Effect of water conservation technologies on growth and yield of green gram pearl millet intercrop in semi-arid Kenya.

Abstract

Water conservation technologies are among the climate smart agriculture practices geared towards increasing crop production in arid and semi-arid areas. Several technologies have been experimented with crops such as maize, sorghum, however, there is limited information on integrating water harvesting technologies with pearl millet and green gram in an intercropping system. A field study was conducted during the 2022/2023 short rains in Kambi Mawe and Katumani. The experiment was laid out in a randomized complete block design with split plot arrangement replicated three times. The main plots were water harvesting technologies (ngolo pits, contour furrows) and Conventional tillage. The split plots comprised of sole pearl millet varieties, sole green gram varieties ad their intercrops. Data was collected on the number of primary branches, nodules, number of pods per plant, number of seeds per pod, plant height, leaf area index, grain weight and harvest index. The land equivalent ratio was also calculated. Mean separation was calculated using Tukey HSD at 5 % probability level. Results showed that water harvesting technologies and cropping systems had a significant effect on the growth parameters, yield and yield component of both pearl millet and green grams. Ngolo pits recorded significantly higher yields compared to contour furrows ad conventional tillage. Intercropping pearl millet with green grams recorded significantly higher yields compared to sole cropping.

Key words: Yield Performance, Land Equivalent Ratio, Pearl Millet, Water Conservational Technologies, Green grams, Yield

Introduction

Erratic rainfall and soil degradation are some factors impinging crop production in most sub-Saharan countries (ASALs) (Kumasi and Asenso-Okyere, 2011; Liliane and Charles, 2020). The problem is exacerbated and felt most acutely in the arid and semi-arid areas which experiences high diurnal temperature, very low soil fertility and escalating population that puts pressure on the production factors (Shackleton and Shackleton, 2012). In Kenya, the most difficult scenarios are encountered in the lower eastern and northern regions (Yvonne et al., 2020). Crop and animal production are the major enterprises in these areas, providing a living for the residents. However, these businesses are extremely vulnerable to the whims of climate change. Crop production has declined over time due to water scarcity caused by the fluctuation of weather patterns caused by climate change. Households in these areas have been left food secure due to total crop failures in some areas as a result of low rainfall amounts that below the crop water demands (Huho et al., 2010). As a result, agricultural production systems must undergo a paradigm shift. According to research, water harvesting is the only solution to such problems in ASAL areas. This can be accomplished through the use of simple technologies that are easily adopted by community members and are less expensive. Zai pits, contour furrows, ngolo pits, tied-ridges, strip bands, and bench terraces are examples of these technologies (Abubakar et al., 2014; Manila et al., 2023).

During the rainy season, these technologies collect water and store it in the soil for future crop use. Water is made readily available in the soil for easy uptake by plant roots, promoting growth and development (Mudatenguha et al., 2013; Kugedera et al., 2018). Another option that has proven to work in smallholder farming systems is the selection and planting of adoptable crops in ASAL areas. Crop varieties that can withstand low soil water content and perform well in arid and semi-arid environments include millet, sorghum, green grams, cowpeas, and dolichos (Recha et al., 2013; Njinju et al., 2022). Smallholder farmers are thus encouraged to use such measures to mitigate the effects of climate change. These crops can be grown as sole crops or as part of an intercrop system.

According to reports, combining water conservation technologies with suitable varieties adapted to arid and semi-arid conditions resulted in improved crop performance and higher farmer returns (Rusinamhodzi et al., 2012). Few studies, however, have attempted to evaluate the combination of water conservation technologies and selected pearl millet varieties intercropped with green grams in the two study areas, thus forming the basis of this study.

Materials and methods

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^{o} 35' South and 37^{o} 14' East), at an altitude of 1624 meters above sea level. According to Jaetzold et al. (2006), 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 (Mbayaki and Karuku, 2021).

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^{o}57'S and longitude 37^{o}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 ^{o}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., 2023;Syano et al., 2023).

Experimental design and treatments

The experiment was laid out in a randomized complete block designed in a split plot arrangement, replicated three times. The water harvesting technologies (ngolo pits, contour furrows) and conventional as the control were the main plots. Cropping systems (sole green grams, sole pearl millet and their intercrops were the split plots.

Agronomic practices

The land preparations, construction of ngolo pits, contour furrows and general crop husbandry practices were applied, from planting, weeding, pest and disease control as outlined in chapter 3, section 3.3.3 of this thesis.

Data collection

Growth parameters

Plant height was recorded from 5 randomly selected pearl millet and green gram plants at different days after emergence (30, 45 and 60 days) from each plots using a tape measure which were then averaged to a mean height.

The number of leaves on each pearl millet was counted manually at the different growth stages (days after emergence). The number of primary branches on five randomly selected and tagged green gram plants from each plot under each treatment was counted at harvest

Number of nodules per plant in green grams was recorded from five randomly selected plants. This was done by uprooting the selected plants at the soil's surface after watering to facilitate removal and avoid stripping off nodules. The roots were washed with clean water, and nodules were separated by plucking and counting.

The leaf area and leaf are index were calculated using Equation 1 and 2, respectively (Koocheki et al., 2016).

$$Leafareindex(LAI) = \frac{Leafarea(m2)}{Plotarea(m2)} \quad (1)$$

Leaf area (m^2) = leaf length x leaf width × K (2)

Where; K is a shape factor with a value of 0.5 for partially unfolded leaves and 0.75 for completely unfolded leaves.

Yield and yield components

The number of pods per plant was done by counting pods from the five randomly selected green grams from each plot. On the other hand, the number of seeds per pod was determined by counting the seeds in each pod. The thousand seed weight was recorded by counting 1000 green grams and pearl millet seeds in the two sites (Kambi Mawe and Katumani) using an electric weighing balance. The yields of pearl millet, green grams, and biomass from each plot in the two sites was recorded from air-dried grains that have been separated and cleaned before drying to 14% moisture content. The grains were weighed and recorded in kilograms (kg) (Equation 3 and 4).

$$Grainyield(kgha-1) = \frac{Graindryyield(kg) \times 10{,}000m^2}{totalareaoftheplots} \quad (3)$$

$$Biomassyield(kgha-1) = \frac{abovegroundbiomass(kg) \times 10{,}000m^2}{totalareaoftheplots} \quad (4)$$

Harvest index

Harvest index was calculated as a ratio of grain yield to the total aboveground biomass using Equation 5.

$$Harvetindex(HI\%) = \frac{Grainyield(kgha-1)}{Abovegroundbiomass(kgha-1)} \times 100 \quad (5)$$

Data analysis

The collected data was subjected to analysis of variance (ANOVA) using GenStat statistical package version 15. Mean separation was done using Tukey HSD at 5% significance level.

Results

Effect of water harvesting technologies and cropping system on green gram height

The green gram height was measured 30, 45 and 60 days after emergence (DAE), as shown in Table 1. Running analysis of variance (ANOVA) revealed that the height of green grams differed significantly ($p < 0.05$), among the water harvesting technologies and cropping systems across the different days after planting. In Kambi Mawe, the highest height was recorded with biashara variety planted under ngolo pits, recording 38.3, 48.3 and 56.3 cm, at 30, 45 and 60 days after planting, respectively. It was also noted that the plant height of biashara intercropped with PM1 and PM3 were significantly higher compared to N26 intercropped with PM1 and PM3 pearl millet varieties. Least green gram heights were observed in plots under conventional tillage.

Table 1: ***Effect of water harvesting technologies and cropping system on green gram height at different days after emergence (DAE) in Kambi Mawe and Katumani***

	Kambi Mawe			Katumani		
Treatments	30 DAE	45 DAE	60 DAE	30 DAE	45 DAE	60 DAE
Water harvesting technologies (T)						
Ngolo pits	33.66^{a}	43.12^{a}	52.40^{a}	8.40^{b}	16.90^{a}	31.74^{a}
Contour furrows	29.67^{b}	38.44^{b}	49.09^{a}	9.32^{a}	16.6^{7a}	31.02^{a}
Conventional tillage	29.20^{b}	37.69^{c}	48.53^{a}	9.94^{a}	15.69^{a}	32.27^{a}
p value	0.026	0.002	0.064	0.005	0.152	0.575
LSD (5%)	3.494	3.028	3.474	0.900	0.995	2.396
Cropping systems (CS)						
Sole biashara	28.29^{b}	36.96^{b}	45.60^{a}	9.02^{a}	16.38^{a}	33.87^{a}
Biashara + PMI	32.89^{a}	39.67^{ab}	48.44^{a}	9.02^{a}	26.38^{a}	30.22^{ab}
Biashara + PM3	31.89^{a}	41.56^{a}	50.89^{a}	8.84^{a}	16.47^{a}	33.40a
Sole N26	22.31^{c}	32.89^{c}	51.33^{a}	9.33^{a}	15.87^{a}	28.89^{b}
N26 + PM1	34.44^{a}	43.00^{a}	51.33^{a}	9.76^{a}	16.20^{a}	33.3^{8a}
N26 + PM3	35.22^{a}	44.44^{a}	52.44^{a}	9.36^{a}	15.80^{a}	30.31^{ab}
p value	<.001	<.001	0.077	0.738	0.887	0.017
LSD (5%)	4.942	4.283	4.913	1.272	1.408	3.388
Interaction						
T × CS	0.823	0.891	0.728	0.787	0.498	0.048
CV%	16.70	11.20	10.30	14.40	9.100	11.20

Legend: PM1, PM3: pearl millet variety, N26- green gram, LSD: least significant difference

Effect of water harvesting technologies and cropping system on nodulation of green gram

In Kambi Mawe, the number of nodules in green gram differed significantly (p <.001) between the water harvesting technologies and cropping systems (p = 0.045) (Table 2). The highest number of nodules (27) were recorded from plots under ngolo pits, followed by 22 nodules from contour furrows and plots under conventional tillage recorded the lowest number of nodules (19). It was noted that biashara variety planted in sole produced more nodules compared to when intercropped with PM1 and PM3 pearl millet variety. Variety comparison showed that biashara recorded higher nodules compared to variety N26.

Table 2: ***Effect of water harvesting technologies and cropping system on number of nodules in Kambi Mawe and Katumani***

	Kambi Mawe		Katumani	
Treatments	Nodules	Branches	Nodules	Branches
Water harvesting technologies (T)				
Ngolo pits	26.76[a]	5.97[a]	4.12[a]	4.16[a]
Contour furrows	22.12[b]	4.72[b]	3.98[a]	4.03[a]
Conventional tillage	19.40[c]	3.60[c]	3.72[a]	3.99[a]
p value	<.001	<.001	0.323	0.932
LSD (5%)	2.238	0.525	0.589	0.932
Cropping systems (CS)				
Sole biashara	22.91[a]	4.71[a]	3.43[a]	4.02[a]
Biashara + PMI	21.58[a]	5.00[a]	3.12[a]	4.52[a]
Biashara + PM3	21.91[a]	4.62[a]	3.11[a]	3.60[a]
Sole N26	22.67[a]	4.09[a]	3.08[a]	3.84[a]
N26 + PM1	24.69[a]	5.22[a]	3.12[a]	4.64[a]
N26 + PM3	22.80[a]	4.93[a]	3.00[a]	3.73[a]
p value	0.451	0.065	0.091	0.514
LSD (5%)	3.164	0.743	0.992	1.318
Interaction				
T × CS	0.192	0.626	0.344	0.881
CV%	14.50	16.30	14.09	33.90

Legend: PM1, PM3: Pearl miller varieties, N26: green gram variety; LSD: least significant difference. CV: coefficient of variation*Means followed by same letter down the column are not significantly different at p ≤ 0.05

Effect of water harvesting technologies and cropping system on green gram yields and yield components

Statistical analysis of the data showed that water harvesting technologies and cropping systems significantly ($p < 0.05$) affected the number of pods in Kambi Mawe (Table 3). The highest number of pods (53 pods) was recorded in plots with biashara variety under ngolo pits, whereas, the lowest number of pods per plant (15) was recorded in conventional tillage with the intercropping of PM1 + N26. Generally, plots with sole varieties (biashara and N26 performed better compared to those intercropped with either PM1 or PM3. Variety effect was also observed, where biashara performed better than variety N26.

Table 3: ***Effect of water harvesting technologies and cropping system on yield and yield components of green grams in Kambi Mawe and Katumani***

	Kambi Mawe				Katumani			
Treatments	NPP	NSP	TSW	Grain	NPP	NSP	TSW	Grain
Water harvesting technologies (T)								
Ngolo pits	42.3^{a}	15.92^{a}	70.3^{a}	1065^{a}	11.79^{a}	7.29^{a}	162.5^{a}	60.3^{a}
Contour furrows	32.8^{b}	12.35^{b}	59.4^{b}	866^{b}	10.28^{a}	7.06^{a}	155.5^{a}	87.8^{a}
Conventional tillage	20.1^{c}	11.3^{c}	47.1^{c}	665^{bc}	9.97^{a}	7.63^{a}	167.4^{a}	65.8^{a}
p value	<.001	<.001	<.001	0.018	0.607	0.376	0.526	0.322
LSD (5%)	7.6	1.26	7.34	269.2	3.282	0.833	21.06	38.63
Cropping systems (CS)								
Sole biashara	35.5^{a}	15.53^{a}	65.6^{a}	894^{a}	9.4^{a}	8.22^{a}	156.9^{a}	61.4^{a}
Biashara + PMI	37.5^{a}	12.71^{b}	56.6^{ab}	1110^{a}	13.58^{a}	7.16^{a}	151.4^{a}	54.7^{a}
Biashara + PM3	28.9^{a}	11.44^{b}	55.3^{b}	759^{a}	8.71^{a}	6.93^{a}	159.7^{a}	78.3^{a}
Sole N26	28.5^{a}	14.29^{b}	62.4^{a}	830^{a}	11.13^{a}	6.96^{a}	163.9^{a}	64.2^{a}
N26 + PM1	28.8^{a}	13.67^{b}	56.0^{ab}	849^{a}	11.53^{a}	7.84^{a}	170.8^{a}	68.3^{a}
N26 + PM3	31.3^{a}	13.51^{b}	57.8^{ab}	748^{a}	7.71^{a}	6.8^{4a}	168.1^{a}	100.8^{a}
p value	0.398	0.045	0.028	0.437	0.147	0.114	0.784	0.592
LSD (5%)	10.75	1.782	10.38	380.7	4.641	1.177	29.78	54.63
Interaction								
T × CS	0.934	0.573	0.054	0.134	0.108	0.787	0.159	0.454
CV%	13.90	14.10	18.40	15.90	16.80	16.80	19.20	15.20

Legend: PM1, PM3: Pearl miller varieties, N26: green gram variety; LSD: least significant difference. CV: coefficient of variation*Means followed by same letter in a columns are not significantly different at $p \leq 0.05$

Water harvesting technologies and cropping systems had a significant ($p < 0.05$) effect on the number of seeds per pod in Kambi Mawe. It was observed that the highest seeds per pod (19) was recorded in biashara green gram variety grown under ngolo pits, while the lowest seeds per pod (10) were recorded in conventional tillage with the intercropping of PM1 + N26. Green grams under ngolo pits performed better compared to those under contour furrows and conventional tillage ($p <.001$). The significant effect of cropping system was also reported ($p = 0.045$). it was noted that biashara variety performed better under sole cropping systems compared to N26 as well as when intercropped with PMI and PM3 pearl millet varieties (Table 3).

The thousand seed weight was also significantly ($p < .001$) affected by water harvesting technologies and cropping systems ($p = 0.028$) and the interaction between water harvesting technologies and cropping systems ($p = 0.054$). Biashara green gram variety planted in ngolo pits recorded the highest (77.3 g ha^{-1}) thousand seed weight compared to those planted in contour furrows and conventional tillage. The lowest seed weight of 38.3 g ha^{-1}) was recorded in conventional tillage where N26 green gram variety was intercropped with PM1 pearl millet variety. Plots with sole crops (biashara and N26) varieties recorded higher seed weights compared to the intercrop plots.

Effect of water harvesting technologies and cropping system on pearl millet height

The pearl millet height recorded at different days after planting at Kambi Mawe and Katumani are presented in Table 4. At Kambi Mawe, water conservation technologies significantly ($p < 0.05$) affected the pearl millet height recorded at 30 and 45 days after planting. The peal millet height followed the trend of ngolo pits > contour furrows > conventional tillage (Table 4). Water conservation technologies did not have a significant effect on the pearl millet height at 60 and 90 days after planting. Similarly, cropping system did not significantly affect the pearl millet height at different days after emergence (Table 4).

At Katumani, the pearl millet height recorded at 30, 45 and 60 days after planting was not significantly ($p > 0.05$) affected by water harvesting technologies and cropping systems, however, crops under ngolo pits recorded relatively higher height compared to those under contour furrows and conventional tillage (Table 4).

Table 4: ***Effect of water harvesting technologies and cropping system on pearl millet height at different days after emergence (DAE) in Kambi Mawe and Katumani***

	Kambi Mawe				Katumani		
Treatments	30	45	60	90	30	45	60
Water harvesting technologies (T)							
Ngolo pits	44.7^{a}	86.9^{a}	147.7^{a}	167.4^{a}	12.66^{a}	24.5^{a}	44.7^{a}
Contour furrows	40.4^{ab}	83.6^{ab}	143.2^{a}	156.7^{a}	11.11^{a}	23.5^{a}	35.1^{a}
Conventional tillage	38.5^{b}	81.0^{b}	139.9^{a}	155.5^{a}	11.02^{a}	20.6^{a}	33.3^{a}
p value	0.035	0.008	0.257	0.566	0.375	0.272	0.09
LSD (5%)	6.10	4.08	12.62	9.89	1.383	5.09	7.23
Cropping systems (CS)							
PM1	41.2a	84.2a	158.3a	170.1a	12.16a	26.9a	35.2a
PMI + Biashara	40.1a	85.9a	156.4a	176.8a	11.51a	20.1a	34.8a
PM1 + N26	39.2a	85.6a	157.1a	169.9a	12.27a	24.9a	40.3a
PM3	39.4a	88.4a	146.4a	159.4a	11.86a	26.9a	39.2a
PM3 + Biashara	39.4a	76.2a	146.9a	158.7a	10.69a	18.0a	36.9a

PM3 + N26	43.9a	76.8a	156.8a	163.7a	11.09a	20.6a	40.0a
p value	0.875	0.291	0.575	0.088	0.543	0.064	0.796
LSD (5%)	8.62	12.84	17.84	13.99	1.963	7.20	10.23
Interaction							
T × CS	0.566	0.834	0.77	0.510	0.694	0.10	0.786
CV%	22.20	16.20	12.1	24.23	17.70	32.8	28.30

Legend: PM1, PM3: Pearl miller varieties, N26: green gram variety; LSD: least significant difference. CV: coefficient of variation*Means followed by same letter in a column are not significantly different at $p \leq 0.05$

Effect of water harvesting technologies and cropping system on the number of leaves

The number of pearl millet leaves recorded at 30 and 45 days after planting in Kambi Mawe and Katumani are presented in Table 5. At 45 days after planting, the number of leaves was significantly affected by water conservation technologies (p = 0.042). More leaves per plant (6) were recorded in pearl millet planted in ngolo pits, while those under conventional tillage had the least number of leaves per plant (5). A similar trend was observed at 60 days after crop emergence. The highest average number of leaves per plant was 7 which was recorded in ngolo plots, followed by 6 in contour furrows and the lowest 4 leaves was recorded in conventional tillage plots. The number of leaves was not significantly different at 30 days after the crop emergence (p = 0.076).

Table 5: ***Effect of water harvesting technologies and cropping system on pearl millet number of leaves at different days after emergence in Kambi Mawe and Katumani***

	Kambi Mawe			Katumani		
Treatments	30	45	60	30	45	60
Water harvesting technologies (T)						
Ngolo pits	5.44a	6.22a	7.34a	3.753a	4.46a	7.24a
Contour furrows	5.66a	5.93b	6.89b	3.467b	4.22a	5.12b
Conventional tillage	5.33a	5.26b	6.21b	3.278c	3.90a	5.07b
p value	0.076	0.042	0.003	<.001	0.094	<.001
LSD (5%)	0.2822	0.3621	0.4965	0.206	0.503	0.59
Cropping systems (CS)						
PM1	5.489a	6.311a	5.422a	3.511a	4.09a	5.64a
PMI + Biashara	5.544a	5.978a	5.622a	3.489a	4.00a	5.71a
PM1 + N26	5.444a	5.644a	5.356a	3.489a	4.20a	5.98a
PM3	5.444a	5.978a	5.267a	3.444a	4.27a	5.69a
PM3 + Biashara	5.111a	5.911a	5.422a	3.444a	4.44a	5.98a
PM3 + N26	5.333a	6.000a	5.378a	3.578a	4.16a	5.87a
p value	0.995	0.239	0.945	0.943	0.855	0.93
LSD (5%)	0.3992	0.5121	0.7021	0.2914	0.712	0.835
Interaction						
T × CS	0.446	0.313	0.865	0.743	0.788	0.361
CV%	7.600	9.000	13.50	8.700	17.70	15.00

Legend: PM1, PM3: Pearl miller varieties, N26: green gram variety; LSD: least significant difference. CV: coefficient of variation*Means followed by same letter in a column are not significantly different at $p \leq 0.05$

Cropping system had no significant effect on the number of leaves at the different sampling times, however, plants under sole cropping had slightly higher number of leaves competed to their counterparts under the intercropped system. For instance, sole pearl millet (PM1 and PM3) recorded 3.1% and 2.74 higher leaves, respectively compared to when intercropped with biashara and N26 green gram varieties.

In Katumani, there was a significant (p < .001) effect of the water conservation technologies on the number of leaves recorded at 30 and at 60 days after crop emergence. It was noted that crops in ngolo pits had the highest number of leaves at the two stages compared to those from contour furrows and conventional tillage, respectively. Similarly, the effect of cropping system was insignificant in influencing the number of leaves (p = 0.93) (Table 5).

Effect of water harvesting technologies and cropping system on pearl millet yield and yield components

Pearl millet grain yield was significantly affected by water harvesting technologies and cropping systems ($p < 0.001$) in Kambi Mawe, however, no significant effect was observed in Katumani. The interaction of water harvesting technologies × cropping system was significant in Kambi Mawe, but not in Katumani (Table 6). Highest grain yield of 2755 kg ha^{-1} was recorded in ngolo pits, while only 1238 kg ha^{-1} was obtained from conventional tillage plots.

Under sole crop systems, PM3 pearl millet gave higher yields (1585 kg ha^{-1}) than PM1 which had 1276 kg ha^{-1}) in Kambi Mawe, but the grain difference between the two varieties was insignificant in Katumani. In Kambi Mawe, intercropping PM1 with biashara and N26 significantly increased the yield of PM1 pearl millet by 15.5% and 7.9%, respectively compared to sole cropping, while intercropping PM3 with biashara and N26 significantly increased the grain yield of PM3 variety by 14.8% and 7.5% compared to sole cropping of PM3 variety. Intercropping PM3 with biashara green gram variety recoded the highest grain yield of 1,590 kg ha^{-1} compared to the other combinations (Table 6).

Table 6*: Effect of water harvesting technologies and cropping system on yield and yield components of pearl millet in Kambi Mawe and Katumani*

	Kambi Mawe			Katumani		
Treatments	1000 seed	Grain	HI	1000 seed	Grain	HI
Water harvesting technologies (T)						
Ngolo pits	39.9a	2755a	41.2a	26.4a	519a	22.1a
Contour furrows	33.4b	1564b	33.1b	29.9a	305b	20.3a
Conventional tillage	29.8c	1238c	22.7c	29.9a	298b	19.4a
p value	0.016	<.001	0.021	0.35	<.001	0.098
LSD (5%)	7.76	52.5	3.600	5.53	77.4	4.9
Cropping systems (CS)						
PM1	32.9b	1376b	39.4a	23.6a	392a	19.3a
PMI + Biashara	34.9b	1589a	31.3b	26.4a	347a	19.2a
PM1 + N26	33.3ab	1486ab	24.2c	27.7a	371a	17.5b
PM3	37.1ab	1385b	39.3a	24.2a	362a	19.9a
PM3 + Biashara	41.5a	1590a	26.7c	30.8a	382a	18.4a
PM3 + N26	38.6ab	1489ab	28.9ab	29.9a	389a	17.8b
p value	0.045	<.001	0.06	0.858	0.958	0.018
LSD (5%)	10.97	74.20	4.100	7.830	109.5	8.100
Interaction						
T × CS	0.939	0.602	<.001	0.746	0.675	0.443
CV%	30.00	13.20	23.5	28.50	30.60	32.20

Legend: PM1, PM3: Pearl miller varieties, N26: green gram variety; LSD: least significant difference. CV: coefficient of variation*Means followed by same letter in a column are not significantly different at $p \leq 0.05$

The harvest index (HI) of PM3 and PM1 did not differ significantly between the two varieties in both sites, however, water harvesting technologies effects on HI was significant in Kambi Mawe (p = 0.021), but not in Katumani (p = 0.098). Cropping system had no significant effect on the harvest index (Tale 4.6). The highest harvest index of 41.2% was recorded in ngolo pits, while the lowest harvest index of 22.7% was obtained from conventional tillage.

The effect of water harvesting technologies and copping systems on 1000 seed weight were significant ($p < 0.05$) in Kambi Mawe, however, they were insignificant in Katumani (Table 6). A thousand seed weight was higher by 6.5g and 10.1 g in ngolo pits compared to contour furrows and conventional tillage, respectively. The weight of 1000 seeds significantly differed between PM3 and PM1 pearl millet varieties in Kambi Mawe, but not in Katumani. Intercropping pearl millet with green had significant effect, irrespective of the green gram variety. For instance, intercropping PM1 with biashara recorded 4.4 g higher than sole cropping of PM3, while intercropping it with N26 had 1.7g higher.

On the other hand, a thousand seed weight of PM1 intercropped with biashara and N26 was 2g and 0.4 g higher than sole cropping of PM1 in Kambi Mawe. In Katumani, intercropping PM1 with either N26 or biashara did not significantly influence the thousand seed weight, however, intercropping PM3 with biashara significantly increased 1000 seed weight by 6.6 g over the sole PM3 (Table 6).

4.7.7 Effect of water harvesting technologies and cropping system on leaf area index

Water harvesting technologies significantly ($p < 0.001$) affected the leaf area index in Kambi Mawe. The leaf area index recorded at 30 and 45 days after planting revealed that highest values (0.344 and 0.446), respectively were obtained from ngolo pits, while lower values (0.232 and 0.373), which were recorded in plots under conventional tillage.

The leaf area index did not differ significantly between PM1 and PM3 peal millet varieties in Kambi Mawe and Katumani. Similarly, the interaction between water harvesting technologies and cropping systems was insignificant in both sites (Table 7).

In Katumani, water harvesting technologies had a significant effect on the leaf area index at 30 days after planting (p = 0.016), but not at 45 days after planting.

Table 7: Effect of water harvesting technologies and cropping system on pearl millet leaf area index in Kambi Mawe and Katumani during 2022/2023 short rain season

	Kambi Mawe		Katumani	
Treatments	30	45	30	45
Water harvesting technologies (T)				
Ngolo pits	0.344^{a}	0.446^{a}	0.0982^{a}	0.1729^{a}
Contour furrows	0.251^{b}	0.379^{b}	0.0809^{b}	0.1937^{a}
Conventional tillage	0.232^{b}	0.373^{b}	0.0805^{b}	0.1728^{a}
p value	<.001	0.012	0.016	0.2200
LSD (5%)	0.0558	0.0523	0.0138	0.02739
Cropping systems (CS)				
PM1	0.291^{a}	0.436^{a}	0.0760^{a}	0.1783^{a}
PMI + Biashara	0.278^{a}	0.390^{a}	0.0843^{a}	0.1948^{a}
PM1 + N26	0.262a	0.394^{a}	0.0797^{a}	0.1651^{a}
PM3	0.296^{a}	0.405^{a}	0.1049a	0.1727^{a}
PM3 + Biashara	0.275^{a}	0.359^{a}	0.0865^{a}	0.1820^{a}
PM3 + N26	0.252^{a}	0.411^{a}	0.0877^{a}	0.1858^{a}
p value	0.872	0.441	0.0800	0.7100
LSD (5%)	0.0788	0.0739	0.0195	0.03874

Interaction				
T × CS	0.985	0.828	0.65	0.834
CV%	29.90	19.30	23.6	22.50

Legend: PM1, PM3: Pearl miller varieties, N26: green gram variety; LSD: least significant difference. CV: coefficient of variation*Means followed by same letter in a column are not significantly different at p ≤ 0.05

Land equivalent ratio

Statistical analysis of data revealed that in Kambi Mawe, the highest total LER of 1.599 was obtained from crops under ngolo pits, while the lowest total LER of 1.257 was attained from conventional tillage. In Katumani, a similar trend in the total LER was observed, where the highest total LER of (1.079) was obtained from ngolo pits and lowest (0.826) recorded in conventional tillage. In Kambi Mawe, the highest total LER of 1.542 was attained by PM3 + biashara (partial LER of pearl millet, 0.567, and green gram, 0.975) and the lowest LER of 0.991) attained combination of PM1 + N26 (partial LER of pearl millet, 0.427, and green grams, 0.564). In Katumani, the highest LER was 1.249 obtained from intercropping PM3 + biashara (partial LER of pearl millet, 0.503 and green gram 0.746) and the lowest LER was 0.773 obtained from combination of PM1 + N26 (partial LER of pearl millet, 0.152 and green gram, 0.621) (Table 8).

Table 8: ***Partial and total LER of two pearl millet varieties (PM1 and PM3) intercropped with two green gram varieties (N26 and Biashara) at Kambi Mawe and Katumani during 2022/2023 short rain season***

	Kambi Mawe			Katumani		
Treatments	Partial LER Millet	Partial LER green gram	Total LER	Partial LER Millet	Partial LER green gram	Total LER
Water harvesting technologies (T)						
Ngolo pits	0.775	0.824	1.599	0.432	0.647	1.079
Contour furrows	0.646	0.719	1.359	0.392	0.479	0.871
Conventional tillage	0.593	0.664	1.257	0.345	0.481	0.826
p value	0.45	0.145	0.434	0.03	0.0125	0.034
LSD (5%)	0.123	0.445	0.568	0.068	0.344	0.566
Cropping systems (CS)						
PMI + Biashara	0.661	0.697	1.358	0.152	0.621	0.773
PM1 + N26	0.427	0.564	0.991	0.494	0.514	1.008
PM3 + Biashara	0.567	0.975	1.542	0.503	0.746	1.249
PM3 + N26	0.891	0.501	1.392	0.459	0.493	0.952
p value	0.011	0.134	0.145	0.894	0.449	0.443
LSD (5%)	0.186	0.432	0.618	0.445	0.309	0.556
Interaction						
T × CS	0.988	0.352	0.672	0.338	0.819	0.852
CV%	12.00	18.00	14.00	17.00	24.00	13.00

Legend: PM1, PM3: Pearl miller varieties, N26: green gram variety; LSD: least significant difference. CV: coefficient of variation.

Discussion

Effect of water harvesting technologies and cropping system on plant height

The plant height of green grams and pearl millet was significantly increased under water conservation technologies (ngolo pits), compared to plants under contour furrows and conventional tillage. The results could be attributed to the soil moisture availability, which facilitates the diffusivity of nutrients and fosters uptake. These findings are consistent with results of Tanto and Laekemariam (2019) who reported higher green gram height under soil and water conservation technologies. Wafula et al. (2022) while working on the effects of in-situ water harvesting technologies on moisture content maize and bans grain yield, reported similar findings in Katumani. Similarly, it was noted that intercropping significantly increased green gram height by (13.99%) for Biashara and (36.66%) for N26 compared to sole crops recorded at 30, 45 and 60 days after planting (DAP). The probable reason for this could be the efficient utilization of the growth resources in the intercrop system. The results conform to those of Mathukia et al. (2015) who reported that intercropping green gram with pearl millet increased green gram plant height.
Xia et al. (2014) in another study reported that contour furrows recorded higher maize height values compared to those under conventional tillage. These results also confirm the findings reported by Kurothe et al. (2014) who showed that contour furrows increased pearl millet in terms of height as compared to planning under conventional tillage. The lowest plant height recorded under conventional tillage on the two sites could be due to low soil moisture availability. The insignificant effect of cropping system, and water harvesting x cropping system on pearl millet plant height in the two sites could be attributed to competition for the resources not being so tense which could have unrestrained resources supply to the plant to affect plant height. Results are conforming to Zegada-Lizarazu et al. (2006) which did not find a significant effect of intercropping on pearl millet plant height , which they attributed to finite competition for resources in of pearl millet/cowpea intercrop. Alla et al. (2015) found that intercropping insignificantly affected maize plant height in maize/cowpea intercrop. In a similar ecological situation, Abou-Kerisha et al. (2010) presented insignificant variation in the average maximum height of maize plants during the selection period, which was attributed to high competition for growth resources.

Effect of water harvesting technologies and cropping system on number of leaves and leaf area index

Water conservation technologies (ngolo pits and contour furrows) increased the LAI by (0.11 and 0.02) units, respectively compared with LAI obtained in conventional tillage. The positive impact of water conservation technologies on growth and development could have swayed this result where the growth of vegetal parts largely the leaves was intensified due to the moisture availability hence this could have contributed to the increased LAI. These findings corroborate with those of Shmme and Raghavaiah (2016) who recorded increased LAI of maize under contour furrows compared to those grown under conventional tillage. The leaf area index of PM3 variety grown as sole surpass LAI of equivalents in the intercrop system with green gram by (0.14%) compared to LAI of pearl millet in an intercrop system. The contest for growth resources in the intercrop system could have adversely impacted the leaf growth hence contributing to the reduction in the LAI as LAI is a function of leaf area and number of leave per plant. Moreover, water harvesting technologies × cropping systems influenced LAI where the water harvesting technologies increased the LAI obtained under the intercropping system, however, this increase was inconsidarate to outcompete the LAI obtained from the sole cropping system. This indicates that crop growth was suppressed to a greater extent in the intercropping system than in the monoculture system. This finding is consistent with the findings of Yang et al. (2018) who reported that intercropping significantly increased the LAI of maize in the maize/cowpea intercrop system in dryland area. This could be attributed to the difference in plant density, varieties used and the test crop and different ecological conditions. This can be attributed to differences in plant density, cultivars used, experimental crops and ecological conditions.

Therefore, since Leaf Area index has a positive and significant correlation with grain yield, these results show that pearl millet under water harvesting technologies and sole cropping system will produce more yields than its counterparts intercropped with green gram.

Effect of water harvesting technologies and cropping system on nodulation

The number of nodules was significantly affected by water harvesting technologies and cropping systems. This was attributed to the shading effect of pearl millet and the stiff competition between the crops. This result is consistent with the findings of Mulika et al. (2019) who reported sole green gram yielded higher amount of nodules than their intercropped counterparts, because of the impact of shading of pearl millet, affecting the light penetration down the canopy.

Effect of water harvesting technologies and cropping system on yields and yield components

Pearl millet and green gram grain and Stover yields were significantly affected by water harvesting technologies. The yields were higher in ngolo pits compared to contour furrows and conventional tillage. This was attributed to the presence of soil moisture in the root zone of the plant. Wafula et al. (2022) reported higher pulse yield(Beans) in Ngolo pit compared to conventional tillage. In another study, Hakim et al (2022) reported higher green gram yield in furrow ridge compared to zero tillage and conventional tillage in Katumani and Mwea, which was due to the water harvesting structures which were able to stored rain water in the soil for the crops to uptake.

Intercropping of green gram and pearl millet reduced the plant height of Biashara by more than (6.1%), while the grain yield of N26 increased by (8.3%). This can be attributed to the shading impact of pearl millet on the green gram competition for space, light, moisture and nutrients. Similar results were obtained by Kumar and Kumar (2018), who found that yield of green gram was by pearl millet where green gram was grown as sole had higher heights compared to green gram in an intercrop with pearl millet.

In addition, Kitonyo et al. (2018) reported that monoculture systems produced higher maize height and yield than intercropping. Layek et al. (2018) reported that intercropping soybean with pearl millet, sorghum, and maize significantly reduced the number of pods per plant, number of seeds per plant, and soybean yield. The study attributes the decline in performance to intense competition from companion plants. Moi et al. (2021) found that intercropping sorghum with cowpea reduced the grain yield of cowpea due to the suppression effect of sorghum on cow pea. Inter-cropping significantly reduced the number of pods of biashara by (22%) and N26 by (10.2%). This may be due to strong competition for resources, which affects the number of pods per plant and the shading effect of pearl millet. These results conform findings of Kumar and Kumar (2018) who found insignificant effect of cropping system on the number of pods per plant in pearl millet- green gram intercropping system.

Intercropping significantly reduced pearl millet yield by 7.2% for PM1 and 6.6 % for PM3 in Kambi Mawe. The most likely reason for this difference be may be the intense competition for limited resources like moisture, nutrients and sunlight in the intercrop systems which affects the pearl millet growth and production of sufficient photosynthate to fill the grain. However, green gram 1000 seed weight was remarkably reduced by (10.3g) for biashara and 6.4g for N26 due to inter cropping effect in comparison to sole cropping. This could be attributed to the intense competition for nutrients in an intercrop system which reduced the translocation of photosynthates during grain filling stage, thus reducing the grain weight. The present study findings are consistent with the results of Rani et al. (2017), who found that there were significant differences in the green gram seeds weight between treatments due to water harvesting technologies and cropping systems. The harvest index of sole pearl millet exceeded intercropped pearl millet by (15.2%) for PM3 and (7.1%) for PM1.This can be attributed to limited competition for growth resources in sole cropping compared to inter-crop system. These results are supported by the findings of Wafula et al. (2022) reported a higher yield of sole maize compared to inter-cropped maize and beans. A positive correlation between grain yield and harvest index was there. This therefore suggests that pearl millet in sole cropping system will yield highly than those under the intercrop system. The water harvesting technologies had a significant effect on the harvest index. Soil moisture influences the mobility and diffusivity of plant nutrients in the soil. This could be the probable reason why higher pearl millet grain yields were realized in the ngolo pits and contour furrows than in conventional tillage.

These results therefore suggest that water harvesting technologies and cropping systems significantly increased the grain yield and yield components of green grams. Hence the appropriate cropping system for green gram production is sole cropping.

Land Equivalent Ratio

The land equivalent ratio is a crucial tool for evaluating the performance of an intercropping system. In this current study, all the different intercropping system combinations were all greater than unity (LER > 1), where the highest was 1.599 and 1.079 in Kambi Mawe and Katumani, respectively, in spite of reduction of the individual yield of pearl millet and green gram in an intercrop system. The effective utilization of available soil moisture, nutrients and light in the intercrop system compared to the monocrop system can be attributed to this. The results of this study imply that sole cropping of either pearl millet or green gram would require 1.079 and 1.599 more units of land in Kambi Mawe and Katumani to obtain the same yield attained from intercropping system. Similar findings were consistent with Ghilotoa et al. (2015) who reported that the total LER was highest where pearl millet and green gram were intercropped than in the sole treatments. These study findings conform with the results of Kumar et al. (2015) who reported high LER greater than unity in an intercrop of pearl millet and green gram. Among all the sole ad intercropping treatments, the intercropping of green grams ad pearl millet produced the highest land equivalent ratio. Intercropping of Biashara with PM3 exhibited the highest total LER value of 1.542 indicating the superiority of the variety over N26 with PM1.

These results are similar with findings of Rani et al. (2017) who presented highest LER value of 1.26 achieved in tied ridges. The results therefore suggest that intercropping pearl millet with either biashara or N26 under ngolo pits is an effectual intercropping combination to increase crop productivity per unit area of land and gurantee economic efficiency. Although this study focused on intercropping pearl millet with green grams for one season, there is need for further studies with other legumes apart from green gram for two or more season at different ecological zones to affirm these findings.

Conclusion

Generally, green grams and pearl millet growth parameters, yield and yield components performed better under water harvesting technologies (ngolo pits) and sole cropping system compared to the intercrop system. This therefore suggests that the combination of ngolo pits with sole cropping of either pearl millet or green gram is the best approach for the realization of increased food production and food security.

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