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Effect of soil moisture conservation and planting methods on soil moisture content and yield of sorghum (*Sorghum bicolor* (L.) Moench) under rain-fed conditions of Tigray, Ethiopia

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Crop production in semi-arid dry land areas of Ethiopia is totally dependent on erratic rainfall-uneven distribution, torrential in intensity, low in amount during crop growing season, and variable from year to year. This results in unpredictable agricultural production and occasional crop failure. Therefore, the study was designed to evaluate the effect of *in-situ* moisture conservation techniques such as tied ridge and mulch and planting methods on soil moisture content, yield and biomass of sorghum during 2006 cropping season. Factorial combinations of treatments were laid out in randomized complete block design with three replications. The results of the experiment indicated that the main effect of planting methods and mulches were highly significant ($p \leq 0.01$) in influencing the grain and biomass yield. Irrespective of planting methods, there were 77.1 and 59.2% advantage of grain and biomass yield due to tied-ridge over the control. Furthermore, sorghum planted in furrows and on top of ridges increased grain yield in the order of 98.3 and 41.6% and biomass yield by 68.5 and 35.7% over flat planting method, respectively. A grain yield increases of 25.9 and 14.4% and biomass yield increase of 23.1 and 18.9% were obtained by applying 6 and 3 t/ha of mulch over the bare plot, respectively. In case of soil moisture content dynamics, highest volumetric soil water content (VSWC) was obtained from the tied-ridges, followed by open ridges over the flat tillage. VSWC was significantly greater under furrow planting and lowest in flatbed method. Like wise, soil surface covered with 3 and 6 t/ha mulch levels gave higher VSWC over no mulch treatment. Therefore, the result indicates that in areas such as Alamata, tied ridge with furrow planting and application of 6 t/ha mulch were the most preferable soil moisture conservation technique and planting method for increasing grain and biomass yield of sorghum.

Key words: *In-situ* moisture conservation, soil moisture content, tied ridge, mulch, planting method, sorghum.

INTRODUCTION

In semi-arid areas of Ethiopia, covering 75% of the territory and inhabited by a third of the population, agricultural challenges are faced due to irregular rainfall and unfavorable soil conditions (Georgis, 2015).

Substantial part of the country fall within the arid and semi-arid agro ecological zones. Crop production in those areas is largely practiced under rain-fed conditions where the crop productivity is very low and sometimes encountered crop failure. Rainfall is highly variable in distribution and erratic with occasional run-off associated with heavy rainfall events contributing to the soil water deficits. Moreover, the severities of these constraints are also amplified by high evapotranspiration, low organic matter content and low water holding capacity of the soil (Georgis, 2014; Mitiku and Kidane, 1994). This leads to crop production instability and uncertainty with recurrent low crop production and sometimes encountered total crop failure.

Sorghum (*Sorghum bicolor* (L.) Moench) is one of the most important dry land cereal crops that supports more than 500 million peoples in more than 100 countries. It is the world's fifth most important cereal after wheat, maize, rice and barley both in terms of area coverage and total production. Sorghum is cultivated in a wide range of agro-ecologies and can be grown under conditions which are unfavorable for most other cereals such as drought and nutritionally poor soils. Hence, it is essentially a crop of hot, warm, and unreliable rainfall areas (Doggett, 1988).

Water is a critical desirable input for crop production and is often the most limiting factor for agricultural production. Crop production in developing countries is mainly dependent on rainfall which is very low or very irregular; creating high risks for yield loss and/or unfavorable growth conditions. Even in seasons with very high rainfall, lack of sufficient soil water supplies at critical growth stages or erosion can cause a reduction in yield. The most important strategy that should be implemented to improve the productivity of crops in dryland areas of rain fed farming is conserving rainfall water in soils.

Exploring innovative water conservation techniques such as tied beds and mulching are of great importance to improve soil moisture retention and consequently, grain yield and other economically important traits of the crop. Moreover, adjusting planting practices in accordance with climate variations and soil types is an appropriate measure for successful crop production. Practicing a suitable planting method enables the crop to flourish in subsequent crop growth and developmental stages (Georgis, 2015, 2014; Chakraborty et al., 2008).
Ridges play an important role in harvesting rain water while the furrow provides as planting belt, receives the rain falling directly on the surface belt and accepts run off from the ridges.

It improves soil moisture storage and prolongs the time of moisture availability and then enhances infiltration of water into the lower soil depths.

The other proven technique practiced in different areas of the world for maintaining soil water content to improve crop performance is covering of plants with mulches. Mulching is a practice in which organic or inorganic materials are spread over the soil surface/ground around the plants (Kader et al., 2017; Kasirajan and Ngouajio, 2012). The effect of mulch depends on its composition and color, the amount applied, the rate at which the mulch decomposes and timing of application (Coen et al., 1992). The importance of mulch as soil moisture conservation is through regulating soil temperature, influencing of soil physical property, improving soil aeration, reducing soil erosion caused by water and wind, enhancing the infiltration of rain-water to the soil and water availability to the crop and reducing evaporation of soil moisture by minimizing the effect of solar radiation at the soil surface (Gan et al., 2013; Kasirajan and Ngouajio, 2012; Awodoyin et al., 2007; Li et al., 2000).

Among the most important *in-situ* moisture conservation practice so as to improve agricultural production is the use of integrated approaches both the conservation structures and mulches. Although some studies have been conducted on the effect of *in-situ* water harvesting especially using tied-ridging, their interactive advantages, along with the other *in-situ* water harvesting methods such as mulch have not been studied in the country in general and the study area in particular. Therefore, the study seeks to evaluate the effectiveness of *in-situ* moisture conservation techniques and planting methods, addressing existing knowledge gaps and contributing to improve productivity under rainfed conditions.

MATERIALS AND METHODS

Description of the study area

The field experiment was conducted on farmers' training center located in Alamata district, during July-November main rainy season of 2006. Alamata is located at 600 km north of Addis Ababa on the main road to Mekelle and 182 km south of Mekelle, Tigray regional capital. The experimental site has an elevation of 1600 m above sea level and lies at 12° 15' N latitude and 39° 35' E longitude. The site receives 663 mm mean annual rainfall that ranges from 400 to 700 mm. The rainfall in the area is very erratic and has a bimodal pattern. The short rains (belg) come from March to May and the main rains (Kremt) occur from July to September. The mean annual minimum and maximum temperatures are 14.6 and 29°C, respectively. In the study area, the lowest temperature occurs during January to February and the highest from June to September (Mullugeta, 2003). Eutric Vertisols, Lithic Leptosol (Cambic) and Lithic Leptosols (Orthic) are the dominant soil types covering nearly 100% of the land in the district. The soil pH ranges from 7.4 to 8.5 and is reported increasing with depths. Total nitrogen was analyzed to be between very low and low ranging

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from 0.03 to 0.13% while phosphorus content on surface layers is between low and medium at 5 to 13 ppm with amount decreasing with depth of soil (RVDP, 1998).

Experimental design and treatments

The treatments consisted of a factorial combination of five planting methods (flat planting, ridge planting on untied ridges, furrow planting between untied ridges, ridge planting on tied-ridges and furrow planting between tied ridges) and three rates of mulch (0, 3 and 6 t/ha). Treatment combinations were laid out in a randomized complete block design with three replications. Sorghum stover was chopped and spread manually as per treatments to the respective plots just after thinning of seedlings. Each experimental plot has an area of 26.25 m^2 with 5.25 m width and 5 m length, separated by an alley of 1.5 m between blocks and 75 cm between plots within a block. A spacing of 75 cm between rows within a plot and 20 cm between plants within a row was maintained. There were seven rows of 5 m length in each plot.

Crop management

The 30 cm height ridges at 75 cm apart were constructed manually after the land was properly ploughed using hand hoes and cross tied as per the treatments with soil bunds across the ridges of 25 cm height at 2.5 m intervals to prevent water flowing out of the furrows between the ridges. Sorghum variety Gobiye, a striga resistant and early maturing type was planted on July 28, 2006. Planting was late due to less amount and poor distribution of rainfall received in July except in the last 2 to 3 days of the last week. Two sorghum seeds were sown at a depth of 4 to 5 cm and at 20 cm spacing and then thinned to one per hill three weeks after planting to maintain the required plant population. All plots were fertilized uniformly with 46 kg N/ha and 20 kg P/ha using urea and di-ammonium phosphate, respectively.

Full dose of phosphorus and half of nitrogen were applied at the time of planting and the remaining half dose of nitrogen was side dressed 4 weeks after emergence. All other cultural practices were applied as per recommendations for the crop.

Data collection

Weather data

Monthly total rainfall, minimum and maximum monthly temperatures of 2006 cropping season and also long-term climatic data were collected from weather station located about 3 km away from the experimental site.

Soil water determination

Soil moisture content data were recorded at planting time, 50% flowering and 90% physiological maturity stages. Soil moisture in 30 cm depth increments within the soil profile up to 90 cm was measured using gravimetric method from each plot in the central rows in two replications using a core sampler.

This method was used to determine the soil moisture by subtracting the oven dry weight of each sampled soils from the fresh weight sample of soils from each plot at depth of 0-30 cm, 31-60 cm, and 61-90 cm in the respective plots (Hillel, 1980).

Oven drying of soils was done at 105°C for 24 h and the water content was determined as follows:

$$\theta m(\%) = \left[\frac{SWf - SWd}{SWd}\right] \times 100 \quad (1)$$

where $\theta m(\%) =$ Percent gravimetric soil moisture content, $SWf =$ Fresh soil water weight, and $SWd =$ Oven dry soil weight.

The gravimetric soil water content was converted to the volumetric basis and calculated by multiplying the gravimetric water content with the average bulk density of soil cores taken from each depth (Hillel, 1980). Bulk density was determined as a ratio of mass to volume of soil cores (0-30, 31-60, and 61-90 cm) (Hillel, 1980) from undisturbed soil collected by core samplers of specific length and diameter from each depth of soil.

$$\theta v(\%) = \theta m(\%) \times \frac{\rho b}{\rho w} \quad (2)$$

$$\rho b = \frac{SW}{V} \quad (3)$$

where $\theta v(\%) =$ Percent volumetric soil moisture content, $\theta m(\%) =$ Percent gravimetric soil moisture content, $\rho b =$ Bulk density (g/cm^3), $\rho w =$ Density of water (g/cm^3), $SWd =$ Oven dry soil weight (g), and $Vc =$ Volume of core sampler (cm^3).

Crop data

Yield and yield component parameters were determined only from sampling areas of each plot. Grain yield was obtained by harvesting of all the plants from the net plot area and adjusted to 12.5% moisture content using the formula (Kindie, 2004). The area weighed in grams and converted to area basis to determine the yield in kg/ha. Sorghum stover yield was calculated by weighing all plants harvested from the net plot from the ground surface and sun dried to a constant weight.

Soil analysis

A total of fifteen sub-samples (three soil samples from each sampling point) were collected with auger from the entire experimental field up to 30 cm depth to analyze some selected physio-chemical properties of the soil before planting. The collected soil samples were bulked to make one composite surface soil sample, air dried, ground, sieved to pass 2 mm size sieve screen and stored in sealed plastic for laboratory analysis. The analysis was made at Tigray regional soil laboratory.

Particle size distribution or soil texture was determined by hydrometer method following the standard procedures using sodium hexa metaphasphate as dispersing agent (Day, 1965). The composite soil sample were analyzed for soil pH by means of pH meter in a suspension of a 1:2.5 soil to water ratio as described by Jackson (1958) soil N using Kjeeldahl method (Bremner and Mulvaney, 1982) and available phosphorus using spectrophotometer from extracts obtained following the Olsen extraction method (Olsen et al., 1954). Organic carbon was also determined following the wet digestion methods as described by

Table 1. Salient physical and chemical properties of the experimental site soil.

Soil pH	Total N (%)	Available P (ppm)	Organic carbon (%)	Particle size distribution (%)			Textural class
				Sand	Silt	Clay	
7.82	0.032	3.89	1.9	34	32	34	Clay loam

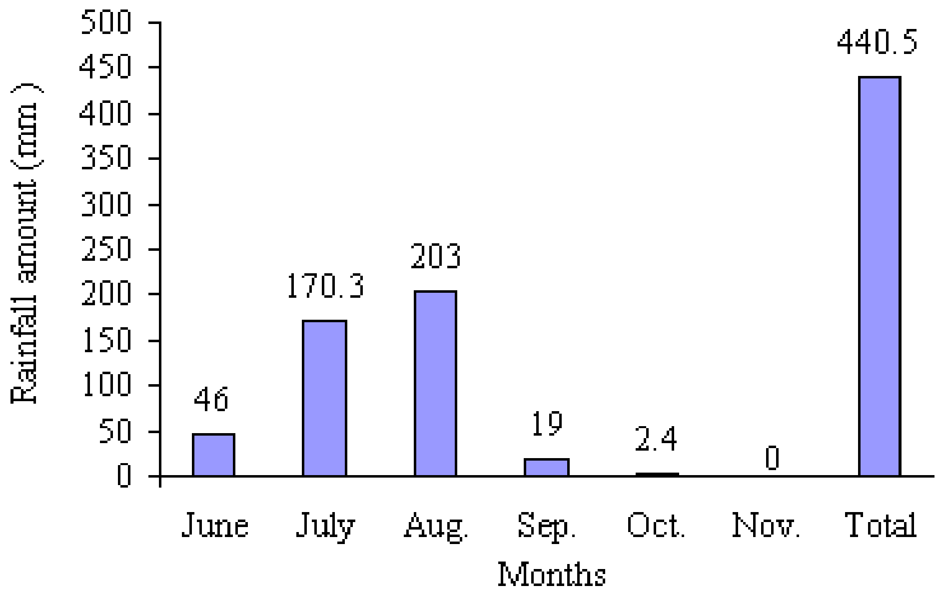

Figure 1. Monthly rainfall data of the year 2006 crop growing season.

Walkley and Black (1934).

Statistical analysis

The collected data were subjected to analysis of variance (ANOVA) using GenStat statistical software appropriate for the design. Least significant difference (LSD) test was used for treatment mean separation.

RESULTS AND DISCUSSION

Pre-sowing surface soil properties

The pre-plant composite surface soil sample (0-30 cm) collected from the experimental site was analyzed for some selected physico-chemical properties of the soil. The soil analysis indicated the textural class of the soil as clay loam (34% sand, 32% silt, and 34% clay) with the soil pH value of 7.82 (Table 1). In other studies, the pH of the soil was reported as 7.5 (RVDP, 1998) and 7.7 (Mullugeta, 2003) in a 1:1 soil water suspension. From the soil pH studied values, it is apparently clear that the level of alkalinity is increasing gradually within the last ten years. Total N content of the study area was 0.032 which is very low. The available P was 3.89 ppm which is below the limit of the low to normal P-status of the soil. The low organic carbon content (1.9%) in surface soils of the study area obtained might be due to low biomass incorporation to the soil because of its use as animal feed and fuel. Therefore, the physicochemical property of the soil revealed the area that needs intervention to improve the soil fertility status, soil moisture content, and soil properties of the area.

Rainfall amount and distribution during the crop growing season of 2006

Among the most yield limiting environmental factors in semi-arid areas such as Alamata is the soil moisture deficit. Total amount of rainfall received during the experimental year was 866.6 mm which was optimal for crop production. However, the amount of rainfall recorded during the cropping season from June-November was 440.50 mm. The rain started late and had no uniform distribution and also ceased early (Figure 1).

Unlike the previous years, during the experimental year 2006, the first event of rainfall started on the 27th June. This was very late and farmers faced a problem in getting their fields prepared. The next good rainfall amount received was on the last week of July that helped for

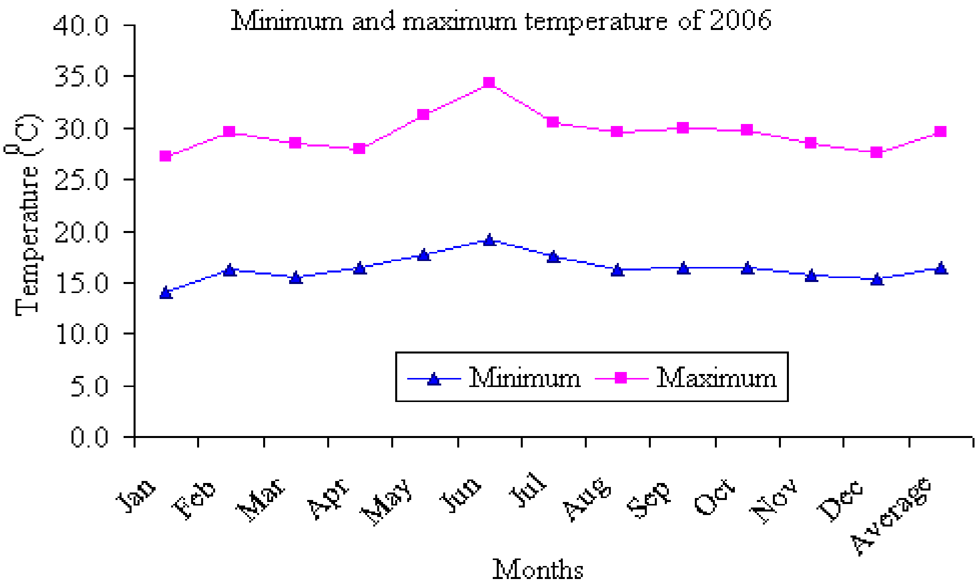

Figure 2. Monthly minimum and maximum temperatures of the year 2006 main growing season.

sowing of the crops. Normally, in the study area, farmers practice sowing from the last week of June to first week of July. But, because of poor distribution and low rainfall amount, sorghum sowing stared from the last week of July. The rainfall distribution was good in the month of August, but reduced from the third week of August. The problem was not in annual rainfall amount; may be sufficient to support the crop growth and development. However, the rainfall distribution was poor; in most of the days there was no rain, less in amount and early cessation during late growing stages of the crop (September- November) which led to drought stress at reproductive stage of the crop.

Temperature of the year 2006

The maximum and minimum annual mean temperatures were 29.6 and 16.5°C, respectively. The lowest temperature occurred during November to March and the highest temperature of the year coincides with the crop growing season from April to October (Figure 2). In addition to soil moisture deficit of the area, the subsequent high solar radiation during the crop growing season (July-November) which brings high evapotranspiration loss, contributed for the depletion of soil water content and subsequent reduction in crop yield per hectare.

Soil water dynamics

Soil profile water content was measured during the growing season at planting, flowering and physiological maturity stages for comparison of treatment effects on rain water harvesting. Volumetric soil water content (%) ranged from 17-27.9%, 14.2-22.5%, and 11.3-17.4% in soil depths of 0-30, 31-60, and 61-90 cm at time of planting, respectively (Figure 3). The amount of soil water harvested due to *in-situ* water harvesting techniques were the highest in the upper soil depth (0-30 cm), followed by the middle (31-60 cm), and lowest (61-90 cm) soil depths. Soil moisture content decreased as the soil depth increased. The change in soil moisture content across soil depths might be due to either less time availability to infiltrate down (since soil samples were collected one day after the rainy day) or probably the rained water was not sufficient in amount to infiltrate down.

In-situ water harvesting techniques with tied and untied furrow planting gave greater soil water content at each depth of the soil profile, followed by tied and untied on ridge planting methods over the least water harvesting technique with flatbed planting methods, respectively. The better presence of soil water in tied or untied ridge with furrow planting was due to ponding of more water in furrows in the upper soil layer and enhance infiltration rate to the deeper soil layers in the middle and lower soil depth than the other planting methods.

Similar pattern of soil moisture content record in each soil depths as of the planting time was observed at flowering stage of the crop. The highest was measured in the upper soil layer, followed by the mid-layer, and the lowest in the deeper soil layer (Figure 4). Among the planting method treatments, in each depth of the soil, tied and untied ridge with furrow planting method showed greater soil moisture content, followed by tied and untied ridge with on ridge planting over least moisture

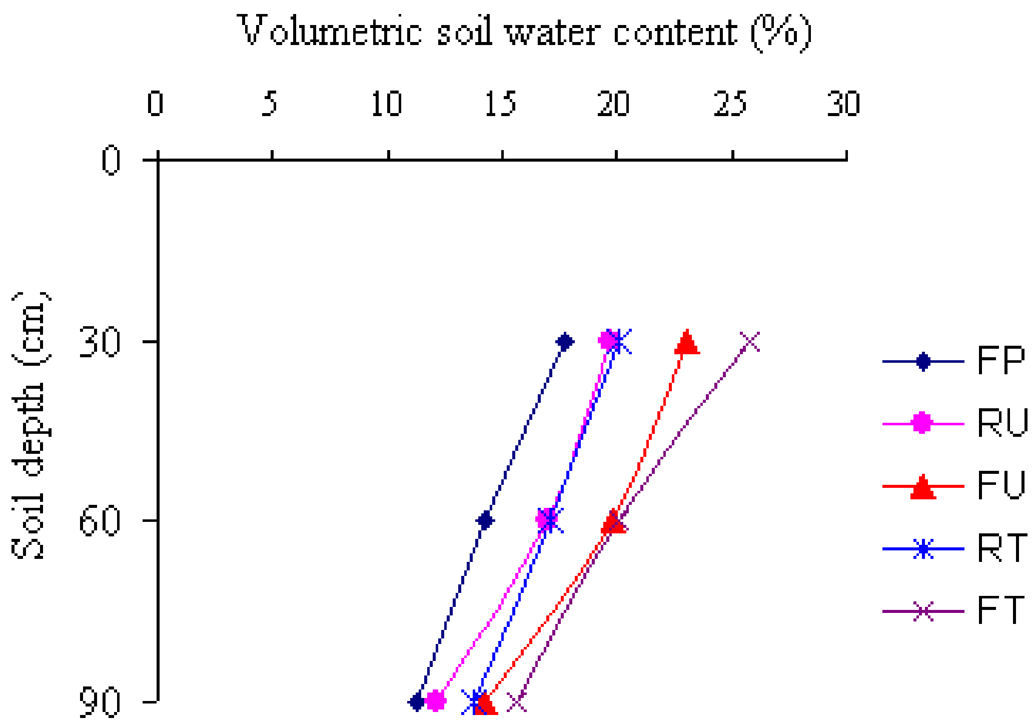

Figure 3. Changes in volumetric soil water content (%) at different soil depths during planting time as influenced by different planting methods. Flat planting (FP), Ridge planting on untied ridges (RU), Furrow planting between untied ridges (FU), Ridge planting on tied ridges (RT) and Furrow planting between tied ridges (FT).

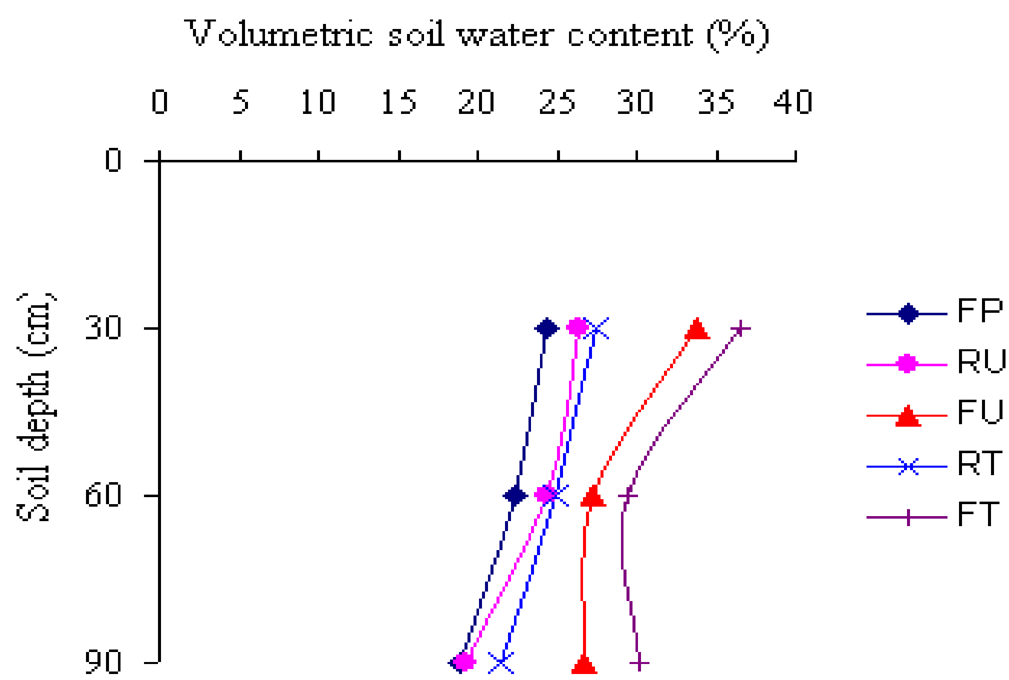

Figure 4. Changes in volumetric soil water content (%) at different soil depths during flowering stage as influenced by different planting methods. Flat planting (FP), Ridge planting on untied ridges (RU), Furrow planting between untied ridges (FU), Ridge planting on tied ridges (RT) and Furrow planting between tied ridges (FT).

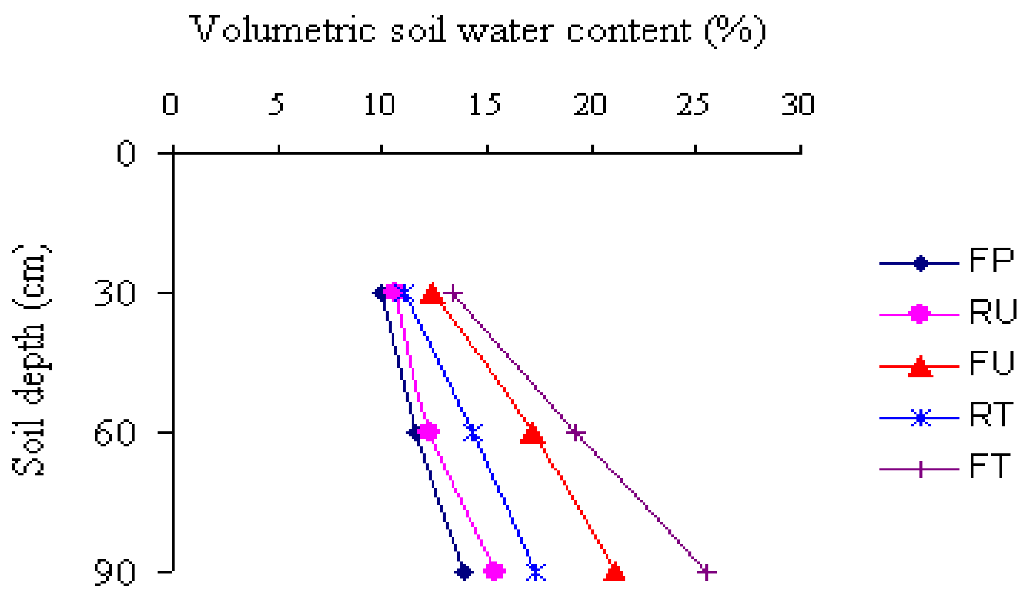

Figure 5. Changes in volumetric soil water content (%) at different soil depths during physiological maturity as influenced by different planting methods.

conservation method and flatbed planting, respectively. This indicates that tied ridge within furrow planting was effective in retaining soil water.

The soil drying at physiological maturity had resulted in very low soil moisture in the upper soil surface unlike to the moisture content recorded during planting and flowering stages of the crop. Soil moisture content determined at physiological maturity stage of the crop was low at each soil depths due to early cessation of rainfall. The extent of depletion was higher in the upper soil depth and intermediate in middle soil depth (Figure 5). Regarding to planting methods, the change in soil moisture across different depths was lowest when sorghum was planted in flatbed, while the change was relatively higher in furrow planting, followed by on ridge planting.

At the three growth stages of the crop where soil moisture content was determined, *in-situ* water harvesting technique (ridge) with tied and untied furrow planting methods gave the highest soil moisture content at each depth of the soil profile and followed by tied and untied on ridge planting methods over the least water harvesting flatbed planting method, respectively. The high soil moisture content obtained in tied riding with furrow planting method was in agreement with the finding shown by Ademe et al. (2018) who reported 33.7% of soil moisture advantage over traditional practice.

Irrespective of planting methods, tied ridging showed the highest soil moisture content at all growth stages in each soil depths, followed by open ridges. On the contrary, the least soil moisture was recorded in traditional practice. The high soil moisture content obtained in tied ridge in this study was in agreement with the finding reported by Ademe et al. (2018) and Araya and Stroosnijder (2010). The improvement in soil moisture content was partly attributed to the surface modifying effect of the ridges probably by reducing soil water run-off and storing more water by restricting water movement from one ridge to other ridges. It was also contributed by the reduction of evaporation losses due to the presence of surface mulching and leaf canopy (Ayala et al., 2023; Araya and Stroosnijde, 2010; Chiroma et al., 2006). Ridges play an important role in harvesting rain water while the furrow provides as planting belt not only to receive the rain falling directly on the surface but also accepts rain water run-off from the ridges. Furrow planting was advantageous over the other planting methods considerably by improving soil moisture storage and prolong the time of moisture availability. Therefore, sorghum roots could easily access moisture which enables them to produce large leaf canopy that shades the furrow area. This reduces the amount of water lost in form of evaporation and thereby prolongs the time of moisture storage to infiltrate into the lower depths of the soil profile.

The effect of sorghum stover mulch on volumetric soil water content is presented in Figures 6 and 7. The soil moisture content was measured two times at flowering and physiological maturity stages of the crop. Irrespective of mulch rates, the lowest soil moisture content was recorded at the time of planting as compared to the samples collected at flowering stage which was mainly due to absence of early application of mulches (Sharma et al., 2011). The soil moisture content at planting was mainly dependent from ridges and evaporation losses.

Regardless of the sampling time, the highest mean soil

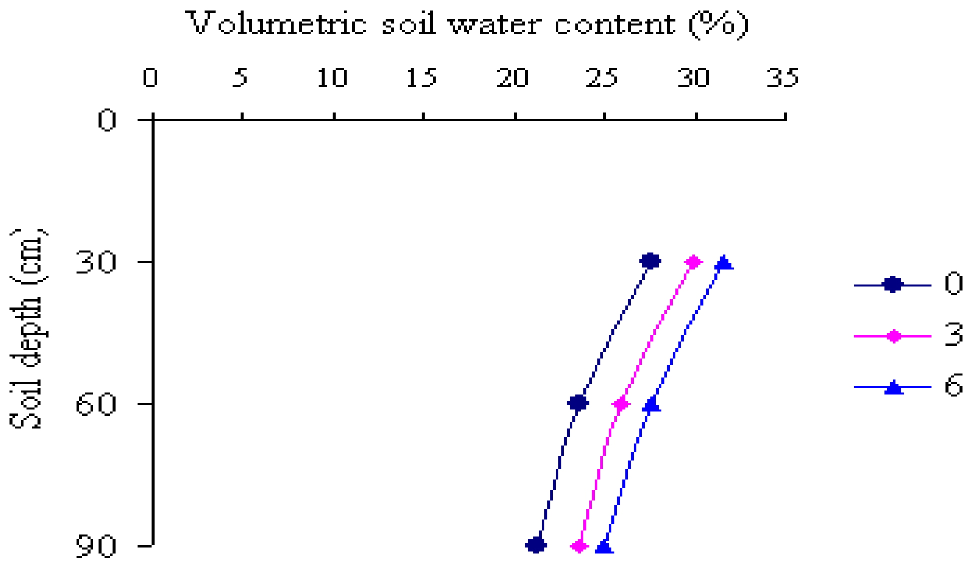

Figure 6. Changes in volumetric soil moisture content (%) at flowering stage of sorghum as influenced by different mulch rates. No mulch (0), 3 t/ha mulch (3) and 6 t/ha mulch (6).

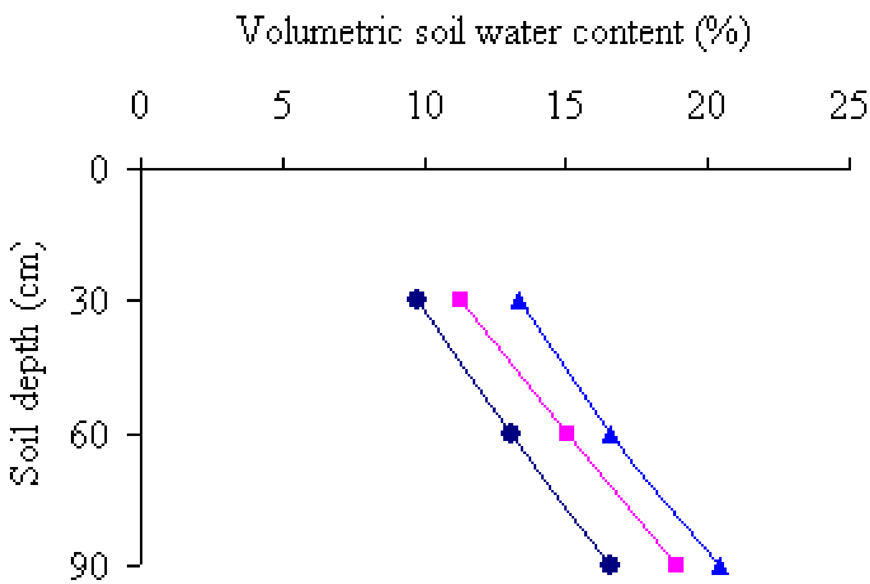

Figure 7. Changes in volumetric soil moisture content (%) at physiological maturity of sorghum as influenced by different mulch rates.

moisture content was recorded in plots that received the highest amount of mulch (6 t/ha), followed by plots treated by 3 t/ha sorghum stover. On the contrary, the least soil moisture content was recorded in plots when mulch application was nil. This result was in agreement with the finding as reported by Patil et al. (2013). Sharma et al. (2011) showed the significant effect of straw mulch in increasing soil moisture content during the growth stages of maize. Mulch is among the most important soil water harvesting methods used to improve plant growth and yield (Yu et al., 2018; Chakraborty et al., 2008). The significant importance of *in-situ* water harvesting methods was clearly pronounced during the long dry spell period of the crop which occurred at reproductive stages of the crop. This was in agreement with Ayala et al. (2023) who reported that soil moisture conservation techniques can prolong moisture availability period in the root zone to enhance yield and yield components of sorghum. Chakraborty et al. (2008) also reported a similar finding that under rice husk mulching, the rate of drying of soil

Table 2. Grain and biomass yield as influenced by the main effect of planting methods and mulch rates.

Treatments	Grain yield (kg/ha)	Biomass yield (kg/ha)
Plating methods		
FP	1128	4282
RU	1511	5524
FU	2162	6893
RT	1683	6098
FT	2312	7537
SEM±	91	1.1
LSD (P < 0.05)	264	511
Mulching rate (t/ha)		
0	1551	5321
3	1775	6329
6	1952	6550
SEM±	71	137
LSD (P < 0.05)	205	396
CV%	16	9

was low as moving from the surface to lower depth (30 - 45 cm) at maturity stage of wheat which improves moisture availability for relatively longer period during crop development stages. During dry periods under no mulch plots, the depletion of soil moisture is higher in lower depths due to the upward movement of water to the dryer depths above. The high soil moisture content record obtained as a result of mulching could be due to the reduced effect of water run-off and surface evaporation, regulating soil temperature fluctuations and improvement in retention and infiltration capacity of the soil (Kader et al., 2019, 2017; Yang et al., 2015).

Effect of soil moisture conservation and planting methods on grain and biomass yield

Grain yield per hectare

The analysis of variance revealed a highly significant ($P \leq 0.05$) difference among the main effect of planting methods and mulches on sorghum grain and biomass yield, whereas their interaction had no influence on the grain and biomass yield (Table 2). The main effect of planting methods showed highly significant variation for grain yield ranging from 1128 to 2312 kg/ha. The lowest mean average sorghum grain yield in the study was obtained on the traditional practice and flatbed planting method (1128 kg) as compared to the highest mean averaged sorghum grain yield recorded in tied ridge with furrow planting (2312 kg/ha). The percentage increment in grain yield of sorghum against the flat bed for FT, RT, FU, and RU were 105, 49.2, 91.7, and 34%, respectively. The increase in grain yield due to furrow and on-ridge planting over flat planting method was 98.3 and 41.6%, respectively. This result agreed with the findings of Ademe et al. (2018) and Heluf (2003) who reported that tied ridging with furrow planting increased grain yield by 35.8 and 21% over the traditional practice, respectively. This is mainly due to the use of soil moisture conservation technique and selection of appropriate planting methods.

According to the result obtained in this study, the use of *in-situ* water harvesting techniques significantly increase sorghum grain yield per hectare. Averaged across *in-situ* moisture conservation techniques, the highest sorghum grain yield was obtained when it was produced under tied ridges (1998 kg/ha) as compared to open-ridges (1836 kg/ha) and traditional tillage (1128 kg/ha). Tied ridge improved sorghum grain yield by 70% over the traditional practices. This result agreed with the previous studies reported by Hussen and Shalemew (2019) and Gebreyesus et al. (2006). Similarly, Georgis (2014) and Araya and Stroosnijde (2010) also reported that tied ridging increased grain yield of sorghum by 150 and 60% compared to the traditional method of moisture conservation, respectively. The higher grain yield obtained in the study was mainly attributed due to soil and moisture conservation techniques employed which reduced water run-off and increase soil moisture availability for longer duration around the crop root zone.

The influence of mulches on sorghum grain yield is presented in Table 2. Sorghum grain yield was significantly ($P \leq 0.05$) influenced by the main effect of mulches ranging from 1551 to 1952 kg/ha depending on the moisture content in the soil as a result of the difference in mulch treatments. The highest grain yield was obtained in plots that received 6 t/ha mulch, followed by 3 t/ha over the control. The yield increase obtained due to 6 and 3 t/ha mulch levels was about 25.9 and

14.5% over the control, respectively. This result agreed with the finding reported by Yu et al. (2018) and Sharma et al. (2011). Such increase in sorghum grain yield obtained in this study under mulched plots may be explained by reduced water run-off, prevention of direct solar radiation impact and improvement in permeability (which increase infiltration rate) collectively improves soil moisture content and likely increase soil moisture availability at the root zone (Kader et al., 2017; Kasirajan and Ngouajio, 2012; Awodoyin et al., 2007).

Biomass yield per hectare

The main effect of planting methods and mulching rates on biomass yield per hectare are presented in Table 2. The analysis of variance indicated highly significant (P≤0.01) difference among the main effect of planting methods and mulch rates, but their interaction was not significant. Significantly higher above ground biomass was obtained in plots provided with *in-situ* water harvesting techniques than to those planted under poor water harvesting methods (flatbed). Similarly, sorghum planted in furrows (7214 kg/ha) gave significantly higher above ground biomass as compared to on ridge (5811 kg/ha) and flatbed (4282 kg/ha) planting methods. The above ground dry biomass increase due to ridges with planting methods of FT, FU, RT and RU against flatbed type of planting were 76, 60.9, 42.4 and 29.0%, respectively. This indicates that the highest biomass yield was obtained under furrow planting over the flatbed planting methods. This result agreed with the previous study which showed a biomass improvement of 27.8% under tied ridge with furrow planting method (Ademe et al., 2018).

Above ground biomass yield was also significantly (P≤0.01) influenced by application of different amount of mulches. Irrespective of planting methods, plots receiving either 3 or 6 t/ha sorghum stover mulch had significantly (P≤0.05) greater above ground biomass over plots treated with no mulch. The highest mean above ground biomass was obtained in plots receiving high amount of mulch (6 t/ha), followed by plots with a mulch level of 3 t/ha. However, the lowest mean above ground biomass yield per hectare was observed in plots where no mulch was applied. The increase in biomass yield obtained in this study is agreement with the findings reported by Gabir et al. (2014), Georgis (2014) and Taye et al. (2013).

Relatively higher amount of moisture conserved as the expense of soil moisture conservation structures and mulch application favored prolonged growth and maturity duration for sorghum planted in furrow. It enhances better amount of water involvement in metabolic activities, cell elongation and transpiration (Lovenstein et al., 1995). This brings a better vegetative and reproductive growth of the crop organs, that is, increase in leaf size, stem length and diameter, plant height, panicle size and other related parameters (data not showed). An increase in these traits in the four planting methods and mulch applications over flatbed planting and nil mulch usage resulted in an increase in the above ground biomass yield of sorghum. The low soil moisture content obtained in flat bed planting and 0 t/ha mulch application during the vegetative and reproductive stages of the crop may be the reason for low above ground biomass. Stover is also an important product highly needed by farmers in the dry land areas such as Alamata due to its alternative use as animal feed, house construction and fuel wood purposes. Any significant increase in this matter has also a great value nearly equal to the grain yield.

Conclusion

Crop production in semi-arid dry land areas of Ethiopia is totally dependent on erratic rainfall-uneven distribution, torrential in intensity, low in amount during crop growing season, and variable from year to year. This results in unpredictable agricultural production and occasional crop failure in any time of the crop growing season. This study explored soil moisture enhancing technologies to improve soil moisture availability in the sorghum root zone and maintains the physical, chemical and biological properties of the soil so as to enhance sorghum productivity in the area.

In this study, tied ridge with furrow planting and application of 6 t/ha mulch enhances the soil moisture availability within the root zone to increase grain and biomass yield of sorghum. This advantage of tied ridges with furrow planting and mulch application was mainly by reducing surface evaporation, water run-off and soil erosion, and solar radiation impact which enhances infiltration of water into the lower soil depths which prolong the time of moisture availability in the root zones of sorghum.

Therefore, it may be concluded that sorghum planted in tied ridges with furrow planting method and application of 6 t/ha mulch can sustainably improve agricultural productivity in areas with water restrictions and are recommended for regions with similar conditions.

In addition, the wise use of soil water conservation practices employing early planting with selection of proper type of variety and appropriate soil fertility enhancing mechanisms are highly important for such dry land areas.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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