalo Agricultural College, Eritrea with the objectives to study the effect of tillage, farmyard manure (FYM) and mulch on productivity, growth and water use efficiency (WUE) of sorghum under rain fed conditions. A split-split plot experimental design was chosen with tillage (conventional tillage CT, reduced tillage RT and no-tillage NT) as main plot, FYM (0, 5, 10, 15 t ha-1) as sub-plot and mulch (0, 4 t ha-1) as sub-sub-plot with three replications. FYM and mulch showed significant effect on grain yield, stover yield, total biomass, Harvest Index (HI), 1000 grain weight and WUE, whereas the effect of tillage was non-significant on grain yield and growth parameters. Highest WUE (14.1 kg ha-1 mm-1) was recorded in mulched no tillage plot with 15 t ha-1 FYM application. Grain yield was maximum (5363.0 kg ha-1) with 15 t ha-1 of FYM application in mulched plots and minimum (2888.9 kg ha-1) with 0 t FYM in non-mulched plots both in RT. Grain yield and WUE were positively correlated (R2 = 0.572). Pearson correlation matrix showed that grain yield, total biomass and HI were positively correlated with plant height, stover yield, WUE and 1000 grain weight, however there existed negative correlation with root length density at 80-100cm.

Keywords: Farmyard Manure; Mulch; Tillage; Water Use; Water Use Efficiency; Yield; Sorghum; Root Length Density

Introduction

Eritrea's agriculture employs more than three fourth of the population but produces about 20 percent of GDP due to its rain fed agriculture [1,2]. Constraints for this are torrential, high intensity, short duration and unpredictable rainfall. Average precipitation in the country is about 384 mm yr^{-1} [3] with only 1% of the total area receiving more than 650 mm of annual rainfall [4]. Rainfall that the country receives if conserved and managed properly can be enough to meet the national water need but the effective rainfall is very low, as the rest is lost through runoff, evaporation and drainage. Although several soil and water management techniques have been implemented in Eritrea for the last decades but these are not practiced on ground [5]. To improve this situation efforts have to be made to increase infiltration rate and water holding capacity of soil; management practices such as minimum tillage, mulching and application of farmyard manure can contribute almost in all aspect of soil quality and fertility to increase crop productivity.

Sorghum (Sorghum bicolor (L) Moench) is the fifth most important cereal after rice, wheat, maize, and barley [6]. It constitutes the main food grain for over 750 million people who live in the semi-arid tropics of Africa, Asia, and Latin America. It is the major crop of Eritrea contributing to about 46 percent of the total cereal production [7] and it forms an important dietary component prepared as 'injera' (leavened bread) or as thick porridge commonly consumed in the country. But sorghum production in Eritrea was reported as low as 0.6 t ha^{-1} [8] whereas the average yield of the sorghum crop exceeds 4.3 t ha^{-1}globally [9]. Low crop productivity, in rainfed agriculture is more due to sub-optimal performance of crops, is related to improper land management aspects than to low soil physical potential [10]. To mitigate and adapt to the ever-changing climatic conditions, studies are needed to develop and improve the agricultural techniques in order to improve crop productivity and water use efficiency; hence we need to focus on technologies that reduce evaporation, enhance infiltration and water holding capacity of soil. Therefore, the present experiment intended to optimize tillage, use of mulch, and application of farmyard manure as soil management practices to increase yield and water use efficiency of sorghum.

Materials and Methods

Study area

The field experiment was conducted in Hamelmalo Agricultural College (HAC), Eritrea at 15°52'21" N and 38°27'42" E latitude and longitude, respectively and an elevation of 1285 m above mean sea level under rain fed conditions; annual average rainfall in the growing season was 434 mm. Soil physico-chemical properties of the experimental field were determined before sowing using standard methods and procedures. The results of the phisico-chemical properties of composite sample of the area are presented in table 1.

Soil parameters	Values	Methods	Reference
Soil texture	Sandy loam	Hydrometer	[11]
Bulk density (g cm^{-3})	1.45	Core sampling	[12]
Saturated hydraulic-conductivity (cm hr^{-1})	4.2	Porchet method	[13]
Field capacity (%) by volume (cm^3cm^{-3})	0.27	Core sampling	[12]
EC (1:5) (dSm^{-1})	0.07	Conductivity meter	[11]
pH (1:5)	8.26	pH mètre	[11]
Organic matter (%)	0.47	Walkley and Black	[11]
Available N (%)	0.007	Kjedehal method	[11]
Extractable P (ppm)	2.6	Sodium bicarbonate extraction	[14]
Exch. K^+ ($cmolkg^{-1}$)	0.87	Flame photometer	[11]
Exch. Ca^{+2} ($cmolkg^{-1}$)	26.3	Titration method	[15]
Exch. Mg^{+2} ($cmolkg^{-1}$)	4.6	Titration method	[15]
Exch. Na^+ ($cmolkg^{-1}$)	0.17	Flame photometer	[11]
CEC ($cmolkg^{-1}$)	28.4	Titration method	[16]

Table 1: Soil physico-chemical properties of the experimental field.

Treatments

Tillage - Conventional tillage (CT), reduced tillage (RT) and no-tillage (NT).

Farmyard manure (t ha^{-1}) - F0 = 0, F1=5, F2 = 10, and F3 = 15

Mulch (t ha^{-1}) - M0= 0, M1 = 4

Experimental design

Split-split plot design was used with three replications. Each replication consisted of 24 plots. Each sub-subplot had dimension of 4.0 × 3.75 sq m. Tillage was taken as the main plot, FYM as subplot, and mulch as sub-sub plot. Sorghum variety [ICSV 210 (Bushika)] was sown at a seed rate of 15 kg ha^{-1}. The seeds were sown in rows of 0.75 m apart at an average depth of (0.03 - 0.05) m manually on 8th July 2018. The plants were thinned to 0.2 m distance within the row in about 10 days after sowing. This variety was developed by the national research institute of agriculture and adopted by the local communities owing to its high yield and drought resistance, was chosen for the trial. All necessary measures for plant protection were done during the time of the experimentation to minimize risks that might be caused by the biotic factors. Insecticide was applied using Knap-sack sprayer when any incidence of pests was observed.

Water use and water use efficiency were determined as per formulae given by Gregory [17]. Plant height of five randomly selected sorghum plants, were recorded with graduated measuring tape at 20, 40, 60, 80 and 100days after sowing (DAS). The crop was harvested from the net plot of 2.8 m by 2.25 m selected at centre of main plot to determine the grain yield and total above ground biomass after drying and finally threshed. All the yield parameters (Grain yield, Stover yield, Total biomass Harvest index) were in kg per plot and converted to kg per hectare.

Harvest Index (HI) as the ratio of the grain yield and the total above ground biomass expressed in percentage was measured, taking dry bio-mass as a basis for estimation.

HI = (grain yield/total biomass) × 100).

To estimate the 1000 grain weight, grains were cleaned counted and then weighed using an electronic digital balance and weight was recorded in grams (gm). Soil root sampling was collected in a metal core sampler of 0.1 m diameter and 0.20 m length down to 1m depth by placing the core on a harvested hill. The numbers of roots within the vertical and horizontal grid line of 1cm were counted. Then roots length (RL), root length density (RLD) and the percent root distribution were calculated as follows.

RL = 11/14 x N Grids units

RLD =RL (cm)/V (cm^3)

Percent root distribution = RLD of the i^{th} layer/RLD in profile x 100

Where, RL = Root length; N = Number of inter sections; V = soil core volume.

Statistical analysis

The data obtained from all the measured parameters of the experiment under various treatments were subjected to statistical analysis using the GENSTAT software (12^{th} ed) and the treatment means were compared with Least Significant Difference (LSD) at 5 per cent level. Pearson correlation coefficient (r) was used to establish relationship among the various parameters.

Results and Discussions

Yield of sorghum and growth parameters

- **Grain yield:** The effect of tillage on the grain yield was non-significant; whereas FYM exhibited significant effect on grain yields (Table 2). The highest grain yield was measured in 15 t ha^{-1} FYM applications and lowest was recorded in control (0 t ha^{-1} FYM). Similar results of FYM application were reported by Melese [18]. Grain yield with 15 t ha^{-1} and 10 t ha^{-1} FYM applications were statistically at par. Mulch also showed significant differences in grain yield; there was an increment of 17.9% in grain yield in mulched over non-mulched plots; this may be attributed to soil moisture conservation due to mulch application. de Carvalho., *et al.* [19] also reported that mulch promoted a 24% increase in productivity of sorghum in relation to the area where conservation was not practiced. Effect of tillage, FYM and mulch interactions on the grain yield was non-significant, however the results in table 4 showed that the highest grain yield was recorded in RTF3M1 (5363.0 kg ha^{-1}) and lowest in RTF0M0 (2888.9 kg ha^{-1}). The increasing trend was observed with every additional dose of FYM and mulching. The grain yields in CT for mulched plots increased linearly up to 15 t ha^{-1} FYM application, whereas for non-mulched plots it increased up to 10 t ha^{-1}FYM application but it decreased at 15 t ha^{-1} dose of FYM application. This might be attributed to the fact that water became limiting factor in non-mulched plots in comparison to mulched plots at 15 t ha^{-1} FYM application.
- **Stover yield:** Perusal of data in Table 2 showed that the effect of tillage on stover yield was non-significant. The highest (8093.0 kg ha^{-1}) and lowest (7487.0 kg ha^{-1}) stover yields were observed in RT and NT, respectively. The effect of FYM on stover yield was also non-significant. The trends of increment were linear with FYM application. The highest (8963.0 kg ha^{-1}) and lowest (7111.0 kg ha^{-1}) stover yields were observed at 15 t ha^{-1} and at 0 t ha^{-1} FYM applications, respectively. Erdem and Alagöz [20] and Amy [21] reported an increment in green biomass due to FYM application. The effect of mulch on stover yield was significant. There was an increment of 14.78% yield in mulched plots over the non-mulched plots. This might be due to the sufficient moisture availability in mulched plots.
- **Total biomass, kg ha^{-1}, harvest index and 1000 grain weight:** Tillage did not show any significant effect on total biomass, harvest index and 1000 grain weight, whereas these were significantly affected by the application of FYM (Table 2). Highest (13,630.0 kg ha^{-1}), (27.1g) and lowest (10519.0 kg ha^{-1}) (25.1g) total biomass and 1000 grain weight were obtained with 15 t ha^{-1} and 0 t ha^{-1} FYM application, respectively. Highest (37.3%) and lowest (32.3%) HI was obtained with 10 t ha^{-1} and 0 t ha^{-1} FYM applications, respectively. This might be attributed to the overall improvement in physic-chemical properties by use of FYM. Erdem and Alagöz [20] and Amy [21] also reported similar results. Mulch also depicted non-significant effect on harvest index but had significant effect on total bio-mass and 1000 grain weight with highest value of 12889.0 kg ha^{-1} and 26.6 g, respectively in mulched plots. This might be attributed to the soil water conservation in mulched plots.
- **Plant height**: Effect of tillage on the plant height was non-significant except at 40 days after sowing (Table 3); the highest was obtained in CT (99.13 cm) and it was statistically at par with RT (98.89). The lowest was in NT (89.83 cm). The effect of FYM on the plant height was significant at 5% level during the whole period of growth (Table 3), which was in line with the work of Amy, [21]. The increasing trend in plant height was observed corresponding to every additional dose of FYM; the highest plant height (226.0 cm) was obtained in F3 (15 t ha^{-1}) treated plots, and the lowest (202.6 cm) was in F0 (No FYM) treated plots at 100 DAS. This might be due to the improvement in nutrient availability and maintenance of good soil structure, creating conducive soil environment to plant roots. Erdem and Alagöz, [20] also reported that FYM maintained soil productivity. The effect of mulch on plant height was also significant at 20, 80 and 100 DAS; during early growing period, the mulched plots were exposed to sub-optimal temperature vis-a-vis excess moisture, which could cause poor aeration in root zone, decreasing uptake of oxygen, nutrients and water. Whereas at 80 and 100 DAS, due to mulch soil moisture was conserved; hence, the effect of mulch showed significant difference in plant height. Melese [18] also reported similar results in his investigation.
- **Root length density:** The root length density along the soil depth is shown in figure 1. The average percentage root distribution from the depth of 0-60 cm was 74%, 74% and 76% in NT, RT and CT, respectively. From this it could be concluded that percent root distribution did not show much difference among the tillage treatments. This might be attributed to the nearly uniform distribution of moisture in the profile throughout the growing period. However, the percentage

root distribution was more for CT in the upper layer which might be due to the low moisture in the upper layer caused by evaporation, which was enhanced by tillage promoting extension of roots in search of moisture to larger volume in the upper layer. Adeyemo and Agele [22] reported the same for root dry weight in their studies.

Treatment	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Total biomass (kg ha^{-1})	HI (%)	1000 grain weight (g)
Tillage					
CT	3970.0	8031.0	12000.0	33.1	25.9
NT	4133.0	7487.0	11555.0	35.7	26.1
RT	4356.0	8093.0	12444.0	35.0	26.6
LSD	NS	NS	NS	NS	NS
CV(%)	12.1	9.0	7.4	9.1	2.0
Farmyard Manure					
F0	3407.0	7111.0	10519.0	32.3	25.1
F1	4000.0	7530.0	11556.0	34.8	25.9
F2	4578.0	7877.0	12444.0	37.3	26.7
F3	4607.0	8963.0	13630.0	34.1	27.1
LSD	554.07	NS	1733.0	2.88	0.66
CV (%)	12.1	9.0	7.4	9.1	2.0
Mulch					
M0	3807.0	7329.0	11111.0	34.3	25.8
M1	4489.0	8412.0	12889.0	34.9	26.6
LSD	242.96	1404.0	429.63	NS	0.25
CV (%)	12.1	9.0	7.4	9.1	2.0

Table 2: Effect of tillage, FYM and mulch on grain yield, stover yield, total bio-mass, harvest-index and 1000 grain weight

Notes: M0 = 0 t ha^{-1} and M1 = 4 t ha^{-1}, F0 = 0 t ha^{-1}, F1 = 5 t ha^{-1}, F2 = 10 t ha^{-1} and F3 = 15 t ha^{-1}, CT= Conventional-Tillage; NT = No-Till and RT = Reduced-Tillage

Treatments	20 DAS	40 DAS	60 DAS	80 DAS	100 DAS
Tillage					
CT	22.0	99.13	177.2	215.4	214.6
NT	18.8	89.83	175.0	219.0	217.3
RT	22.2	98.89	178.4	218.2	217.6
L.S.D (5%)	NS	*5.865*	NS	NS	NS
CV%	8.7	4.5	5.5	3.1	3.3
SEM	0.80	1.49	2.0	3.36	3.43
FYM					
F0	18.6	88.3	169.1	204.8	202.6
F1	20.5	92.5	174.4	223.6	214.3
F2	21.6	98.0	180.1	226.7	223.2
F3	23.3	105.0	184.0	214.8	226.0
L.S.D (5%)	1.111	4.76	6.4	8.033	8.475
CV%	8.7	4.5	5.5	3.1	3.3
SEM	0.37	1.6	3.05	2.70	2.85
Mulch					
M0	21.7	96.6	175.3	214.5	214.2
M1	20.3	95.3	178.5	220.5	218.8
L.S.D (5%)	*0.886*	NS	NS	3.267	3.473
CV%	8.7	4.5	5.5	3.1	3.3
SEM	0.30	0.70	2.28	1.12	1.19

Table 3: Effects of tillage, FYM, and mulch on plant height of sorghum at 20, 40, 60, 80, and 100 days.

CT = Conventional-Tillage, NT = No-Tillage and RT = Reduced-Tillage, F0 = 0 t ha^{-1}, F1 = 5 t ha^{-1}, F2 = 10 t $ha^{-1}$and F3 = 15 t ha^{-1}, M0 = t ha^{-1}, M1 = 5 t ha^{-1}.

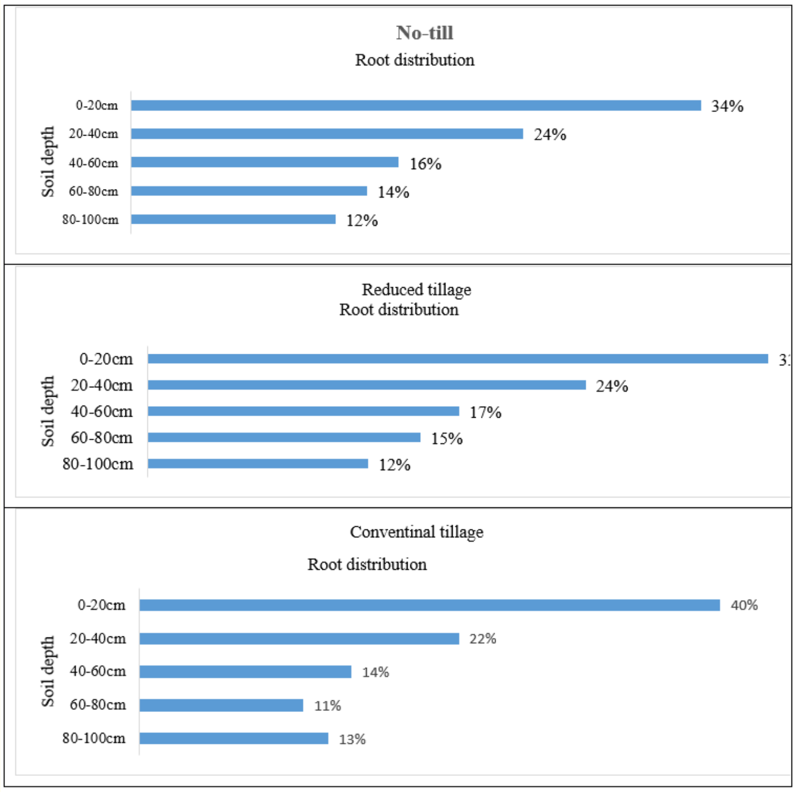

Figure 1: The average percentage of root distribution along the soil profile.

Water use (WU) and water use efficiency (WUE)

Perusal of data in table 4 showed that highest WUE (14.1 kg ha^{-1} mm^{-1}) was recorded in no-tillage with 15 t ha^{-1} of FYM application under mulched condition (NTF3M1), whereas highest water use was recorded in CTF0M0 (511.1 mm) and it gave lowest (6.0 kg ha^{-1} mm^{-1}) WUE. Similar results were reported by Zhang., *et al.* [23]. These results indicated that in no-tillage practices, FYM application and mulch improved water holding capacity and reduced soil moisture loss due to evaporation. Sunday., *et al.* [24] also reported that surface mulch proved to be useful for enhancing soybean WUE especially in a bad rainfall season.

Treatments	Grain yield (kg ha^{-1})	WU (mm)	WUE (kg ha^{-1} mm^{-1})
NTF0M0	3037.0	353.1	8.6
NTF0M1	4148.1	360.7	11.5
NTF1M0	3777.8	307.1	12.3
NTF1M1	4222.2	337.8	12.5
NTF2M0	4251.9	334.8	12.7
NTF2M1	4400.0	314.3	14.0
NTF3M0	4148.1	296.3	14.0
NTF3M1	5066.7	359.3	14.1
RTF0M0	2888.9	300.9	9.6
RTF0M1	3807.4	377.0	10.1
RTF1M0	4074.1	384.3	10.6
RTF1M1	4251.9	369.7	11.5
RTF2M0	4770.4	375.6	12.7
RTF2M1	5037.0	387.5	13.0
RTF3M0	4592.6	345.3	13.3
RTF3M1	5363.0	397.3	13.5
CTF0M0	3066.7	511.1	6.0
CTF0M1	3481.5	476.9	7.3
CTF1M0	3333.3	387.6	8.6
CTF1M1	4370.4	464.9	9.4
CTF2M0	4148.1	406.7	10.2
CTF2M1	4814.4	436.4	11.1
CTF3M0	3659.3	321.0	11.4
CTF3M1	4844.8	411.5	11.7

Table 4: Effects of tillage, FYM and mulch on water use efficiency of sorghum.

Notes: M0 = 0 t ha^{-1} and M1 = 4 t ha^{-1}, F0 = 0 t ha^{-1}, F1 = 5 t ha^{-1}, F2 = 10 t ha^{-1} and F3 = 15 t ha^{-1}, CT = Conventional Tillage, NT = No-Till and RT = Reduced-Tillage.

Grain yield versus WUE curve indicated positive correlation (R^2 = 0.572) between the two. The highest WUE (14.1 kg ha^{-1} mm^{-1}) obtained yield of 5000 kg ha^{-1} grain using proper soil management practices (Figure 2). This was in accordance with the definition of WUE which increased with increase in numerator or decreased with decrease in denominator, hence as yield increased i.e. numerator increased the WUE increased.

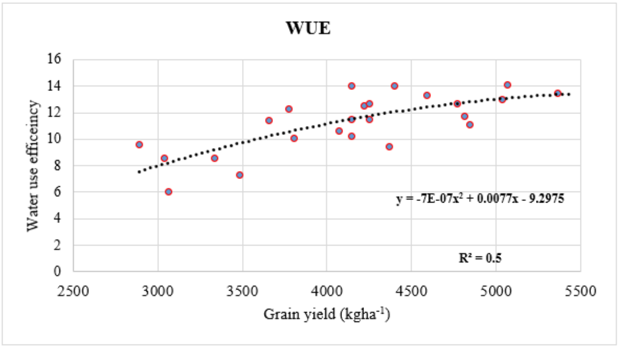

Figure 2: Water use efficiency.

Simple correlation matrix of the agronomic parameters

Pearson correlation (2-tailed) matrix of growth and yield parameters are shown in Table 5. Pearson correlation was used in this study as it measures the strength of association between variables. Grain yield, total biomass and harvest index (HI) showed positive correlation with plant height, stover yield, 1000 grain weight and WUE however, there was negative correlation with root density from 80-100cm; negative correlation might be due to the deeper movement of roots under water stress conditions. Positive correlation indicated that the parameters have influence on the increase of sorghum grain yield. Faye., *et al*. [25] demonstrated that upon drought conditions, pearl millet reduced root growth in the dry topsoil layers and increased their root growth in deeper soil horizons.

	Grain Yield	Total Biomass	HI
Plant Height100	0.742**	0.702**	0.369
Root density from 80-100 cm	-0.400	-0.185	-0.505*
Stover yield	0.670**	0.949**	-0.155
1000 Seed Weight	0.946**	0.902**	0.470*
WUE	0.742**	0.625**	0.498*

Table 5: Pearson correlation matrix of the agronomic parameters.

****.** Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at the 0.05 level (2-tailed).

Conclusions

FYM application and mulch had significant effect on growth and yield of sorghum. Grain yield with 15 t and 10 t ha^{-1} FYM applications, were statistically at par. The lowest yield was recorded in the control (0 t ha^{-1} FYM). Significant effect of mulch on grain and stover yields demonstrated that mulched plots conserved more moisture compared to non mulched plots. The mulched plots had 17.9 and14.78% higher grain and stover yield, respectively over non-mulched plots. Water use efficiency versus grain yield curve demonstrated that WUE of 14.1 could yield 5000 kg ha^{-1}. The effect of tillage was non- significant on yield and growth parameters.

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