Performance of Maize under Micro-Catchment Rainwater Harvesting in Western Pare Lowlands and Morogoro, Tanzania

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Abstract

Micro-catchment Rainwater Harvesting (RWH) has been defined as a method of collecting run-off from a Catchment Area (CA) over short distances not exceeding 100 m and supplying it to an adjacent Cultivated Basin (CB). It is a system that is designed to concentrate rainwater so as to utilize it more effectively in areas where the seasonal rainfall amounts are frequently lower than crop water requirements. The Catchment to Basin Area Ratio (CBAR) is an important parameter in the design of micro-catchment systems. It usually varies between 1:1 and 10:1. However, methods for deciding the optimum level of CBAR for different farming systems are not available. The purpose of the experiments reported here was to evaluate the CBAR for maize production in semi-arid areas of Tanzania. The experiments were run between 1992 and 1995 in semi-arid areas of Morogoro and Mwanga Districts of Tanzania, to assess the performance of maize grown in micro-catchment systems with CBAR varying from 0:1 to 4:1. Maize var. TMV1 was grown in Mwanga District while maize var. Staha was used as a test crop in Morogoro District. Grain was harvested in five out of six experimental seasons in Mwanga (Masika 1993, 1994 and 1995 and Vuli 1994/1995 and 1995/1996). In Morogoro, grain harvest was obtained only in two seasons (Masika 1993 and 1994) out of four. The results showed that micro-catchment RWH farming is feasible during Vuli. The yield benefits due to RWH were found to be 120 – 152 % and significant at P = 0.05. The benefits during Masika were found to be very low at only 12 – 17 % and not significant at P = 0.05.

Key words: Micro-catchment, rainwater harvesting, catchment area, cultivated basin

Introduction

Rainwater harvesting is defined as a process of collecting, concentrating and stroring various forms of runoff for various purposes (Myers, 1975). The collected runoff can be used for several purposes such as to improve soil-moisture for plants, to supply water for livestock and domestic purposes and to recharge the groundwater (Frasier, 1994).

Depending on the storage capacity available in the root zone, the first step in the management of rainwater for plant growth is to capture it and enhance its infiltration into the soil profile. The next step of equal importance is to prevent or reduce water losses from the root zone. The third step is to implement cultural practices to ensure that the crop makes the most effective use of the scarce water. The techniques for achieving these have been developed and promoted extensively under the subject of Soil and Water Conservation (SWC) (Tiffen *et al.*, 1994, Thomas, 1997, Hudson, 1992).

In order to improve the productivity of rainwater in semi-arid areas it is often necessary to concentrate it into a small area of use. The focus of this paper is on micro-catchment RWH systems. A number of techniques have

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Ngatoluwa, R.T., H.A. Mansoor, and A.S. Nyaki. 1995. Report on soils of rain-water harvesting experimental site at Kisangara. Soil-Water Management Research Programme, Sokoine University of Agriculture, Morogoro. 28pp.

Rao, K.P.C., A.L. Cogle, and K.L. Srivastava. 1991. Conservation effects of porous and vegetative barriers. Resource Management Program, International Crops Research Institute for Semi-Arid Tropics (ICRISAT), Annual Report 1991. Pantacheru, Andhra Pradesh, India.

Reijntjes, C., B. Haverkort and A.N. Bayer. 1992. Farming for the Future. Macmillan – ILEIA.

Rockstrom, J. and A. de Rouw. 1997. Water, nutrients and slope position in on-farm pearl millet cultivation in the Sahel. Plant and Soil 195: 311 – 327

Selvaraju, R., P. Subbian, A. Balasubramanian, and R. Lal. 1999. Land configuration and soil nutrient management options for sustainable crop production on Alfisols and Vertisols of Southern peninsular India. Soil and Tillage Research. 52: 203 – 216.

Singh, G., C. Ventataramanan, G. Sostry, and B.P. Josh. 1994. Manual of soil and water conservation practices. Oxford and IBH publishing.

Stocking, M. and L. Peake. 1987. Erosion-induced loss of soil productivity: In (Sentis I. P. (ed): Trends in Research and International Co-operation in Soil Conservation and Productivity), Venezuela Soil Science Society, Maracay.

Tarimo, A.J.P, S.Y. Thadei, F.J. Senkondo, J. J. Msaky, U. Tanaka, S. Araki, S. Kobayashi, Y. Takamura, J. Itani, and M. Tsunoda. 1998. *Ngoro* as a multi-functional system of sustaining productivity. Final Report. Integrated agro-ecological research project of the Miombo woodlands in Tanzania. Faculty of Agriculture, Sokoine University of Agriculture, Chapter 3: p117- 203

Thomas D.B. (ed). 1997. Soil and water conservation manual for Kenya. Soil and Water Conservation Branch, Government of Kenya, Nairobi. 296 pp.

Tiffen M., M. Mortimore and F. Gichuki. 1994. More People Less Erosion. John Wiley & Sons, West Sussex. 311 pp.

Truong, P. N. V and W. Scattini. 1990. Vetiver-the hedge against soil erosion?. *Australian Journal of Soil and Water Conservation* 3: 16-18.

responses to water conservation can be obtainned only in seasons of below-average rainfall.

Given the small increment in yield which was realized, farmers are unlikely to adopt the above conservation measures in this agro-ecological zone and especially for lowly valued maize in light of the investment costs in terms of labour and capital. According to Singh *et al.* (1994), SWC measures such as stone bunds or those involving earth movement require specialized knowledge, high labour and therefore cost. Such measures are therefore unlikely to be readily adopted if there are no tangible benefits to the farmer.

The gradual and natural formation of bench terraces, was an indication of the net movement of the soil down slope. In the absence of barriers, the almost invisible soil movement can not be checked, and its eventual loss from the crop fields can not be stopped. Thus, if the long term goal is to conserve soil on the slopes and pediments of western Pare (>8% slope) rather than water, then, any of the contour barrier practices evaluated in this study could be adopted.

Conclusions

Contour barriers had no significant effect on soil moisture conservation and on maize grain yield compared to the control. Given the small increment in yield which was realized, stones bunds, contour ridges and live barrier practices can not be recommended for moisture conservation in this agro-ecological zone. However, since the barriers were effective in controlling soil crip down slope, they could be recommeded as long-term measures for soil erosion control where this is considered a threat.

References

Critchley, W.R.S. 1989. Runoff harvesting crop production: Experience in Ki District 1984 - 1986. In: Thomas D.I E.K. Biamah, A.M. Kilewe, L. Lur gren and B.O. Mochonge. (eds) Soil a Water Conservation in Kenya. Procee ings of 3rd National Workshop, Kabe Nairobi, 16 - 19 September 1986. U versity of Nairobi and Sida, Nairobi: 396 - 406.

Doorenbos, J. and A. H. Kassam. 1979. Yie Response to Water. *FAO Irrigati and Drainage paper* No. 33. FA(Rome, 193 pp

Gebremedin, Y.H. 1996. The effect of cr productivity under different soil ma agement practices. MSc. Thesi Sokoine University of Agricultur 135 pp

Hatibu, N., J.W. Gowing, O.B. Mzirai ar H.F. Mahoo. 1999. Performance maize under micro-catchment rai water harvesting In Western Pa Lowlands and Morogoro, Tanzani *Tanzania J. Agric. Sc.* 2(2): 193-204

Hudson, N. 1995. Soil Conservation. Batsfor London. 192pp

Hudson, N.W. 1991. A study of the reaso for success or failure of so conservation projects. FAO So Bulletin No. 64, FAO, Rome. 65pp.

Internation Fund for Agricultural Developme (IFAD). 1992. Soil and wate conservation in sub-saharan Africa Towards sustainable production by th rural poor. IFAD, Rome. 110pp

Laing, D.R. and Ruppenthal 1991. Vetive News Letter No. 8, June 1992, Asi Technical Department, The Worl Bank, Washington DC.

Mahoo, H.F, M.D.B. Young and O. B. Mzi rai. 1999. Rainfall variability and it implications for the transferability o experimental results in the semi-ari areas of Tanzania. *Tanzania J. Agric. Sc.* 2(2): 127-140

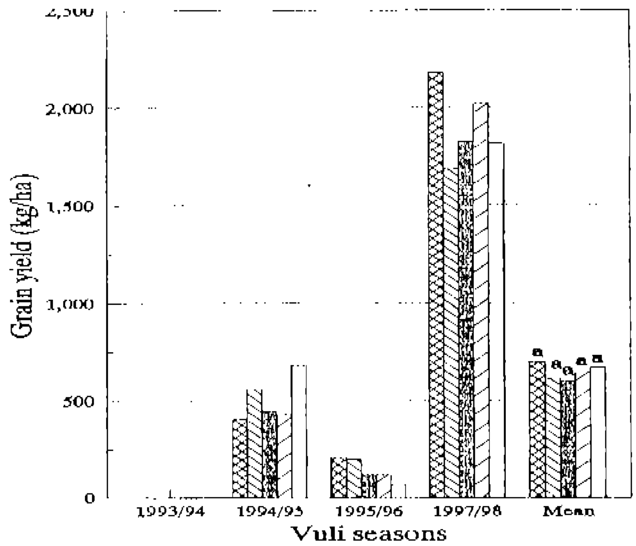

Figure 7: **Effect of different treatments on grain yield of maize during short rains (*Vuli*)**

Discussion

Rainfall data indicated that the amount is low and the distribution is very erratic. Over the study period and during *Vuli*, the amount varied from 0 mm to 97 mm in October, 2 mm to 200 mm in November, 35 mm to 273 mm in December, 3 mm to 367 mm in January, and 163 mm to 937 mm, in total. Short rains are indeed very inadequate. The *Vuli* rains are often lower than 200 mm which is too low to support a maize crop. Maize in WPLL requires at least 600 mm of well distributed rain (Hatibu *et al.*, 1999). The amount of rainfall received would still be insufficient even for drought torelant crops for example sorghum which requires 450 mm per season (Dorenboos and Kassam, 1979). That in a way explains the poor formance of the maize crop observed in this study. At times, the amount of water received from individual rainfall events was too low and very poorly distributed to even permit germination and emergence. The 1993/94 and 1998/99 *Vuli* seasons were such examples as the crop failed completely at establishment resulting in low biomass and no grain yield at all. There was no demonstrated advantage interms of grain yield between different treatments during *Vuli*. It is evident from this study that when seasonal rains are very low compared to crop water requirements as was the case during *Vuli*, the benefits interms of increased crop yield from SWC measures may not be realised. This may explain the low adoption rates of SWC measures in semi-arid areas (Hudson, 1991).

During all the *Masika* seasons except in 1994, flat cultivation (FC) had slightly lower grain yield that was not statistically differrent from that in treatments with barriers (SB, CR and LB). The above can be attributed to lack of significant differences in soil moisture between treatments. Similar findings were reported by Gebremedhin (1996) for a maize crop planted on flat and on ridges during long rains. Adequancy of rainfall and its good distribution were given as explanations which ruled out moisture differences despite enormous runoff losses from flat cropping. Results from almost similar studies by Critchley (1989) in Kitui District in Kenya, showed that crop yield

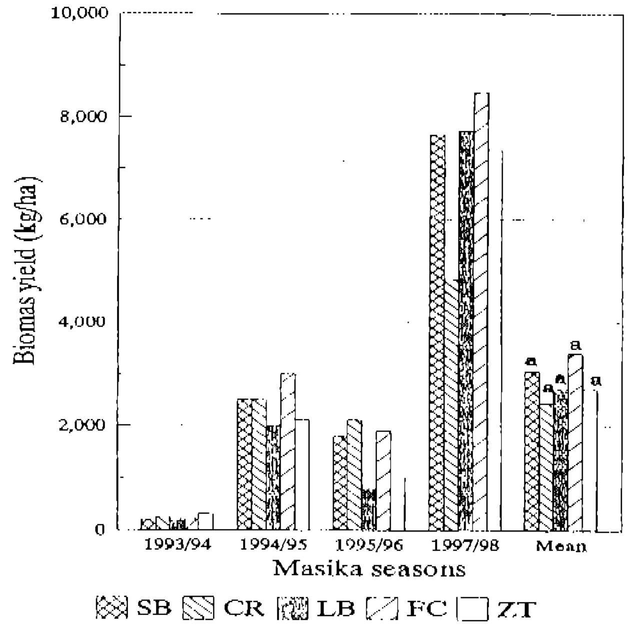

Figure 5: **Effect of different treatments on biomass yield of maize during short rains (*Vuli*)**

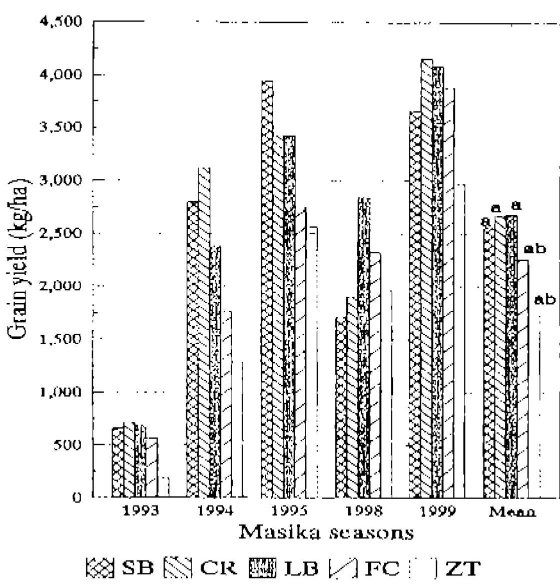

Figure 6: **Effect of different treatments on grain yield of maize during long rains (*Masika*)**

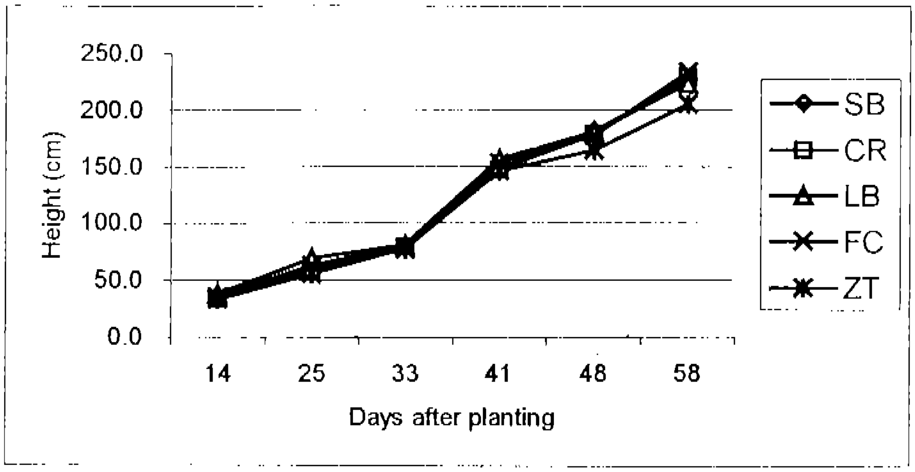

Figure 3: **Plant height as affected by conservation treatments during *Masika* 1999 season**

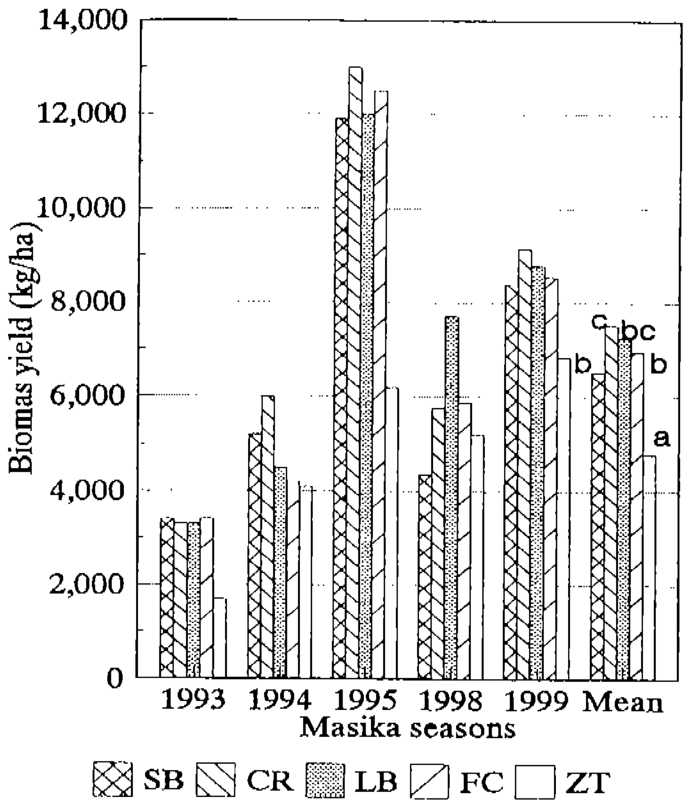

Figure 4: **Effect of the different treatments on biomass yield of maize during long rains (*Masika*)**

Soil moisture

Soil moisture measurements for the 1998 and 1999 *Masika* seasons are presented in Figure 2. Differences in soil moisture between treatments were not statistically significant (P= 0.05). However, SB, CR and LB had more profile moisture than the controls (ZT and FC). In all soil layers, SB had slightly less soil water than LB and CR.

Plant height

Plant height was affected by the treatments as shown in Figure 3. There were no conspicuous differences between treatments with regard to this parameter except for ZT, which tended to have shorter plants than in other treatments.

Biomass

Total biomass was affected by the treatments as presented in Figures 4 and 5. During *Masika* seasons, total biomass yield followed almost the same trend as that for grain yield (Figures 6 and 7). Overall, ZT producec least biomass closely followed by FC.

Grain yield

Grain yield was affected by the different t ment as shown in Figure 6 for long rains in Figure 7 for short rains. During the rains, ZT had the lowest grain yield over entire study period. For most seasons excej 1998, the yield under ZT was significa (P= 0.05) lower than in treatments with b: ers. During short rains between 1993 1999, statistical analysis indicated no sig cant difference between treatments. With exception of 1997/98 (*El Nino* effect), y was always less than 700 $kgha^{-1}$. In 199: season for example, grain yield varied betw 70 to 210 $kgha^{-1}$. There was no grain y during 1993/94 *Vuli* season. During 199ξ *Vuli* season, the rains failed (see Table 1) thus the sown seed did not germinate.

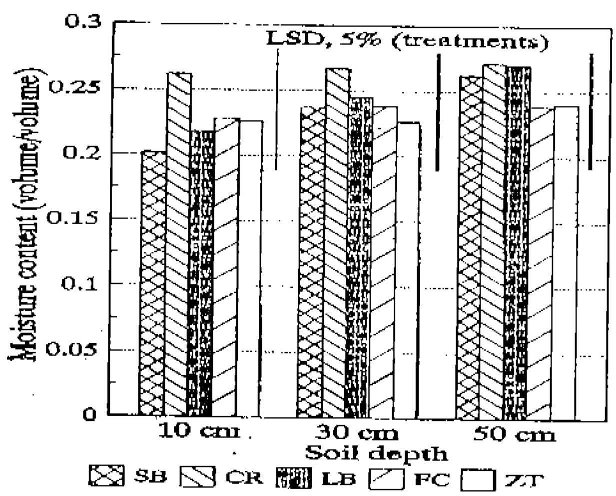

Figure 2: **Average soil moisture content in different conservation treatments during *Masika* 1998 and 1999 seasons at 10, 30 and 50 cm depth.**

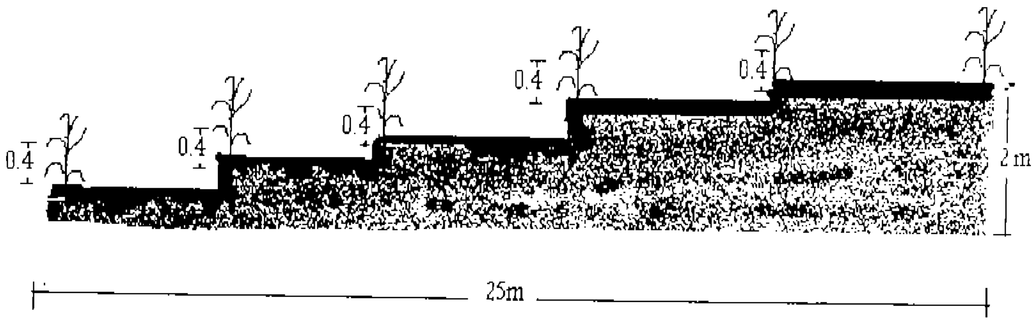

Figure 1b: Live barrier treatment in the conservation tillage experiment at final stage in *Masika* 1999

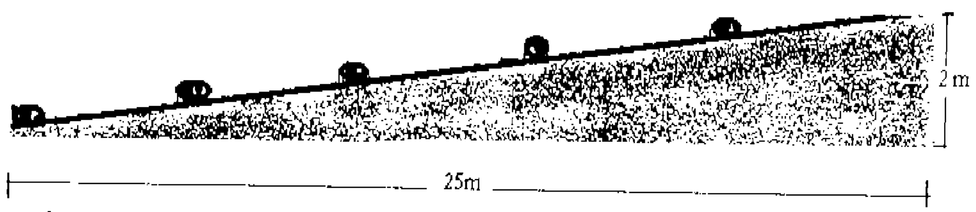

Figure 1c: Stone bunding treatment in the conservation tillage experiment at initial stage in *Masika* 1993

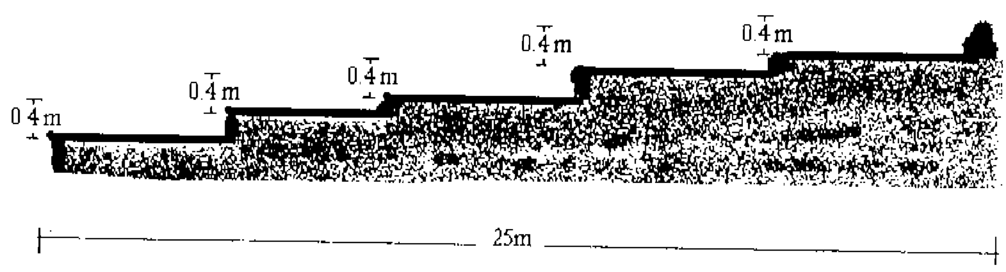

Figure 1d: Stone bunding treatment in the conservation experiment at final stage in *Masika* 1999

Three sub-sampling plots were marked out in the upper, middle and lower parts of the main plot. Each subplot had an area of 6.6 m^2 and measured 2.2 m wide and incorporated 4 crop rows. Maize ears were removed from the stem leaving the husks intact and still attached to the stems. Stems were then cut at ground level for biomass determination. The grain and vegetative parts were oven dried to constant weight at 60° C. The weights were used to calculate grain and biomass yield. The sampling area was used to extrapolate yield per hectare.

The deposition of soil material on the upper side of the barriers was monitored at the end of each season by determining the depth of the deposition.

Rainfall was recorded using a standard rain gauge located at about 30 m from the plots. An automatic tipping electronic rain gauge (with data logger) was installed during the last two seasons.

Soil moisture was monitored fortnightly using a Theta Probe at 10, 30 and 50 cm depth. A soil auger was used to make a hole to the desired depth before introducing the probe.

Analysis of variance (ANOVA) was performed with Statgraphics Version 5 (Statistical Grap ics Corporation, USA).

Results

Rainfall data

During *Vuli*, total rainfall amount varied fro 163 mm (in 1998/99) to 937 mm (in 1997/9 (Table 1a). In *Masika*, seasonal rainfall varie from 265 to 564 mm respectively for 1993 an 1998 (Table 1b). It is important to note that *I Nino* affected the 1997/98 *Vuli* and 1998 *M sika* seasons cited above. The rainfall amou during *Vuli* was for example, more than thre times the average amount that is usually le than 300 mm. More detailed analysis of rai fall patterns in the study area is given by M hoo *et al.*, (1999).

Changes in plot configuration

Initially (i.e. in 1993), all plots had a unifor slope of 8% (Figure 1 a and c). Graduall plots with treatments involving barriers (liv barriers and stone bunds) were transforme into bench terraces Figures 1(b) and 1(d) When the study ended in 1999, the terrac steps measured between 0.35 to 0.40 m i height.

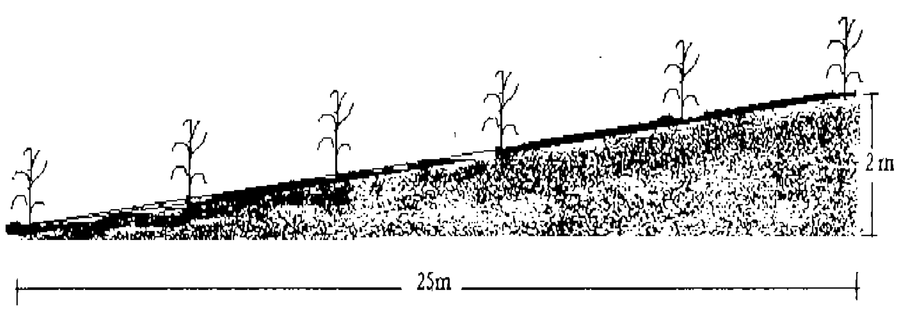

Figure 1a: Live barrier treatment in conservation tillage experiment at initial stage in *M sika* 1993

Table 1 (a): Monthly rainfall data during *Vuli* at Kisangara from 1993 to 1999

Month	1993/94	1994/95	1995/96	*1997/98	1998/99
October	45.4	18.5	10.0	97.0	0.0
November	18.7	51.1	2.0	200.0	95.8
December	90.8	246.0	115.0	272.7	34.8
January	14.0	3.0	69.5	367.0	32.4
Season total	168.9	318.6	196.5	936.7	163.0

(**El Nino* rains).

Table 1(b): Monthly rainfall data during *Masika* at Kisangara from 1993 to 1999 (**El Nino* rains)

Month	1993	1994	1995	*1998	1999
February	47.5	66.0	61.5	77.2	5.0
March	74.1	189.6	196.5	20.5	194.1
April	99.7	36.5	149.5	299.7	92.7
May	43.8	88	102.1	164.5	75.0
June	0.0	1.0	0.0	1.6	29.8
Season total	265.1	381.1	509.6	563.5	396.6

Experimental design and lay-out

The study comprised of three (3) conservation treatments and two, (2) control treatments. Conservation treatments were: stone bunds (SB), contour ridges (CR), and live barriers of vetiver grass (LB). Control treatments were flat cultivation (FC) and zero tillage (ZT). A Complete Randomised Block Design (CRBD) with three replicates was adopted. The blocks (replications) run across the general slope. Each plot measured 25 m along the slope and 5 m across. Contour ridges, live barriers and stone bunds were spaced 5 m apart in each plot. Thus, each plot had four barriers. The stone bunds were built to a height of about 0.4 m.

Agronomic practices

Tillage for the SB, LB, CR, and FC treatments was done using a hand hoe, which is the common means of land preparation in the area. For the ZT treatment, the soil was loosened only where seed was sown. The land is usually clear of vegetation at the beginning of the rain season. The grass had since long died or been eaten by termites (or grazing animals under traditional practice). Thus, sowing without any primary tillage was not much of a problem.

Maize cultivar TMV1 was used as a test crop. Seed was sown at a spacing of 30 cm x 75 cm by placing two seeds per hill. Phosphatic fertilizer was applied at planting at a rate of 40 kg P/ha as TSP 46%. Sulphate of Ammonia (SA) at a rate of 40 kg N/ha was applied between the 2nd and the 3rd week after planting depending on soil moisture condition.

Measurements

Plant height was determined on 20 randomly selected plants from the central row in each treatment. Measurements were taken at 14, 25, 33, 41, 48 and 58 days after planting. Grain yield and biomass were determined at harvest.

one type of grass which has been widely promoted for soil and water conservation (Truong and Scattini, 1990). Work carried out at ICRISAT, India by Rao *et al.* (1991) revealed that vetiver grass was superior in reducing soil and water losses when compared to stone bunds, lemon grass and bare ground (control). They reported that the vetiver grass reduced rainfall runoff by 57% and soil loss by over 80%. At CIAT, Colombia, Laing and Ruppenthal, (1991) reported that vetiver hedges reduced soil loss from 142 tons/ha for bare fallow to 1.3 tons/ha for cropped cassava between vetiver hedges. Rainfall runoff was reduced from 11.6% to 3.6%.

Runoff plots involving flat and ridge cropping on a 4% slope at SUA, Morogoro showed that these treatments had no effect on maize grain yield (Gebremedhin, 1996). The yield was 2,300 $kgha^{-1}$ and 2,600 $kgha^{-1}$ respectively in flat and ridge cropping. The above was against the background of 1,570 m^3ha^{-1} (157mm) and 352 m^3ha^{-1} (35.2 mm) loss in runoff. Soil loss in flat and ridge cropping was 12.5 tha^{-1} and 2.5 tha^{-1} respectively. The lack of statistical significancy in grain yield was attributed to adequate and well-distributed rains.

Soil bunding is by far the most effective and widely practiced field measure for controlling or preventing erosion (Singh *et al.*, 1994). The conservation treatments meant to reduce or prevent sheet erosion also desirably conserve moisture. Land configuration options for sustainable crop production in southern India indicate that, for slopes less that 8% with scanty or erratic rainfall, contour soil bunding is practised to intercept the run-off flowing down the slope by an embankment whose ends may be closed or open to conserve moisture as well as reduce soil erosion (Selvaraju *et al.*, 1999). However, by their nature earth bunds can easily be washed away by flash floods. This problem is reduced by using barriers which are permeable.

Permeable barriers do not completely stop the runoff but slow it down and spread the water over the field thus enhancing water infiltration and reducing soil erosion. Silt trapped on the higher side of the barrier build-up to form natural terraces (Hudson, 1995). Compared with impermeable soil bunds, permeable contour-line barriers have the advantage of low risk of being damaged (Reijntjes *et al.*, 1992).

The new approach to soil and water conservation in semi-arid area is to focus on productivity enhancement rather than just erosion control (Stocking and Peake, 1987). This is because, in the semi-arid areas, crop yields are likely to be reduced more by loss of water rather than by that of soil. Therefore, it is important to reassess existing soil and water conservation techniques, interms of their effects on water conservation and hence productivity.

The main objective of this study was therefore to compare the performance of three soil conservation techniques, in relation to productivity of maize on fields with a 8% slope, in drought prone areas.

Materials and methods

Site description

The study was conducted in the Western Pare Lowlands (WPLL) in Kisangara village, Mwanga District, Kilimanjaro Region. The experimental site was located on an 8% slope. Before 1993 the area was under sisal. The climate is semi-arid with two rainy seasons. The short rains (*Vuli*) last from October to January. The long rains (*Masika*) last from February to June. Monthly rainfall amounts from 1993 to 1999 during *Vuli* and *Masika* are presented in Tables 1 (a) and (b), respectively. The soils on the experimental site are *Acri Ferric Luvisol* (FAO) or *Typic Plinthustalf* (USDA) (Ngatoluwa *et al.*, 1995).