Soil and Water Conservation: An Overview

Chapter · January 2019
DOI: 10.1007/978-3-319-69626-3_91-1

3 authors, including:


Shadrack Nyawade
International Potato Center


Nancy Karanja
University of Nairobi

S

Soil and Water Conservation: An Overview

Charles K. K. Gachene, Shadrack O. Nyawade and Nancy N. Karanja
Department of Land Resource Management and Agricultural Technology, College of Agriculture and Veterinary Sciences, University of Nairobi, Nairobi, Kenya

Definitions

Buffer strip	An area of land maintained in permanent vegetation that helps to trap sediment by slowing down runoff, thus enhancing filtration of nutrients.
Conservation tillage	A tillage system that creates a suitable soil environment for growing a crop and that conserves soil, water, and energy resources mainly through reduction in the intensity of tillage and retention of plant residues.
Crop residue	Any type of vegetative cover retained in the field and may include standing stubble, dispersed straw, living vegetation, or mulch.
Soil and water conservation (SWC)	Any practice that reduces soil erosion and water runoff, thus conserving soil.
Soil erosion	Detachment and transportation of soil and soil material from the place of origin by water, wind, ice, or gravity and deposition to another place.

Introduction

Loss of soil quality due to soil erosion remains a major factor of low crop productivity in tropical and subtropical countries. Soil and water conservation (SWC) efforts should therefore be geared toward soil erosion control for enhanced maintenance of soil organic matter and soil physical properties. The main factors causing soil erosion can be divided into three groups: (1) energy factors, e.g., rainfall erosivity; (2) protection factors, e.g., plant cover and land management; and (3) resistance factors, e.g., soil erodibility. This entry mainly covers soil erosion by water. Soil erosion is a major threat to the soil resource, soil fertility, productivity, and, lastly, to food and fiber production (Boardman et al. 2009). According to Ighodaro et al. (2013), soil erosion is the biggest environmental problem the world faces second only to population growth. Worldwide, erosion on cropland averages to about 30 t/ha/year, and each year about 10 million ha of cropland is

W. Leal Filho et al. (eds.), *Zero Hunger*,
https://doi.org/10.1007/978-3-319-69626-3_91-1

Soil and Water Conservation: An Overview, Plate 1 A stream heavily laden with sediment: siltation leads to poor water quality

rendered unproductive and abandoned due to soil erosion (Nyawade et al. 2018a, b). Pimentel (2006) reports that soil erosion is highest in Asia, Africa, and South America where soil losses range from 30 to 40 t/ha and that it is severe in small farms located in marginal areas where soil quality is poor and the topography often steep (Plate 1). Soil erosion is severe in small farms located in marginal areas where soil quality is poor and the topography is often steep (Plate 1). Although the problem is as old as settled agriculture, its extent and impact on human welfare and global environment are more now than ever before. However, human alterations of land use and cover have caused erosion rates to increase for many areas of the world, resulting in considerable land and environmental degradation (Valentin et al. 2008; Martínez-Casasnovas et al. 2009; Farhan et al. 2014; Tesfahunegn et al. 2014). While temporary solutions such as increased fertilizer have offset some of the effects of erosion on soil productivity, they are not complete substitutes for topsoil (Gachene et al. 1997) and represent the greatest input cost for compensating yield losses caused by erosion (Pimentel 2006).

Studies conducted on a humic Nitisol at Kabete, Kenya, indicated that soil erosion by water can lead to substantial loss in maize growth and grain yield (Gachene et al. 1998) (Table 1).

Thus, in order to maintain long-term productivity and preserve soil and environmental quality, it is important to implement SWC practices that prevent and minimize soil erosion, rather than manage the effects of erosion after it has occurred (Yannelli et al. 2013). Runoff and soil loss prediction has been widely used as a tool to guide in SWC planning (Murillo et al. 2011; Renschler and Harbor 2009; Gobin et al. 2004).

Reflecting Back on the History of Soil and Water Conservation Measures

Historical evidence shows that many parts of the world were experiencing high rates of soil erosion in the 1930s leading to a decline in agricultural

Soil and Water Conservation: An Overview, Table 1 Effects of soil erosion on maize growth and yield

Soil loss (t/ha)	Leaf area index	Crop height (cm)	Grain yield (kg / ha)
0.77	4.85	247.3	828.6
40.54	4.67	235.0	601.6
171.31	5.52	226.7	517.8
247.27	2.89	163.4	300.0

Source: Gachene et al. (1998)

productivity. For instance, SWC in Kenya (as was the case in most of the East and Central African region) was introduced in the 1930s. Due to serious erosion problems in both the settlers and the African farms, SWC was made compulsory by the African Land Development Board (ALDEV) and the Swynnerton Plan (1953–1957). *Colonial Era (1930–1962):* Colonial authorities addressed the problem of soil erosion by implementing district level bylaws specific to the *African held land* which focused on coffee and cotton. Local administration and agricultural technicians rigorously enforced these stipulations, and stiff penalties were imposed on farmers who failed to comply. SWC measures that were enforced included contour farming, tree planting, terrace strip cropping, and destocking. This was followed by a *The lost Decade–No Approach (1963–1972):* period of laxity by the people toward coerced soil conservation. This was because soil conservation had become both politically and socially untenable. During this period, more terraces disappeared through destruction and neglect than were being constructed coupled with few initiatives toward soil conservation. This was followed by *Revival of Soil Conservation (1972–1988).* Land degradation was considered to be a serious problem in Kenya during the United Nations Conference on the Human Environment in Stockholm in 1972. National Soil and Water Conservation Program (NSWCP) was launched in 1974 with support from Swedish International Development Cooperation Agency (SIDA). This program aimed at increasing and sustaining agricultural production through simple, cheap, and effective soil conservation measures. This was individual farm based with a package of tools given out to farmers. Lessons learnt in this phase led to an introduction of a community-based SWC approach (the catchment approach).

Agronomic and Vegetative Measures of Soil and Water Conservation in Croplands

Agronomic and vegetative SWC approaches have gained considerable application particularly in sub-Saharan Africa due to their low cost of adoption compared to the structural SWC measures. These techniques are categorized into five groups: crop management, soil management, contour farming, organic matter and fertilizer management, and agroforestry.

Crop Management Practices

The use of cropping systems and mulching to conserve soil and water in arable lands is increasingly gaining interest and is often evaluated in runoff plots (Plate 2). Good crop management reduces soil erosion by water and wind to tolerable levels and can improve soil fertility. To achieve these practices, select appropriate crops for the soil and slope, plant early, and use suitable cropping systems and rotations to keep the soil covered. Besides their role in crop diversification, intercropping systems are important in soil erosion control and soil fertility improvement. In a study conducted in central Kenya to quantify the losses of soil organic matter due to soil erosion under different potato-based cropping systems, Nyawade et al. (2018b) observed 34% reduction in soil organic matter losses when *Dolichos lablab* was intercropped with potato crop. This

Soil and Water Conservation: An Overview, Plate 2 Runoff plots installed at right angle to the contours and parallel to the slope

observation was attributed to the Dolichos's indeterminate growth pattern which enabled it to provide effective postharvest cover. Mulching is particularly applicable where crop residues have limited competitive use rather than for soil erosion. The mulch protects soil surface against raindrop impact, decrease runoff velocity by impacting roughness, and thus improves water infiltration capacity. Mulching also enhances burrowing activity of earthworms which improves percolation of water through the soil profile, thus improving soil moisture storage in the root zone. Integrated use of contour hedgerows and mulching remarkably reduced runoff from 100 mm to 20 mm and soil loss from 100 to 2 Mg ha^{-1} in a sloping semiarid land in Eastern Kenya (Kinama et al. 2007).

Soil Management Practices

Designing sustainable soil management practices remain a major challenge in East and Central African region. Losses of SOC, N, and P due to soil erosion and poor cropping systems are estimated to be at rates of 270 million tons per year in Africa. Given the inherent low fertility of many soils in tropical and subtropical regions, the use of farmyard manure and inorganic fertilizer is particularly important due to their ability to improve both soil water content and soil properties. For instance, extensive work on highly weathered soils in Kenya (Otieno et al. 2018), Tanzania (Okalebo et al. 2006), Uganda (Pincus et al. 2016), Democratic Republic of the Congo (Munyahali et al. 2017), and Angola (Rodrigues et al. 2018) has demonstrated the potential of crop residues to restore soil fertility. Improvement of soil productivity in degraded soils therefore not only requires the application of chemical fertilizers but also strategies that, for instance, integrate legume cover crops into cropping systems (Nyawade et al. 2018b; Nyawade 2015).

Conservation Tillage

Proper tillage systems which cause minimum disturbance to the soil and have the ability to increase soil water content are essential for effective SWC. Such systems include conservation tillage (zero and minimum tillage), contour tillage, contour ridging, and ripping. The concept of conservation tillage, though not new, is gaining popularity in East Africa for sustainable crop production, especially in dry areas. After several decades of SWC efforts in Africa, conservation tillage has been recognized as the missing link between biological methods of agroforestry, farm inputs, and mechanical approaches such as terracing. The method aims at reducing labor in land preparation through tillage systems that promote soil fertility and soil water conservation. Conventionally, tillage is conducted to prepare a seed bed and also to control weeds. However, conventional tillage has been found to destroy the structure of the soil and cause compaction. This has negative effects on soil aeration, root development, and water infiltration, among other factors. More important, but less noticeable, is the destruction of soil microbiology by disturbance and turning over of soil, which is then exposed to drastic atmospheric and climatic conditions. Conservation tillage, therefore, takes care of this by applying four main principles: (1) zero or minimum soil turning, (2) permanent soil cover (3), stubble mulch tillage, and (4) crop selection and rotations. An important aspect of conservation tillage practice involves ripping the land with tined implements or subsoiling the land immediately after crops are harvested, to break the plow pans. Suitable equipment includes animal-drawn subsoilers, rippers, "ridgers," planters, and weeders.

Grass Strips and Vegetative Buffers

Grass strips are the least costly and least labor-demanding soil conservation structures. They combine characteristics of both biological and structural measures. Grass strips are a popular and easy way to terrace land, especially in areas with relatively good rainfall where grass is used also as fodder. The grass is planted in dense strips, about 0.5–1 m wide, along the contour, at intervals equivalent to calculated terrace spacing. These lines create barriers that minimize soil erosion and runoff through a filtering process. Silt builds up in front of the strip, and with time, benches are formed. The spacing of the strips depends on the slope of the land. On gentle sloping land, the strips are made with a wide spacing (20–30 m), while on steep land, the spacing is about 10–15 m. The grass needs to be trimmed regularly to prevent spreading to the cropped area. The grass is cut and normally used as livestock fodder or as mulch. Many grass varieties are used, such as napier, guinea, and guatemala grass. The main drawback with grass strips is that they harbor rodents, and in dry areas, they may not survive the dry spells.

Organic Matter and Fertilizer Management

Adding manure and fertilizers to the soil supplies the plant nutrient for vigorous crop growth. The elevated nutrient levels boost crop growth, thus covering the ground quickly, protecting it from erosion, and allowing water to seep in.

Contour Farming and Contour Bands

Contour farming entails preparing the land, planting, and weeding across the slope. It slows down runoff, thus giving the water time to infiltrate into the soil. Experiments show that contour farming alone can reduce soil erosion by as much as 50% on moderate slopes. For slopes steeper than 10%, a combination of measures should be recommended. *Trash lines* made by laying crop residues along contour slow down runoff and trap eroded sediment. However, these structures can be destroyed by termites. *Grass barrier strips* planted along the contour are effective soil conservation measures on soils that absorb water quickly and on slopes as steep as 30%. The effectiveness of contour farming in water and soil conservation depends not only on the design of the system but also on the soil, climate, slope aspect, and land use. The beneficial effect is least marked on compact or slowly permeable soils because these soils become saturated quickly compared to highly permeable soil. Contour bunds have shown great potential to reduce runoff and soil loss in Southern Africa (Thierfelder and Wall 2009).

Contour bunds are soil conservation structures that involve construction of an earthen bund by excavating a channel and creating a small ridge on the downhill side. The difference from earthen bunds is in the fact that contour bunds are used for draining excess runoff from steep cultivated slopes, while earthen bunds are used for runoff harvesting usually on relatively less steep lands. Thus contour bunds resemble narrow channel terraces which in Kenya are referred to as *fanya chini* terraces. Contour bunds are used for prevention of flooding and are popular in the highland areas of Ethiopia. Contour ridges have received application in semiarid areas to harvest water and in higher rainfall areas for growing potatoes.

Agroforestry

Agroforestry practices combine the use of agricultural crops and/or animals with trees/shrubs on the same land (Kinama et al. 2007). In East Africa, two agroforestry technologies are commonly practiced: improved/managed fallow and hedgerow intercropping (alley cropping) with the aim to improve soil fertility and crop production (Sjögren 2015). Under improved fallows, fast-growing trees which are usually legumes are planted in a crop-fallow rotation (Sanchez 1999). Hedgerow intercropping is where rows of trees are combined with rows of agricultural crops. The major species that have been found to be suitable are *Leucaena leucocephala*, *Sesbania sesban* (L.), *Gliricidia sepium*, *Tephrosia vogelii*, and *Cajanus cajan* (L.). Most of the positive impacts of trees with regard to soil improvement have a direct link to soil moisture retention. A meta-analysis of maize yield response to woody and herbaceous legumes in Malawi, Zimbabwe, Zambia, Kenya, and Tanzania showed that improved fallows with *Sesbania sesban* increased maize yields by approximately 30–50% as compared to continuous maize cropping for 1–3 seasons after the fallow (Sileshi et al. 2008). Trees cushion the impact of raindrops on the soil, so reducing the amount of rain splash erosion. When planted along contours, trees can interrupt the flow of water running off the surface. Trees shade the soil, reducing soil temperature and cutting the amount of water that evaporates into the air. Trees break the wind, reducing the amount of wind erosion.

Structural Measures of Soil and Water Conservation

Structural measures of SWC in croplands often aim at changing the slope profile and are primarily constructed to control runoff and soil erosion. Their construction usually involves earth movements and requires substantial initial inputs of labor or money. These structures are often located along the contour and in marginal rainfall areas where rainfall needs to be conserved on-site. The appropriate type of physical structure depends on climate and need to retain or discard the runoff, farm sizes, soil characteristics (texture, drainage, and depth), availability of an outlet or waterway, labor availability and cost, and the adequacy of existing agronomic of vegetative conservation measures.

Diversion Ditches

Diversion ditches are surface drainage structures constructed across the field to intercept and divert surface runoff from the slope above and drain it to a safe outlet. They are used to protect cultivated lands, collect water for ponds or other storage schemes, and control development of gully heads. They are referred to as cutoff drains when constructed at the boundary between cropland and the adjacent non-arable land. Channel may either be grass lined or earth lined. Grass-lined channel is more stable and is suitable for broad shallow channels, while narrow and deep channels are often earth lined. Short ditches ($\leq$ 250 m long) are suitable in areas with highly erodible soils. On stable soils like red clay loams, the length of the channel should not be more than 500 m.

Infiltration Ditches

These are used to harvest water from roads or other sources of runoff. They consist of a ditch, 0.7–1.5 m deep, dug along the contour, upslope from a crop field. Water is diverted from the roadside into the ditch which is closed at the other end.

Water Retention Pits

These are series of pits that trap runoff and allow it to seep into the soil. The size of the pits depends on the projected amount of runoff. A typical size is 2 m^2 and 1 m deep. Vegetation such as bananas and tree crops should be planted around the pits and kept from children and livestock.

Waterways

These structures divert runoff safely from hillslopes to valley bottoms where it joins a stream or river. It may be natural or artificially made and well stabilized with grass, stone, masonry, or concrete. Reinforced concrete waterways are more efficient but have not been widely adopted by smallholder farmers due to their high cost. Creeping grasses such as signal grass (*Brachiaria humidicola*) and bahia grass (*Paspalum notatum*) are suitable for lining waterways as they cover the ground closely and require little maintenance. Generally, grass species that are weedy and those that can block the waterways and divert runoff should be avoided.

Terraces

Terracing by excavating ditches, construction of earth and some stone bunds, and vegetative barriers are normally defined as SWC structures and are primarily promoted to reduce soil erosion. On sloping lands, terracing is necessary for reducing overland flow rates, thereby contributing to water and nutrient conservation. Although terracing steep lands especially in the Eastern African region has been an indigenous technology among some communities, new methods have been evolving over the years as the need to be innovative with ever-decreasing space for cultivation grows with the population, especially in the densely populated and erosion-prone highlands. Therefore simply put, terraces are earth embankments built across a slope to intercept runoff water, reduce soil erosion, and increase in situ water infiltration. Level terraces can reduce runoff by 92% and soil loss by 87–95%, while graded terraces can reduce runoff by 77–92% and soil loss by 98%. Terraces can be designed to channel excess water into waterways or stable outlet. In East and Central Africa, three main types of terraces are used on croplands: bench terraces, *fanya juu* terraces, and channel terraces. *Fanya juu* terrace is made by digging a trench and throwing the soil upslope to form an embankment along a contour, while in *fanya-chini*, the soil is thrown downslope. Terraces are stabilized with the non-weedy grass species. In humid and sub-humid areas, farmers prefer fodder grasses like napier grass for stabilization (Plate 3).

Planning and Layout of Structural Soil and Water Conservation Measures

The main considerations when laying out terraces are indicated in Box 1. The first step to planning the structural soil and water conservation measures entails assessment of soil textural class (Hurni et al., 2016). Clay soils generally require graded structures with waterways constructed to get rid of excess runoff. Due to their good infiltration, sandy to silty soils generally need level structures with no waterways. However, with level structures, a cutoff drain is needed to remove the excess runoff. The second step in planning is to measure the slope gradient on the cultivated land that need to be conserved. For slopes with gradients less than 15% and of sandy to silty texture, grass strip is adequate. Such structures should be laid at a vertical interval of 1 m. On a 15% sloping clay soil, broad bed and furrow system should be recommended. For slopes between 15% and 50%, only contour structures should be constructed at a vertical interval of 2.5 m. Land with a slope gradient above 50% should be changed into grassland or forestland. Revegetation should be ensured on all structures.

Box 1: Considerations for Laying out Terraces

The main considerations when planning and laying SWC structures are the percent slope of the land (%S); the vertical interval (VI), defined as the difference in height between two terraces expressed in feet or meters; and the horizontal interval (HI) – the equivalent of surface distance between two terrace lines measured in feet or meters.

$$VI\ (m) = \left[\frac{(\%\mathrm{S} + 2)\ \mathrm{x}\ 0.3}{4}\right]$$

The VI is converted to the horizontal interval using the formula: $HI = \left[\frac{VI\ \mathrm{x}\ 100}{\%\mathrm{Slope}}\right]$

Soil and Water Conservation: An Overview, Plate 3 Well-developed level bench terraces with bananas planted along the terrace ditch

Gully Control, Roads, and Riverbank Protection

Gully Control

Gully erosion is geographically a widespread problem and is the worst stage of soil erosion (Xin et al. 2010; Klaus et al. 2014; Duvert et al. 2010) (Plate 4). Due to the high costs associated with gully rehabilitation, most gully control activities have in the past been implemented by the government or with external assistance. Moreover, most gullies lie on public land, e.g., grazing lands, footpaths, and farm boundaries. As such, the responsibility for their rehabilitation is usually beyond the scope of the individual. Gully can also originate from any depression such as cattle trails, footpaths, cart tracks, and traditional furrows and indicate neglect of land over long period of time. Gully control measures should be based on a clear understanding of the causes of gulling, the processes involved, and the stage of development. If a gully has reached bedrock and is stabilizing naturally, control measures may not be necessary, but possibility of reclaiming the gully for productive use should be investigated. The control of a large gully is costly and may only be justified on economic ground if it can be developed for productive purposes such as fuel-wood, fodder, bananas, or water storage.

The need for permanent or temporary structures for gully control and rehabilitation depends on an estimate of the size of catchment and expected discharge. Check dams for stabilizing gully floors should be keyed into the gully sidewalls and have a central spillway of sufficient size to take the expected discharge and a stone apron to absorb the energy of water discharged through the spillway. The spacing of check dams should be close enough so that deposition of sediments will level the ground in between. Runoff from roads is a major cause of gullying. The damage can be minimized by correct alignment of roads, diverting runoff for productive purposes, and disposing of the excess runoff through properly designed drains and waterways. When gully rehabilitation is planned, it will be important to consider the priority areas, its purpose, and the required amount and type of physical and biological structures to be used.

Soil and Water Conservation: An Overview, Plate 4 Poorly laid out gabions: if not well designed, gully control measures can lead to even more severe problem

Gully Stabilization

Consideration should be given to ways of stabilizing the gully head, floor, and sidewalls. The gully head is often the most difficult to deal with, especially if it is more than 2 m high because of the erosive power of falling water. Control structures for large gullies require an engineering design and are expensive. If the stabilization of gully head appears too costly or difficult, there are two approaches: first is to divert runoff away from the gully head so that it ceases to erode, and the second is to place a check dam close enough to the gully head so that it will trap sediment, raise the floor level, and submerge the head (Felfoul et al. 2003). The use of stepped gabions (rectangular boxes of varying sizes mostly made of galvanized steel wire woven into mesh and that are filled with either stones and placed as building blocks), brushwood carpet, sandbag, grass sods, and check dams are alternative measures which can be used for gully head treatment. In particular, check dams are constructed across the gully bed to stop channel/bed erosion. By reducing the original gradient of the gully channel, check dams diminish the velocity and erosive power of runoff flow, thus in most cases allowing vegetation an opportunity to establish.

Gully Utilization and Maintenance

Maintenance of gully control structures is a very important point worth to be emphasized. Treated gullies should be checked regularly and the healing process monitored closely. Structures built in the gully for stabilization purpose should be observed for damage especially during rainy seasons and after heavy storms. The use of gully will depend on whether it has been established to a protected waterway or the water has been diverted and the gully stabilized for other uses (Wan and Yang 2007). Under condition when the water is discharged through the gully after the necessary stabilization activities have been undertaken, the side of the gully can be used for growing grass or fodder. But in conditions when the gully is not used as a waterway, it can be used for growing horticultural crops or plants such as banana or other fruit trees.

Roads and Riverbank Protection

Road construction through steep lands without adequate provision for drainage systems is a major cause of gully erosion. For instance, studies in Kiambu District of Kenya (Mati 1984) showed that over 50% of the gullies emanate from road drainage. Thus in the early 1990s, soil conservation activities were introduced into road rehabilitation projects to protect land from damage caused by road drains (Mati 1992). However, even then, the main aim was to drain away surface runoff which was seen as a destructive problem. These perceptions were later changed in the early 2000s to embrace the concept of water harvesting, even from gullies, for productive purposes. Inadequate drainage systems for roads (small number of culverts, insufficient capacity of road ditches, etc.) are a major cause of gullying. If road cuts and fill slopes are not revegetated during or immediately following road construction, gullies may form. Although the road-caused erosion may occur anywhere in the world, the problem is particularly severe in developing countries due to neglect in maintenance and the lack of provision of safe outlets for excess runoff.

Stream bank erosion is the scouring of soil material from the stream bed and cutting of the stream banks by the force of running water. Stream bank erosion is often increased by the removal of vegetation, overgrazing, or tillage near the banks. Scouring is influenced by the velocity and direction of the flow; depth, width, and alignment of the stream; and soil texture. In order to control erosion of riverbanks, it is necessary to determine the area that is likely to be flooded and the potential area for erosion. Steep banks will be eroded and, if cultivated, should be kept under natural vegetation or planted with fodder grasses. Flat valley bottoms are often areas of deposition, and if flood waters are shallow and slow moving, they may be safely used for crops such as bananas.

Conservation of Grazing Land

General Principles

The main factors influencing erosion on grazed lands are type of grazing systems, stocking rate, forage type and growth patterns, and soil characteristics. Overgrazing leaves little vegetative cover to protect the soil from erosion, while heavy animal traffic can compound the problem by compacting the soil. Rotational grazing systems may prevent overgrazing and leave vegetation intact better than continuous grazing systems. Sustainable conservation of grazing land should be built on the recognition that these lands, besides their role in providing improved livestock feed and water, are a major source of watershed filtration, groundwater recharge, and carbon sequestration. Conservation of grazing lands should be based on effective monitoring of frequency of grazing, intensity and timing of grazing, duration of grazing, and need for reseeding.

Effect of Land Tenure on Conservation of Grazing Land

Overgrazing without effective SWC measures contributes to increased soil erosion, and in certain cases, land may be so badly degraded that it is abandoned by farmers. This is especially common in communal lands perceived to be *the land of commons*. In a study conducted in Amhara region of Ethiopia, more than 50% of the respondents felt insecure in lands they possessed without title deeds (Kahsay 2011). As a result, they were reluctant to adopt SWC measures despite their awareness on land degradation problem. In Kenya (Kisii, Vihiga, and larger part of central Kenya highlands), land tenure problems are more common in continuously fragmented lands, resulting in low adoption of soil conservation techniques. In Western Uganda, farmers adopted the use of structural soil and water conservation measures only after land registration program. The results are also consistent with the finding by Muchomba (2017), who indicated that “renting out land is common among elderly and female-headed households who lack labor power.” Such lands if rented out lack the primary care and are often overgrazed. Customary land tenure systems contribute to land degradation as they are weak in collective management of common resources.

Water Conservation on Grazing Land

In most countries, hardly any priority is given to SWC practices in grazing lands. Concentrated grazing around the watering point leads to excessive trampling which causes soil compaction and increased prevalent to soil erosion. Jawuoro et al. (2017) thus recommended that watering points should be increased in communal grazing lands to reduce animal trampling effect. Range reseeding as a strategy to rehabilitate the degraded rangelands has also been proposed (Jawuoro et al. 2017). According to the survey conducted by Violet et al. (2011), *fanya juu* and *fanya chini* terraces are gaining popularity in Kenya and have a great potential to reclaim the degraded lands. Weimer (1980) demonstrated the suitability of *C. gayana* grass strip as a cost-effective soil erosion control measure in grazing lands.

Water Harvesting Systems

The line between SWC and rainwater harvesting (RWH) technologies for crop production is very thin. SWC can be described as activities that reduce water losses by runoff and evaporation while maximizing in soil moisture storage for crop production, but the same could be said of RWH. The two are differentiated by the fact that under soil and water conservation, rainwater is conserved in situ (Box 2) wherever it falls, whereas under water harvesting, a deliberate effort is made to transfer runoff water from a "catchment" to the desired area or storage structure. The important thing is that both systems complement each other, and under rain-fed agriculture in dry areas, both are necessary nearly all the time. A lot of rainwater is lost as it falls and runs off especially in the arid and semiarid lands without any attempt to collect it. This water can be harvested and stored for later use when it is needed. Simple runoff water harvesting systems can be established from water pan, a pond 400–1000 m^3 dug in the ground to collect runoff from fields. A rock catchment is another water harvesting technique which has hardly been explored in sub-Saharan Africa. These catchments can be constructed wherever there are large rock outcrops that catch the rainwater enabling it to freely flow.

Box 2: Rainwater Harvesting Technologies

RWH technologies can be divided into two main types depending on the source of water collected. In situ rainwater harvesting are soil management strategies that enhance

(continued)

Box 2: (continued)

rainfall infiltration and reduce surface runoff and include terracing, pitting, or conservation tillage practices. The in situ systems have a relatively small rainwater harvesting catchment typically not greater than 5–10 m from point of water infiltration into the soil. The rainwater capture area is within the field where the crop is grown, and the soil serves as capture and storage medium at the same time.

Ex situ technologies are defined as rainwater harvesting systems that have rainwater harvesting capture areas external to the point of water storage where runoff on land such as grazing land or uncultivated land is collected and directed into the cultivated area by small canals or to a storage construction so that the water can be used later. The rainwater capture area varies from being a natural soil surface with a limited infiltration capacity to an artificial surface with low or no infiltration capacity. Commonly used impermeable surfaces are rooftops that can provide the platform to collect substantial amounts of water for crop production.

Agronomic Aspects of Water Harvesting

Rainwater harvesting techniques have been proposed to increase water supply for crop production in what is referred to as runoff farming. These techniques can be designed to control the development of surface runoff from a large watershed and divert it into a smaller lower-lying runoff receiving area also referred to as cultivated area. It thus makes it possible to divert the runoff water to be used for agricultural production in areas that normally do not receive sufficient rainfall. The more common methods of RWH include level contour bunds, grass strips, cutoff drains, hill terracing and graded bench terraces, vegetative barriers, conservation tillage, runoff harvesting, and innovative technologies that trap and retain soil, improve its fertility, or facilitate soil moisture conservation and storage.

Socioeconomic Factors in Water Harvesting

Low adoption rates of water harvesting systems in Africa have partly been attributed to the socioeconomic factors. Changing land ownership from customary to private tenure systems has led to the shifts in land use from forestland to cropland, thus destroying the water catchment systems. Households with low market access have been shown to exhibit low adoption of rainwater harvesting techniques in Ethiopia, Kenya, and Tanzania (Nkonya 2002). NEMA (2000) reported access to credit facilities as a necessity for effective rainwater harvesting as poor farmers have little income to invest in non-food projects. To counter the high investment costs and initial negative returns which were found to be the main hindrances to adoption and maintenance of SWC measures by smallholder farmers, there was need to gradually invest in SWC measures and the introduction of high value crops that would give better returns to investment in a shorter period. The promotion of dairy cattle under zero-grazing system was floated as an option to increase the adoption of SWC. Apart from improving yields, the implementation and maintenance of SWC measures in the long run will have economic, ecological, and social benefits.

Extension of Soil and Water Conservation

Common Approaches to Soil and Water Conservation Extension

The most common SWC approach is the Catchment Approach (1988–1998): This strategy addresses SWC measures in clearly delineated catchments. The benefits are viewed in terms of high visibility of conservation efforts, continuous treatment of farms, safe conveyance of excess runoff in the high rainfall areas, water harvesting in the arid and semiarid lands, and development of a cadre of highly specialized staff (Maeda et al. 2010). The approach is more demand driven and holistic in all technical areas.

Participatory Methods of Extension

Development of participatory methodologies in research, extension, and training has enabled faster outscaling of successful SWC interventions (Udayakumara et al. 2010). Appropriate extension tools have been developed that allow farmer participation in research and development. However, these success cases are few calling upon the need to have continuous collation of information and building on knowledge gained from the successful practices so as to reach as many farmers as possible.

Legislation for Soil and Water Conservation

The 68th UN General Assembly had declared 2015 as the International Year of Soil. The aim was to raise awareness on the importance of soils for food security and essential ecosystem functions. In addition, the Business Principles for Sustainable Soil Management ("Soil Principles") are being developed by the UNGC Food and Agriculture Business Principles (FAB Principles) to create awareness of the need to protect the soils through enlightened programs and policy and to support and strengthen the existing policies and policy frameworks on soil conservation. These "Soil Principles" will offer a reference point when considering measures to intensify agriculture or conserve ecosystems. One of the draft principles is to encourage the active participation of government and policy makers in the management of soils. In addition, the Sustainable Developments Goals (SDGs) by the United Nations provide an opportunity to elaborate the Soil Principles and place them within the greater framework of a post-2015 SDGs agenda. Countries therefore need to take advantage of this global mobilization to advocate for the sustainable management of agricultural soils as part of the post-2015 development agenda.

An unfavorable policy and legal environment in the area of SWC, under which farmers and other stakeholders operate, has exacerbated the problem of declining land productivity and land degradation (Mariara et al. 2010). In most countries, there are hardly any formal institutional arrangements between different institutions on matters relating to soil as a resource leading to lack of coordination in problem identification for investment programs and delivery of services. The policy and legal provisions relating directly or indirectly to SWC are thus scattered in a number of policies and statutes. This is due to the fact that there are many players dealing in land resource issues. In particular, the main players in soil management arena in such countries include agricultural sector ministries, departments and agencies, as well as private sector, teaching institutions, and farmer organizations.

For most countries, existing statutes are not adequately enforced to address issues of SWC particularly on cultivated slopes, along riverbanks, around water bodies, and catchment areas. With regard to the conservation of riverbanks, water bodies, and catchment areas, researchers and extension agents have recognized poor land use practices and riverbank cultivation as some of the key factors that have resulted in increased runoff, soil erosion, and siltation of dams and other water reservoirs. However, other countries such as New Zealand (New Zealand Government 2018) have well published acts that make provision for the conservation of soil resources and for the provision of damage caused by soil erosion.

Cross-References

- ▶ A Stream Heavily Laden with Sediment: Siltation Leads to Poor Water Quality
- ▶ Runoff Plots Installed at Right Angle to the Contours and Parallel to the Slope
- ▶ Well-Developed Level Bench Terraces, with Bananas Planted Along the Terrace Ditch
- ▶ Poorly Laid Out Gabions
- ▶ Considerations for Laying Out Terraces
- ▶ Rainwater Harvesting Technologies

References

Boardman J, Shepheard ML, Walker E, Foster IDL (2009) Soil erosion and risk-assessment for on- and off-farm impacts: a test case using the Midhurst area, West Sussex, UK. J Environ Manag 90(8):2578–2588

Duvert C, Gratiot N, Evrard O, Navratil O, Némery J, Prat C, Esteves M (2010) Drivers of erosion and suspended sediment transport in three headwater catchments of the Mexican Central Highlands. Geomorphology 123:243–256

Farhan Y, Zregat D, Nawaiseh S (2014) Assessing the influence of physical factors on spatial soil erosion risk in Northern Jordan. J Am Sci 10:29–39

Felfoul MS, Snane MH, Albergel J, Mechergui M (2003) Relationship between small dam efficiency and gullyerodibility of the lithologic formations covering their watershed. Bull Eng Geol Environ 62:315–322

Gachene CKK, Jarvis NJ, Linner H, Mbuvi JP (1997) Soil erosion effects on soil properties in a highland area of Central Kenya. Soil Sci Soc Am J 61:559–564

Gachene CKK, Mbuvi JP, Jarvis NJ, Linner H (1998) Maize yield reduction due to erosion in a high potential area of Central Kenya highlands. Afr Crop Sci J 6(1):29–37

Gobin A, Jones R, Kirkby M, Campling P, Goversa G, Kosmas C, Gentile AR (2004) Indicators for pan-European assessment and monitoring of soil erosion by water. Environ Sci Policy 7:25–38

Hurni H, Berhe WA, Chadhokar P, Daniel D, Gete Z, Grunder M, Kassaye G (2016) Soil and water conservation in ethiopia: guidelines for development agents. Second revised edition. Bern, Switzerland: Centre for Development and Environment (CDE), University of Bern, with Bern Open Publishing (BOP), p 134

Ighodaro ID, Lategan FS, Yusuf SFG (2013) The impact of soil erosion on agricultural potential and performance of Sheshegu community farmers in the Eastern Cape of South Africa. J Agric Sci 5:140–147

Jawuoro SO, Koech OK, Karuku GN, Mbau JS (2017) Effect of piospheres on physic- chemical soil properties in the Southern Rangelands of Kenya. Ecol Process 6(14):1–7

Kahsay T (2011) The effect of land tenure systems on soil conservation practices in northern Ethiopia: A case study of Habru District in Amhara National Regional State (ANRS). Dublin, Ireland. Retrieved from http://kimmagedsc.ie/wp-content/uploads/2013/10/Tesfu-Kahsay.pdf

Kinama JM, Stigter CJ, Ong CK, Ng'ang'a JK, Gichuki FN (2007) Contour hedgerows and grass strips in erosion and runoff control on sloping land in semi-arid Kenya. Arid Land Res Manag 21(1):1–19

Klaus DP, Sebastian O, Johannes BR, Irene M, Ali AH (2014) Soil erosion in gully catchments affected by land-leveling measures in the Souss Basin, Morocco, analyzed by rainfall simulation and UAV remote sensing data. Catena 113:24–40

Maeda E, Petri KEP, Mika S, Clark BJF (2010) Potential impacts of agricultural expansion and climate change on soil erosion in the Eastern Arc Mountains of Kenya. Geomorphology 123:279–289
Mariara JK, Linderhof V, Kruseman G, Atieno R, Mwabu G (2010) Poverty-environmental links: the impact of soil and water conservation and tenure security on household welfare in Kenya. J Dev Agric Econ 2:041–053
Martínez-Casasnovas JA, Ramos MC, García-Hernández D (2009) Effects of land-use changes in vegetation cover and sidewall erosion in a gully head of the Penedès region (Northeast Spain). Earth Surf Process Landf 34:1927–1937
Mati BM (1984) A technical evaluation of soil conservation activities in Kiambu District. Soil and Water Conservation Branch, Ministry of Agriculture, Nairobi
Mati, BM (1992) An evaluation of the needed soil conservation works along Minor Roads Programme (MRP) soil conservation. Pilot Project, Muranga District
Muchomba FM (2017) Women's land tenure security and household human capital: evidence from Ethiopia's land certification. World Dev 98:310–324
Munyahali W, Pypers P, Swennen R, Walangululu J, Vanlauwe B, Merckx R (2017) Responses of cassava growth and yield to leaf harvesting frequency and NPK fertilizer in South Kivu, Democratic Republic of Congo. Field Crop Res 214:194–201
Murillo JFM, Vicente ML, Poesen J, Sinoga DR (2011) Modelling the effects of land use changes on runoff and soil erosion in two Mediterranean catchments with active gullies (South of Spain). Landf Anal 17:99–104
NEMA (2000) Environmental economics guidelines for Uganda. National Environment Management Authority, Kampala, pp 34–46
New Zealand Government (2018) Soil conservation and River Control Act 1941. Public Act 1941 No 12. http://legislation.govt.nz/act/public/1941/0012/latest/DLM230365.html. Accessed 20 July 2019
Nkonya E (2002) Soil conservation practices and non-agricultural land use in the south western highlands of Uganda. The International Food Policy Research Institute (IFPRI), Kampala, p 29
Nyawade OS (2015) Effect of potato (*Solanum tuberosum* L.) cropping systems on soil and nutrient losses through runoff in a Humic Nitisol, thesis. University of Nairobi, Kenya, p 80
Nyawade SO, Karanja NN, Gachene CKK, Schulte-Geldermann E, Parker M (2018a) Effect of potato hilling on soil temperature, soil moisture distribution and sediment yield on a sloping terrain. Soil Tillage Res 184:24–36
Nyawade SN, Karanja N, Gachene C, Schulte-Geldermann E, Parker M (2018b) Susceptibility of soil organic matter fractions to soil erosion under potato-legume intercropping systems in Central Kenya. J Soil Water Conserv 73:568–577
Okalebo JR, Othieno CO, Woomer PL, Karanja NK, Semoka JRM, Bekunda MA, Mugendi DN, Muasya RM, Bationo A, Mukhwana EJ (2006) Available technologies to replenish soil fertility in East Africa. Nutr Cycl Agroecosyst 76:153–170
Otieno HM, Chemining'wa GN, Zingore S (2018) Effect of farmyard manure, lime and inorganic fertilizer applications on soil pH, nutrients uptake, growth and nodulation of soybean in acid soils of Western Kenya. J Agric Sci 10(4):199–208
Pimentel D (2006) Soil erosion: a food and environmental threat. Environ Dev Sustain 8:119–137
Pincus L, Margenot A, Six J, Scow K (2016) On-farm trial assessing combined organic and mineral fertilizer amendments on vegetable yields in Central Uganda. Agric Ecosyst Environ 225:62–71
Renschler CS, Harbor J (2009) Soil erosion assessment tools from point to regional scales-the role of geomorphologists in land management research and implementation. Geomorphology 47:189–209
Rodrigues MÂ, Ladeira LC, Arrobas M (2018) Azotobacter-enriched organic manures to increase nitrogen fixation and crop productivity. Eur J Agron 93:88–94
Sanchez PA (1999) Improved fallows come of age in the tropics. Agrofor Syst 47:3–12
Sileshi G, Akinnifesi F, Ajayi K, Oluyede C (2008) Meta-analysis of maize yield response to woody and herbaceous legumes in sub-Saharan Africa. Plant Soil 307:12–19
Sjögren H (2015) Agroforestry systems with trees for biomass production in Western Kenya. Department of Forest Ecology and Management Swedish University of Agricultural Sciences, Umeå. PhD thesis, p 43
Tesfahunegn GB, Tamene L, Vlek PLG (2014) Soil erosion prediction using Morgan-Morgan-Finney model in a GIS environment in Northern Ethiopia catchment. Appl Environ Soil Sci. https://doi.org/10.1155/2014/468751
Thierfelder C, Wall PC (2009) Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. Soil Tillage Res 105:217–227
Udayakumara EPN, Shrestha RP, Samarakoon L, Vogt DS (2010) People's perception and socioeconomic determinants of soil erosion: a case study of Samanalawewa watershed, Sri Lanka. Int J Sediment Res 25:323–339
Valentin C et al (2008) Runoff and sediment losses from 27 upland catchments in Southeast Asia: impact of rapid land use changes and conservation practices. Agric Ecosyst Environ 128:225–238
Violet NG, Gachene CKK, Ngugi JN, Thuranira EG, Baaru MW (2011) Adoption and opportunities for improving soil and water conservation practices in Kathekakai settlement scheme, Machakos District
Wan R, Yang G (2007) Influence of land use/cover change on storm runoff-a case study of Xitiaoxi River Basin in

upstream of Taihu Lake watershed. Chin Geogr Sci 17:349–356

Weimer CG (1980) Soil conservation in Kenya especially in small-scale farming in high potential areas using labor intensive methods, farm management branch project management and evaluation division ministry of agriculture, Nairobi

Xin Z, Yu X, Lu X (2010) Factors controlling sediment yield in China's Loess Plateau. Earth Surf Process Landf 36(6):816–826

Yannelli FA, Tabeni S, Mastrantonio LE, Vezzani N (2013) Assessing degradation of abandoned farmlands for conservation of the Monte Desert Biome in Argentina. Environ Manag 53(1):231–239