Chapter 11
In Situ Soil Moisture Conservation: Utilization and Management of Rainwater for Crop Production

P. Kathuli and J.K. Itabari

Abstract The salient results of in situ soil water conservation technologies that have been extensively tested and found suitable for increasing soil moisture for increased land productivity in the arid and semi-arid lands (ASALs) of eastern Kenya are reviewed in this paper. The technologies reviewed are *fanya juu* terraces, contour bunds, negarims, trapezoidal bunds, on-farm micro-catchments, *Zai* pits, *tumbukiza*, tied ridges, deep tillage and sub-soiling and ripping. These technologies hold rainwater on the soil surface thereby allowing it more infiltration time leading to enhanced soil moisture status, which would not be attained in the absence of these interventions. *Zai* pits, *tumbukiza* and deep tillage when used together with soil fertility improvement can increase crop yields by 4–10 times when compared to other similar fields cultivated conventionally. When tied-ridging tillage is used together with fertilizer, manure or their combination it can increase crop yields by 100–300 %. Sub-soiling and ripping increases crop yields by 50–100 % when used together with soil fertility improvement. Micro-catchment technology at 1:1 and 2:1 catchment to cultivated land ratio can increase crop yields, but is not practised due to land limitation. Use of fertilizers and or manures with in situ soil moisture conservation leads to improved water use efficiency by crops planted in the semi-arid eastern Kenya. It is, therefore, proposed that in situ rainwater conservation technologies should be an integral part of the farming systems for increased soil moisture conservation, crop production and food security in the semi-arid Eastern Kenya.

Keywords In situ rain water harvesting · Soil fertility improvement · Crop yields · Semi-arid eastern Kenya

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Introduction

In situ soil moisture conservation entails capturing rain water and retaining it in soil for in situ plant utilization for growth and increase in grain and biomass yield. This is achieved through rain water harvesting on-farm where crops or fodder are planted to benefit from the conserved rainwater. It reduces rainwater loss through runoff, thereby increasing the amount of rain water that will be useful for crop and fodder production through increased rain water infiltration time and hence increase in food security (Itabari and Wamuongo 2003).

Arid and semi-arid lands (ASALs) constitute 83 % of Kenya's land mass and support over 25 % of the human population. The problem of food insecurity in this region is mostly due to declining land productivity (Itabari et al. 2011), which is mainly attributed to inadequate soil moisture to support crop and fodder production. The rain water balance in the ASALs of eastern Kenya shows that 60–70 % of the rainwater is lost as runoff, leaving only 25–30 % for crop and fodder production (Kilewe 1987). Most soils in this region have developed hardpans at a depth of around 10 cm, which limit rain water infiltration. This leads to rain water loss through runoff, which carries away top fertile soil required for healthy crop growth. The soils in the region are susceptible to hardpan formation due to their inherent low organic matter and weak soil aggregate stability. The soil aggregates are broken down to fine aggregates, which join and form a seal of impermeable layer with time. The soils become susceptible to erosion (Kilewe 1987), losing rain water due to decreased infiltration as the bulk density of the few centimeters depth of the top soil increases, thereby limiting infiltration. This has been observed in semi-arid Makueni District (Miriti et al. 2009) where the top 0–15 cm soil had higher bulk density than the soils below this depth. An appropriate soil management technique is required for soils in the ASALs because of these inherent properties.

Also, the low and erratic 100–700 mm annual rainfall in the region means that crops and fodder production can only be achieved if in situ form of rain water harvesting is carried out for rainfed cropping system to increase soil moisture amounts and retention for crop production. In situ rain water harvesting can increase crop production by more than 40 % (Kathuli et al. 2010; Gichangi et al. 2007; Itabari et al. 2003) provided other crop and fodder agronomic practices are carried out. In other arid and semi-arid regions of eastern Africa, in situ rain water harvesting increases rain water productivity or efficiency from 1–1.5 to 3–4.5 kg/mm rain (Steiner and Rockstrom 2003).

Crop water utilization and efficient use of rain water is based on the principle that, the loss of rain water from the moment it reaches the soil surface and ensuring that its utilization by crops is as efficient as possible. The amount of water available for utilization by a crop is expressed as $T_{crop(mm)} = P\text{-}R\text{-}D\text{-}E\text{-}T_{weeds} - \Delta_s$ (Itabari 1999) where T = transpiration, P = precipitation, R = runoff, D = drainage, E = evaporation from the soil surface and Δ_s is change in soil water stored within the rooting zone.

The equation shows that, in order to have good rain water utilization by plants, T_{crop} must be optimized. This can only happen if R, D and E are minimized through soil management. The water utilization efficiency is calculated as $\mathrm{WUE} = \mathrm{Crop\,Yield}/\mathrm{T_{crop}} = \mathrm{kg/mm\,rainfall}$

The objective of this paper was to review the salient results of in situ soil water conservation technologies that have been extensively tested and found suitable for increasing soil moisture for increased land productivity in the ASALs of eastern Kenya and particularly in areas found within agro-ecological zone IV and V.

Materials and Methods

Secondary data from research conducted in the ASALs of eastern Kenya was collected from journals, conference and workshop proceedings and technical reports. The data represent the status of in situ soil moisture conservation in the ASALs of eastern Kenya. These lands are found in agro climatic zone (ACZ) IV, V, VI and VII. Agro-climatic zone IV has mainly low to medium altitudes, ranging from 1,300 to 1,800 m above sea level. The mean annual temperatures here range from 18 to 21 °C. Agro-climatic zone V falls within 1,800–1,300 m above sea level, and the mean annual temperatures range from 21 to 24 °C. For agro-climatic zones VI and VII, the mean daily maximum temperature varies from 32 to 37 °C in the cooler and hotter months, respectively. The mean minimum temperature is about 22–23 °C, giving a diurnal variation of 10–15 °C (Sombroek et al. 1982; Jaetzold and Schmidt 1983).

The annual rainfall ranges from 500 to 800 mm, and is erratic in amount and distribution. It is bimodal in the areas along the coastal hinterland and in the areas around the eastern slopes of the central highlands, and unimodal in the areas to the West of the central highlands. In the areas where it is bimodal, it is almost evenly distributed between the 'long rains (March–May) with a peak in April, and the 'short' rains (October–December) with a peak in November. The rates of evaporation are generally high due to the high daytime temperatures. Rates of up to 8.2 mm per day have been recorded at Katumani, which lies in ACZ IV (Stewart and Hash 1982), and over 3,000 mm year^{-1} for agro-climatic zones VI and VII (Sombroek et al. 1982; Jaetzold and Schmidt 1983).

The predominant soil types are Luvisols, Acrisols and Vertisols. There are other soil types, but they are of less significant in terms of the agricultural area they occupy. Their texture ranges from sandy loam to loamy sand with a tendency to harden when dry, but are friable when wet. They are deep and well-drained in the wetter areas, but tend to be shallow in the drier areas due to the presence of petroplinthite horizons. They have low organic matter content (less than 1 % C), mainly due to the poor growth of the natural and human-modified vegetation and removal of crop residues for livestock feed. They have a low water-holding capacity, are generally medium to slightly acidic (pH 5.0–6.5) in the surface horizons, poor structural development, are highly erodible and prone to surface sealing and capping through the energies of high-intensity rainfall and solar radiation (Muchena 1975).

Results

Some of past researched technologies on in situ rainwater conservation technologies include the tied and open-ridges, *zai* pits, semi-circular hoops, stone bunds, negarims, contour bunds, terraces, trapezoidal bunds, micro-catchments (Itabari et al. 2004), deep tillage and sub-soiling/ripping (Kathuli et al. 2010; Miriti et al. 2009; Steiner and Rockstrom 2003). These technologies allow rain water retention for a prolonged duration on the soil surface for increased infiltration and retention and better rain water use efficiency (Steiner and Rockstrom 2003; Itabari 1999). The following is a description of each of these in situ rain water conservation and utilization with highlights on successes and constraints.

Fanya Juu Terraces

Fanya juu terraces are constructed by heaping soil up-slope to make an embankment which forms a runoff barrier leaving a trench used for retaining or collecting runoff. The canal is 0.6 m deep and 0.6 m wide. The soil embankment is about 0.7 m from the surface. Runoff from external catchments is led into the canals for retention to allow more time for water to infiltrate into soil. Crops like bananas, pawpaws and citrus can be grown in the ditches. This technique is recommended for areas with slopes greater than 5 % (Plate 11.1).

Plate 11.1 Suitable land topography for construction of fanya juu terraces for in situ conservation of rain water for crop and fodder production in ASALs of eastern Kenya

Contour Bunds

Small earth, stone or trash lines embankments are constructed along a contour line to form an embankment. The embankments trap rain water flowing down the slope and retain it behind the bunds. The area behind the bunds can be levelled to ensure homogeneous infiltration. The spacing of the contour bunds depends on slope and soil type. Land on steep slopes will require closer contour bunds. Catchment to cultivated area ratio should be 2:1. A successful sorghum crop has been achieved with 270 mm rainfall using this technology (Itabari and Wamuongo 2003).

Semi-circular Bunds (Hoops)

These are semi-circular earth embankments with tips of the bunds on the contour. Water is collected within the hoop from the area above it and confined to the depth defined by the height of the bund and position of the tips. Excess water is discharged around the tips. An illustration on use of this technology is shown in Plate 11.2.

Negarims

These are small V-shaped embankments, with the apex at the lowest point. Water is collected from the V-shaped basin and stored in the soil profile at the apex. This technique is good for the establishment of trees and shrubs. Catchment area ranges

Plate 11.2 Semi-circular bund ready for grass reseeding in semi-arid Taveta sub-county

Plate 11.3 Farmers in semi-arid Makueni County demonstrating negarim making for tree crop establishment (Kathuli and Mweki 2012)

from 16 m^2 in agro-ecological zone (AEZ) IV to 1,000 m^2 in AEZ V. The soil embankment is 15–20 cm for water collection while the apex basin is 40 cm deep for water storage (Plate 11.3).

Tied Ridges

These are made to increase surface storage and to allow more time for rainwater to infiltrate the soil. Oxen made furrows are manually tied at 3–5 m intervals. The lower furrow is tied starting from the point between the above tied furrows such that tying is not perpendicular to prevent possible erosion in the farm to give a pattern similar to house construction using bricks. The cross ties are usually of lower height than the furrow so that if they fill, the overflow is along the furrow but not down the slope. This technology is recommended for land having a slope greater than 2 % so that the furrows retain rain water that would be lost as runoff if the structures were not in place. Effect of tied and open ridging technology of rainwater harvesting on mean maize grain yields across various sites in semi-arid eastern Kenya is shown in Tables 11.1, 11.2 and 11.3.

Data from Gichangi et al. (2007) on maize grain yields across various sites in semi-arid of eastern Kenya (Table 11.1) show that tied-ridging with manure, manure and fertilizer application can increased crop yields from 100–359 %.

Similar results were obtained in Mwala during the short rains of 2007 although the maize total dry matter (TDM) yields were not significantly different from conventionally cultivated fields (Table 11.2).

Tied-ridging with fertilizer use significantly ($P = 0.05$) out-yielded plots with conventional cultivation during the 1995 short rains (Table 11.3).

Table 11.1 Effect of tied-ridge rain water harvesting on mean maize grain yields across various sites (kiomo, masii, mavuria and kwa vonza) in semi-arid eastern Kenya

Treatments	Mean grain yield (kg/ha)		Percentage of yield increase + water harvesting	Percentage of increase − water harvesting
	Tied ridging	Open ridging		
0 t/ha FYM	655.0	483.0		
10 t/ha FYM	1319.4	788.0	101.4	63.1
20 t/ha FYM	1866.9	1284.0	185.0	165.8
20 kg N/ha	1466.9	1167.0	123.8	141.6
20 kg N, 20 kg P_2O_5	2035.0	1603.0	256.5	231.9
10 t FYM, 20 kg N	2536.8	1784.0	287.3	269.4
10 t FYM, 20 kg N, 20 kg P_2O_5	3007.0	2,155	359.1	346.2
$Lsd_{0.05}$	407.6	407.6		

FYM farmyard manure
Source Gichangi et al. (2007)

Table 11.2 Effect of tied ridging on TDM yield (kg/ha) of maize in mwala (aez 4), yatta and kitui (aez 5) during the 2007 short rains

District	Farmers	Tied ridging	Open furrows
Mwala	P. Kyululi	1,414	1,393
	A Musyoka	3,814	3,384
Yatta	T. Muthama	308	254
	M. Ndolo	193	125
Kitui	M. Mwava	204	157
Mean yields		1186.6	1062.6

Source Kathuli et al. (2010)

Table 11.3 Effect of tied-ridging and fertilizer on grain yield and water-use efficiency (wue) of sorghum at masinga during the 1995 short and long rains

Treatments/seasons	Grain yield (kg ha^{-1})	ET	WUE (kg ha^{-1} mm^{-1})
Short rains			
Flat cultivated − fertilizer	190b	299.0	0.64
Flat cultivated + fertilizer	380b	299.2	1.27
Tied ridging − fertilizer	360b	297.8	1.21
Tied ridging + fertilizer	820a	300.5	2.73
Long rains			
Flat cultivated − fertilizer	80c	276.09	0.29
Flat cultivated + fertilizer	350abc	276.86	1.26
Tied ridging − fertilizer	310bc	275.53	1.13
Tied ridging + fertilizer	1030a	276.97	3.75

Values in the same column followed by the same letter are no significantly different ($P = 0.05$) level
Source Itabari (1999)

Plate 11.4 Illustration of a trapezoidal bund in semi-arid Taveta sub-county

Trapezoidal Bunds

These are bunds with trapezoidal-shaped earth embankments (Plate 11.4).

Tips of embankments are placed on the contour. The embankment top is level and higher than the ground level at the tips. Water flowing down-slope is trapped and retained behind the bund up to the level of the tips and any excess overflows around the tips into other bunds in the system or natural drainage course. The size of enclosure depends on slope and may vary from 0.1 to 1.0 ha. Embankment base width varies from 2.6 to 5.8 m. ratio of catchment to cultivated area varies from 1:1 to 5:1 depending on rainfall regime, soil properties and crop water requirements. This technology can increase sorghum yields by 30–90 % in ASALs of eastern Kenya (Itabari and Wamuongo 2003).

Zai Pits

These are small planting pits 30 cm in diameter and 15–20 cm deep. Manure or compost is placed at the bottom of the pit and mixed with soil before planting. During digging, the soil is thrown down-slope to form a small embankment. The pits are made at a spacing on one meter row to row and pit to pit can be 30 cm. the pits should not be perpendicular to each other to avoid possible erosion in case of a heavy rainfall. These are useful for establishing vegetables and field crops. Some results obtained from *zai* pits are shown in Table 11.4.

Sub-soiling and Ripping

This involves use of a sub-soiler and a ripper which are drawn by animals. The sub-soiler is made of a round steel metal with a sharp end with an attachment to the ox plough. It is adjustable and penetrates the soil to a depth of 15 cm breaking soil

Table 11.4 Effect of tillage and fertilizer on grain yield and water-use efficiency (wue) of sorghum at masinga during the 1995 short and long rains

Treatments/seasons	Grain yield (kg/ha)	ET	WUE (kg/ha/mm)
Short rains			
Zai pitting − fertilizer	850a	297.9	2.85
Zai pitting + fertilizer	1010a	298.8	3.38
Long rains			
Zai pitting − fertilizer	900ab	275.10	3.27
Zai pitting + fertilizer	780ab	275.99	2.83

Values in the same column followed by the same letter are no significantly different at $P \leq 0.05$ level
Source Itabari (1999)

hardpan, usually formed at 10 cm soil depth due to continuous cultivation at this depth. The ripper opens the narrow furrow left by the sub-soiler to 8 cm wide ready for planting. The seeds are placed at the bottom of the furrow and covered lightly. The furrow traps rain water and holds it for some time as it infiltrates the soil. Sub-soiling/ripping increases crop production by 40–60 % in the ASALs (Steiner and Rockstrom 2003; Mwangi et al. 2005). In the absence of in situ rainwater harvesting, these lands lose 60–75 % of rain water through surface runoff due to their topographic features and inherent soil properties (Kilewe 1987). Combination of this in situ rainwater harvesting technologies and integrated soil fertility improvement technologies has led to increased crop yields (Mwangi et al. 2005, Kathuli et al. 2010). Similar results were obtained by use of sub-soiling/ripping in situ water harvesting technologies with sorghum, sorghum-cowpea intercrop and sorghum rotation with and without manure which resulted in increased sorghum yields (from 0.36 to 1.96 t/ha) where manure was applied in Makueni county (Kitinya et al. 2011). Results of on-farm trials involving the use of sub-soiling and ripping technology for in situ rain-water harvesting for soil moisture conservation on total dry matter yield and grain yields are shown in Tables 11.5 and 11.6, respectively.

Tumbukiza

These are planting pits, 60 cm wide and 60 cm deep. They are modifications of *Zai* pits. The top 0–20 cm soil is mixed with manure or compost prior to planting. 5–7 maize seeds can be planted per pit. They are spaced 100 cm row to row and 75 cm pit to pit and can also be used to establish fodder crops. This technology is illustrated below (Plate 11.5).

Table 11.5 Sub-soiled/ripped and conventionally tilled farms during the 2007 short rains and the 2009 long rains in mwala

Farmers name	District	Season	Total dry matter yield (kg/ha)		Yield increase (%)
			Treatments		
			Sub-soiling/ ripping	Conventional tillage	
A Muli	Mwala	SR 2007	239	102	134
Tabitha	Kitui	SR 2007	50	25	100
Kalumu	Kitui	SR 2007	350	167	109
Mean			213	98	117
Alize Musyoka	Mwala	LR 2009	189.8	222.2	
B Muoki	Mwala	LR 2009	766	570.0	34
M Kiingu	Mwala	LR 2009	283	438	
A Muli	Mwala	LR 2009	590	189	212
Mean			457.2	355	29
Lsd (5 % level)			392.3	392.3	
CV%			47.4	47.4	
s.e.d			123.3	123.3	
($P \leq 0.05$)			NS	NS	

Source Kathuli et al. (2010)

Table 11.6 Effect of integrated soil fertility and tillage methods on maize grain yields (kg/ha) in mwala aez-4 and yatta aez-5 during the 2009 short rains and kitui aez-5 during the 2007 short rains

Site	Soil fertility management	Treatments		Yield change (kg/ha) (%)
		Sub-soiling /ripping	Conventional tillage	
Kyasioni (AEZ-5) Yatta	5 t/ha FYM	1,530	1,630	−6
	5 t/ha FYM + 20 kg N/ha	1,710	1,080	+58
	(20 kg N + 20 kg P_2O_5)/ha	3,710	933	+298
	5 t/ha FYM +(10 kg N + 10 kg P_2O_5)/ha	2,210	1,340	+65
	Mean	2,290	1,246	+84
Kyawango (AEZ-4) Mwala	5 t/ha FYM	2,430	1,680	+45
	5 t/ha FYM + 20 kg N/ha	2,950	1,810	+63
	(20 kg N + 20 kg P_2O_5)/ha	2,220	2,020	+10
	5 t/ha FYM + (10 kg N + 10 kg P_2O_5)/ha	3,370	2,450	+38
	Mean	2743	1,990	+38
Kauwi (AEZ-5) Kitui	5 t/ha FYM	50	25	+100
	5 t/ha FYM	350	167	+109
	Mean	200	96	+108

Source Kathuli et al. (2010)

Plate 11.5 Napier planted in conventionally cultivated field and in tumbukiza planting pits at Katumani Machakos

Table 11.7 Sorghum and cowpea grain yields from a runoff harvesting trial at katiorin (1981) with different tillage treatments

Treatments	Sorghum(kg/ha)		kg/ha
Treatments	First harvest	Ratoon harvest	Cowpea
Impounded plot, deep tillage	420	595	70
Impounded plot, zero tillage	120	–	–
3 m contour ridges hoop, zero tillage	410	900	130
Control plot deep tillage	60	325	20

Source Imbira (1989)

Deep Tillage

Once soils are deep ploughed, rain water infiltration is increased. Rain water storage by the soil is also increased and yield can increase 3 times in comparison to land tilled conventionally (Imbira 1989). Field data on effect of deep tillage on sorghum grain yield from dry land Katiorin during the 1981 long and short rains are shown in Table 11.7.

Deep tillage increased sorghum yield by 3.5 times when compared to a farm with same management and less deep tillage. Both plots had rainwater harvesting with one plot being deep-tilled.

Micro-catchments

This involves capturing runoff from upper part and collecting it in adjacent lower part of the farm. The soil in the lower farm is cultivated to increase water infiltration. The ratio of the catchment to cultivated area usually varies from 1:1 to 5:1 depending on the rainfall regime, soil properties and crop water requirements. Yield increase of 30–90 % has been obtained using this technology in the semi-arid Baringo sub-county on a sorghum crop (Imbira 1989) (Table 11.8).

Table 11.8 Yield of sorghum from trial plots using on-farm external catchment systems during the 1982–1983 long rains

Plot	Year	Catchment: cultivated area ratio	Experimental plot yield (kg/ha)	Control plot yield (kg/ha)	Percentage of yield increase (%)
Katiori	1982	2:1	775	135	474
Marigat	1983	1:1	540	10	5,300

Source Imbira (1989)

Discussion

The technologies reviewed here allow rain water retention for a prolonged duration on the soil surface for increased infiltration and retention and better rain water use efficiency (Steiner and Rockstrom 2003; Itabari 1999). In absence of these technologies, the farms would be losing about 70 % of rainwater to runoff and leaving only 25–30 % for crop or fodder production (Kilewe 1987).

Fanya juu terraces are constructed on land with slope ranging from 2–22 % (Itabari et al. 2011). These structures form a runoff barrier which collects runoff rainwater and eroded soil. The water collected spreads back in the terrace and is retained for a longer time allowing infiltration and raising soil moisture for fodder and crop production. The effects of fanya juu terrace (Plate 11.1) indicates that, the trapped rain water would have been lost in the absence of these structures thus limiting crop productivity. The in situ conserved rain water will increase crop and fodder productivity in ASALs where water is the most limiting crop and fodder production constraint (Itabari et al. 2011). However, these structure require periodic maintenance to increase the embankment height as more soil is removed from upper side of the terrace and deposited in the lower side to form a bench terrace. There are reports of increased crop productivity in those farms where terraces are periodically maintained (Itabari et al. 2011).

The contour bunds embankments trap rain water flowing down the slope and retain it behind the bunds. The area behind the bunds can be levelled to ensure homogeneous infiltration. This technology concentrates rain water in a smaller area for cultivation of early maturing crops. The technology has led to a satisfactory sorghum crop with rainfall of 270 mm using a catchment to cultivated area ratio of 2:1. However adoption of this technology is not wide spread (Itabari and Wamuongo 2003) due to land scarcity.

Semi-circular bunds (hoops) are common is ASALs of Turkana and Baringo counties. The bunds are used to capture rainwater that would be lost as runoff in the absence of these structures due to land topography. The rainwater is retained in the structures allowing longer infiltration time. They are used to rehabilitate degraded lands (Kitheka et al. 1995) in ASALs of Kenya. Restoration of productivity is achieved within three seasons. The bunds are used for the reseeding of grass, fodder, shrubs and can be used to grow early maturing crops like cowpea and green grams (Plate 11.2). Adoption of the technique has been hampered by labour involved in construction of the structures.

Negarims are suitable in establishment of trees or tree crops (Itabari et al. 2011). Under very low rainfall, the runoff is concentrated into a planting pit thus increasing soil moisture for tree crop establishment and growth (Kathuli and Mweki 2012). These structures improve fruit tree establishment by 60 % leading to increased yields and farm income. The structures are recommended in areas with 300–700 mm annual rainfall and with 1–5 % slope (Critchley et al. 1991).

The effect of tied-ridging with and without fertilizer use on sorghum grain yield and water use efficiency in semi-arid lands of Masinga in eastern Kenya during the 1995 short and long rains (Table 11.3) shows that, tied-ridging plus fertilizer significantly ($p = 0.05$) increased sorghum grain yield in both seasons. Rain water use efficiency was similarly enhanced by combination of tied-ridging and fertilizer use. Evapotranspiration (ET) remained fairly constant within the seasons. Tied-ridging has been shown to increase total dry matter of maize by less than 1 % in very poor seasons (Table 11.2) (Kathuli et al. 2010) while in good rainfall seasons, sorghum yields increased by 3–5 % across short rains and long rains (Table 11.3) (Imbira 1989) and maize yields increased by 63–340 % due to tied ridging with integrated soil fertility management (Gichangi et al. 2007). Tied ridging allows rain water to be conserved in situ as it infiltrates the soil. The prolonged time it is retained on furrows allows increased infiltration and hence increased soil water which is used by crops. The water use efficiency by crops is increased with addition of manures and fertilizers (Tables 11.1, 11.3 and 11.4).

Similarly, *Zai* pitting significantly ($p \leq 0.05$) increased sorghum grain yields and improved sorghum water use efficiency in Masinga, Machakos County during the 1995 short rains. Sorghum yields increased 4 times with fertilizer and 2 times without fertilizer use on *Zai* pits. *Zai* pitting without fertilizer application significantly ($p = 0.05$) increased sorghum grain yields by 10 times over the plot without *Zai* pitting and with no fertilizer during the same period (Tables 11.3 and 11.4). This is attributed to limited rainfall with same fertilizer during the short rains. *Zai* pits can increase crop yields by a bigger margin with soil fertility improvement. This is because rainwater is concentrated into a smaller area increasing soil water per unit soil volume thus providing adequate soil moisture that favor crop growth and yield increase.

Sub-soiling and ripping can increase crop yields in semi-arid eastern Kenya (AEZ 4 and 5). A yield increase of 117 % of maize total dry matter from 98 to 213 kg/ha in conventional and subsoiled/ripped tillage treatments respectively was recorded in short rains 2007 while 29 % yield increase from 355 to 457 kg/ha of total maize dry matter was recorded in long rains 2009. Use of this technology with integrated soil fertility improvement increased maize grain yield from a mean of 84–108 % because of soil moisture retention and conservation. Fertilizer nutrients applied become available over longer duration of crop growth due to availability of minimum soil water which is required for crop nutrient uptake either by mass flow or diffusion (Tisdale et al. 1985).

The constraints arising from this technology are excess covering of planted seeds with soil. Seeds should be covered lightly depending on size. The cost of sub-soiler and ripper are also prohibitive but this has been solved with a modified mould board plough which is fitted with a shear modification and mould board modification for in situ hardpan breaking and making planting furrow similar to what is made by the subsoiler and ripper. The cost of modification is about US$7.5 and can be fabricated by farmers using locally available materials.

Planting pits (Tumbukiza) resulted in increased maize yields in Mwala district and Mukuyuni division in Machakos district (KASAL) project (2007–2011). A farmer reported a yield of 4–90 kg bags of maize from pits made in 0.25 acres of land in Mukuyuni while another one reported yield of 4 bags of 90 kg maize from 0.25 acres due to pitting in Makutano community association in Katangi Machakos County. Similar observations were made in KASAL project in Mwala district-Mbiuni division, KwaLumbu Village. In the short rains of 2009, a high yielding maize crop was observed planted in planting pits in Kako division of Makueni District. It seemed, pitting increased the yield of the crop as the soils were of low fertility and highly eroded over time. Tumbukiza concentrates rainwater in a smaller area thus raising soil water content per unit volume of soil. This raises the water level in the soil which favors crop nutrient uptake (Tisdale et al. 1985), growth and eventually increased yields. Overall *tumbukiza* can increase crop yields due to rainwater harvesting and conservation.

Deep tillage assists the soil to conserve water for crop growth. Deep tillage increases soil porosity and air spaces which are filled with rain water raising the soil water holding capacity (Hillel 1980). The soil that is not deep tilled would not exhibit such level of porosity and air spaces for rain water holding and hence the difference in sorghum and cowpea yield performance from dry land Katiorin planted during the 1981 short and long rains in those two contrasting managed soils (Table 11.7). This technology is recommended to farmers for increased crop production.

Micro-catchments (runoff-run on) technique involves spreading runoff from part of land on to an adjacent cultivated land without using any structures. The soil in the cultivated area is loosened to increase infiltration. The ratio of the catchment to cultivated area usually varies from 1:1 to 5:1 depending on the rainfall regime, soil properties and crop water requirement. Gibberd (1995), working in semi-arid Eastern Kenya, reported that runoff harvesting using a catchment to cultivated area ratio (C: CA) of 1:1 increased yields of most dry land crops by 30–90 %. Itabari et al. (2004), working with green grams in the same region, reported that a C: CA of 1:2 increased net benefits by 17 % where no furrows were made in the cropped area and by 40 % where connected furrows were made in the cropped area during the long rains of 2002, which had a total of 310 mm of poorly distributed rainfall. The technique has also been shown to substantially increase crop yields in Kitui District (Critchley 1989) and in Baringo County (Table 11.8), where its effectiveness was shown to increase with increasing catchment to cultivated area ratio. In another runoff-run on study in Baringo County, Kinyali et al. (2000) reported that runoff harvesting increased soil water regime by 66 % and the subsequent yield from the runoff treatment was 19 bags per acre whereas the rainfed treatment produced no yield. Manure in combination with semi-circular bunds water harvesting technology resulted in increased grass biomass yields (0.5–3 t/ha) and better ground cover (Munyao et al. 2011). The yields obtained through use of this technology are very high (400 %) yield increase from catchment to cultivated area ratio of 1:1–2:1 (Table 11.8). It is advisable for small scale farmers to use this technology. This technology would however be constrained by lack of land for capturing the rain water. Land next to homestead always has a good crop due to runoff harvesting from the homestead.

Conclusions and Recommendations

There are many technologies for in situ rain water harvesting and their impact is enhanced by combining these technologies with integrated soil fertility improvement. The in situ rainwater harvesting technologies have potential to increase crops and fodder production and it is recommended that, farmers and scientists should be encouraged to test these technologies for wider verification and adoption.

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