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Rainwater Harvesting Technologies for Small Scale Rainfed Agriculture in Arid and Semi-arid Areas

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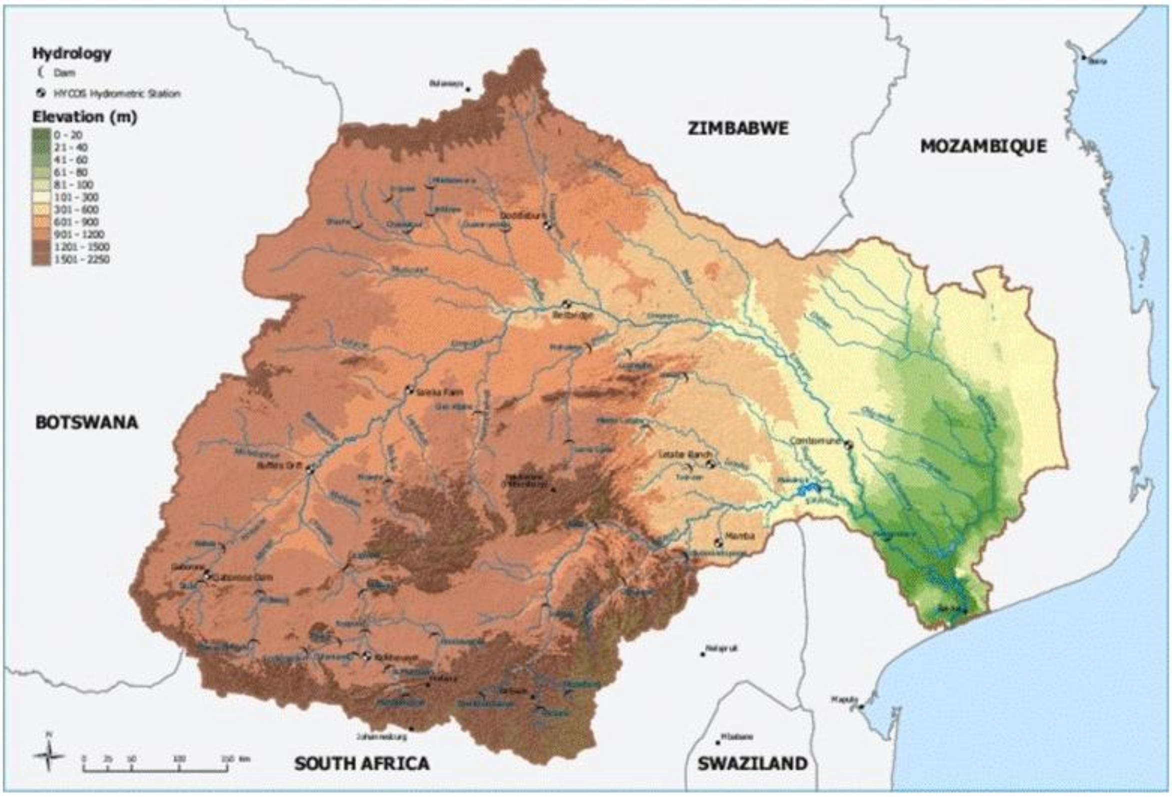

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CONTENTS

1. INTRODUCTION

The best land for agricultural production has been reducing by the time, due to high agricultural expansion. The population density is growing up, as a consequence the demand for land resources such as food, fuel and shelter has been increasing. There is a need for exploitation of land which is less suitable for agriculture, or land in less favorable climates. Arid and Semi-arid regions can be explored as a way of minimizing the land scarcity (Hudson, 1987).

Arid and Semi-arid zones are characterized by low erratic rainfall of up to 700 mm per annum, periodic droughts and different associations of vegetative cover and soils. Interannual rainfall varies from 50-100 % in the arid zones of the world with averages of up to 350 mm. In the Semi-arid zones interannual rainfall varies from 20-50 % with averages of up to 700 mm (CASL, 2006).

The majority of the population in the Arid and Semi-arid areas depend on agriculture and pastoralism for subsistence. These activities face many constraints due to predominance of erratic rainfall patterns, torrential rainfall which is majority lost to run-off, high rate of evapotranspiration further reducing yields, weeds growing more vigorously than cultivated crops and competing for scarce reserves of moisture, low organic matter levels and high variables responses to fertilizers (CASL, 2006).

There is a need of a more efficient capture and use of the scarce water resources in Arid and Semi-arid areas. An optimization of the rainfall management, through water harvesting in sustainable and integrated production systems can contribute for improving the small-scale farmers' livelihood by upgrading the rainfed agriculture production.

This paper is a review of simple and chip water harvesting techniques, which have been tested and found useful somewhere, and which might be suitable for use in other conditions. The paper also tries to show some successful cases of application of water harvesting techniques in African countries, which have increased the overall productivity of smallholder farm and hence improved farmers' livelihood.

2. RAINWATER HARVESTING

2.1 GENERAL APPROACH

Rainwater harvesting is broadly defined as the collection and concentration of runoff for productive purposes such as crop, fodder, pasture or trees production, livestock and domestic water supply in arid and semi-arid regions (Fentaw et al., 2002; Gould, 1999; Stott, 2001). For agriculture purposes, it is defined as a method for inducing, collecting, storing and conserving local surface runoff in arid and semi-arid regions (Prienz & Singh, 2001). It is an ancient practice and still forms an integral part of many farming systems worldwide. The first use of such techniques is believed to have originated in Iraq over 5000 years ago, in the Fertile Crescent, where agriculture once started some 8000BC (Hardan, 1975).

Rain water harvesting systems have the following characteristics: it is practiced in Arid and Semi-arid regions, where surface runoff often has an intermittent character; it is based on the utilization of runoff and requires a runoff producing area and a runoff receiving area; because of the intermittent nature of runoff events, water storage is an integral part of the system and it can be done directly in the soil profile or in small reservoirs, tanks and aquifers (Oweis et al., 1999).

The aim of the rainwater harvesting is to mitigate the effects of temporal shortages of rain to cover both household needs as well as for productive use. It has been used to improve access to water and sanitation, improve agricultural production and health care thus contributing to poverty alleviation, reverse environmental degradation through reforestation and improved agriculture practice, aid groundwater recharge, empower women in the management of water and other natural resources and address floods and droughts by storing excess water (Oweis, 1999; TWDB, 2006).

In crop production systems, rainwater harvesting is composed of a runoff producing area normally called catchment area and a runoff utilization area usually called cropped basin. The major categories are classified according to the distance between catchment area and cropped basin as follow: In-situ rainwater harvesting, Internal (Micro) catchment rainwater harvesting and External (Macro) catchment rainwater harvesting (Hatibu, N. & Mahoo, H., 1999).

According to Critchley & Siegert (1991), the physical, Chemical and biological proprieties of the soil affect the yield response of plants to rainwater harvested. In general the following are the most suitable soil characteristics: (1) medium textured soils - the loams, since these are ideally appropriated for plant growth in terms of nutrient supply, biological activity and nutrient and water holding capacities; (2) soils with a relatively high content of organic matter - where this content is low, the application of crop residues and animal manure is helpful in improving the structure; (3) deep soils, which have more than one meter deep, due to their capacity to store the harvested runoff as well as providing a greater amount of total nutrients for plant growth; (4) soils with macro and micro nutrients levels increased - where it is impossible to avoid poor soils, attention should be given to the maintenance of nitrogen and phosphorus, once they are usually the elements most deficient in these soils; (5) soils which are neither sodic nor saline because high percentages of sodium and salt can reduce moisture availability; (6) a moderate infiltration rate, which can be desirable for producing high runoff in the catchment area and at the same time allowing adequate moisture to the crop root zone without causing waterlogging problems; (6) soils with available water capacity between 100-200 mm/meter.

Rainfall characteristics, such as frequency, duration and intensity are more relevant for better results of water harvesting technologies than the total amount of rainfall. Especially in semi (arid) zones the variability of rainfall or the inter and intra-annual variation is very high. Minimum requirements for the frequency distribution of showers are very difficult to establish and depend also strongly on other factors such as the length of the dry spells between showers. Of critical importance to water harvesting are the duration and intensity of rainfall because runoff only occurs when certain thresholds are exceeded. Either the rainfall intensity should exceed the infiltration rate, or the rainfall intensity and duration should exceed the storage capacity of the soil. The threshold amount of rainfall required to generate runoff on slopes in arid zones is rather low, for example 3-5 mm on stony soils in the Negev. On the shallow medium textured soils of the Johdpur (India) the threshold is 3-5 mm on wet soils and 7-9 mm on dry soils (Reij et al., 1988).

Vegetation strongly influences the water harvesting systems on the infiltration, crusting, runoff and erosion processes. By interception and evaporation the vegetation reduces the amount of rainfall reaching the ground. On the other hand, its presence breaks the impact of raindrop, which reduces soil erosion to about one percent of its value on bare soil and minimizes the crusting formation. Straw mulch, roots, litter and other crop residues reduce the velocity of runoff; as a consequence there is a large difference in terms of infiltration rates between bared soils and soils covered with any type of vegetation. Infiltration rates bellow grass tuffs appeared to be 5-10 times higher than between tuffs in open grassland (Reij et al., 1988).

Other important requirements to be considered in the implementation of water harvesting systems for crop production are the slope of the area and operation costs. Such techniques are not recommended for areas where slopes are greater than 5 %, due to uneven distribution of runoff and large quantities of earthwork required which is not economical (Critchley & Siegert, 1991). Labor cost for construction and maintenance of water harvesting systems is the most important factor to be considered, which determines if a technique will be widely adopted at the individual farm level. Many farmers in arid and semi-arid areas do not have the manpower available to move large amounts of earth that is necessary in some of the large water harvesting systems (Rosegrant et al., 2002).

This paper will only focus on the In-situ rainwater harvesting and Internal (Micro) catchment rainwater harvesting, due to their relative simplicity and low implementation costs. External (Macro) catchment rainwater harvesting involves the collection of runoff from large areas, which are at an appreciable distance from where it is being used, and thus requires a high labor investment for its implementation.

2.2 IN-SITU RAINWATER HARVESTING

2.2.1 Introduction

In-situ rain water harvesting, also called soil and water conservation, involves the use of methods that increase the amount of water stored in the soil profile by trapping or holding the rain where it falls (Hatibu & Mahoo, 1999; Stott et al., 2001). In this application there is no separation between the collection area and the storage area, the water is collected and stored where it is going to be utilized (UNEP, 1997).

In-situ rainwater harvesting involves small movements of rainwater as surface runoff, in order to concentrate the water where it is wanted most. It is basically a prevention of net runoff from a given cropped area by holding rain water and prolonging the time for infiltration. This system works better where the soil water holding capacity is large enough and the rainfall is equal or more than the crop water requirement, but moisture amount in the soil is restricted by the amount of infiltration and or deep percolation (Hatibu & Mahoo, 1999).

In-situ rainwater harvesting has been extensively used in north-eastern Brazil, in the Chaco region of Paraguay and in Argentina. It can be used to augment the water supply for crops, livestock, and domestic use. Its practice is recommended for low topography areas, with small and variable volume of rainfall. The technology has the following advantages: minimal additional labor, flexibility of implementation, rainwater harvesting is compatible with agricultural best management practices, additional flexibility in soil utilization and as a way of recharging groundwater aquifers artificially. Slope of the land less than 5 %, impermeable soils and low topographic relief are the main requirements for its better performance (UNEP, 1997).

The in-situ rainwater harvesting for crop production purposes is better achieved by the following means: conservation tillage, conservation farming and conventional tillage. Where these biological soil conservation measures cannot be done to full effect, particularly in areas of high intensity storms, or where there are periods of poor crop cover, earth works (physical control measures) can provide surface protection by holding water to give it time to soak through the surface. Such physical conservation measures involve land shaping, the construction of contour bunds, terraces and ridges (FAO, 1993).

2.2.2 Conservation tillage

According to the Conservation Technology Information Center in West Lafayette, Indiana, USA, conservation tillage is defined as any tillage or planting system in which at least 30 % of the soil surface is covered by plant residue after planting to reduce water and wind erosion (FAO, 1993; Evans et al., 2000; Carthy, 2001; Veenstra et al., 2006; Nyagumbo, 1999). Crosson (1981), considers conservation tillage as a practice which includes tillage systems that create as an environment as possible for the growing crop and that optimize conservation of soil and water resources. This involves maximum or optimum retention of residues on the soil surface and the utilization of herbicides to control weeds where tillage is not or cannot be performed. Conservation tillage takes into account both environmental and tillage factors. Environmental factors include slop, vegetation, soil type, rain pattern and intended crops. Tillage factors involve type of implements, timing of operations, depth of the tillage and soil condition (Bwalya, 1999).

There are five types of conservation tillage systems: no-tillage, mulch tillage, strip or zonal tillage, ridge till and reduced tillage (FAO, 1993). The common element in these systems is the presence of crop residue on the soil surface to reduce water and wind erosion. The amount of crop residue may vary widely, but it must be enough to reduce erosion significantly in comparison with tillage systems that bury or remove the residue. The other particularity of conservation tillage systems is that it relies more on herbicides and less on cultivation for weed control, in order to reduce the disturbance or inversion of the soil (Crosson, 1981). This practice also involves ripping the land with tinned implements or sub-soiling the land immediately after crops is harvested, to break the plough pans (Mati, 2005).

No-tillage system

The no-tillage system is specialized type of conservation tillage consisting of a one-pass planting and fertilizer operation in which the soil and the surface residues are minimally disturbed, as shown in the figure 1 (FAO, 1993). OISAT (2005) describes the technique as a system where the soil is not disturbed between harvesting one crop and planting the next. It is a crop production where the soil is not traditional tilled or cultivated though sticks or other planting equipments are used to make the opening for seeds. This is the most effective conservation practice for reducing soil erosion and improving water quality. The crop residue cover and infiltration rates associated with no-tillage maximize the volume reduction of agricultural runoff and contaminants (Evans et al., 2000). Weed control is generally achieved with herbicides such as glyphosate or gramoxylin or in some cases with crop rotation (Peet, 2001). The system eliminates all mechanical seedbed preparation, except for the opening of a narrow (2-3 cm wide) strip or small hole in the ground for seed placement to ensure adequate seed/soil contact (FAO, 1993).

Fig. 1: Maize production by implementing no-till system (Satorre, 2006)

Mulch tillage system

Mulch tillage system, also called stubble mulch farming, is based on the principle of causing least soil disturbance and leaving the maximum of crop residue on the soil surface (30 % or more) and at the same time obtaining a quick seed germination (FAO, 1993; OISAT, 2005). The soil is prepared in such a way that plant residues or other mulching materials are specially left on or near the surface of the farm (OISAT, 2005). A chisel plough can be used in the previously shredded crop residue to break open any hard crust or hard pan in the soil; care should be taken not to incorporate any crop residues into the soil. In situ mulch, formed from the residue of a dead or chemically killed cover crop left in place of concern, can be used as surface covering. The beneficial effects of mulching include protection of the soil against raindrop impact, decrease in flow velocity by imparting roughness, and improved infiltration capacity. The quantity of mulch required for maintenance of favorable infiltration capacity and structural stability depends on the rate of residue decomposition, climate, soil proprieties, relief and rainfall characteristics. Studies relating soil loss to bare ground indicate that about 70% of the soil surface must be covered by mulch to be effective (FAO, 1993).

Strip tillage system

In the strip or zonal tillage system, the seedbed is divided into a seedling zone and a soil management zone. The seedling zone (5-10 cm wide) is mechanically tilled to optimize the soil and microclimate environment for germination and seedling establishment. The inter-row zone is left undisturbed and protected by mulch. Strip tillage can also be achieved by chiseling in the row zone to assist water infiltration and root proliferation (FAO, 1993).

Ridge till system

In the ridge till system, the soil is left undisturbed prior to planting but about one-third of the soil surface is tilled at planting with sweeps or row cleaners; planting of row crops is done on performed cultivated ridges, while weeds are controlled by herbicides (FAO, 1993).

No till tied ridging is a variation of ridge till system, with cross-ties along the furrows on the semi-permanent ridges, to trap runoff. The ridges are laid across the main slope at a grade of 0.4-1%. Normally once constructed, the ridges are not destroyed for a period of six seasons depending on the crop rotations practiced by the farmer. Planting is done on top of the ridges. In subsequent season, land preparation simply involves planting on top of the ridges. For good emergence, planting is recommended only when the ridges are fully moist. In drier areas, planting also may carry out in the furrows where most of the runoff water collects (Nyagumbo, 1997; Mati, 2005).

The effectiveness of tied ridges depends on soil, slope, rainfall and design characteristics; on clay soils it can induce waterlogging, which may be followed by mass movement; in severe storms, poorly designed ridge-furrow systems may fail, the row catchments can over-top and the water flow unimpeded down the slope causing soil loss (FAO, 1993).

Ngolo pit is another variation of ridge till system. This is characterized by a combination of soil conservation techniques of pits and ridges at most 20-30 cm wide and 10-20 cm high, on slops about 35-60 % steepness. The size of the ridge affects the density of the plant population and the water holding capacity of the pit. A major feature of the system is that the fields contain a large number of pits. It is usually done in a two-crop-rotation system in which beans are planted in the late rainy season of the first year and maize in the following year (Mati, 2005).

Growing a crop on or between ridges has the following advantages and disadvantages: on lightly sloping land, ridges along the contour can curb rainwater runoff and thus erosion by increasing the surface relief; however, tillage along the contour lines is complicated, especially if a particular field has slopes in more than one direction, it can easily lead to increased erosion; in high rainfall areas and poorly drained soils, ridges allow a better water management; on the other hand, ridges often dry faster and will take longer to wet after a dry spell, and germination of a crop planted on ridges is quite often observed to be slower than a crop planted on flat land; by ridging, any organic matter or fertilizer which is present at or near the soil surface, will be concentrated in the ridge and will thus be of greater benefit to the crops (Meijer, 1992).

Reduced tillage

Reduced tillage is any farming practice which involves less cultivation than used in conventional fallowing (LWC, 1978). The aim of this system is to minimize soil disturbance, while at the same time achieving a viable seedbed for crop growth. As with no-tillage systems, weeds and diseases are usually controlled with herbicides and grazing. Crop residues are usually burnt and or incorporated into the soil (Valzano et al., 2005; Steiner, 2002).

There are three different types of reducing tillage: reduced cultivation, direct drilling and minimum tillage. Reduced cultivation involve grazing of crop stubble and weed growth after harvest followed by seedbed preparation which includes only one cultivation followed by an application of a contact herbicide before or after sowing. Direct drilling involves no cultivation prior to sowing directly into undisturbed soil; stubbles from the previous crop and subsequent weed growth are removed by grazing during the fallow and the stubble remaining is usually burnt after the seasonal break of rain; the fallow is sprayed with a contact herbicide prior to sowing. Minimum tillage involves the retention of stubble and most of the weeds are controlled with herbicides during the fallow and one mechanical cultivation (LWC, 1978).

In general, the following resources are required to the implementation of conservation tillage systems: labor, machinery and equipment, fuel, fertilizers, pesticides and management. Few amount of labor per hectare is needed with this practice, the application of chemicals for weed, insect or disease control reduces the number of passes over the field. The direct planting into untilled soil requires low power machineries, and thus reduced amount of fuel. Nitrogen is the most deficient element in the soil because the cool and moist soils with conservation tillage slow its mineralization and promote denitrification. Increased amount of pesticides is required to control weeds, especially with no-tillage systems. Management skills are needed to correct previous mistakes in plowing and planting as well as in the seed placement, to know the proprieties of a wider variety of pesticides and of how to apply them to get adequate pest control, or of crop rotation sequences and disease and insect –resistant varieties as substitutes of pesticides (Crosson, 1981).

Conservation tillage systems have the following advantages: conserves water by reducing water evaporation with mulch covering, reduces erosion because the topsoil is protected, reduces soil compaction, protects impact from rain and wind, improves the soil condition with the increased organic matter content, natural enemies have places to stay and lessens the overall production cost (Steiner, 2002). However, there are also disadvantages: it needs an understanding of the concept and requires careful farm management practices to be successful, most soil pest population are increased, weeds compete with the main crops, high tendency of the insect pests and diseases from the crop residues, organic matter are not evenly distributed or are concentrated at the topsoil and improvement on the soil condition takes a long time to be achieved (OISAT, 2005).

When adopting conservation tillage systems, a farmer must have a carefully planned weed control strategy, especially in the early years when weed levels will be high, as they are not longer controlled by primary tillage. A number of weed control methods are available for smallholder farmers under conservation tillage systems. The choice of each depends on the ecological and socio-economic circumstances of specific farm household: green manures or cover crops and crop residues, crop rotations, plant density, in-row slashing of weeds, superficial weeding (hoeing, ridging) by hand, drought animals or tractors, pulling out, and or slashing even at crop maturity and post harvest to prevent seed production, herbicide application and increased rates of nitrogen (Steiner & Twomlow, 2003).

2.2.3 Conservation farming

Conservation farming includes any farming practice which improves yield, or reliability, or decreases the inputs of labor or fertilizer (Hudson, 1987). This concept embraces everything as practiced in conservation tillage and goes further to include all socio-cultural and traditional practices and decisions related to sustained chemical and physical fertility of the soil (Bwalya, 1999). For Sheng et al. (1991), it is a type of farming system that reduces soil erosion and maintains or improves land productivity at the same time for the purpose of benefiting farmers' and nations' soil and water resources. Some of these practices, such as strip cropping, contour farming, terrace farming and farming on a rade (these last two are very expensive techniques in terms of construction and maintenance, and thus unfeasible to the subsistence farming), contribute for reducing runoff by controlling water movement over the surface. The principle is to minimize the concentration of runoff volume and to slow down the runoff velocity, allowing the water more time to soak into the soil, limiting its capacity to transport soil particles and diminishing its ability to cause scour erosion (FAO, 1993). Other practices, like cover crops, alley cropping, no-tillage farming, reduce runoff through improved infiltration capacity and soil transmission characteristics. Crop rotations, mixed cropping and inter-planting contribute for improving soil fertility (Hudson, 1987).

Strip cropping

Strip cropping consists on farming of sloping land in alternate contoured strips or inter-tilled row crops and close-growing crops (for example a cover crop or grass) aligned at right angles to the direction of natural flow of runoff (see figure 2). The close-growing strip slows down runoff and filters out soil washed from the land in the inter-tilled crop. Usually, the close-growing and inter-tilled crops are planted in rotation (FAO, 1993).

Strip cropping provides effective erosion control against runoff on well-drained erodible soils on 6 to 15 % slopes). However, the system leaves grass strips which can harbor pests and vermin that can destroy crops if not managed correctly. Maintenance of the grass strips during winter can be a problem, especially if the grasses are not hardy. Also, a poor choice of strip crop can led to use of a crop that competes with the main crop (UNEP, 1997). The strips width is varied with the erodibility of the soil, and slope steepness. Its implementation is most useful on gentle slopes, where it may reduce erosion to acceptable levels without any banks or drains (Hudson, 1987).

Fig. 2: Strip cropping in Mpumalanga province, South Africa

Contour farming

Contour farming involves aligning plants rows and tillage lines at right angles to normal flow of runoff. It creates detention storage in the soil surface horizon and slows down the runoff, thus giving the water time to infiltrate into the soil (FAO, 1993). This is important where cultivation is done on slopes ranging from 3% to 8% (UNEP, 1997). All farm husbandry practices such as tilling and weeding are done along the contours so as to form cross-slope barrier to the flow of water. Where this is not enough it is complemented with ridges which are sometimes tied to create a high degree of surface roughness to enhance the infiltration of water into the soil (Hatibu & Mahoo, 1999). The implementation of the system results in less benefit to compacted or poorly permeable soils because these soils become saturated quickly. Also, special skills may be required to construct effective contour lay outs (UNEP, 1997).

Cover crops

Planted cover crops or green manures such as *Mucuna pruriens utilis, Pueraria phaseoloides, Centrosema pubescens, Setaria spp., Stylosanthes spp.* and *Glicine spp.*, provide another technique of achieving in-situ mulch (see figure 3). The technique has the advantages of conserving soil water, to improve water use efficiency, to control weeds and to increase soil organic matter (FAO, 1993). Perennial grasses like *Imperata cylindrical*, *Cynodon dactylon* or other problem weeds such as *Striga spp*. or *Chromolaena odorata* can be suppressed by one or two seasons of cover crops (Steiner & Towmlow, 2003).The effectiveness of cover crops in soil and water conservation depends on species characteristics including simplicity and rapidity of establishment of surface cover, vigor of growth, depth of rooting and so on (FAO, 1993).

Fig. 3: A solid ground cover of crop residues and cover crops prevents weed growth and seed production after harvest during the dry season (Steiner & Towmlow, 2003).

Alley cropping

Alley cropping is an agro-forest system integrating trees and shrubs with annual food crop production. In this system, arable crops are grown in the spaces between rows of planted wood shrubs or trees, which are pruned during the cropping season to provide in-situ green manure and to prevent shading of crops. The beneficial effects of the system in reducing erosion, surface runoff and soil moisture loss depend on the proper choice of the protective species. Promising results of maize production with *Gliricidia* and *Leucaena* have been obtained (FAO, 1993).

No-tillage farming

No-tillage farming, also Known as zero-tillage, chemical tillage, direct seeding, direct planting, direct drilling, no-plow-tillage, no-till or sod planting, consists on planting crops in previously unprepared soil by opening a narrow slot, trench, or band only of sufficient width and depth to obtain proper seed coverage. No other soil preparation is done. Cultivation is made unnecessary by using herbicides to control unwanted weeds and grasses, allowing chemical energy to substitute for much of a farmers’ tractor power (Philips & Young, 1973).

The benefits of the no-till farming system include soil moisture conservation due to reduction in storm runoff, improved infiltration capacity, enhanced earthworm activity, reduced evaporation loss, reduced soil erosion, and increased organic matter content. Its effectiveness is improved when used in association with planted cover crops. The system is less effective on hydromorphic soils with poor internal drainage, soils with compact surface and subsoils. Increasing costs of herbicides can limit its use continuously, being necessary to make mechanical cultivation (FAO, 1993).

Crop rotations

Crop rotations are another well established and simple practice. The object may be to improve fertility by the use of legumes or to help control pest or disease (Hudson, 1987). A suitable crop rotation combines cereals and legumes (Steiner, 2002).

Mixed cropping and inter-planting

Mixed cropping and inter-planting is a technology that involves a combination of crops with different planting times and different length of growth periods, which spreads the labor requirement of planting and of harvesting (Hudson, 1987). The use of legumes in this system contributes for improving the nitrogen status for the cereal crops. Other advantages include maximization of soil fertility, minimization of erosion and weeds labor and reduction of the crop loss risk (FAO, 1993). Inter-planting, preferentially spreading types of crops, legumes, pumpkins or sweet potatoes as shown in the figure 4, contribute to a faster and denser ground cover and suppresses weed growth at least during the growing season (Steiner & Towmlow, 2003).

Fig. 4: Inter-planting with spreading types like pumpkins and creeping cowpeas (Steiner & Towmlow, 2003).

2.2.4 Conventional tillage

In conventional tillage, plowing and several diskings are used to prepare soils for planting. In addition, harrowing and dragging are sometimes performed during or after plowing (Young, 1982; OISAT, 2005).

According to IFOAM (2001), there are different cultivation practices, depending on the aim of the soil cultivation and they are implemented during different stages of the cropping cycle:

Post-harvest soil cultivation is done to incorporate the residues of the previous crops into the soil before preparing the seedbed for the next crop, with the objective of accelerating its decomposition. Crop residues, green manure crops and farmyard manure should be worked only into the top soil layer (15 to 20 cm), as decomposition in deeper soil layer is incomplete; they can produce substances which can harm the next crop;

Primary tillage is usually implemented for annual crops or new plantations, using a plough or similar instrument; as a principle, soil cultivation should achieve a flat turning of the top soil and a loosening of the medium deep soil, otherwise it will mix the soil layers harming soil organisms and disturbing the natural structure of the soil;

Secondary soil cultivation is done to crush and to smooth the ploughed surface, before sowing or planting with the purpose of preparing a good seedbed. If weed pressure is high, seedbeds can be prepared early thus allowing weed seeds to germinate before the crop is sown for being eliminated after some days with shallow soil cultivation. Where water logging is a problem, seedbeds can be established as mounds or ridges;

Shallow soil cultivation in between the crop is done to suppress weeds, to enhance the aeration of the soil, to reduce the evaporation of the soil moisture from the deeper soil layers and to stimulate the decomposition of organic matter, thus making nutrients available;

Deep tillage is normally implemented to increase the soil moisture holding capacity through increased porosity, to enhance infiltration rates and to reduce the surface runoff by providing surface micro-relief or roughness. It also allows roots proliferation to exploit soil water and nutrients at deep horizons.

The conventional tillage operations are expensive and require high farm labor supply (OISAT, 2005). Most tilled soil is left susceptible to water runoff along with wind and water erosion. The soil compaction is sometimes greatly increased, especially if the soils are cultivated in wet conditions or burdened with heavy machinery, which results in suppressed root growth, reduced aeration and water logging (Young, 1982; Mati, 2005). Where soil compaction is a problem, farmers should be aware of the following aspects: the risk of soil compaction is highest when the soil structure is disturbed in wet conditions, do not drive vehicles on the land soon after rains, soils rich in sand are less prone to soil compaction than soils rich in clay, high content of soil organic matter reduce the risk of soil compaction, it is very difficult to restore soil structure once soil compaction took place, deep tillage in dry conditions and the cultivation of deep rooted plants can help to repair soil compaction (IFOAM, 2001).

2.3 MICROCATCHMENT RAINWATER HARVESTING

2.3.1 General design principles

Microcatchment rainwater harvesting systems has the following characteristics: overland flow harvested from short catchment length, catchment length usually between 1 and 30 cm, runoff stored in soil profile, ratio catchment : cultivated area usually from 1:1 to 3:1, normally no provision for overflow and even plant growth. These are the typical examples of this type of system: Negariam microcacthments, contour bunds and semi-circular bunds (Critchley & Siegert, 1991).

The general design principle of Microcatchment rainwater harvesting systems involves a catchment area, which collects runoff coming from roofs or ground surfaces and a cultivated area, which receives and concentrates runoff from the catchment area for crop water supply. The relationship between the catchment area and the cultivated area, in terms of size, determines by what factor the rainfall will be multiplied. For a more efficient and effective system, it is necessary to calculate the ratio between the two if the data related to the area of concern in terms of rainfall, runoff and crop water requirements is available (Moges, 2004).

According to the Critchley & Siegert (1991) and Moges (2004), the calculation of the ratio between the catchment area and the cultivated area is given by equation 1:

$$\frac{catchment\,area}{cultivated\,area} = \frac{crop\,water\,requiremnt * design\,rainfall}{design\,rainfall * runoff\,coefficient * efficiency\,factor} \qquad (1)$$

The calculation of crop water requirements reads as follow on the equation 2:

$$ET_{Crop} = kc * ET_0 \qquad (2)$$

Where: *ETcrop* is the water requirement for a given crop in mm per unit of time. *kc* is the crop factor, which is given in the tables for each crop growth stage such as initial stage (little water is used by the crop), crop development stage (the water consumption is increased), mid-season stage (the water consumption reaches a pick) and late season stage (once again less water is required). *ETo* is the reference crop evapotranspiration in mm per unit of time, which is defined as the rate of evapotranspiration from a large area covered by green grass that grows actively, completely shades the ground and which is not short of water. The rate of water which evaporates depends on the climate, and it can be estimated according to several methods such as Pan evaporation method and Blaney-criddle method.

Designed rainfall is defined as the total amount of rain during the crop season at which or above each the catchment area will provide sufficient runoff to satisfy the crop water requirements. The design rainfall cannot be neither sub-estimated nor super-estimated. If the actual rainfall in the cropping season is bellow the design rainfall, there will be moisture stress in the plants; if the actual rainfall exceeds the design rainfall, there will be surplus runoff which may result in damage to the structures. Its value is determined by means of a statistical probability analysis, according to the equation 3:

$$P(\%) = \frac{m - 0.375}{N + 0.25} * 100 \qquad (3)$$

An analysis of more than 15 years of observations (N) is used to obtain annual rainfall totals for the cropping season. These total values are ranked from the largest (m=1) to the lowest (m=x) and the probability of occurrence P (%) for each of the ranked observations is calculated from the equation mentioned above. The system becomes more reliable and thus meets the crop water requirements more frequently if the design rainfall is based on a higher probability, which means a lower design rainfall. However the associated risk would be a more frequent flooding of the system in years where rainfall exceeds the design rainfall.

Runoff coefficient is the portion of rainfall which flows along the ground as surface runoff. It depends among other factors on the degree of slop, soil type vegetation cover, antecedent soil moisture, rainfall intensity and duration. The coefficient ranges usually between 0.1 and 0.5. To determine the ratio of catchment to cultivated area it is necessary to assess either the annual (for perennial crops) or the seasonal runoff coefficient (K). This is defined as the total runoff observed in a year (or season) divided by the total rainfall in the same year (or season) as follow in the equation 4:

$$K = \frac{yearly(seasonal)totalrunoff\,[mm]}{yearly(seasonal)totalra\inf\ all[mm]} \qquad (4)$$

Runoff plots of a minimum size of 3-4 m in width and 10-12 m in length are used to measure surface runoff under controlled conditions. Around the plots earthen embankments, metal sheets or wooden planks are driven into the soil with 15 cm of height above ground to stop water flowing from outside into the plot and vice-versa. A rain gauge must be installed near of each plot and at the its lower end a flume must be placed to guide the runoff water into a 0.20 m^3 barrel. The plots should be established direct in the project area and their physical characteristics, such as soil type, slop and vegetation must be representative of the sites where water harvesting schemes are planned. It is advisable to construct several plots in series in the project area, so that a comparison of the measured runoff volumes and a judgment on the representative character of the selected plot sites can be done.

Many types of synthetic membrane materials have been used to increase runoff in the catchment area. Plastic membranes, such as polyethylene and vinyl are very effective but generally last less than a year. Butyl rubber and chlorinated polyethylene sheeting last much longer. Asphalt, concrete and other hard surfaces can also be used to channel water to cultivated area (Matthew & Bainbridge, 2000).

Efficiency factor takes into account the inefficiency of uneven distribution of the water within the field as well as losses due to evaporation and deep percolation. Where the cultivated area is leveled and smooth the efficiency is higher. Microcatchment systems have higher efficiencies as water is usually less deeply ponded. Normally the factor ranges between 0.5 and 0.75.

2.3.2 Description of the major techniques

Microcatchment rain water harvesting system is a method of collecting surface runoff from a small catchment area and storing it in the root zone of an adjacent infiltration area (Cofie et al., 2004). The system is mainly used for growing medium water demanding crops, such as maize, sorghum, groundnuts and millet (Hatibu & Mahoo, 1999). It has also been used to supplement rainfall for native vegetation (Matthew & Bainbridge, 2000).

Microcatchment systems provide many advantages over other irrigation schemes. They are simple and inexpensive to construct and can be built rapidly using local materials and manpower. The runoff water has a low salt content and, because it does not have to be transported or pumped, is relatively inexpensive. The system enhances leaching and often reduce soil salinity (Matthew & Bainbridge, 2000) The major techniques include: Pitting (wor105), earth basins, Strip catchment tillage, Semi-circular bunds (wor105), earthen bunds, Meskat-type system, Negarim microcatchments (water harvesting sudan), contour ridges (swim07) and stone lines (Critchley & Siegert 1991).

Pitting system

Pitting system consists of small circular pits, with about 30 cm in diameter and 20 cm deep, dug to break the crusted soil surface, to store water and to build up soil fertility. The variations of the system include Zai, Tassa, Half moon, Katumani pitting, Planting pits, Chololo pits and Five by nine pits. They are used in areas with rainfall of between 350 – 600 mm (Hatibu & Mahoo, 1999).

The Zai technique utilizes shallow, wide pits that are about 30 cm in diameter and 15-20 cm in depth, in which four to eight seeds of a cereal crop are planted, as shown in the figure 5 (Itabari & Wamuongo, 2003). Organic manuare and compost are usually added into the pit to improve fertility. It works by combination of water harvesting and conservation of both moisture and fertility in the pit. In the Njombe district of southern Tanzania, the pits are made bigger and deeper (at least 0.6 m deep), and a 20 liter volume of manure is added. Since the area receives an annual rainfall close to 1000 mm, the farmers plant about 15 to 20 seeds of maize per pit and the yield is more than double of those on conventional tilled land (Mati, 2005).

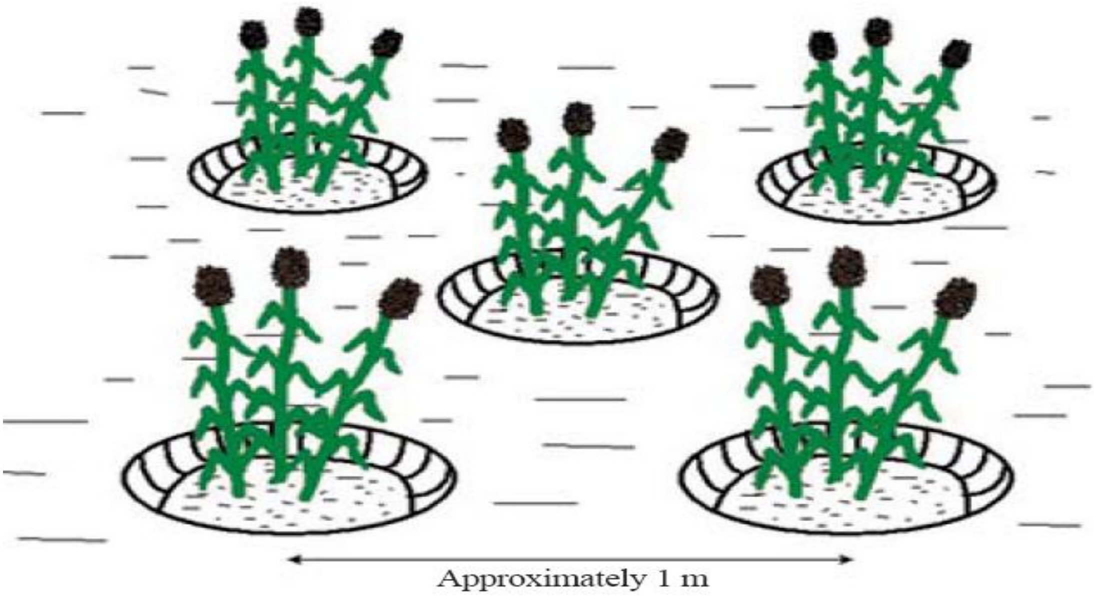

Fig. 5: Zai pits for water harvesting and conservation (Mati, 2005)

Chololo pits technique is a pitting method, which comprises a series of pits which are about 22 cm in diameter and 30 cm in depth. The pits are spaced 60 cm apart within rows, and 90 cm between rows, with the rows running along the contour. The soil removed during excavation is used to make a small bund around the hole. Inside the pit ashes (to expel termites), farmyard manure and crop residues are added, then covered with the requisite amount of soil while retaining sufficient space in the hole for runoff to the pond. One or two seeds of either maize / millet or sorghum are planted per hole. Crops usually survive even during periods of severe rainfall deficits and yields have been noted to be triple. The required labor for digging the holes is low (Mati, 2005).

Five by nine is a pitting method for maize crops, which are 60 cm square and 60 cm deep. They are larger than Zai pits but have a square shape. The name “Five by nine” is based on the five or nine maize seeds planted at the pit diagonals (five for dry areas and nine for wet areas). This type of pit can hold more manure than a Zai pit. Hence, it is capable of achieving higher yields that have a long-lasting effect. The pit can be re-used for a period up to 2 years (Mati, 2005).

Strip catchment tillage

Strip catchment tillage involves tilling strips of land along crop rows and leaving appropriate sections of the inter-row space uncultivated so as to release runoff (see figure 6). It is normally used where the slops are gentle and the runoff from the uncultivated parts adds water to the cropped strips. The catchment : besin area ratios used are normally less than or equal to 2:1. The system can be used for almost all types of crops and is easy to mechanize. Herbicides are used to control weeds in the catchment area (Hatibu & Mahoo, 1999).

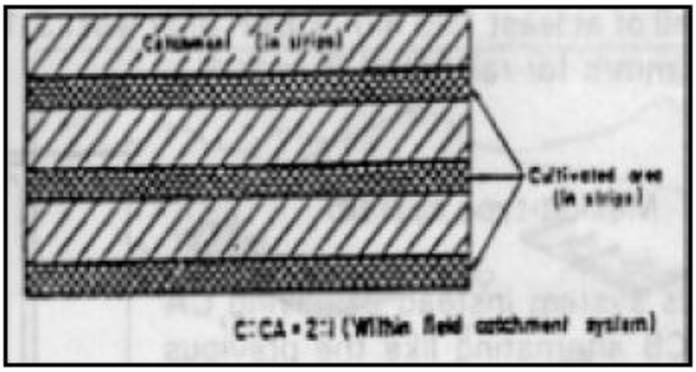

Fig. 6: Strip catchment tillage (Hatibu & Mahoo, 1999).

Earth basins

Earth basins are normally small, circular, square or dimond shaped microcatchments , intended to capture and hold all rainwater that falls on the field for plant use. They are constructed by making low earth ridges on all sides, to keep rainfall and runoff in the mini-basin. Runoff water is then channeled to the lowest point and stored in an infiltration pit. The technique is suitable in dry areas , where annual rainfall amounts are at least 150 mm, slops steepness ranges from flat to about 5 %, and soil that is at least 1.5 m deep to ensure enough water holding capacity. Earth basins are especially for growing fruit crops, and the seedling is usually planted in or on the side of the infiltration pit immediately after the beginning of the rains. The size of the basin may vary between 1 m to 2 m in width and up to 30 m in length for large external catchments with a deep at about 0.5 m (Mati, 2005).

Earthen bunds

Earthen bunds are various forms earth-shapings, which create run-on structures for ponding runoff water. The most common are within-field runoff harvesting systems, which require less mechanization, relying more on manual labor and animal drought. The variations of the system include contour bunds, semi-circular bunds and negarims microcatchments. Contour bunds are not suitable for small scale agriculture, they are most appropriate for large scale especially when mechanized.

The normal designs for semi-circular bunds involve making earth bunds in the shape of a semi-circle with tip of the bunds in the contour, as shown in the figure 7. In Busia, district of Kenya, semi-circular bunds are made by digging out holes along the contours. The dimension of the holes and the spacing of the contours are dictated by the type of crop. For common fruits, the holes are made with a radius of at least 0.6 m and a depth of 0.6 m. the sub-soil excavated from the pit is used to construct a semi-circular bund with a radius ranging from 3 m to 6 m on the lower side of the pit. The bund height is normally 0.25 m. the pits are mixed with mixture of organic manure and top soil to provide the required fertility and also to help retain the moisture. It is a common farmers practice to plant seasonal crops such as vegetables including beans and other herbaceous crops in the pits before the tree crops develops a shady canopy (Mati, 2005). The technique is found in areas with annual rainfall ranges from 200 mm to 275 mm, and land slops are less than 2 percent steepness. The main problems associated with this type of bund are: difficult to construct with animal draft, high level of labor is required, regular maintenance needs to be done and it doe not allow the use of mechanization (Critchley & Siegert 1991).

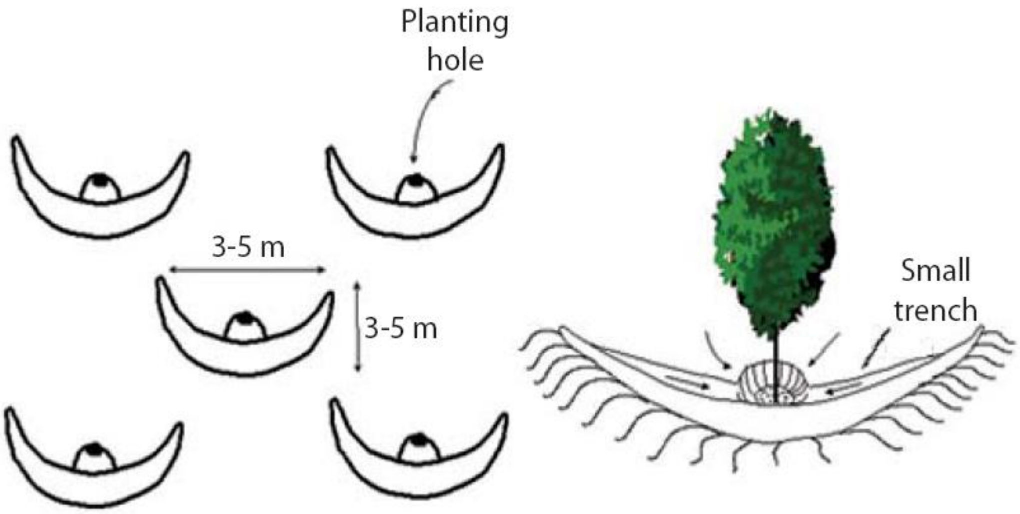

Fig. 7: lay out of semi-circular bunds (Mati, 2005)

Negarims microcatchments are regular square earth bunds, which have been turned 45 degrees from the contour to concentrate surface runoff at the lowest corner of the square where there is an infiltration pit dug, as shown in the figure 8. The shape of the infiltration pit can be circular or square, with dimensions varying according to the catchment size, as illustrated in the appendix 1. Three seedlings of at least 30 cm should be planted in each infiltration pit after the first rain of the season (Critchley & Siegert 1991). Manure or compost should be applied to the pit to improve fertility and soil water holding capacity. The bund height changes with the catchment size and slop of the area, as shown in the appendix 2. The system is used for the establishment of fruit trees and grass in arid and semi-arid regions where the seasonal rainfall can be as low as 150 mm (Mati, 2005). The catchment areas range from 10 m^2 to 100 m^2 depending on the specie of tree to be planted (SCTD, 2001).

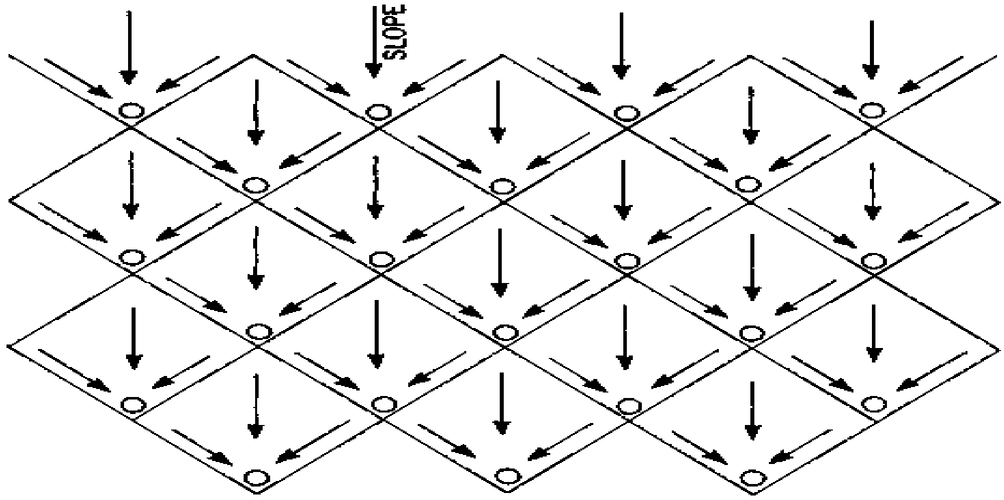

Fig. 8: Negarims microcatchments for tree crops (Critchley & Siegert 1991)

For constructing Negarims microcatchments, these stages must be followed: (1) to find a contour line by using a line level. Straight lines are found after the smoothing of the land; (2) to mark the tips of the bund along the contours by using a tape measure. The distance between tips (a-b) depends on the selected catchment size (see appendix 3); (3) two pieces of string of the same length (length string according to the catchment size) are held in each tip to meet each other at the apex c. A hoe is used to construct the catchment sides (a-b) and (b-c) on the ground and the same procedure is repeated until all bund alignments in the first row have been determined; (4) the subsequent rows of microcatchments are constructed by using the same procedure as for the first row, with the apexes of the bunds of the upper row as tips for the following row. Figure 9 shows how the bunds are then laid out using the contour as a reference (Critchley & Siegert 1991)

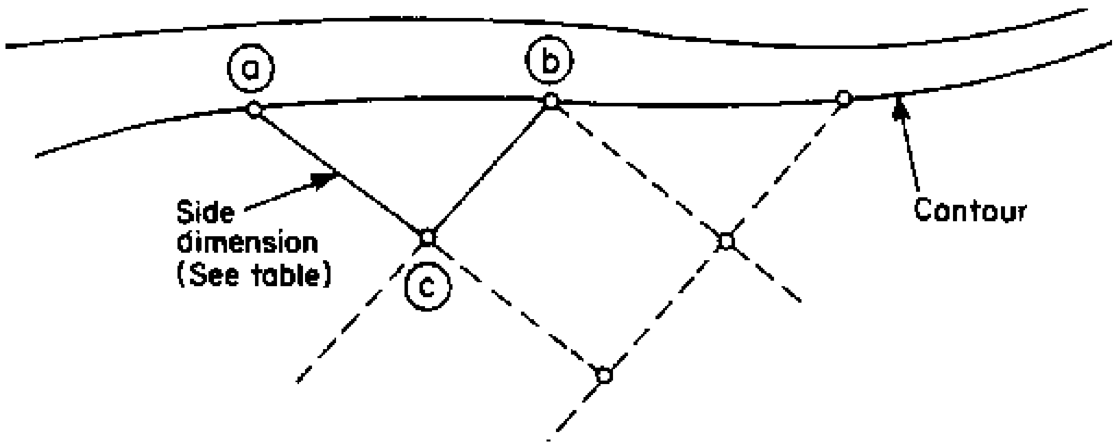

Fig. 9: Laying out the bunds using contours (Critchley & Siegert 1991)

Negarims microcatchments are appropriated for small scale tree planting in any area which has a moisture deficit. Besides harvesting water for trees, they simultaneously conserve soil. The system is efficient and precise, and relatively easy to construct. However, there are the following limitations on its implementation: not easy mechanized, therefore limited to small scale and very difficult cultivation between tree lines (Critchley & Siegert, 1991).

Contour ridge

Contour ridge is a microcatchment technique which consists on making ridges following the contour at a spacing of usually 1.5 to 2 meters, which means with a ratio between catchment and cultivated area from 2:1 to 3:1, respectively (Haile & Merga, 2002). Runoff is collected from the uncultivated strip between ridges and stored in a furrow just above the ridges. Crops are planted on both sides of the furrow. The system is simple to construct – by hand or by machine and can be even less labor intensive than the conventional tillage of a plot. The following conditions are the most suitable for its implementation: annual rainfall between 350 and 750 mm, all soils which are suitable for agriculture, slops from flat up to 5 % and smooth areas (Critchley & Siegert, 1991).

The overall lay out of the contour ridge system consists of parallel earth ridges approximately on the contour at a space of between one and two meters (see figure 10). Soil is excavated and placed down slop to form a ridge, and the excavated furrow above the ridge collects runoff from the catchment strip between ridges. Small earth ties of 15-20 cm high and 50-75 cm long are provided above the furrow every 4 to 5 meters to ensure an even storage of runoff. A diversion ditch with 50 cm deep and 1-1.5 m wide is usually done before the contour ridges are built to protect the system against runoff from out side (Critchley & Siegert 1991).

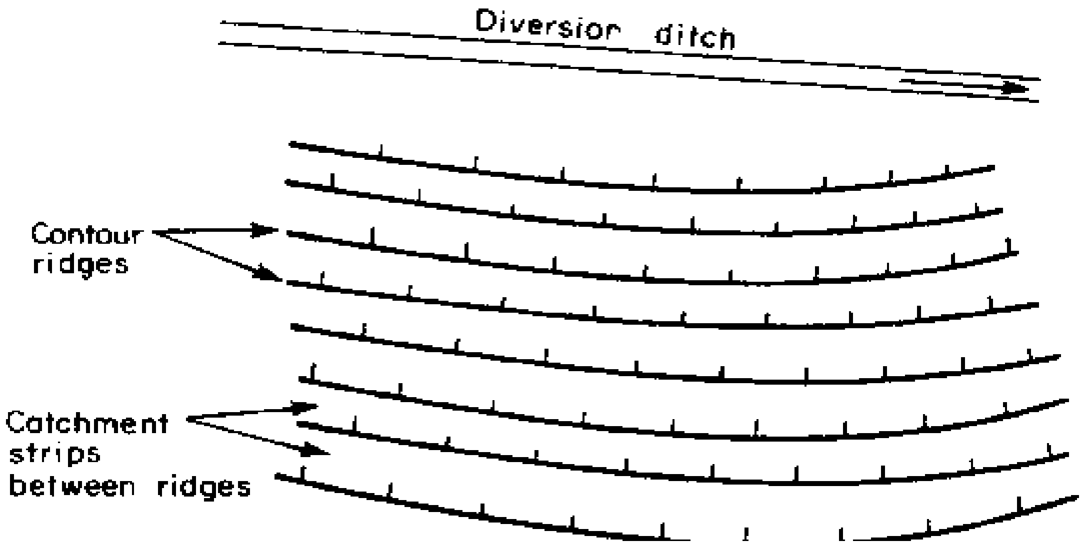

Fig. 10: Contour ridges field lay out (Critchley & Siegert 1991)

In the contour ridge system, the main crop (usually a cereal) is seeded into the upslop side of the ridge between the top of the ridge and the furrow. An intercrop, usually a legume, can be planted in front of the furrow (see figure 11). It is recommended the use of approximately 65 % of the plant population of rainfed cultivation, so that the plants can have more moisture available in years of low rainfall. Weeding must be carried out regularly around the plants and within the catchment strip (Critchley & Siegert 1991).

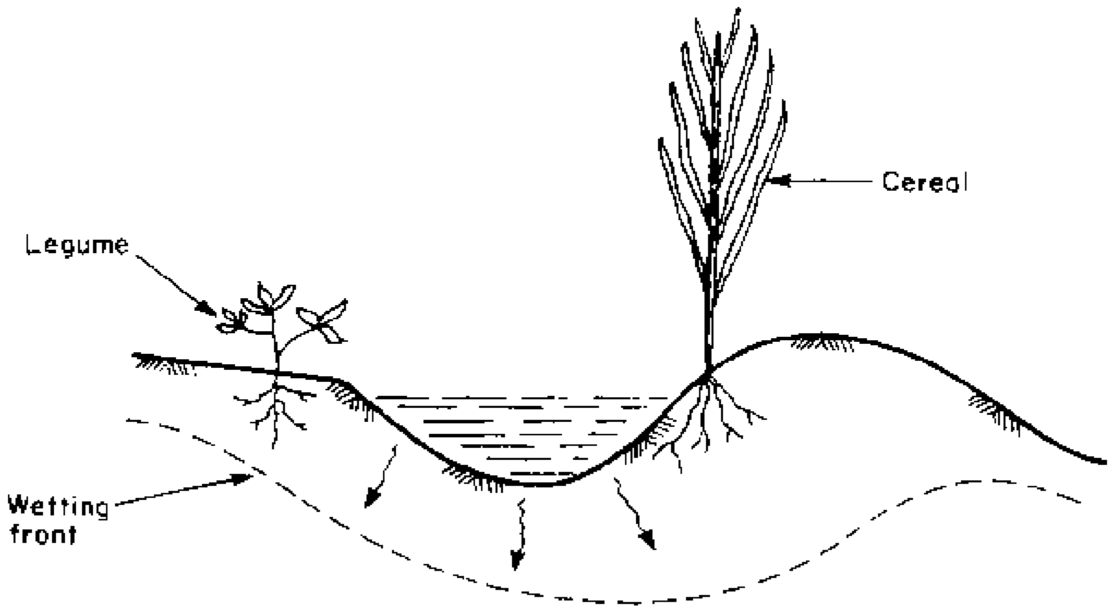

Fig. 11: Contour ridges planting configuration (Critchley & Siegert 1991).

Broadbed and furrow systems are a modification of contour ridges, with a catchment ahead of the furrow and a within-field microcatchment water harvesting system (see figure 12). In Ethiopia, Kenya and Tanzania, the systems are made as small earthen banks with furrows on the higher sides, which collect runoff from the catchment area between the ridges. The catchment area is left uncultivated and clear of vegetation to maximize runoff. Crops can be planted on the sides of the furrows and on the ridges. Plants that need much water, such as beans and peas, are usually planted on the higher side of the furrow, and cereal crops such as maize and millet, are usually planted on the ridges. The distance among the ridges varies between 1 m and two m depending on the slop gradien, the size of the catchment area desired and the amount of rainfall available. The system is most suitable in areas where the annual rainfall is from 350 mm-700 mm, even topography, gentle slops of about 0.5-3 % steepness and soils fairly light due to high infiltration rates (Mati, 2005).

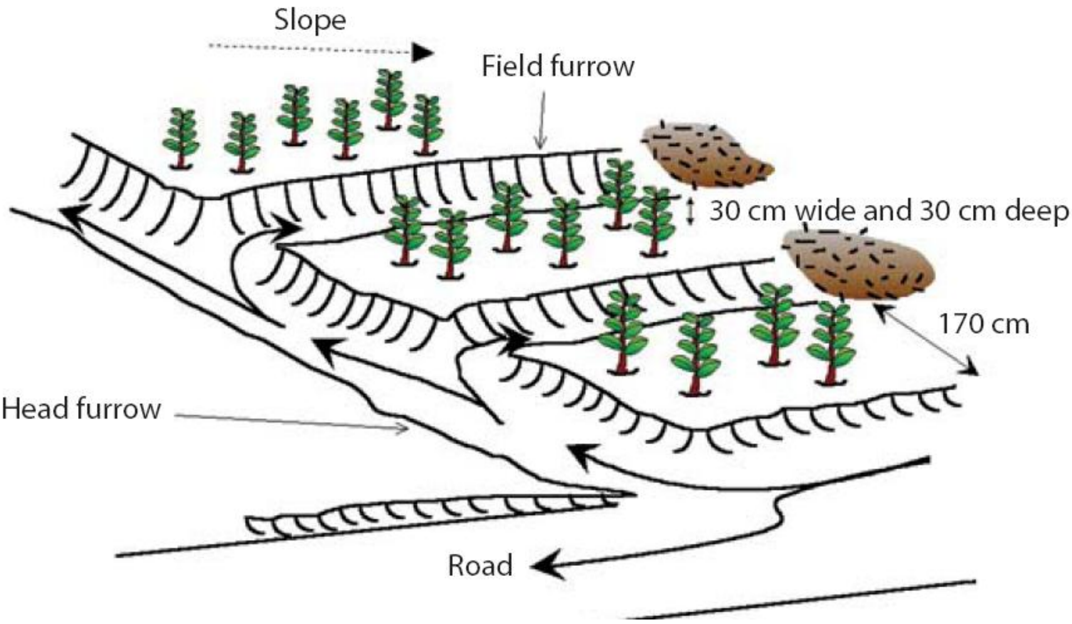

Fig. 12: Broadbed and furrow system (Mati, 2005)

In-field rainwater harvesting technique

In-field rainwater harvesting technique is a microcatchment technique which combines the advantages of water harvesting, no-till and basin tillage to stop runoff completely on clay soils (Hensley et al., 2000). The technique consists of a catchment area which promotes in-field run-off and a cropped basin which allows the stoppage of ex-field runoff completely, maximizes infiltration and stores the collected water in the soil layers beneath the evaporation sensitive zone. Ridges are immediately done after each cropped basin to allow a better conservation of water in the soil profile. Mulch is placed in the cropped basin to minimize evaporation losses. The ratio between the catchment area and the cropped area, according to the field experiences with crops in the semi-arid areas, is about 2:1 (Rensburg van et al., 2003). Figure 13 illustrates the field lay out of the technique. Herbicides are used to control weeds in the catchment area.

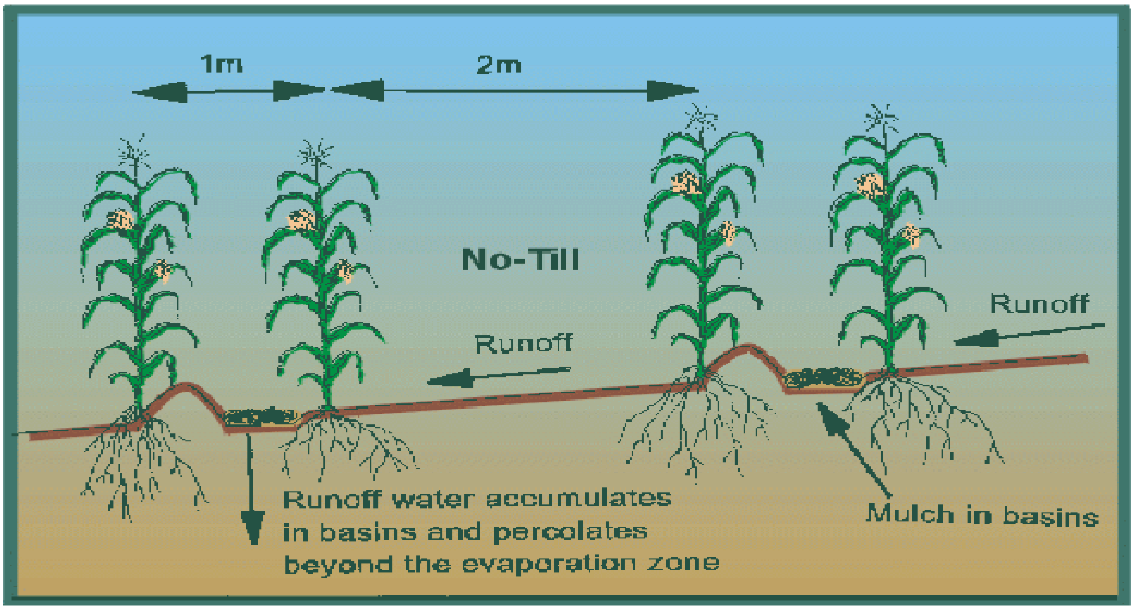

Fig. 13: In-field rainwater harvesting technique (Botha et al., 2007)

Meskat-type system

Meskat-type system is a type of microcatchment system in which the catchment area diverts runoff water directly onto a cultivated area at the bottom of the slop (Rosegrant et al., 2002). In this system instead of having catchment area and cultivated area alternating like the previous methods, here the field is divided into two different parts, the catchment area and cultivated area which is placed immediately bellow the catchment area (see figure 14). The catchment area must be compacted and free of weeds. The recommended ratio between the catchment area and cultivated area in Semi-arid areas is 2:1 (Hatibu & Mahoo, 1999).

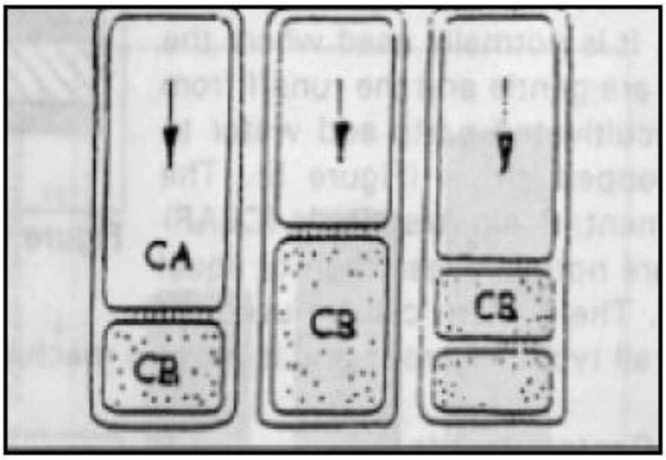

Fig. 14: Meskat-type system (Hatibu & Mahoo, 1999)

3. EXPERIENCES FROM AFRICAN COUNTRIES

In this section, some rainwater harvesting technologies commonly used in African countries are described in terms of their implementation method, advantages and disadvantages and obtained results.

3.1 IN-SITU RAINWATER HARVESTING

3.1.1 Zimbabwe

Nyabungo (1999) describes experiences on maize production using tillage systems from on-station and on-farm research in Zimbabwe carried on between 1988 and 1997. On-station, four conservation tillage methods namely No-till tied ridging, Mulch ripping, Clean ripping and Hand hoeing were compared to the control - conventional tillage system in a completely randomized block design, with three replications. On-farm, no-till tied ridges was compared to the farmer's conventional tillage practice to assess the performance and acceptability of the technique.

No-till tied ridging method consisted on constructing cross-ties on the semi-permanent ridges along the furrows to trap runoff. The ridges were laid across the main slop at a grade of 0.4 to 1%. Planting was done on top of the ridges after being fully moist in areas with high rainfall and in dry areas it was done in the furrows where most of the runoff water collects.

Mulch ripping involved the retention of stover on the surface and use of a ripper to open up planting lines. Crop rows were alternated between seasons. Planting was carried out along the rip lines. No ploughing took place.

Cleaning ripping was the same as mulch ripping except that no stover was retained after harvesting to mimic livestock grazing situations. An ox-drown ripper was used to open up rip lines into which planting was done.

Hand hoeing involved the use of hoes to pen up planting holes to mimic situations where draft power is not available. Weed control was achieved by hand weeding.

A farmer's practice of conventional tillage was used, which involved ploughing with mouldboard to a deep of about 23 cm and planting into a clean seed bed.

For on-station research, experimental trials were established in Makoholi experimental station – Masvingo Province, on sandy soils. The average annual rainfall is about 450 – 650 mm. The experimental trials focused on the effects of hand or animal powered conservation tillage systems on surface runoff, sheet erosion and weed control.

The following were the main results for on-station experimental trials: sheet erosion was significantly reduced by using conservation tillage methods especially no-till tied ridging and mulch ripping, while with conventional tillage system after four cropping seasons was observed a dramatic increase on soil loss levels probably due to declined soil organic carbon bellow some threshold value bellow which soil erodibility abruptly increased. The general trend showed a gradual decline in organic carbon for all treatments but a rather steeper gradient with conventional tillage practice and the lowest gradient with mulch ripping (41% of organic carbon reduction for conventional tillage compared to 9% for mulch ripping after five years of cropping). Weed control was a problem for all tillage systems, with the greatest effect for conventional tillage and the lowest effect for tied ridging.

On-farm research trials were composed by eight farmers from Masvingo Province. Conclusions from the obtained results showed that there was no scope for giving blanket recommendations to farmers on no-till tied ridging. There was a need to offer farmers a basket of technology options from which they could select the ones most suited to their resource endowments. Maize yields were completely different from farmer to farmer, depending on their management skills, seasonal rainfall and soil type. It was also realised from the study that tied ridging alone could not bring better yield results to the farmers; there is a need to incorporate the fertility component. Tied ridges could not work without the support of structures such as contour ridges, infiltration pits and other preventive structures. Tied ridges on sandy soils did not overally increase soil water content within the root zone due to the low water capacity of sands. Sandy soils under conventional tillage tend to develop a hard pan which limits the rooting volume.

3.1.2 Tanzania

Mmbanga and Lyamchai (2001), describe on-farm and on-station experimental trials carried out in the northern zone of Tanzania.

On-farm trials were conducted in two districts of Arusha and Kilimanjaro regions (Arumeru and Hai districts) during the 1997/98, 1998/99, 1999/00 and 2000/01 seasons. The first two seasons were used to verify moisture conservation methods (tied ridges, open ridges, potholes (small holes) and flat planting) and maize varieties appropriate for moisture stressed areas (Katumani, Tuxpeno, TMV-1 → open pollinated and CG4141 → hybrid variety). The following seasons (1999/2000 and 2000/01) were used to demonstrate appropriate technology (tie ridging), with further verification. The annual rainfall in these regions is on average between 300 and 600 mm. In Arumeru district, soils are stony with shallow depth, hard pan and slops from 2 to 5%. In Hai district, soils are deep with slops up to 2%, there is no hard pan presence. A split plot experimental design was used for the verification trials and a strip plot for the demonstrations, with moisture conservation methods assigned to the main plots and varieties to the subplots. Nitrogen fertilizer was applied to all plots at the recommended rate of 60 kg/ha in the form of urea.

The same moisture conservation methods used on-farm was used on-station. Five maize varieties were used for this trial: Katumani, Kito, TMV1 → open pollinated and CG4141, C5051→ hybrids. Within the ridges, three seed placements were used namely crest, side and bottom of the ridge. A split-split plot design was used where main plots were moisture conservation methods, subplots were seed placements and varieties were sub-sub plots. All other husbandry practices were performed (thinning, weeding, (fertilizer application100 kg/ha nitrogen as urea and 60 kg/ha P205 as triple super phosphate) and insect control).

Results of yield responses to soil moisture conservation, in which CG4141 maize variety is used, showed significant maize yield increases under tie ridging for both on-farm and on-station trials (see figures 15 and 16, respectively). An increase of 47% on yield of CG4141 was observed by using tie ridging instead of flat planting on-farm trial. Figure 17 presents percent moisture retained in the different moisture conservation methods on-station and it is consistent with the maize yield increase. Tie ridging retained more moisture than the other methods. Seed placement had significant difference only in the 1998/99 season. Bottom seed placement had the least yield and crest the highest (see figure 18). There was adequate rainfall during this season on-station. Therefore, the low yield in the bottom seed placement could be attributed to water logging in tie ridging and probably removal of nutrients in the open ridges.

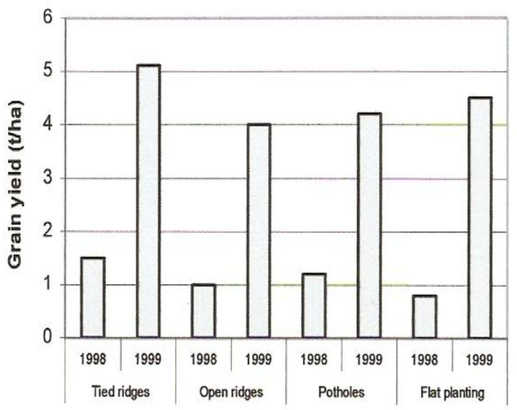

Fig. 15: Effect of soil moisture conservation methods on maize grain yield on-farm

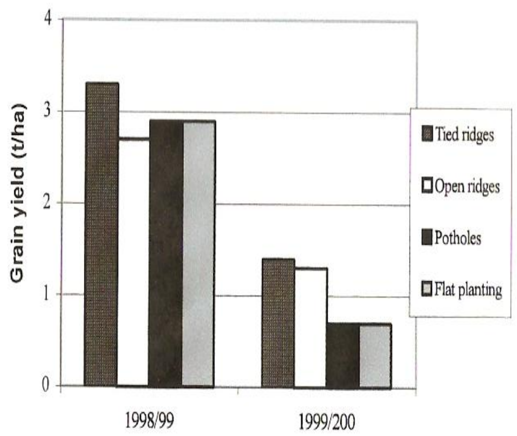

Fig. 16: Effect of soil moisture conservation methods on maize grain yield on-station

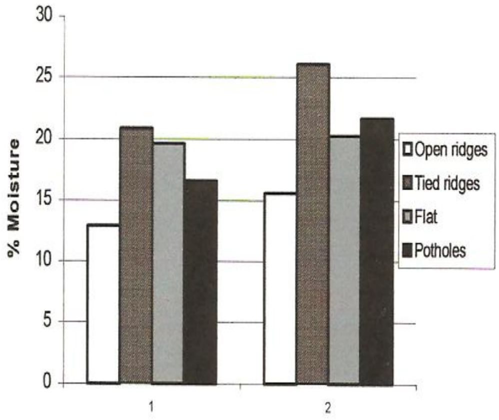

Fig. 17: Moisture retained in the soil up to physiological maturity during 1999/00 and 2000/01

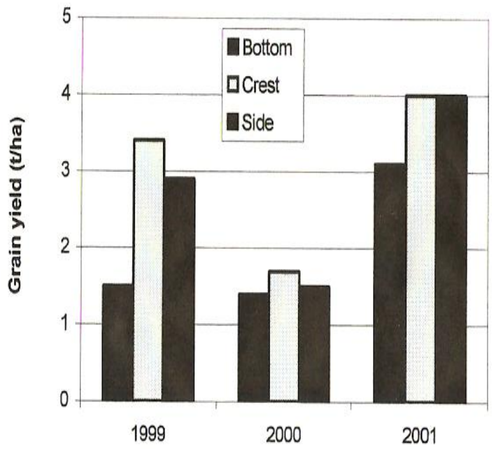

Fig. 18: Maize grain yields as affected by seed placement across seasons

Evaluation of farmer’s views on moisture conservation showed that farmers of all categories appreciate tie ridging more than the other methods. However, its adoption is still minimal. One reason for the no adoption of the system is the labour involved in the technology. The cost of making tie ridging is estimated at 33% higher than conventional land preparation using hand hoes in Tanzania.

Recommendations can be done after the study in odder to not implement tie ridges where the average annual rainfall is more than 800 mm, as they may cause water logging. In drier areas with about 500 mm rainfall, tie ridging is recommended to farmers who have easy access to capital resources. Potholing is recommended to farmers with scarce resources. In areas with clay or sandy soils, tie ridging is not recommended due to high water percolation and water logging respectively. Crest and side seed placement with the ridges is recommended since water logging will be eliminated.

3.2 MICROCATCHMENT RAINWATER HARVESTING

3.2.1 Niger

Olaleye et al. (2006) describes field experiments conducted in Semi-arid areas of Niger (Damari and Kakassi) which are characterized by low, erratic rainfall (300-600 mm), and infertile soils which are crust-prune. The soil type was ferric lixisol with pH 5.9, organic carbon 6.4 g/kg and available phosphorus of 26.0 mg/kg. The experiments consisted of Zai and traditional flat planting between 1999 and 2000. The experimental design was a randomized complete block design with three replications. The treatments in each type of planting technique were: crop residue, organic manure and control (no amendment). Results showed that higher grain yields were recorded in Zai plots compared to flat et Damari and Kakassi in 1999 and 2000 cropping seasons (see figure 19).

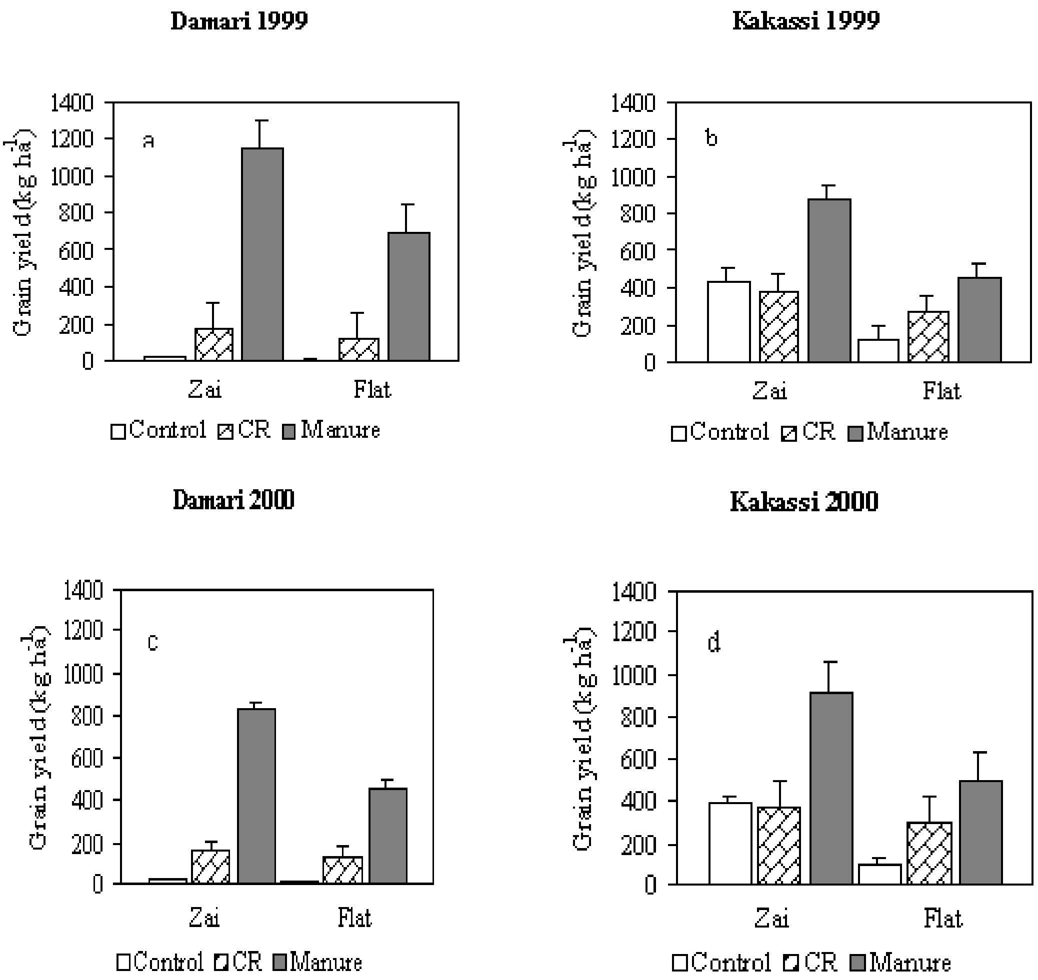

Fig. 19 : Effect of improved Zai planting versus conventional planting (flat) in Niger (Olaleye et al.,2006)

Higher grain yields in 1999 and 2000 on Zai treatments compared to flat planting may be attributed to a build-up in the soil organic matter contents which may have increased the soil water holding capacity.

3.2.2 South Africa

Botha et al. (2003), describes on-station and on-farm field experiments which were conducted in the Free State Province, South Africa. Three ecotopes, namely Glen (on-station), Khumo and Vlakspruit (on-farm), were selected. These selected ecotopes are representative of more than half a million hectares of land in the Free State Province. The data related to the annual rainfall and evaporative demand, monthly temperature, topography and soil of each ecotope is presented in the table 1.

Table 1: Ecotope characterization

Ecotope	Rain (mm)	Evaporation (mm)	Max T (C)	Min T (C)	Slop (%)	Soil
Glen	543	2198	24.8	7.5	1	45% clay
Khumo	588	-	-	-	2	17% clay
Vlakspruit	588	-	-	-	3	42% clay

In-field rainwater harvesting technique, which combines the advantages of water harvesting, no-till, basin tillage and mulching, was used. The technique consisted of promoting rainfall runoff on a 2 meter wide strip between alternate crop rows, storing the runoff water in the one meter basins where it infiltrates deep into the soil.

The main objective, using on-station field experiments, was to evaluate different water conservation crop production techniques. A randomized block design with two crops, 8 treatment combinations and three replicates was employed. Crops were planted annually, following three growing seasons (99/00, 00/01 and 01/02). Two crops were grown in rotation: maize-sunflower-maize (block B) and sunflower-maize-sunflower (block A). The treatments ware as follows: organic mulch in the basins, bare runoff area (**ObBr**), with recommended level of fertilizer (**Lo**); organic mulch in the basins, stones on the runoff area (**ObSr**), with recommended level of fertilizer (**Lo**); organic mulch in the basins, organic mulch on the runoff area (**ObOr**), with recommended level of fertilizer (**Lo**); stones on the basin, organic mulch on the runoff area (**SbOr**), with recommended level of fertilizer; **ObBr**, with high level of fertilizer (**Hi**); **ObSr**, with high level of fertilizer (**Hi**); **ObOr**, with high level of fertilizer (**Hi**) and **SbOr**, with high level of fertilizer (**Hi**).

The effect of different mulch treatments (bare, maize, stalks and reeds as organic mulch, and stones) for Glen ecotope is summarised in table 2.

Table 2: Rainfall and in-field runoff on Glen ecotope with three different mulch treatments

Ecotope	Glen			
Season	Rain	In-field runoff		
		Bare	Stone	Organic mulch
	mm	mm	mm	mm
99/00	479	110	59	16
00/01	544	255	175	26
01/02	591	280	168	54
Average	538	215	134	32

The results of the first season indicate that runoff was lower in all the treatments, comparing to the following two years. This can probably be attributed either to the fact that the establishing of the experiment was nearly established (i.e. soil crust not yet fully formed), and/or low rainfall intensities during the rain events. The runoff averages strongly indicate that water harvesting is influenced by mulching. The bare treatment stimulated the highest runoff through the formation of a surface crust, which is natural characteristic of this soil. On the other hand, organic much enhanced infiltration rather than runoff. The average runoff from the organic mulch was almost seven times less than the bare plot.

The effect of different mulch treatments from the runoff area on sedimentation in basins is presented in table 3. The results show that the most soil transportation occurred on the bare surface treatment, followed by the stone and mulch treatments. It is therefore concluded that mulch on the runoff area will be the best treatment in terms of sustainability regarding the surface storage capacity of the basin. The capacity of the basin with a bare runoff area will be reduced relatively quickly, and progressively lose their designed water storage capacity. The land will be then eventually have the same surface characteristics as with conventional tillage.

Table 3: The amount of sediment collected in the basin of the respective treatments on the Glen ecotope

Season	Sediment load (g m-^{2} season-^{1})		
	Bare	Stone	Organic mulch
00/01	4204	1673	539
01/02	3244	2242	562
Average	3724	1958	551

Results from two levels of nitrogen (recommended level (Nrec)= 15 kg N ha^{-1} and high level (Nh)= 90 kg N ha^{-1}), which were applied in both the sunflower-maize-sunflower (SMS) and maize-sunflower-maize (MSM), are summarized in table 4. Results from block A indicate that the high nitrogen application within the SMS significantly influences seed yield response. Maize that followed sunflower responded negatively, while sunflower responded positively when it followed maize. This can be explained by the ability of crops to extract water from the potential root zone. Sunflower has the ability to extract more water from the profile than maize. Results from the MSM rotation experiment (block B) showed no significant response to the high nitrogen application level. On the other hand, at least the maize (01/02 season) responded positively to the low nitrogen application. The yield increased from 2612 kg/ha with no N added to 3330 kg/ha when 15 kg/ha N was applied. Comparing this yield with the 99/00 season leads to the conclusion that 15 kg/ha N application represents the optimum nitrogen level for the ecotope when the available water fluctuates between 370 mm and 420 mm.

Table 4: Effect of nitrogen application on seed yield of maize and sunflower

Parameter	Rotation	Block A		Rotation	Bloc B	
		Nitrogen levels			Nitrogen levels	
		Nrec	Nh		Nrec	Nh
Seed (kg/ha)	99/00 (S)	2250a	2083a	99/00 (M)	3607a	3612a
	00/01 (M)	2848a	2792a	00/01 (S)	1921a	1932a
	01/02 (S)	2473a	2619b	01/02 (M)	3330a	3421a

On-farm experimental trials were placed in Khumo and Vlakspruit ecotopes with the objective of comparing conventional tillage (CON) with different mulch combinations on the runoff area and in the basins. Results of Kumo and Vlakspruit ecotopes are presented in tables , respectively. It can be seen from both ecotopes that all the in-field rainwater harvesting techniques (ObBr, SbOr and ObSr) produced significantly higher seed yields than the CON treatment, irrespective of season. Comparing the three in-field rainwater harvesting techniques in Khumo ecotope revealed that there is no statistical differences between treatments except for the 99/00 season where ObSr > ObBr, while for Vlakspruit ecotope it is significantly different among all of them. The mean biomass yield also reflected the trend and differences between the in-field rainwater harvesting treatments were not significant during the course of the three seasons.

4. APPENDIXES

Append. 1: Quantities of earth works for Negarims Microcatchments

(1)	(2)	(3)	(4)	(5)	(6) [
Size Unit Microcatchment (m^2)	Size Infiltration Pit (m)	Ground Slopes Suitable for 25 cm Bund	Volume Earthwork Per Unit**	No. Units Per ha	Earthworks m^3/ha
Sides (x) Area	Sides,(y) Depth	Height*	(m^2)		
3 m x 3 m = 9 m^2	1.4 x 1.4 x 0.4	up to 5%	0.75	1110	835
4 m x 4 m = 16 m^2	1.6 x 1.6 x 0.4	up to 4%	1.00	625	625
5 m x 5 m = 25 m^2	1.8 x 1.8 x 0.4	up to 3%	1.25	400	500
6 m x 6 m = 36 m^2	1.9 x 1.9 x 0.4	up to 3%	1.50	275	415
8 m x 8 m = 64 m^2	2.2 x 2.2 x 0.4	up to 2%	2.00	155	310
10 m x 10 m = 100 m^2	2.5 x 2.5 x 0.4	up to 1%	2.50	100	250
12 m x 12 m = 144 m^2	2.8 x 2.8 x 0.4	up to 1%	3.25	70	230
15 m x 15 m = 225 m^2	3.0 x 3.0 x 0.4	up to 1%	3.50	45	160

Fonte: (Critchley & Siegert, 1991)

Append. 2: Bund heights (cm) on higher ground slops for Negarims Microcatchments

Size Unit Microcatchment	Ground slope			
(m^2)	2%	3%	4%	5%
3x3	even bund height			
4x4	of 25 cm			30
5X5			30	35
6X6			35	45
8X8		35	45	55
10X12	30	45	55	
12X12	35	50	not recommended	
15 X 15	45			

Fonte: (Critchley & Siegert, 1991)

Append. 3: Distance between tips in relation to catchment size for Negarims Microcatchments

Microcatchment dimension	Distance a - b
(m)	(m)
3x3	4.2
4x4	5.7
5x5	7.1
6x6	8.5
8x8	11.3
10x10	14.1

Fonte: (Critchley & Siegert, 1991)

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