Effect of Water Conservation Technologies on Water use Efficiency of Pearl Millet Green Gram Intercropping System in Semi-Arid Kenya

Karanja K. Stephen [a*], Kinama M. Josiah [a] and Cheboi J. Juliana [a]

[a] *Department of Plant Science and Crop Protection, University of Nairobi, Nairobi, Kenya.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

The insufficient and inadequate soil moisture content in Kenyan's arid areas has steadily reduced crop production. A field experiment was conducted during 2022/2023 short rain season to evaluate the effect of water conservation technologies and cropping systems on soil moisture dynamics and water use efficiency of selected pearl millet and green gram varieties planted in sole and intercrop system in Kambi-Mawe and Katumani research stations. The experiment was arranged in a split-plot design with individual treatments arranged in a randomized complete block design, replicated

three times. The main plots comprised of water conservation technologies (ngolo pits, contour furrows) taking conventional tillage as a control. The cropping system included sole cropping of pearl millet (PMI, PM3), sole green gram varieties (N26 and Biashara) and their intercrops. Soil samples were collected at the depth of 0-20, 20-40 and 40-60 cm at 30 days, 45 days and 60 days after crop emergence and transported to laboratory for fresh weight determination. They were oven-dried at 105°C for 48 hours and the dry weight recorded. Water use efficiency (WUE) was calculated using seasonal crop evapotranspiration (ET) and crop yield. Collected data was analysed using GenStat statistical software 15th edition while mean separation was done using Tukey HSD at p ≤ 0.05 significance level. Results illustrated that water conservation technologies and cropping system significantly increased the soil moisture content recorded at different sampling times. Generally, significantly higher soil moisture was recorded in ngolo pits, followed by contour furrows, while conventional tillage recorded relatively lower soil moisture. Plots under intercropping systems recorded lower soil moisture compared to those under sole cropping irrespective of the crops. Higher WUE values were recorded in ngolo pits, and conventional tillage recorded the lowest values.

1. INTRODUCTION

Water scarcity and shortages have become global issues that have resulted in losses and limitations in agricultural productivity [1]. The challenge is exacerbated by climate change and greater variability. Despite climatic constraints, conservation agriculture holds promise as it minimizes soil disturbances and ensures efficient conservation of soil moisture. Intensive tillage practices and bare soil surfaces expose the soil to erosion and moisture loss agents [2]. The use of excessive tillage operations is harmful to the soil and increases the cost of production. Conventional tillage is known to deteriorate soil structure [3]. Low crop production due to moisture stress exacerbates food and nutrition insecurity in sub-Saharan Africa [4].

Water loss management includes crop management practices and remedial aspects of breeding that enable effective use of limited ASAL water using soil and water conservation techniques. This practice is adopted in many semi-arid environments with low and unreliable rainfall, such as in Eastern Kenya [5] (Johnson et al., 2018). It is necessary to shift from traditional tillage systems to climate smart agricultural interventions. This included, but not limited to water conservation technologies such as zai pits, ngolo pits, contour furrows, tied ridges, minimum tillage, and the use of mulch for the purpose of protecting soil from degradation, conserving soil moisture, and increasing the water use efficiency for crops. Furthermore, the use of appropriate cropping systems such as

intercropping could provide solutions to increased productivity and minimize the occurrences of low production in the case of failure of one crop.

Water conservation technologies such as tied ridges, contour furrows and zai pits have been reported to improve soil water retention and consequently increasing water use efficiency (WUE) [6,7]. Through their ability to harvest rain-water and store it in the soil, water conservation technologies increase the water holding capacity, infiltration, and reduces the evapotranspiration process from the surface of the soil [8,9]. Reports by Zougamore et al. [10] have shown that water conservation technologies have the potential to increase crop yield as a result of moisture availability and improved nutrient uptake from the soil. This is due to higher diffusivity and movement of the available nutrients to the root zone, which increases uptake and growth of the crops [11].

Ngolo pits are remarkable soil and water conservation technology where pits are laid out in the grind on sloping land to cover the entire surface, the size of the pits range from 1.2 to 2 m in dimeter and have a depth of 0.3 m. The pits collect water during the rainy season and water to be stored for use during the cropping season. Contour furrow is a tillage method that promotes drainage and planting operations following contour lines. Additionally, the furrows increase the roughness of the soil surface, reducing runoff velocity and rainwater ponding in the furrows [12].

Danjuma and Mohammed [13] defined Zai as a pit system dug on the farm with a dimeter of 20-40 cm and depth of 10-20cm to collect water where it falls allowing its availability to crops. Zai' is a hole dug in the ground that varies in size and dimensions depending on the farmer's ingenuity in different regions.

Conventional tillage is a soil inversion system that alters the natural structure of the soil [14] and [15]. It involves ploughing and harrowing with a mouldboard or disc-plough for large mechanized farms or ox plough and hand-hoeing for smallholder farmers inverting the soil depth of 10-20 cm [16].

Water productivity is a key challenge that needs to be improved by an on- farm water balance [17]. The use of water conservation technologies coupled with proper cropping systems provide effective measures to reduce soil water evaporation, improving the soil moisture retention capacity, making water available for uptake and improving WUE [18]. This current experiment was conducted to evaluate the effect of water conservation technologies on water use efficiency of selected pearl millet and green grams varieties under varied cropping.

2. MATERIALS AND METHODS

2.1 Experimental Sites

Two experiments were conducted concurrently under rainfed conditions at Katumani and Kambi Mawe (KALRO) Kenya Agriculture and Livestock Research Organization Katumani Research stations during the 2022/2023 short rain season. Katumani is located at (1° 35' South and 37° 14' East), at an altitude of 1624 meters above sea level. According to Jaetzold et al. [19], the centre is classified as agro-climatic zone IV, experiencing a bimodal rainfall pattern. The long rains occurring between March and May (MAM), while the short rains occur from October to December (OND).

The temperature in Katumani ranges between a minimum of 14 ^{0}C and maximum of 27 ^{0}C.

The area's dominant soils were formed from a pre-Cambrian basement system rock primarily composed of quartz felspatic gneiss parent material, which was classified as Ferro-chromic Luvisol in the FAO-UNESCO System [20].

Kambi Mawe, on the other hand, is a KALRO Sub-Centre in Makueni County, about 75 kilometers from Katumani, at an elevation of 1150 meters above sea level. The center is located at latitude 01°57'S and longitude 37°40'E. The area experiences a bimodal rainfall pattern, with the long rain (LR) season occurring from March to May and the short rain (SR) season from October to December. The average temperature in the area is 24°C and an average annual rainfall of 510 mm. The soil types in Kambi Mawe are Chromic Luvisols, which have low nitrogen (N) and phosphorus (P) levels Omakwe et al., [21] Syano et al., [22].

2.2 Experimental Deign and Treatments

The treatments were spread out in a randomized complete block design (RCBD) in a split-plot arrangement and replicated in triplicate. The main plots were water conservation technologies (ngolo pits, contour furrows) and conventional tillage as the control, whereas the cropping systems consisted of sole and intercrop systems of two crop varieties of pearl millet (PM1 and PM3) and green grams (N26 and Biashara). The main plots were separated by 2 m pathway while each split-plot was separated by 1 m pathway. Three seeds were plated per hill but later thinned to one seed after Under the intercrop systems, a row of green gram was sown between two rows of pearl millet. Green gram varieties (*Vigna radiata L.*) (Biashara and N26) and pearl millet varieties (*Pennisetum glaucum* L.) (PM1 and PM3), adapted to the ecological conditions of the study areas were used as test crops for this study. Conventional tillage was done using oxen plough to break the hard pan a month before planting.

2.3 Agronomic Practices on the Experimental Plots

Primary tillage was done with a hand hoe prior to the start of rains in the 2022/2023 short rain season, primarily in both sites. It was followed by construction of the water conservation structures (ngolo pits and contour furrows). The control method was the conventional tillage (farmers practice). The main blocks which comprised of water conservation technologies were allocated randomly within the 2 by 2-meter square area. Contour furrows were prepared by digging furrows of 0.5 meters' depth.

Table 1. Summary of treatment combinations at KALRO Katumani and Kambi Mawe experimental sites

Technologies	Crop	Varieties and cropping systems
Ngolo pits	Pearl millet	Sole PM1
		Sole PM3
	Green gram	Sole Biashara
		Sole N26
	Millet + Green gram	PM1 + Biashara intercrop
		PM1 + N26 intercrop
		PM3 + Biashara intercrop
		PM3 + N26 intercrop
Contour furrows	Pearl millet	Sole PM1
		Sole PM3
	Green gram	Sole Biashara
		Sole N26
	Millet + Green gram	PM1 + Biashara intercrop
		PM1 +N26 intercrop
		PM3 + Biashara intercrop
		PM3 + N26 intercrop
Conventional tillage	Pearl millet	Sole PM1
		Sole PM3
	Green gram	Sole Biashara
		Sole N26
	Millet + Green gram	PM1 + Biashara intercrop
		PM1 +N26 intercrop
		PM3 + Biashara intercrop
		PM3 + N26 intercrop

During the construction of ngolo pits, a squares measuring 1.5 m × 1.5 m was demarcated. Soil from the centre of the square was dug using hand hoe. The soil dug from the center was heaped evenly on the sides, leaving a pit, 0.5 m deep at the center (ngolo) as described by Kato *et al.* [23].

Planting was done by placing seeds in holes 5 cm deep. In the sole crop system, a spacing of 75 cm and 25 cm between rows and within plants, respectively was used for pearl millet while green gram was sown at 60 cm and 30 cm between rows and within plants, respectively. In the intercrop system, pearl millet was sown at 90 cm and 20 cm spacing between rows and within plants, respectively and a row of green gram was sown between rows of pearl millet with a spacing of 30 cm from plant to plant. Three seeds of pearl millet and green gram were planted per hill and later thinned to one plant per hill.

2.4 Data Collection

2.4.1 Weather data

The weather data comprised of rainfall, maximum and minimum air temperature, solar radiation, sunshine hours, and wind speed at 2 m above ground. All these were derived from the meteorological weather stations based at KALRO-Katumani and Makindu research station in Machakos and Makueni Counties, respectively. Minimum and maximum thermometer, gun ballani, and anemometer were used for measuring air temperature, solar radiation and wind speed, respectively. The weather data were used to compute the crop water use and use efficiency using the seasonal crop evapotranspiration (ET) and crop yield using the soil water balance equation (Equation 1):

$$ET = P + I – D + W_g – R + \Delta S \qquad (1)$$

Where;

ET = Evapotranspiration (mm)
P = Total season precipitation (mm)
I = Soil water drainage (mm)
W_g = Amount of water used by the crop through capillary rise from groundwater (mm)
R = Surface runoff
ΔS = Change of soil water content from planting to harvest in the measured soil depth (mm)

2.5 Soil Sampling

The initial soil characterization was done by sampling soil from a deepness of 0-30 cm through employment of a soil auger from different plots in a zig-zag manner using an Edelman soil auger. A composite was taken to the laboratory for physical and chemical analysis.

2.6 Soil pH

Soil pH was analysed using 1:2.5 ratio soil-in-water (w/v) suspension as described by Okalebo et al. [24]. A conical was filled with 25 millilitres of distilled water and 5 grams of air-dried soil sample. The pH of the soil was measured by stirring the suspension and letting it stand for half an hour. Afterwards, the pH meter was calibrated using buffer solutions with pH values of 4 and 7.

2.7 Soil Texture

Soil texture was ascertained using the hydrometer method, and textural classes was concluded using the USDA textural triangle Bouyoucos, [25]. The described method was used to calculate soil bulk density Brown and Wherett [26].

2.8 Soil Organic Carbon

The determination of soil organic carbon (SOC) was done using the Walkley-Black method Schumacher [27]. Ten millilitres of potassium dichromate solution were added to a measuring cylinder along with five grams of air-dried soil. The soil was then stirred gently using a stirring rod. This suspension was then let to settle for thirty minutes before 10 millilitres of concentrated sulfuric acid was then added to the suspension. This was followed by adding 10 ml of ferrous sulphate to the suspension, slowly until the solution turned pale green. Organic carbon was determined using the formulae described by [28] Schumer, 2002) (Equation 2).

$$\% organic carbon = \frac{[M*(V1-V2)]}{S} * 0.39 * 2.71 \quad (2)$$

Where;

M is the molarity of ferrous sulphate 9 from blank titration), V1 is the volume of ferrous sulphate needed for the blank, V2 is the volume of ferrous sulphate needed for the soil sample, while S is the weight of the soil sample.

2.9 Total Nitrogen

Total nitrogen was determined using a micro-Kjeldhal digestion method as described by [29] (Keeney and Nelson, 1982). This was done by transferring 0.5 mm of air-dried soil into the digestion tube followed by 2.5 ml of the Kjedhal catalyst. The mixture was heated at 100 ^{0}C, for two hours. The mixture was then allowed to cool after which 2 ml of hydrogen peroxide was added until a clear and colourless solution was obtained. To find out the total nitrogen, this solution was made up to 75 mL with distilled water.

Total nitrogen was calculated using Equation 3:

$$\% Total nitroegen = \frac{[(a-b)*75}{Weight\ of\ soil\ (g)} * 1000 \quad (3)$$

Where; a is the nitrogen content of soil sample, b is the nitrogen content of blank, 1000 is the coefficient of conversion from ppp to N to percent N, while 75 ml is the final volume of te digest.

2.10 Available Phosphorus

The determination of available phosphorus was done using the Olsen method Elrashidi [30]. This included adding 0.025 hydrochloric acid and 0.03 ammonium phosphate concentrate to a 100 ml conical flask containing 5g of air-dried soil representative that had been traversed in a 2 mm sieve. The mixture was then put on a mechanical shaker for five minutes. It was then allowed to cool in order to develop change the colour to blue. This was then followed by adding distilled water to make up to 25 ml and allowed to stand for one hour. 0.1, 2.0, 2.4, 3.6, 4.8, and 6.0 mg. The absorbance at 882 nm was measured with a spectrometer and the available P was calculated using the following formula below (Equation 4).

$$Phosphorus = [a-b)*14\frac{}{s}* \\ moisture conversion facot \quad (4)$$

Where; a- is the phosphorus in the soil sample, b is the phosphorus in the blank sample, whereas S is the weight of the soil in grams.

2.11 Soil Moisture Determination

Soil samples were collected randomly from the experimental plots using the soil auger at 0-20, 20-40 and 40-60 cm depths down the soil profile. The collected samples were then thoroughly

mixed to get a composite sample. 50 g soil was placed in a pre-weighed khaki bags (W1) and the joint weight of the soil and bag (W2) were recorded. The soil together with the khaki bags were taken to the laboratory at KALRO Katumani oven - drying at 105°C for 24 hours. The oven-dried weight was recorded as (W3) and the difference inn oven dried ad fresh soil samples was calculated to get the amount of soil moisture content.

Soil moisture content was computed gravimetrically using (Equation 5).

$$Gravimetric moisture content (\%) = \frac{W2 - W3}{W3 - W1} \times 100 \quad (5)$$

Where:

W1 = the weight of empty khaki bag
W2 = weight of the khaki bag + fresh soil
W3 = weight of the khaki bag + oved dried soil sample

The gravimetric soil moisture content was then changed into volumetric proportion by multiplying with bulk density (Equation 6) and converted to volumetric water (mm) by multiplying by soil depth and divided by 10 (Equation 6 and 7).

$$Volumetric moisture (\%) = Gravimetric water (\%) \times Bulk Density \left(\frac{g}{cm3}\right) \quad (6)$$

$$Volumetric water (mm) = \frac{volumetic\% \times SoilDepths(cm)}{10} \quad (7)$$

2.12 Determination of Water use Efficiency

According to Monteith's [31] description, the crop WUE was calculated using the seasonal crop evapotranspiration (ET) and crop yield. Equation 4 of the soil water balance was used to calculate the seasonal evapotranspiration (Equation 8)

$$ET = P + I - D + W_g - R + \Delta S \quad (8)$$

Where;

ET = Evapotranspiration (mm)
P = Total season precipitation (mm)
I = Soil water drainage (mm)
W_g = Amount of water used by the crop through capillary rise from groundwater (mm)
R = Surface runoff
ΔS = Change of soil water content from planting to harvest in the measured soil depth (mm)

The variance between input (rainfall, R, and irrigation, I) and output (evapotranspiration, ET, and root zone drainage, D) was deemed to be the same as the change in root zone soil moisture (ΔS). Equation 9 illustrates how soil moisture variation in the root zone (ΔS) was calculated by measuring soil moisture (gravimetrically) at the start and finish of crop growth stages (Equation 6).

$$\Delta S = (R + I) - (ET + D) \quad (9)$$

Where,

ΔS = Change in soil water storage in the root zone
ET = Evapotranspiration
R = Rainfall
D = Root zone drainage.

Runoff in the study area was assumed to be negligible due to the sandy nature of the soil and the low slope of less than 2.5%. Similarly, drainage below the root zone is determined during the growing season and is therefore considered negligible [32].

The WUE was then figured from the water use and total biomass yield (Equation 7) [2,3].

$$Water use efficiency \left(\frac{\frac{Kg}{ha}}{mm}\right) = \frac{Yield\left(\frac{Kg}{ha}\right)}{Crop evapotranspiration (mm)} \quad (10)$$

2.13 Statistical Analysis

The field data on soil moisture and water use efficiency were subjected to analysis of variance (ANOVA) using GenStat statistical software, 15th Edition Payne et al., [33]. A two-way ANOVA was carried out to determine the significance levels. Mean separation was performed using Tukey HSD significance level at 5% probability level. Iterate measurements were used to analyse soil gravimetric moisture content. Graphs were displayed through application of Excel software.

3. RESULTS

3.1 Soil Moisture Content

In Kambi Mawe, there was a significant interaction between days after planting × depth, time × water conservation technologies, cropping systems × depth a between time × water conservation technologies and depth ($p < 0.001$).

The average soil moisture content in the conservation technologies was in the order of ngolo pits > contour furrows > conventional tillage. Soil moisture varied significantly ($p < 0.001$) with days after planting. Soil moisture was higher at planting, compared to soil moisture recorded 30 days, 60 days and at harvest (Table 2).

There was no significant variation of soil moisture among the cropping systems ($p = 0.052$). At all the sampling times, however, the interaction between cropping systems × depth was observed ($p = 0.022$). Plots with sole crops (pearl millet and green grams) had higher soil water content compared to their intercrops irrespective of the variety (Table 2).

With regard to depths, the soil moisture content was significantly ($p < 0.001$) higher at the 40-60 cm depth than in the 20-40 cm and 0-20 cm and varied significantly among the water conservation technologies and cropping systems.

In Katumani, there were significant interactions between time × conservation technologies, time × depth and time × water conservation technologies × depth ($p < 0.001$). However, the water conservation technologies did not significantly affect the soil moisture content ($p = 0.120$). Higher moisture of 10.93 cm3 cm-3 was recorded in sole plots of biashara variety under ngolo pits, while the intercrop plots under conventional PM1 pearl millet variety had the lowest soil moisture content of 9.77 mm.

Comparison of soil moisture content with sites showed that higher moisture content was recorded in Kambi Mawe compared to the soil moisture recorded in Katumani. It was also observed that the soil moisture content increased significantly with depth. Higher soil moisture was recorded at 40-60 cm depth compared to soil moisture at 20-40 cm and 0-20 cm.

Table 2 shows the interactive effects of *in-situ* water conservation technologies, cropping systems and depth on soil moisture content (SMC) recorded at different days after emergence (DAE).
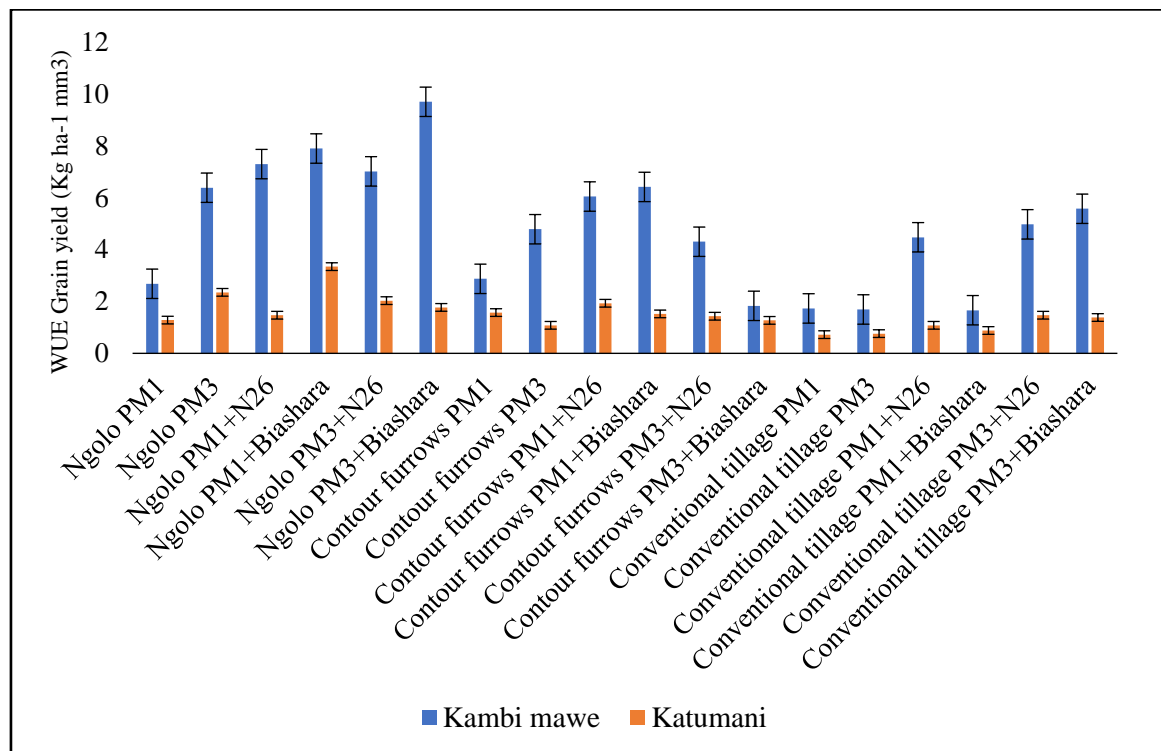

Fig. 1. Effect of water conservation technologies and cropping systems on WUE of pearl millet grain yield

Table 2. Interactive effects of in-situ water conservation technologies, cropping systems on soil moisture content (mm) at different sampling times during the 2022/23 cropping season at Kambi Mawe and Katumani experimental sites

Treatments	Kambi Mawe				Katumani			
	Planting	30days	60days	Harvest	Planting	30days	60days	Harvest
Water conservation technologies (T)								
Ngolo pits	17.91	15.91	14.88	10.51	14.17	12.40	10.97	10.41
Contour furrows	15.39	15.01	13.13	10.12	12.32	11.78	10.06	9.49
Conventional tillage	13.29	13.21	12.03	10.29	12.14	10.58	9.17	9.22
Cropping systems (CS)								
PM1	15.87	14.63	14.55	10.89	12.27	12.65	9.77	9.49
PMI + Biashara	16.68	14.71	13.83	10.49	12.09	12.19	10.72	9.41
PM1 + N26	15.49	14.39	14.91	10.82	12.83	11.81	10.39	9.48
PM3	15.98	14.34	13.34	10.91	12.52	11.84	10.34	9.01
PM3 + Biashara	16.34	14.75	13.05	10.39	11.93	11.71	10.40	9.32
PM3 + N26	15.64	15.04	13.82	10.44	11.91	11.06	10.39	9.00
Biashara	16.17	14.53	14.78	10.21	11.33	11.82	10.93	9.10
N26	15.83	14.86	13.43	10.82	11.72	11.24	10.49	9.48
Depths								
0-20 cm	14.05	12.39	13.74	16.48	14.18	15.38	22.51	10.36
20-40 cm	16.28	15.61	13.57	21.54	16.46	15.31	19.34	15.08
40-60 cm	18.75	16.32	14.59	22.84	18.67	14.68	21.11	18.01
Significance levels								
	Time	T	CS	Depth	time× T	T × CS × Depth		
Kambi Mawe	<.001	0.014	0.052	0.001	0.022	0.012		
Katumani	<.001	0.120	0.533	0.009	0.043	0.017		

Legend: T- water conservation techniques, CS- cropping systems

Table 3. Effects of water conservation technologies and cropping systems on water use efficiency of pearl millet in Kambi Mawe and Katumani during 2022/2023 cropping season

Technologies	Cropping System	Kambi Mawe WUE (kgha^{-1} mm^{-1})	Katumani WUE (kgha^{-1} mm^{-1})
Ngolo	PM1	2.68[c]	1.28[a]
	PM3	6.38[b]	2.35[a]
	PM1+N26	7.29[ab]	1.47[a]
	PM1+Biashara	7.89[b]	3.34[a]
	PM3+N26	7.01[b]	2.03[a]
	PM3+Biashara	9.69[a]	1.77[a]
Contour furrows	PM1	2.87[c]	1.57[a]
	PM3	4.78[b]	1.08[a]
	PM1+N26	6.04[ab]	1.93[a]
	PM1+Biashara	6.41[ab]	1.52[a]
	PM3+N26	4.30[b]	1.43[a]
	PM3+Biashara	1.83[d]	1.27[a]
Conventional tillage	PM1	1.73[d]	0.72[a]
	PM3	1.69[d]	0.76[a]
	PM1+N26	4.47[c]	1.08[a]
	PM1+Biashara	1.66[d]	0.88[a]
	PM3+N26	4.97[b]	1.47[a]
	PM3+Biashara	5.57[ab]	1.38[a]
Summary of p-values			
Water conservation technologies		0.048	0.900
Cropping systems		0.001	0.768
Interaction (T × CS)		0.036	0.639

Legend: T-water conservation technologies, CS-cropping systems

Table 4. Physical and chemical properties of the soil in the study sites

Soil properties	Parameters	Units	Kambi Mawe	Katumani
Physical	Bulk density	g/cm3	1.35	1.46
	Ksat	cm/hr	1.34	1.19
	Sand	%	73	69
	Silt	%	8.0	7.0
	Clay	%	19	24
	Textural class		SCL	SCL
Chemical	pH (H_2O)	v/v (H_2O)	6.4	6.8
	Organic carbon (OC)	%	1.3	1.4
	Total Nitrogen	%	0.15	0.23
	Phosphorus (P)	ppm	23.9	32.1
	Potassium (K)	Cmol/kg	1.9	1.9
	Calcium (Ca)	Cmol/kg	5.57	6.34
	Magnesium	Cmol/kg	1.78	1.23
	Zinc (Zn) (ppm)	ppm	13.5	14.5
	Iron (Fe)	ppm	63.8	56.3
	Copper (Cu)	ppm	15.9	16.5

Table 5. Monthly climatic data during crop growing seasons

Site	Months	Rainfall	Temperature		WS	ET_o
		(mm)	Tmax	Tmin	m/s	mm/day
Kambi Mawe	November	11.2	29.0	19.0	74.3	102.0
	December	91.9	29.3	19.1	77.2	108.6
	January	11.2	31.0	19.5	86.3	148.7
	February	139.3	29.0	19.0	120.1	102.0
Katumani	November	54.1	25.7	15.9	73.1	100.4
	December	25.1	24.0	14.4	70.8	163.1
	January	23.5	25.2	16.5	89.6	199.5
	February	0	27.9	13.8	78.9	222.5

Legend: Tmax- maximum temperature; Tmin- minimum temperature; WS- wind speed

3.2 Water use Efficiency of Pearl Millet

Highest water uses efficiency (WUE) of pearl millet (9.69 kg ha^{-1} mm^{-1}) was recorded in ngolo pits where PM3 was intercropped with biashara green gram variety, while the lowest value (2.68 kg ha^{-1} mm^{-1}) was recorded in conventional tillage with sole cropping of PM1 in the Kambi Mawe. Similar trends were observed for contour furrows and conventional tillage where the WUE values ranged from 2.17 to 5.34 kg ha^{-1} mm^{-1} and 1.73 kg ha^{-1} mm^{-1} to 5.57 kg ha^{-1} mm^{-1} recorded from PM1 variety to the intercrop between PM3 and biashara green gram variety, respectively. The effect of water conservation technologies, cropping systems as well as their interactions, were significant ($p = 0.048$), ($p = 0.001$), and ($p = 0.036$) in Kambi Mawe (Table 3).

The effect of water conservation and cropping systems were not significant in influencing the WUE of pearl millet in Katumani.

4. DISCUSSION

4.1 Soil Moisture Content

The volumetric soil moisture content was considerably ($p < 0.001$) higher in water conservation technologies compared to conventional tillage in Kambi Mawe. This can be attributed to increased rainwater storage in the pits and furrows during the growing season. Similar finding has been presented by Zougamore et al. [34] who reported an increase in soil moisture content under tied ridges to up to 20% in comparison to the conventional tillage practice. This can be ascribed to the high total porosity resulting from the low bulk density caused by soil disturbance caused by the construction of water conservation structures.

Furthermore, the higher soil moisture stored under ngolo pits compared to conventional tillage may be due to the design of the pit, which allows for the catchment and retaining of more water

than relatively flat surfaces in conventional tillage system which had little potential to capture ad store rain water [35] Wafula et al. while working in Katumani reported similar findings where ngolo pits recorded a leading soil moisture content in comparison to conventional tillage under the maize-bean intercropping system.

The average soil moisture content for the total growing period at the different depth followed the tendency of ngolo pits > contour furrows > conventional tillage, with highest soil moisture recorded at the lower depths (40-60 cm). This could be attributed to the high uptake by the roots at the upper 0-20 cm depth. This is the depth where the plant roots are active, and therefore, the uptake for water and nutrients is high to support vegetative growth Esilaba et al. [36] reported similar findings in a study on maize-cowpea/ maize-dolichos intercrop at Katumani research center Parvin [37] also reported that soil moisture content increased with depth.

4.2 Water use Efficiency of Pearl Millet

Water use efficiency point out to the ratio of biomass accumulation signified as carbon uptake or grain yield to the amount of water consumed Ullah et al., [38]. Higher WUE values recorded in Kambi Mawe compared to Katumani could be attributed high amount of water utilized in Kambi Mawe as a result of the significant effect of the water conservation technologies. Further reasons might be because of the little and insufficient rainfall amount prevailing in Katumani throughout the entire growing season, which led to stunted growth and eventually low yields. There is a positive correlation between yield and water use efficiency. These findings agree with [39] Hatfield and Dold who asserted that highest WUE is attained at the highest yields.

Sufficient moisture conditions in the pits could have increased the supply of essential nutrients present in the soil, thereby promoting pearl millet growth. As a result, land cover development increased, which helped reduce soil evaporation losses and improve water use efficiency of pearl millet. [40] Monteith found that early canopy development allows crops to intercept more radiation, promote root growth, and dispense more water extracted by roots to transpiration, thereby increasing water use efficiency.

In this study, it was observed that the increase in water use efficiency corresponds to the decrease in water use (ETc) of pearl millet. This is in contrast to the findings of Jones [8], who observed that plants tend to be more efficient in water use when water supply is low.

5. CONCLUSION

The outcome from the experiment indicate that soil and water conservation technologies had a significant effect on soil moisture content, crop water use efficiency and yields of pearl millet and green gram. This is due to the fact that the soil and water conservation technologies conserved mores water at beneath the soil profile and kept the soil micro and macro pores intact, maintaining the soil structure, hence creating a conducive environment for the proliferation of the crops. Furthermore, this conditions could have created a friendlier environment for the diffusivity of soil nutrient in the soil, hence promoting faster and quicker uptake by the plant roots.

The water and soil conservation structures act as water reservoirs, to capture and store water for a long period for easy infiltration. This makes the infiltration process easier, which increases the soil's moisture content. When contrasted with contour furrows and conventional tillage, ngolo pits yielded a high up moisture content, higher water use efficiency as well as pearl millet and green gram yields. More rainwater was retained in ngolo pits, where it was at the lowest point relative to surface flow and had more span to seep into the soil. The increase in grain yield due to increased water storage capacity from available rainfall was the primary cause for the increment of pearl millet's water use and water use efficiency under ngolo pits. The findings also demonstrated the importance of seasonal variations for pearl millet and green grams. This was primarily ascribed to the rainfall's distribution, intensity, and quantity.

Conversely, intercropping increased the number of plants, which increased competition for nutrients, moisture, and light energy in the soil. The soil moisture content was over extracted as a result. The amount of moisture in the soil was not significantly affected by the various varieties.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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