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Effect of Moisture Conservation Methods and Plant Density on the Productivity of Two Maize (*Zea mays* L.) Varieties under Semi-Arid Tropics of Hamelmalo, Eritrea

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Abstract

The productivity of maize in Eritrea in general and under semi-arid tropics of Hamelmalo in particular is low because of moisture stress. The low moisture content is ascribed to the low and erratic distribution of rainfall, high temperature, lack of suitable varieties, and competition by weeds and low soil fertility. To overcome some of these problems, a field experiment was carried out to assess the effect of moisture conservation methods (MCM) and plant density on the productivity of two maize (*Zea mays* L.) varieties under semi-arid tropics of Hamelmalo, Eritrea. The experiment was conducted in split-split plot design with three MCM viz tied ridge, ridge and furrow and flat-bed in main plots; two maize varieties viz early local and 04sadve hybrid in sub plots and three plant densities by manipulating the plant to plant distance viz 35 cm, 25 cm and 15 cm at a fixed 75 cm row spacing in sub-sub plots, each replicated thrice. The experiment was focused in addressing the effective moisture conservation techniques, optimum plant density to each variety thus to improve productivity. The crop experienced 10˚C to 34.8˚C minimum and maximum temperature, respectively and received 429.1 mm total rainfall. The results of the experiment indicated that among all the combinations, 04sadve hybrid variety sown at 75 cm × 25 cm spacing in ridge and furrow method or at 75 cm × 15 cm spacing in tied ridge or flat-bed method and early local variety sown at 75 cm × 15 cm spacing in flat-bed being statistically at par resulted in significantly higher moisture conservation and consequently higher grain yield (4509 $kg \cdot ha^{-1}$) and higher water use efficiency. It is, therefore, recommended that tied ridge or flat-bed of moisture conservation method at 15 cm plant spacing and 04sadve is preferable to optimize productivity in Hamelmalo area, Eritrea.

Keywords

Eritrea, Moisture Conservation Methods, Maize Varieties, Water Use Efficiency

1. Introduction

Maize (*Zea mays* L.), also locally known as *efun* in Eritrea, ranks third after sorghum and pearl millet among summer food grains and fifth among all food grains after sorghum, pear millet, wheat and barley in both area and production. The productivity of this crop in Africa in general and Eritrea in particular is much lower than its average productivity (4472 kg/ha) in the world. The low productivity of maize in Eritrea is attributed to the lack of quality seeds of high yielding varieties, moisture stress due to low and erratic rainfall, high temperature, low soil fertility, competition by weeds, inappropriate tillage and sowing system, lack of nutrient supplying capacity of the soil and timely non availability of the fertilizer to the farmers [1]. In addition to these, the degraded land with limited soil moisture availability at critical stages of crop growth is other major constraints of low productivity. Among these moisture stresses due to low and erratic rainfall, lack of appropriate methods of soil moisture conservation, lack of adaptable varieties to moisture stress and their optimum population density are the dominant in reducing its average productivity. In Eritrea, maize is produced in very marginal areas like highland and thus the production is not sufficient to meet the aggressive demand by the consumers.

Maize contains both corneous and soft starch 61 percent with high content of essential amino acid. It is kernel contains 13.5 percent moisture, 10 percent crude protein, 4.3 percent oil and 70.3 percent carbohydrate [2]. It has the highest production potential among the cultivated field crops and is known as "queen of cereals". Its uses as main source of food and for local drink as well as animal feed make it a multipurpose crop [3]. The grain of this crop is an excellent source of human diet in the form of bread, roasted and local drink. The oil content of hybrid corn ranges from 3.5 to 6 percent with average of 4.5 percent [4]. Stover and grain are used as animal feed and have wide ranges of industrial applications in pharmaceuticals, cosmetics and textile industries in developed countries. It has a great potential for efficient input use, crop diversification, foreign exchange earnings and greater employment through agro-industries and food security especially popcorn [2].

In Africa it is being grown in an area of 27,114 thousand ha with a production of 435,182 thousand metric tones and average productivity of 1605 kg/ha [3] whereas in Eritrea it covers an area of 19,621 ha of land with annual production of 29,053 tones and an average productivity of 1480.7 kg/ha [5].

The average annual rainfall in Eritrea is around 450 mm and is not uniformly distributed indicating moisture stress as one of the major constraints for crop productivity [6]. In order to protect the crop from frequent agricultural drought development, efficient rain water conservation methods are necessary for sustainable high yields. Testing, thus, identifying suitable varieties under low moisture concomitant to soil moisture conservation techniques is of paramount importance to improve productivity. Increase in intra-row spacing results in larger leaf area by reducing the competition for space, sunlight and nutrients. Competition among maize plants for light, soil fertility and other environmental factors increases markedly with higher population and *vice versa* [7]. Therefore, optimum plant population is the pre-requisite for maximum utilization of inputs for higher productivity [8].

The experimental farm of Hamelmalo Agricultural College in Eritrea is part of semi-arid agro ecological zone having average annual rainfall of about 468 mm with erratic and unreliable distribution which greatly influence the yield of crops [6]. In the absence of effective soil moisture conservation technologies farmers grow maize only in limited areas and have no choice except to grow monoculture of sorghum and pearl millet. No research was conducted on the response of moisture conservation and plant population on the performance of maize varieties in Eritrea. Keeping in view the above factors, thus, a study was conducted to assess the effect of moisture conservation methods and plant density on the productivity of maize under semi-arid conditions.

2. Materials and Methods

The field experiment was conducted during summer season, 2014 at the Model Integrated Watershed Management farm area of Hamelmalo Agricultural College (HAC), located in Hamelmalo, Eritrea. The site is located 12 km North of Keren at latitude of 15˚52'21"N and longitude of 38˚27'42"E, and at an altitude of 1285 m above mean sea level. The climate of the area is semi-arid with 429.1 mm average annual rain fall for the growing season with average annual maximum and minimum temperatures of 34.8˚C and 10˚C, respectively. The weekly rainfall distribution at Hamelmalo Agricultural College during the experimental period was exceptionally uniform throughout the growing season. Before sowing of the crop a composited representative soil sample was taken from 30 cm soil. The sample was thoroughly mixed and analyzed for its physico-chemical properties. The soil of the experimental field was sandy loam in texture, alkaline in reaction (pH 8.2), very low in organic matter content (0.27%), very low in available nitrogen, low in available phosphorus and low in potassium [9].

The experimental field was ploughed with disc plough followed by disc harrow. Weeds and crop residues were removed manually. Field was leveled and surface of plots was configured manually with hoe and shovel depending on the different MCM (Tied ridge, Ridge and furrow and flat-bed) which are allocated to the main plot. To the sub plot two varieties (early local and 04sadve (hybrid) were allocated and three plant spacing 35 cm, 25 cm and 15 cm, respectively with a constant row spacing for 75 cm was used. The crop was sown on 28th June, 2014 at 5 - 7 cm depth by dibbling method with hand tool. The field experiment was conducted in split-split plot design with three replications. Fertilizers were applied as per recommendation of National Agricultural Research Institution (NARI) at the rate of 18 kg N and 46 kg P_2O_5 through 100 kg·ha^{-1} DAP at the time of sowing. Top dressing of 23 kg N/ha from 50 kg Urea ha^{-1} was done in two equal splits at 20 and 40 days after sowing (DAS). Three hand weeding were done at 20, 40 and 60 days after sowing (DAS). A uniform application of Malatox at 40 DAS was applied to control minor attack of stem borer and ants. Harvesting was done when the cob husks dried and turned yellowish in colour. Soil moisture content was determined by gravimetric method [10] at 20 days interval from time of sowing up to 100 DAS. Soil samples were taken by tube auger from 15 cm and 30 cm soil layers from the net plot area and were weighed and oven dried at 105˚C till constant weight was obtained. Percent soil moisture content on dry weight basis was calculated following the formula:

$$\text{Soil moisture}\left(\%\right)=\frac{W_1-W_2}{W_2}\times 100$$

where W_1 = Fresh weight of soil before oven dry, and W_2 = weight of oven dried soil.

Water used (mm) by the crop was taken as the evapotranspiration of the crop (ETc). Soil moisture content of the sandy loam soils at field capacity, permanent wilting point and available water ranged between 10% - 18%, 4% - 8% and 6% - 10%, respectively [11].

The amount of water (mm) lost through evapotranspiration from the soil and crop was calculated as follows:

$$\text{Evapotranspiration of the crop}\left(\text{ETc}\right)\left(\text{mm}\right)=\text{Evapotranspiration}\left(\text{ETo}\right)\times \text{Kc}$$

where ETo is evaporation recorded using the US open pan evaporimeter and Kc is the crop coefficient given by FAO [12]. The water used in evapotranspiration, and for metabolic activities was calculated by multiplying the ETo with the crop coefficient value of 1.2 [12]. The water used Efficiency was calculated following the formula given by [13] as follows:

$$\text{WUE}\ \frac{\text{kg}}{\text{ha}}\Big/\text{mm}=\frac{\text{Grain yield kg/ha}}{\text{Water used}\left(\text{mm}\right)}.$$

The data on yield attributes, biological yield, grain yield and water use efficiency after harvest of the crop were collected. The data obtained from all the measured parameters of the experiment under various treatments were subjected to statistical analysis by using the GENSTAT software (4th ed) and IBM SPSS statistical package version 20. The treatment means were compared with LSD at 5 per cent level of significance (95% confidence limit) for the analysis of variance.

3. Results and Discussions

3.1. Effect on Soil Moisture Contents

The critical perusal of the data in (**Table 1**) revealed that moisture conservation methods significantly influenced the soil moisture content in both soil layers at all the observation stages except at 15 cm at 20 DAS and 60 DAS. Among the

Table 1. Effect of treatments on periodic soil moisture content (%) at different soil depth.

Treatments	Moisture %									
	At sowing		20 DAS		40 DAS		60 DAS		80 DAS	
	Depth (cm)									
	15 cm	30 cm	15 cm	30 cm	15 cm	30 cm	15 cm	30 cm	15 cm	30 cm
MCM										
Tied Ridge	10.3a	9.4a	12.7a	14.2a	11. 2a	13.1a	12.3a	11.8a	5.8a	5.9a
Ridge and Furrow	9b	6.2b	11.0a	7.4b	9b	9.2c	9.7a	9.2b	4b	5.3b
Flat bed	7.5c	7.5b	11.5a	10.5b	10.8a	10.8b	11.1a	9.b	4.1b	4.5c
CV%	3.3	9.9	11.7	12.8	5.8	2.7	8.3	3.2	5.5	0.001
LSD (0.05)	0.68	1.74	NS	3.11	1.36	0.69	NS	0.73	0.57	0.002
Varieties										
Early local	9.05a	7.44a	11.96a	11.15a	10.25a	11.19a	10.82a	10.54a	4.44a	4.95b
04sadve	8.81a	7.98a	11.53a	11.15a	10.45a	10.85a	11.25a	9.63b	4.78a	5.53a
CV%	5.3	12.2	15.4	8.6	5	9.7	5.5	9.3	12.3	0.2
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	0.42	NS	0.0015
Plant-plant spacing (cm)										
35 cm	9.4a	8.0a	12.1a	10.8a	11.1a	11.4a	11.7a	10.63a	5.0a	5.8a
25 cm	8.9a	7.5a	11.6a	10.4a	10.3b	11.1a	11.1b	10.2a	4.6b	5.20b
15 cm	8.4b	7.6a	11.5a	10.8a	9.6c	10.5a	10.4c	9.4b	4.2c	4.8c
CV%	5.3	12.2	15.4	8.6	5	9.7	5.5	9.3	12.3	0.2
LSD (0.05)	0.63	NS	NS	NS	0.36	NS	0.42	0.64	0.39	0.007

Means with the same letters under the same column are not significant (P > 0.05) different using Duncan Multiple Range Test (DMRT). MCM = Moisture conservation method; DAS = days after sowing.

moisture conservation methods, tied ridge being effective in checking runoff losses and increasing infiltration of water resulted in significantly highest soil moisture content in both the layers of the soil at all the stages of the observation. At 15 cm soil layer during sowing and at 30 cm soil layer at harvesting flat-bed method was inferior to ridge and furrow method and at 40 DAS flat-bed method and ridge and furrow method were inferior in moisture conservation. However, it was statistically at par with ridge and furrow methods at 30 cm soil layer at sowing and 60 DAS and at 15 cm soil layer at harvesting (80 DAS). [14] have also revealed that tied ridge was effective in reducing runoff and increase soil water storage, ultimately increasing the yield of the crop.

Varieties did not significantly influence the moisture conservation in two soil layers at all the stages of observation except in 30 cm layer at 60 DAS and 80 DAS. The significantly higher soil moisture content at 30 cm soil layer in the early local grown plots at 60 DAS may be attributed to density of its lesser roots in the 30 cm soil layers which could utilize less moisture from the deeper layer as compared to hybrid variety. Similar, observations were made by [15].

The variation in plant spacing did not significantly influence the soil moisture content at sowing and 20 DAS because of the less variation in the canopy formation due to plant spacing at initial stages of the growth. But at 40 and 60 stages of observation, plant spacing influenced the moisture content significantly in both the layer of the soil except in 30 cm soil layer at 40 DAS. Increasing in plant density by decreasing in plant to plant spacing from 35 cm to 15 cm decreased the moisture content in both the soil layers because of utilization of moisture by higher plant population.

3.2. Interaction Effects of MCM and Varieties

Moisture conservation methods and varieties interacted significantly influencing the soil moisture content (SMC) in 30 cm layer at harvest (80 DAS) stage of observation (Table 2). Combination of tied ridge orridgeand furrow with 04sadve hybrid variety resulted in significantly higher soil moisture content in both the soil layers as compared to local variety. Among all the combination of MCM and variety, tied ridge and 04sadve hybrid variety resulted in significantly highest SMC in both layer followed by combination of ridge and furrow and 04sadve. These findings are inconformity with those of [15] who reported that tied ridge decreased surface runoff from the field and increased retention of rain water with in the soil.

3.3. Effect on Yield Attributes

3.3.1. Cob Length

The data presented in (Table 3) indicated that MCM, varieties and plant spacing did not significantly influence the cob length but numerically tied ridge methods produced longest cob due to more retention and infiltration of rain water. 04sadve hybrid variety was numerically superior in mean cob length (14.88 cm) over early local variety. According to [16] maximum cob length was obtained

Table 2. Interaction effect of MCM and varieties at harvest (80 DAS) on moisture content (%).

MCM	Varieties			
	Early local		**04sadve**	
	Depth of soil layer (cm)			
	15	**30**	**15**	**30**
Tied Ridge	4.5b	4.5d	7.1a	7.3a
Ridge and Furrow	3.4c	4.1e	4.58b	6.6b
Flat bed	5.5b	6.3c	2.7c	2.7f

	LSD (0.05)		CV%	
Comparison between two varieties means at same MCM means	15	30	15	30
	0.81	0.002	11.1	0
Comparison between two varieties means at same or different MCM means				

Table 3. Effect of different treatments on the yield and yield attributes of maize.

Treatments	No. of cobs per plants	Cob Length (cm)	No. of rows per cob	1000 grain Weight (g)	Biological yield ($kg \cdot ha^{-1}$)	Grain yield in ($kg \cdot ha^{-1}$)	WUE (kg/mm)
				MCM			
Tied Ridge	1.48a	14.9a	12.32a	258.2a	7943a	3284a	5.66a
Ridge and Furrow	1.2a	13.6a	10.5b	232.3a	6764a	2805a	4.83b
Flat bed	1.3a	14.5a	11.2ab	253.7a	8123a	3280a	5.65a
CV%	8.7	4.5	4.5	3.7	9.4	5.9	5.9
LSD (0.05)	NS	NS	1.147	NS	NS	NS	0.73
				Varieties			
Early local	1.31a	13.7a	9.9b	244.8a	6790a	2815b	4.85b
04sadve	1.3a	14.9a	12.8a	251.3a	8430a	3432a	5.91a
CV%	15.8	10.9	9.20	14.0	21.4	20.1	20.1
LSD (0.05)	NS	NS	1.221	NS	NS	234.2	0.81
				Plant spacing (cm)			
35	1.4a	14.1a	11a	255.4a	6758b	2800c	4.83b
25	1.4a	14.5a	11.51a	236a	7330b	3073b	5.3b
15	1.2b	14.2a	11.5a	252.7a	8742a	3496a	6.03a
CV%	15.8	10.9	9.2	3.3	21.4	20.1	20.1
LSD (0.05)	0.1432	NS	NS	NS	1122.8	215	0.74

Means with the same letters under the same column are not significant ($P > 0.05$) different using Duncan Multiple Range Test (DMRT). WUE = water use efficiency.

from hybrid variety Azam and minimum from Pahari. This is attributed due to hybrid varieties have very deep root and vigorous vegetative growth where they can extract more moisture from the deep root soil. Plant spacing did not significantly influence the cob length but there was a trend of cob length increase using 25 cm plant spacing while reduction at 15 cm spacing ascribed to highest plant density (Table 3). The same scenario was reported by [17] cited in [18] where decrease in ear (cob) length as a result of increased in plant population.

3.3.2. Number of Cobs per Plant

The data on the effect of different treatments on number of cobs per plant presented in (Table 3) indicated that moisture conservation method and varieties did not significantly influence the number of cobs per plant, but numerically highest number of cobs per plant (1.48) was obtained in tied ridge. This numerical increase could be accredited to more available moisture content in tied ridge MCM (Table 1) followed by flat-bed method. The data further shown that 25 and 35 cm plant spacing being at par produced significantly higher cob number over 15 cm plant spacing due to lower plant population leading to less mutual competition for available nutrients, moisture, space and light. This finding is in agreement with [19] cited [20] who also reported higher numbers of cobs and grain yield as a result of lower plant density.

3.3.3. Number of Rows per Cob

The data in (Table 3) indicated that while MCM and varieties significantly influenced the number of rows per cob, but plant spacing did not significantly influenced the number of rows per cob. Among the MCM tied ridge and flat-bed methods being statistically equal produced significantly higher number rows per cob because of higher moisture contents conserved by the two methods (Table 1) which produced better growth and development of the crop. The results are partly in agreement with those of [21] who reported that rows per cob were increased at certain levels of moisture due to increase in cob size. Similar to this finding [22] reported the superiority of hybrid maize over composite cultivarsin increasing number of rows per cob due to its uniformity in flowering and disease resistance and genetic potential.

3.3.4. Thousand Grain Weight (g)

Thousand grain weight was not influenced significantly by the treatments understudy (Table 3). Among the MCM ridge followed by flat-bed method produced numerically higher 1000 grain weight. Hybrid 04sadve variety produced numerically higher 1000 grain weight over the local variety. Among the plant spacings, 35 cm plant to plant spacing produced numerically highest test weight as compared to the others. These finding are in accordance to those of [23] who reported that increasing crop density reduced the thousand grain weight.

3.3.5. Interaction Effect of MCM and Varieties on Number of Cob per Plant

MCM and varieties interacted significantly to influence the number of cobs per plant (Figure 1). The data presented indicated that irrespective of MCM, 04sadve hybrid variety resulted in significantly higher number of cobs per plant than early local variety due to its genetic superiority. Among all the combination of MCM and varieties, tied ridge and 04sadve hybrid variety being statistically at par with tied ridge and early local variety and flat-bed method with early local resulted in significantly higher number of cob per plant due to higher moisture

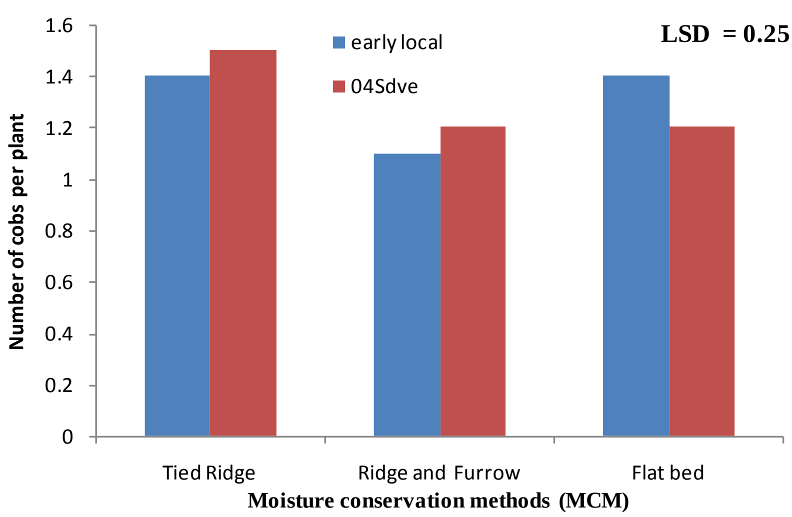

Figure 1. Interaction effect of MCM and varieties on number of cobs per plant.

conservation by these methods (Table 1) and efficient utilization of conserved moisture by both the varieties.

3.4. Effect on Biological and Grain Yield

3.4.1. Biological Yield ($kg \cdot ha^{-1}$)

Moisture conservation methods did not significantly influence the biological yield but numerically flat-bed methods produced highest biological yield followed by tied ridge methods due to higher soil moisture content (Table 1). There was no significant variation among the studied varieties, but a trend of biological yield increase was noted from 04sadve hybrid compared to the early local. The higher biological yield from 04sadve variety may be attributed to higher density of roots in the deeper layer which could utilize high moisture from the deeper layer. The mean value with respect to leaf area of hybrid variety 9022-13 (673.2 cm^2) indicated that the variety was superior to other varieties tested [24]. The plant spacing significantly influenced the biological yield. Significantly highest biological yield was obtained with the highest plant density of 15cmplant spacing. The higher plant population utilized the high moisture content from the deeper layers and intercepted more photosynthetically active radiation for higher photosynthetic activity. [25] found vigorous vegetative growth, greater dry matter accumulation and fewer photos assimilates partitioning from vegetative to reproductive phase as the main indicators of higher biological yield.

3.4.2. Grain Yield ($kg \cdot ha^{-1}$)

The grain yield was not significantly influenced by the MCM due to uniform distribution of rains and the moisture conserved by MCM at almost all the critical stages (Table 3). However, tied ridge produced numerically highest grain yield (3284 kg/ha). Whereas the hybrid variety 04sadve produced significantly highest grain yield over early local variety because of its genetic potential which helped it to utilize available moisture, nutrient and light more efficiently and thus produced significantly higher number of grain rows per cob, numerically higher cob length and 1000 grain weight (Table 3). Increasing plant density by decreasing plant spacing from 35 cm to 15 cm resulted in significant increase in grain yield of maize due to sufficient available moisture provided by uniform distribution of rain and moisture conserved by different methods. This is similar to the findings of [19] cited in [20] who also reported higher grain yield with higher plant density obtained following narrow spacing.

3.4.3. Interaction Effect of MCM, Varieties and Plant Spacing on Grain Yield ($kg \cdot ha^{-1}$)

Moisture conservation methods, varieties and plant spacing significantly influenced the grain yield (Figure 2). A perusal of the data indicated that combination of 04sadve hybrid variety sown at 25 cm spacing in ridge and furrow method resulted in significanly higher grain yield (4509 kg/ha) followed by a combination of 04sadve variety sown at 15 cm plant spacing in tied ridge (4023 kg/ha) and both the varieties sown at 15 cm spacing in flat-bed method (4057 kg/ha) which were statistically at par.

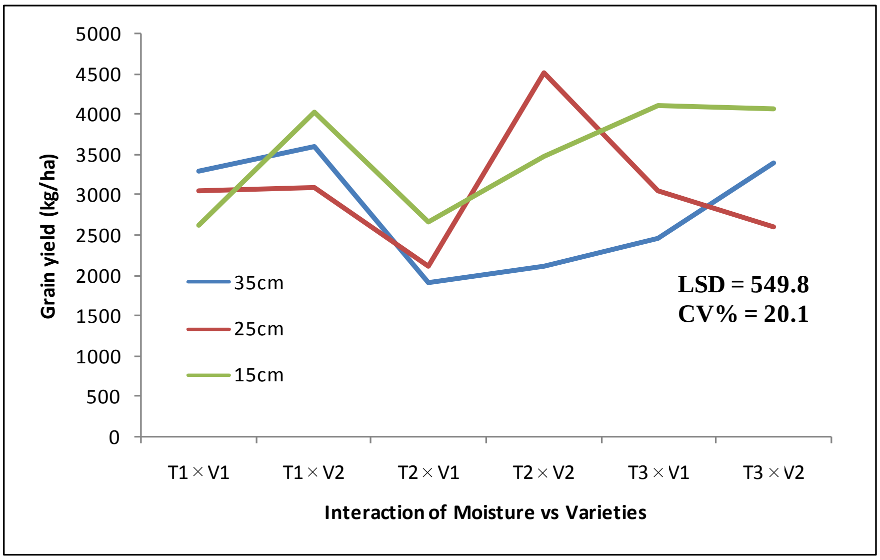

Figure 2. Interaction effect of MCM and Varieties and Plant spacing on grain yield (kg/ha) of maize. Where: T1 = tied ridge, T2 = ridge and furrow, T3 = flat-bed, V1 = early local variety and V2 04sadve variety.

3.5. Effect on Water Use Efficiency (WUE)

The WUE based upon grain yield was significantly influenced by moisture conservation methods, varieties and plant spacing (Table 3). Among MCMs, flat-bed and tied ridge being statistically at par resulted in significantly higher WUE as compared to ridge and furrow methods. Tied ridge and flat-bed method gave WUE of 5.66 and 5.65 kg/ha/mm, respectively. The higher WUE due to their methods is attributed to their efficiency in conserving more rain water (Table 1) which helped in increasing the grain yield. The significantly higher WUE of 04sadve hybrid variety over early local may be attributed to its vigorous vegetative growth, greater dry matter accumulation and more photo assimilates partitioning from vegetative to reproductive phase due to efficient use of resources. Similarly, in 2013 they were tested in the post graduate research growth and yielded kg/ha of 04sadve greater than early local [26]. Moreover, according to [27] improved crop growth increases the ability of the crop to extract more moisture from the soil. Plant spacing significantly influenced the WUE. Increasing in plant density with decrease in plant spacing from 35 cm to 15 cm numerically increased the WUE but statistically WUE at 15 cm spacing was at par with 25 cm spacing. The increase in WUE with increase in plant density could be ascribed to efficient utilization of conserved to moisture by better interaction of photosynthetically active radiation (PAR) reduced evapotranspiration and more translocation of photosynthates to the grain.

4. Conclusion and Recommendation

Because of the uniform distribution of rainfall during the experimental year, all the three methods of moisture conservations were found equally effective in influencing grain yield, biological yield and water use efficiency. Hybrid variety

04sadve was found to be superior to the early local variety. Highest plant density obtained with 75 cm × 15 cm spacing resulted in significantly higher grain yield, biological yield and water use efficiency. Among all the combinations 04sadve hybrid variety sown at 75 cm × 25 cm spacing in ridge and furrow method produced significantly higher grain yield (4509 kg·ha^{-1}), although it was statistically at par with combination of 04sadve variety sown at 75 cm × 15 cm spacing in tied ridge and both varieties sown at 75 cm × 15 cm spacing in flat-bed method of moisture conservation. It is, therefore, recommended that 04sadve hybrid variety sown at 75 cm × 25 cm spacing in ridge and furrow method and 04sadve hybrid variety sown at 75 cm × 15 cm spacing in tied ridge should be introduced at Hamelmalo and other areas of the country with similar climatic conditions.

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