Open Access Journal

Journal of Sustainable Research in Engineering Vol. 5 (1) 2019, 12 - 24

Journal homepage: http://sri.jkuat.ac.ke/ojs/index.php/sri

ISSN (Online): 2409-1243

Assessment of the Best Moisture Conservation Technique in Sorghum Production under Spate Irrigation: A Case Study of Ewaso Nyiro South Drainage Basin

Celestine Kilongosi[1,3]*, James Raude[2], Raphael Wambua[1], Maimbo Malesu[3] and Alex Oduor[3]

[1]Department of Agricultural Engineering, Egerton University. P.O Box 536- 20115 Njoro, Kenya.
[2]Soil, Water and Environmental Engineering Department, Jomo Kenyatta University of Agriculture and Technology, (JKUAT). P.O Box 62,000 - 00200 Nairobi, Kenya.
[3]Water management unit, East and Southern Regional Office, World Agroforestry Centre (ICRAF), Nairobi, Kenya

*Correspondent author- Email: kilongosicelestine@gmail.com

Abstract Kajiado County is an arid and semi-arid area in Kenya that experiences frequent flash floods. Most of the water evaporates due to the high temperatures experienced in the area. However, to attain reasonable crop yield the soil moisture can be conserved for longer provision to the plants. The objective of this research was to assess the best technique in retaining the soil moisture content of a spate-irrigated sorghum field in Ewaso Nyiro South Drainage Basin. The conservation techniques used were Chloris gayana grass-mulch, ridges and ridge-furrow mulch. The techniques were then compared to the control which was the traditional way of growing sorghum in the area. The experiment was set-up in a Randomized Complete Block Design (RCBD) of three blocks of 10m by 10m. The blocks were further subdivided into four equal plots of 5m by 5m. The effect of the treatments on moisture retention was monitored using YL-69 sensors installed at depths 20 cm and 40 cm respectively for 125 days. At the 20-cm depth, there was no significant difference in terms of moisture retention from the different treatments. However, at the 40-cm depth, mulch treatment had the highest moisture retention value of 31.69%. This was closely followed by the combined ridges and mulch, ridges and control which had means of 31.61%, 31.59% and 30.39% respectively. These findings are important as they can be used by agriculturalists, farmers and relevant stakeholders in prioritizing soil moisture conservation techniques for increased crop production.

Keywords: Mulch, ridges, ridge-furrow mulch, soil moisture, spate irrigation, YL-69 moisture sensors

1. Introduction

Soil and water conservation techniques have been invented for varied reasons all over the world [1, 2]. The conservation measures are mainly used to retain soil moisture, reduce soil erosion and retain nutrients with the end goal of increasing crop yields [3]. Water retention characteristics of the soil play an important role in determining good irrigation practices as well as control of runoff. Different studies on moisture conservation have been carried out. For instance, a study by [4] was conducted in Cyili sub-catchment and from the findings it was concluded that mulching, ridges and supplementary irrigation were effective in saving water and improving the grain yield productivity. The study aimed at identifying the best water conservation measure for optimized maize yield production in the hot and dry regions. The treatments used were the rainfed (control), ridges, mulching and supplementary irrigation. From the experiment, it was concluded that mulching, ridges and supplementary irrigation saved water and improved grain yield per hectare in the drought prone agro-ecological zone though the extent to which each conservation measure retained moisture content was not evaluated. To assess the importance of water use and stress avoidance to the plants in Upper Ewaso Ng'iro River Basin, a study was conducted on Acacia tortilis, Acacia xanthophloea and acacia drepanolobium [5]. The results indicated that the overall fitness is strongly influenced by water use than stress avoidance but a consideration of both is critical for predicting basin-scale patterns of species distribution. [6] conducted a field study to compare fields with similar soil types farmed with soil conserving practices in Central Ohio to determine if no-till and cover crops can influence soil moisture retention through the build-up of soil organic matter content. The soil moisture content was measured at depths 0-20 cm, 20-40 cm and 40- 60 cm. From the experiment, the author concluded that the use of cover crops did not influence the amount of soil moisture retained.

A study of the effect of different conservation techniques on crop yield under spate irrigation can help in determining which methods are recommended and applicable for moisture retention since spate irrigation is practiced mainly in the Arid and Semi-Arid Lands (ASALs). Such a study is important for policy and decision makers as well as extension officers in that it can be used to choose measures that can best help farmers in conserving their soil moisture for improved land productivity. The ASAL areas can highly benefit as they receive an average of 600 mm of rainfall per year [7]. This therefore, prompted the need for this research in Kajiado County which is one of the semi-arid areas in Kenya. Kenya has a land mass of 582,000 km^2 out of which approximately 80% of the land is arid and semi -arid (ASAL) receiving a mean annual rainfall less than 750 mm. The ASAL supports about 20 % of the population in Kenya. This clearly shows that Kenya is poorly endowed with a potential for practicing rain-fed agriculture. However, different areas of the country like Kajiado County receive recurrent flash floods which can be used for spate irrigation which targets 50,000 ha as outlined in Kenya's Vision 2030 development blue print. This vision is cascaded and outlined in the County Integrated Development Plans (CIDPs). It is also of interest to the European Commission and IFAD, who are supporting an on-going Flood Based Livelihoods Systems project in Kenya implemented by ICRAF and the Government of Kenya. The main aim of this research was to assess the best technique in retaining soil moisture on a spate-irrigated sorghum field in Kajiado County. Particularly, the moisture conservation techniques considered in this research were grass mulch, contour ridges and ridge-furrow mulch.

2. Materials and Methods

2.1 Study area

Ol Donyo Nyoike ranch lies in Ewaso Nyiro South sub-catchment area, within the Kajiado County of Kenya. The ranch is communally owned and used by the Maasai community for livestock grazing. River Ewaso Nyiro which is the main river in the sub-catchment flows from the Mau Escarpment to the south through the rift valley and to the east of Nguruman Escarpment. Ewaso Nyiro River has many tributaries which traverse different parts of the County. Ol Donyo Nyoike ranch is fed by River Olkeju Ng'iro which is one of its tributaries [8]. The study area, of 4.176 km^2 in area, is sandwiched between Ngong meteorological station to the upstream and Magadi meteorological station in the downstream. It lies between latitudes 1° 41′ 58.26″ and 1° 41′ 57.39″ S and between longitudes 36° 23′ 22.35″ and 36° 23′ 21.82″ E as illustrated in Figure 1.

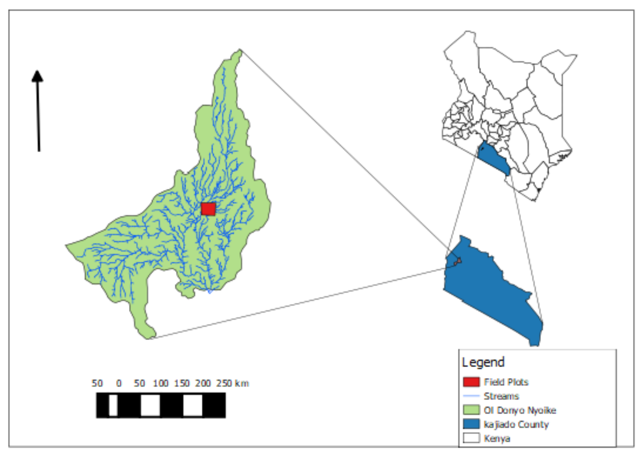


Fig 1: Map of Kajiado County showing Ol Donyo Nyoike sub-catchment

The study area experiences bimodal distribution of rainfall with the long rains running from March to May and the short rains from October to December. The annual mean rainfall is 600 mm and varies with altitude. For instance, the amount of rainfall increases from 500 mm in the plains to 1250 mm in the highlands. Temperature also varies with altitude and ranges from 12^{0}C in the highlands to 34^{0}C in the plains [7,9].

The sub-catchment lies within an altitude of between 848 and 1654 m above sea level. The highest point has an altitude of between 1,500 and 1,654 m above sea level. The lowest was at a point between 848 and 900 m above sea level as presented in the DEM shown in Figure 2.

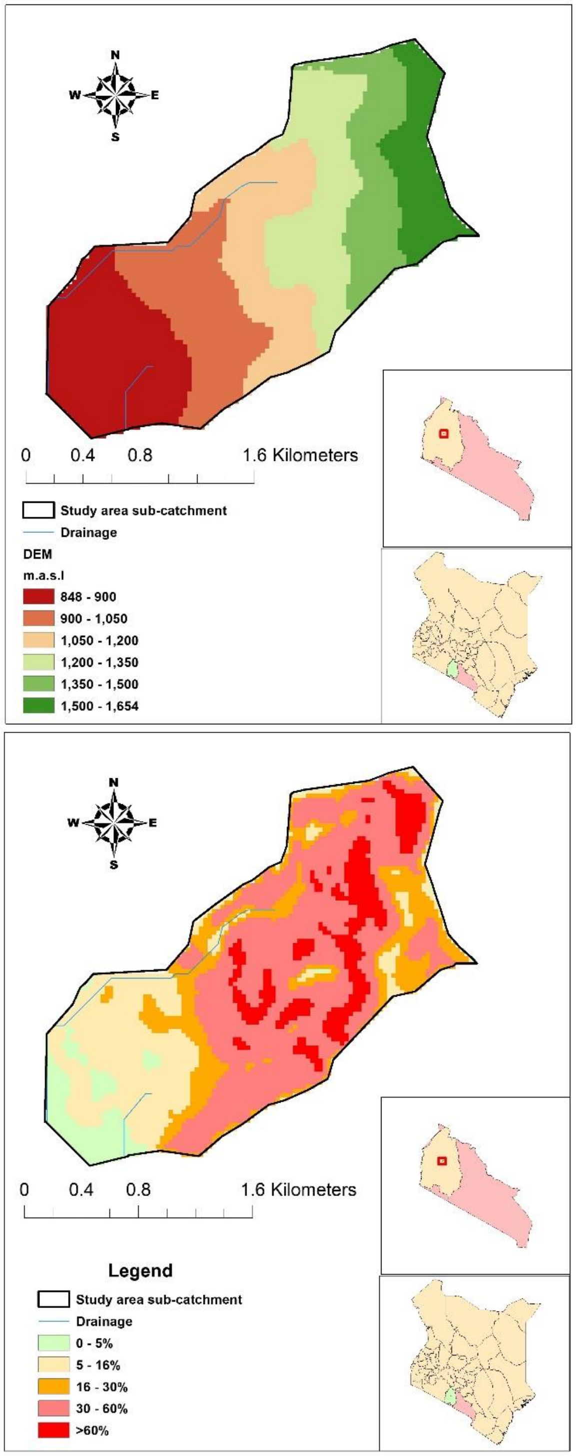


Fig 2: DEM and slope of the study area

From the slope map, presented in Figure 2, there are five slope categories of 0-5%, 5-16%, 16-30%, 30-60% and >60%. The largest proportion of the land has a slope steepness ranging from 30 to 60%. From the slope map, a smaller proportion of the land has a slope greater than 60%. The smallest portion of the sub-catchment had a slope of between 0 and 5% and was only visible in the lower part of the sub-catchment. In the field plots however, the slope lied between 0% and 0.1%.

2.2 Experimental set up

The experiment was laid down in Randomized Complete Block design (RCB) of three blocks. Each block consisted of four plots measuring 5m by 5m. Around the plots, the three blocks were surrounded by short bunds to spread the flow of water without causing erosion. Since the field plots were technically flat, no erosion measurements were put into consideration. The particle size distribution analysis of the soil in the study area was conducted using Laser Diffraction Particle size analyzer (LA-950V2 HORIBA). The analysis was conducted in the wet mode where sodium hexametaphosphate (calgon solution) was used as the dispersing agent. To understand the soil-water dynamics, the saturation water content of the soil was calculated as:

$$\theta_{sat} = 100(1 - \frac{\rho_b}{\rho_p}) \quad (1)$$

where:

θ_{sat} = Volumetric soil-water content at saturation (%)

ρ_b = Bulk density of soil (g/cm^3)

ρ_p = Particle density of soil (g/cm^3)

The soil moisture conservation techniques randomly applied into the field were mulch, ridges and combined ridges and mulch. These were then compared to the traditional way of growing sorghum in the area; considered as the control treatment. This experimental set-up (Figures 3 and 4) were repeated three times to filter out the possible variabilities.

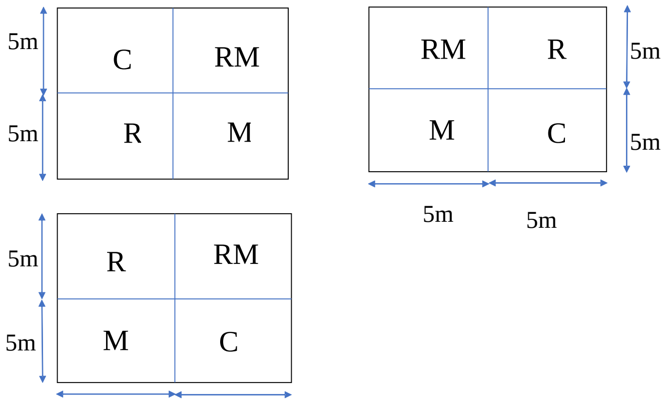


Fig 3: The experimental layout of the plots (C = Control; R = Ridges; RM = Combined ridges and mulch; M = Mulch)

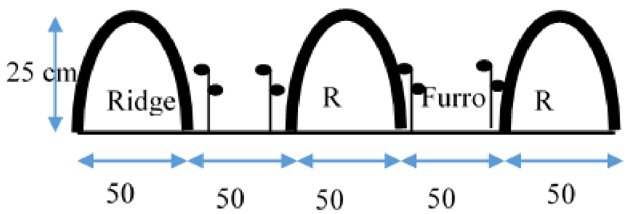


Fig 4: Dimensions of the ridges and furrows

Ridging is done by constructing small earth banks parallel to the contours of a slope. The water is held between the ridges where the crops are planted and is thus allowed to infiltrate into the soil. It is mainly used on slopes with a gradient up to 7% and in most of the cases, clay soils are used for construction [10]. The ridges are effective in transforming the land into small pockets of water hence effective for soil moisture retention [11]. In this study, ridges measuring 50 cm wide, 25 cm high and 50 cm apart were constructed. The crops were planted on the furrows. In the cases of mulch and combined ridges and mulch, a 5-cm grass thickness was placed at the furrows where the sorghum crop was planted. A study by [12] concluded that Chloris gayana is good as a cover crop and in improving the infiltration and water holding capacity of the soil. The extent in which Chloris gayana improves the soil water holding capacity was not clearly stated and hence this study focused on establishing this extent. Apart from being biodegradable, grass mulch was also preferred since use of plastic materials were banned by the Kenyan government though plastics are more effective in conserving soil moisture. Selection of different moisture conservation techniques is as presented in Figures 3 and 4.

The crop water requirement and yield were assessed during the growth period. The reference evapotranspiration (ET_o) was estimated using the Hargreaves formula as presented in Equation 2.

$$ET_o = 0.0023 \times Ra \times (T_{ave} + 17.78) \times \sqrt{\Delta T} \qquad (2)$$

Where:

ETo = Reference evapotranspiration (mm/day)
Ra = Extraterrestrial radiation (mm/day)
ΔT = Temperature range (^{0}C)

The temperature range and average were calculated using Equations 3 and 4.

$$\Delta T = T_{max} - T_{min} \qquad (3)$$

$$T_{ave} = \frac{T_{max} + T_{min}}{2} \qquad (4)$$

Where:

T_{ave} = Average temperature (^{0}C)
T_{min} = Minimum temperature (^{0}C)
T_{max} = Maximum temperature (^{0}C)

The obtained ET_o was then multiplied with the sorghum crop coefficient (K_c) to provide the crop water requirement as presented in Equation 5.

$$ET_C = K_C \times ET_O \qquad (5)$$

The plots were planted with sorghum on the 7th of September 2017 and harvested on the 10th of January 2018.

Soil moisture at 20 cm and 40 cm depths was measured using digital moisture sensors (YL-69). Holes for the placement of the sensors were dug using a regular closed soil auger. All the sensors were connected to the Arduino micro controller which was the main server of all the connections. The YL-69 moisture sensor consists of two probes which measured the volumetric soil moisture content. The YL-69 soil moisture sensors were used in this study due to their low cost, good operation ability and their high level of accuracy. To get useful soil moisture data, all the sensors placed in the field were calibrated against the available soil type. For wet and dry soils, the resistances were low and high respectively. In turn, the moisture readings were respectively high and low for the wet and dry soil conditions.

All the soil clogs were broken to ensure consistent water movement. The analogue output, which measures 1024 units, was used in the measurement of the soil moisture content in this study. The moisture content of a sensor not dipped in the soil was 971, which denoted the dry condition. The value 971 was mapped to zero. With the saturated soils, the moisture condition was 399. The value 399 was mapped to 100%. The values obtained were used as the threshold values or the baseline from which the other sensors were based upon. To calibrate the additional soil moisture sensors to the threshold values (971 – 399), the sensors were dipped in both dry and saturated soils. The potentiometer (knob on the probe's interface) was used to adjust the sensor values to the desired results. The obtained values were also mapped to 0 and 100% as in Equation 6.

$$value = map(value, 971, 399, 100, 0) \quad (6)$$

The percentage volumetric soil moisture content was recorded every fifteen minutes for the entire growth period and relayed to the cloud for storage. The delay of the readings for fifteen minutes was aimed at extending the lifespan of the soil moisture sensors. The delay also ensured that the sensors had enough time to send their readings to the cloud hence the accuracy in the values. For analysis purposes, the average daily moisture content readings were used.

A sim card with 3G data was used as the source of internet to send the data to the "ThingSpeak" cloud. To visualize the data in android phones, the "ThingView" application was installed in the mobile phones. Click 'Get started' to create a free account. To enter the three blocks, the 'New channel' option was selected and their names entered to represent each block. To enter the sensor depths, two 'fields' were selected. The values in the "ThingView" application were observed as graphs or charts. However, all the data was recorded in the server for a later download. To share the information with the public, the 'Make public' option was checked. To save the information on the application, the 'save channel' option was checked. Weather monitoring sensors were installed to record the humidity, wind speed and temperature. DHT -11 sensor was used to take temperature and humidity readings. Rain gauges were also installed to record the amount of precipitation in the study area. Rainfall sensors were installed at the neighboring upper sub-catchment by the Kenya Meteorological Department and Igad Climate Prediction and Applications Center (ICPAC).

3. Results

From the particle size distribution analysis, the results show that soil texture in the plots was clay with a bulk density of 1.23 g/cm^3 while the particle density was assumed to be 2.65 g/cm^3, which is typical of such soils. Using Equation 1, the volumetric soil water content at saturation was 53.6%.

From the weather sensors, zero amount of precipitation was recorded at the study area during the entire study period. However, significant precipitation depths were recorded in the neighboring upper sub-catchment as presented in Table 1.

Table 1: Observed precipitation depths during the growth period

Day	Precipitation depth (mm)
12	52.72
34	68.48
41	69.22
83	44.62
86	18.89
120	14.22

The total precipitation depth for the entire crop growth recorded was 267.95 mm. The highest and the least precipitation depths of 69.22 mm and 14.22 mm were recorded on the 41st and 120th days respectively. Six flood events were observed at the study area.

On the mobile phones, the amount of soil moisture retained was presented as presented in Figure 5.

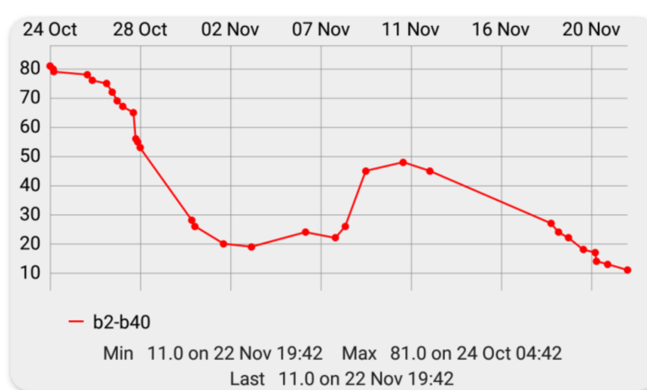


Fig 5: Volumetric moisture content against dates

The chart in "ThingView" application, depicted the minimum and maximum volumetric moisture content values as well as the last value recorded and the time at which the values were taken. The block and the depth at which the sensor is placed is also indicated in the chart.

From the graph, the volumetric moisture content increased with occurrence of a flood.

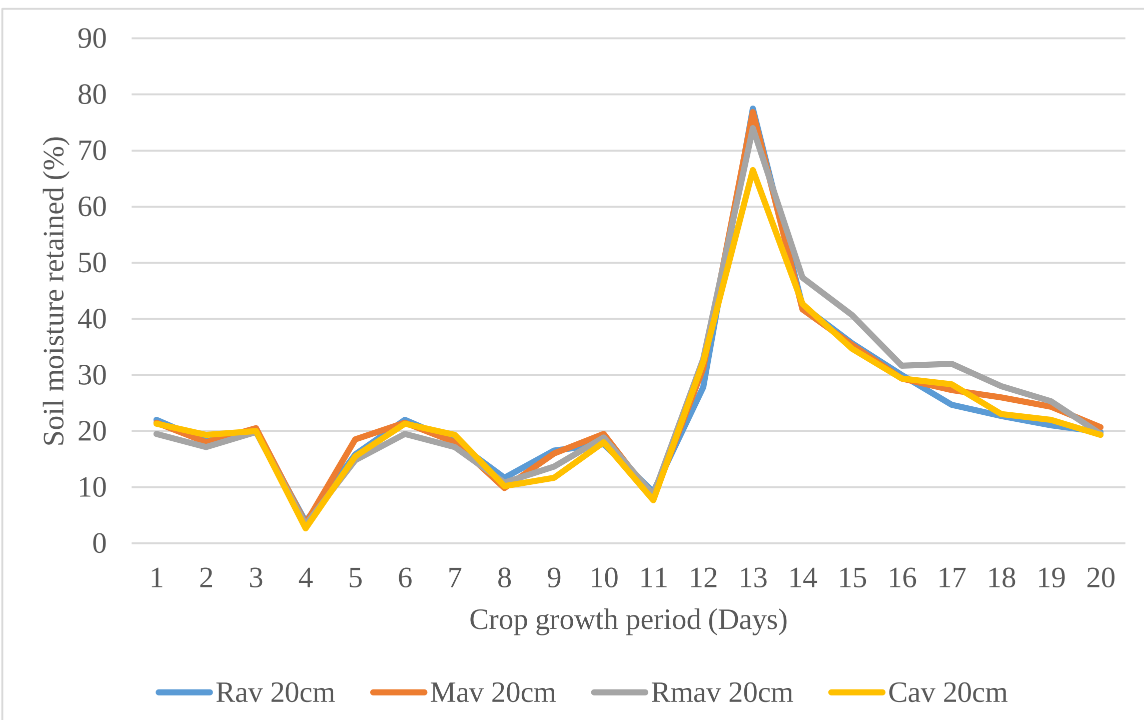
Using the Hargreaves formula, the water requirement of the sorghum was slightly different under the different moisture conservation techniques. The water requirement per growth stage ranged from 38.3 mm in the initial stage to 177.6 mm in the mid-season stage. In addition, the seasonal water requirement of sorghum in this study was 386.9 mm, 395.7 mm, 390.1 mm and 386 mm under control, mulch, combined ridges and much and finally under the ridges respectively.

3.1 Moisture retention at different depths

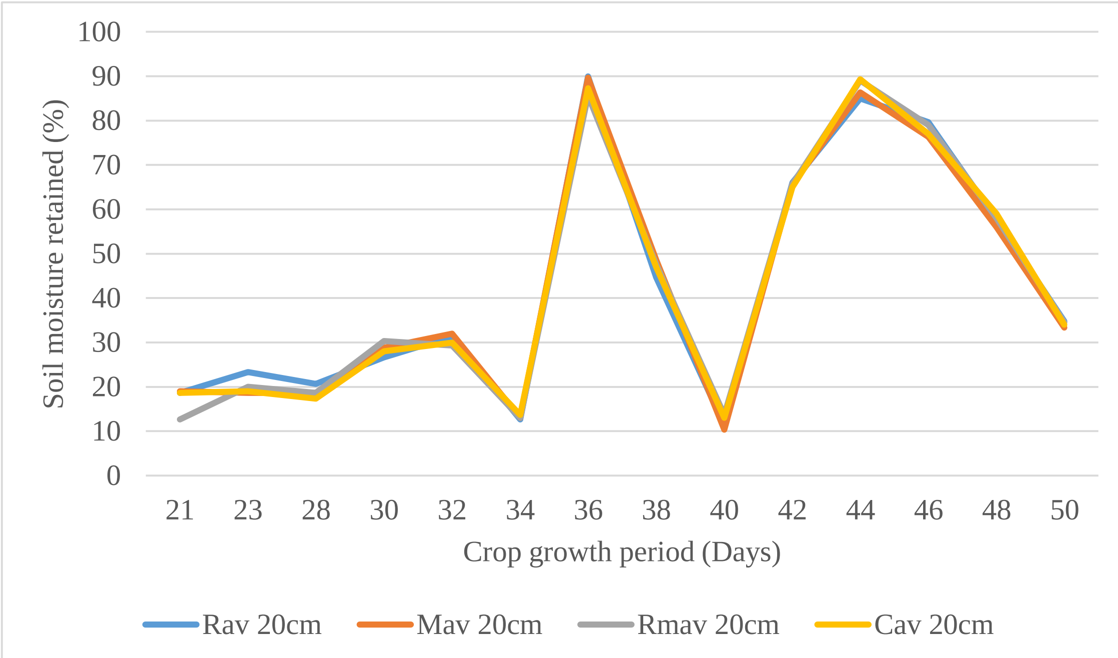
The moisture retained at the different crop growth stages under the different moisture conservation techniques is as illustrated in Figures 6 (a-d) and 7 (a-d) for the entire sorghum crop development period corresponding to 125 days. Letters a, b, c and d in the figures represent initial, development, mid-season and late development stages respectively.

In the initial stage, one flood event was observed on the 12th day. The volumetric moisture content of the soil under each treatment increased. On the 13th day, the moisture content values recorded under combined ridges and mulch, ridges, mulch and control were 74.00%, 77.50%, 76.83% and 66.50% respectively. At the end of the growth stage, the moisture content values under combined ridges and mulch, ridges, mulch and control were 19.50%, 19.83%, 20.67% and 19.33% respectively.

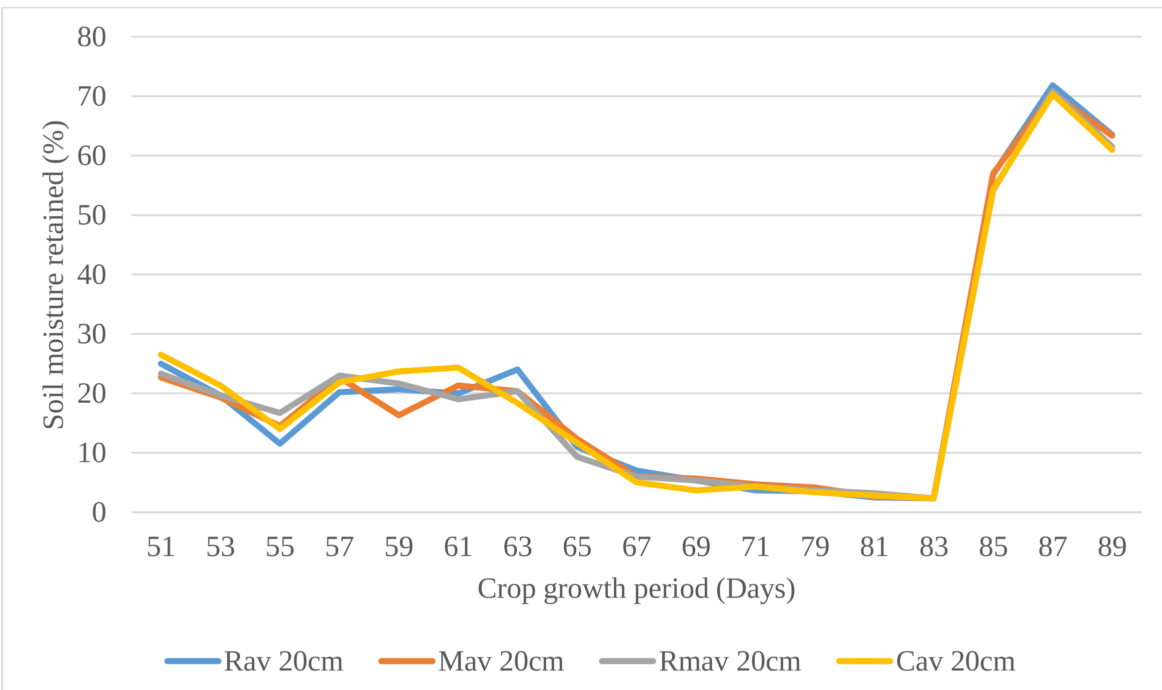
In the development stage, two flood events were observed on the 34th and 41st days. The moisture absorbed by the soil varied from 85.67% and 90.00% with the different moisture conservation techniques. At the end of the growth period, the moisture content values by the ridges, mulch, control and combined ridges and mulch were 34.83%, 33.33%, 34.00% and 34.50% respectively.



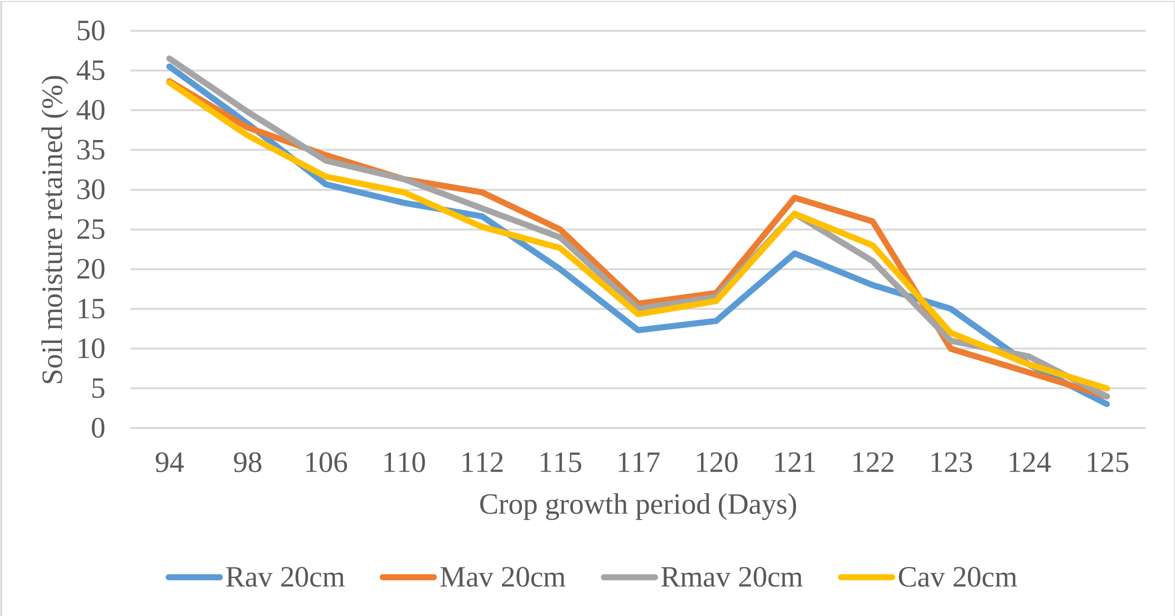
(a)


100
90
80
70
60
50
40
30
20
10
0
Soil moisture retained (%)
21 23 28 30 32 34 36 38 40 42 44 46 48 50
Crop growth period (Days)
Rav 20cm
Mav 20cm
Rmav 20cm
Cav 20cm

(b)


80
70
60
50
40
30
20
10
0
Soil moisture retained (%)
51 53 55 57 59 61 63 65 67 69 71 79 81 83 85 87 89
Crop growth period (Days)
Rav 20cm
Mav 20cm
Rmav 20cm
Cav 20cm

(c)



(d)

Fig 6 (a-d): **Moisture retained per different crop growth stages at 20-cm depth** (Rav = Ridges average Mav = Mulch average RMav= Combined ridges and mulch Cav = Control average)

In the mid-season stage, two floods were observed on days 83 and 86. The flood event on day 83 raised the moisture levels to values between 43.00% to 46.00%. The flood event on day 86 increased moisture content levels to values between 70.00% and 72.00%. The last flood event occurred on day 120 at 9.00 am which translated to an increase in the soil moisture levels to a moisture content of between 22.00% and 29.00%. the moisture content reduced with time and at harvesting, day 125, the moisture content recorded was 5.00% at the control, 3.00% for the ridges and 4% for the combined ridges and mulch. The low values of moisture retained in the ridges and the combined ridges and mulch could be attributed to the washed away ridges since the surface area under direct evaporation was increased.

To statistically assess the effect of different moisture conservation techniques on moisture retention, an analysis of variance (ANOVA) was done. An analysis of variance (ANOVA) was conducted to determine which conservation measure was suitable for retaining the highest moisture content in the soil. This analysis was conducted at 95% confidence interval and results are presented in Table 2.

Table 2: ANOVA test at 20 cm depth (C = Control, M = Mulch, RM = Combined ridges and mulch, R = Ridges)

Moisture conservation technique	Count	Sum	Average	Variance
RM	3	99.94	33.31	4.10
M	3	100.11	33.37	0.54
C	3	99.00	33.00	6.98
R	3	99.61	33.20	3.63
Block 1	4	130.95	32.74	0.18
Block 2	4	126.77	31.69	0.66
Block 3	4	140.94	35.23	0.57

Source of variation	df	SS	MS	F	Fcritical	P-value
Treatments	3	0.24	0.08	0.12	4.76	0.95
Blocks	2	26.50	13.25	19.94	5.14	0.002
Error	6	3.99	0.67			
Total	11	30.72				

At the 40-cm depth, the moisture conservation graphs are illustrated in Figure 7 (a-d).

In the initial stage, the ridges acted as pockets hence much of the water could infiltrate deeper into the ground. This in turn led to the high moisture content values recorded under the ridges and combined ridges and mulch unlike the control and mulch. On the 14th day, the combined ridges and mulch, ridges, mulch and control retained moisture values of 57%, 52%, 55% and 48.3%. The low values under the control were observed due to high levels of evaporation from the bare soil. At the end of the growing season, the control still recorded the least amount of moisture retained of 31.50%. The highest was recorded under the ridges with a value of 36.83%.

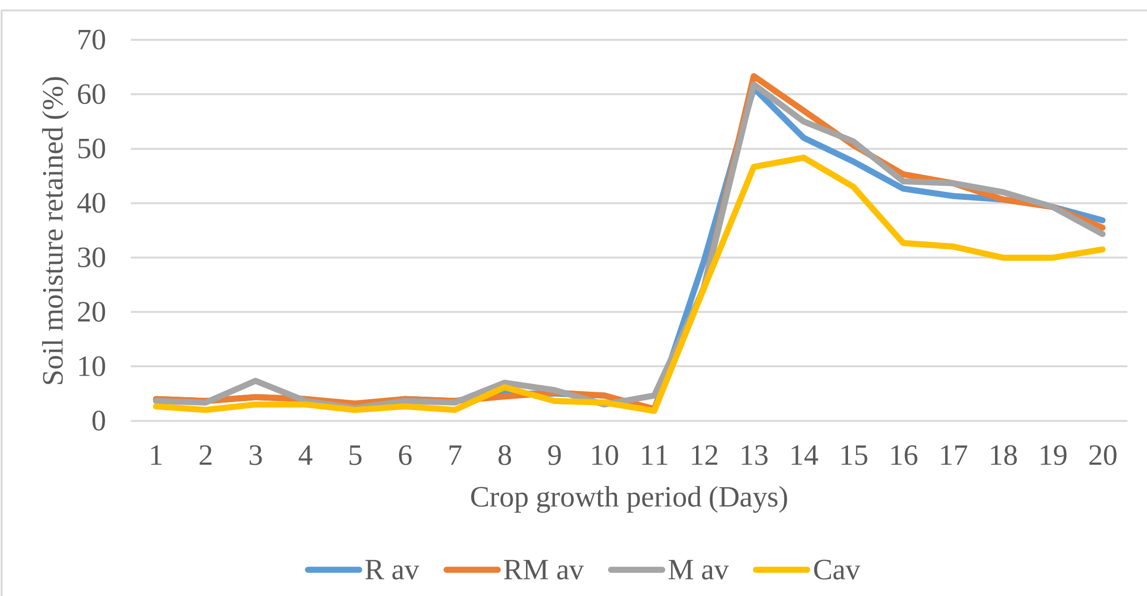
In the development stage, two flood events were observed. On day 34, the moisture content increased to values of between 85% to 90% in all treatments. After 6 days, the moisture content in all treatments had reduced to levels between 14.7% and 17.3% after which another flood event was observed on day 41. The moisture content increased to levels between 80% and 85%.

Like other aforementioned crop growth stages, the control recorded the least value of moisture retained of 34.67% as compared to the highest value of 38.33% under the ridges in mid-season stage. The moisture retention curves of the sensors at this depth are illustrated in Figure 7. In determination of the most suitable technique, the statistical analysis was conducted. ANOVA was used as tabulated in Table 3.

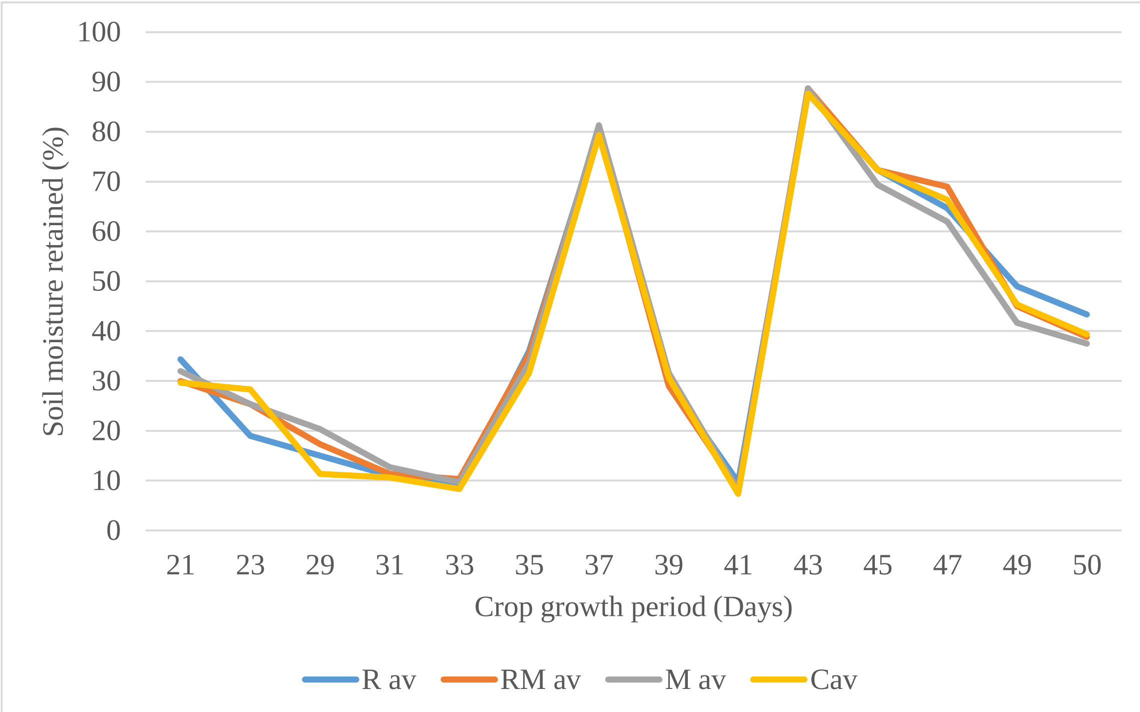
Table 3: **ANOVA test at 40 cm depth (**C = Control M = Mulch RM = Combined ridges and mulch R = Ridges)

Moisture conservation technique	Count	Sum	Average	Variance
RM	3	94.83	31.61	12.54
C	3	91.16	30.39	14.39
M	3	95.05	31.69	10.52
R	3	94.77	31.59	15.44
Block 1	4	115.24	28.81	0.92
Block 2	4	118.70	29.68	0.20
Block 3	4	141.87	35.47	0.38

Source of variation	df	SS	MS	F	Fcritical	P value
Treatments	3	3.49	1.16	6.99	4.76	0.02
Blocks	2	104.78	52.39	315.44	5.14	8.36 E-07
Error	6	1.00	0.17			
Total	11	109.27				

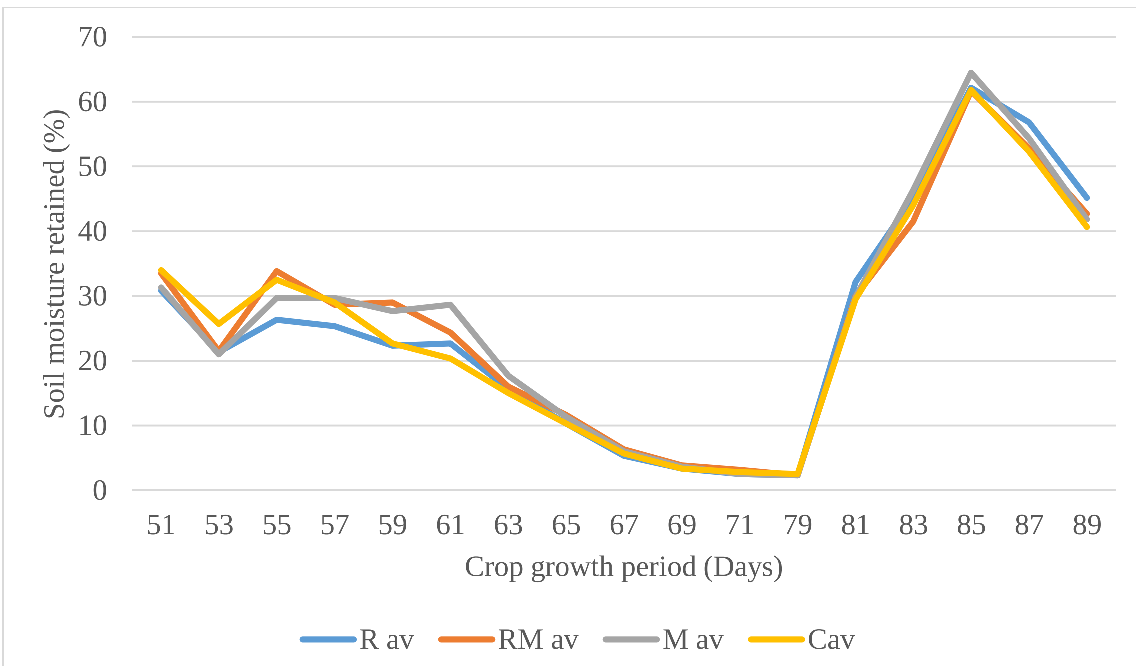


(a)



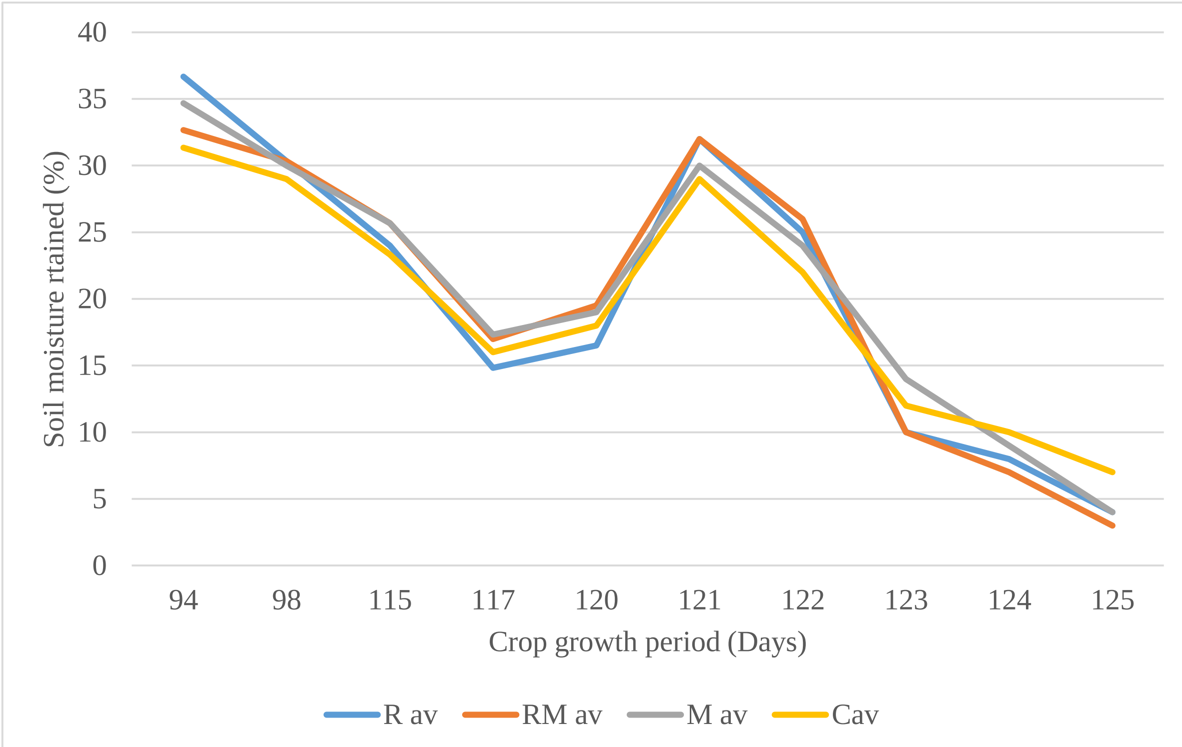
100
90
80
70
60
50
40
30
20
10
0
Soil moisture retained (%)
21
23
29
31
33
35
37
39
41
43
45
47
49
50
Crop growth period (Days)
R av
RM av
M av
Cav

(b)



70
60
50
40
30
20
10
0
Soil moisture retained (%)
51
53
55
57
59
61
63
65
67
69
71
79
81
83
85
87
89
Crop growth period (Days)
R av
RM av
M av
Cav

(c)



(d)

Fig 7 (a-d): Plot of the moisture retained per crop growth stage at the 40-cm depth (Rav = Ridges average; RMav = Combined ridges and mulch average; Mav = Mulch average; Cav = Control average)

3.2 Yield of sorghum

Due to the small significant differences in the amount of soil moisture retained at the 40-cm depth, the amounts of yield from each treatment were assessed as presented in Table 4.

Table 4: Yield of sorghum under different moisture conservation techniques

Treatment	Yield (kg/ha)
Control	5200
Mulch	6500
Combined ridges and mulch	8100
Ridges	7100

4. Discussion

From the analysis results summarized in Table 2, it was evident that there was no significant difference at the 20-cm depth in terms of moisture retention from the different treatments. This could have been attributed to the high amount of evaporation from the soil regardless of the moisture conservation technique. A study conducted by [6, 13], concluded that there were no significant differences between the treatments in soil moisture within the soil profile. However, the treatments were observed to have different means with the highest recorded under the mulch conservation at 33.37%. This was followed by the combined ridges and mulch which had a value of 33.31%, then the ridges with a value of 33.20% and finally the control which had a value of 32.99%. The observed p-value was 0.945. This value was high in comparison to the level of significance of 0.05 hence the lack of significant difference in how the treatments retained moisture content. A study conducted by [14] to assess the effect of soil and water conservation measures on cowpea cultivation in Ghana confirmed the same that contour ridges conserved soil moisture better than the normal farmer's practice [14]. Like in this study, the results of the study in Ghana confirmed that the farmers' practice (control) had the least moisture retention capacity [14].

From the analysis, it was deduced that at least one of the moisture conservation techniques was different from the others in terms of moisture retention at the 40-cm depth. From the analysis, the treatments had a p-value of 0.022

which was less than the alpha level of 0.05 meaning there was a significant difference on at least one of the treatments. To determine the best treatment in retaining moisture content in that area an analysis of their means was done. From the means, the mulch treatment had the highest value of 31.69%, followed by the combined ridges and mulch which had a mean of 31.61% and then ridges which had a mean of 31.59% and finally the control which had a mean of 30.39%. Therefore, it was quite evident that mulch was the best in retaining the moisture content at this depth of 40cm. [15] confirmed similar results by conducting a study in Ethiopia to assess the effect of organic mulching on soil moisture yield and yield contributing factors of sesame. The authors indicated that at depth 0.21 m to 0.4 m, sudan grass conserved the highest soil moisture content of 17.3% as compared to other materials. This agrees with the findings from this study in that the experimental plots under mulch retained the highest amount of moisture content though with different moisture content values. From the results, it was evident that the variation of the means for the mulch, ridges and combined ridges and mulch was not very high hence the analysis on their production.

From the production analysis, the quantity in kgs of sorghum harvested was highest under combined ridges and mulch with an average value of 8100 kg/ha. The least yield returns were recorded under the control treatment which had an average of 5200 kg/ha across the three blocks. The control represents the current scenario where sorghum is grown under no conservation measures. Production increased by 25% and 36.5% with the use of mulching and ridges respectively in comparison to the control. From these results, in this study area, production can be optimized by use of combined ridges and mulch since the productivity increases by 55.8% when combined ridges and mulch conservation measures are used. The cause of the high yields under the combined ridges and mulch could be attributed to the water pockets which help in retaining the soil moisture and the mulch which in overall improved the organic matter content of the soil and in turn increase the nutrient availability in the soil.

Generally, the soil and moisture conservation techniques were not only aimed at improving the yield but also reducing the yield and income variability in the arid and semi-arid area. This is mainly because of the ability of the conservation techniques to retain water that would have been lost to runoff but it was made available to the plants. Agricultural production in the study area is only limited to hand-to-mouth, hence the use of the different conservation techniques will help in investment strategies to benefit the local farmers. Since the grass mulch is accessible from the ranch, the use of combined ridges and mulch is feasible in this area because it does not require additional costs for the application. Also, this would act as a pilot study for other areas in the country with similar conditions. For upscaling purposes, the field plots should be levelled for homogeneity. Soil monitoring in a levelled ground will require less soil moisture sensors unlike a heterogeneous field which requires more number of sensors for better monitoring of the soil moisture dynamics.

5. Conclusion

The experimental results indicate that YL-69 sensor has the potential of measuring the moisture content of the soil. This is a step towards precision farming in Africa. From the results, it was concluded that the mulch was the best in moisture retention. However, the combined ridges and mulch was the best in terms of land productivity as it produced 55.8% more as compared to the control due to the presence of the water pockets and mulch which improved the water content and soil quality respectively. This therefore suggests that the farmers should incorporate soil moisture conservation measures preferably the combined ridges and mulch to bridge the food security gaps occasionally experienced in the area. Increased productivity in the area will also improve the farmers' levels of income and in turn improve their livelihoods. The information from this research is useful in that it can be used in areas with similar conditions.

6. References

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