Technical Manual No. 24

A guide for selecting the right soil and water conservation practices for small holder farming in Africa

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World Agroforestry Centre

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World Agroforestry Centre (ICRAF)

The World Agroforestry Centre (ICRAF) is one of the Centres of the CGIAR Consortium. Its vision is rural transformation in the developing world as smallholder households increase their use of trees in agricultural landscapes to improve food security, nutrition, income, health, shelter, social cohesion, energy resources and environmental sustainability. The Centre's mission is to generate science-based knowledge about the diverse roles that trees play in agricultural landscapes, and to use its research to advance policies and practices, and their implementation to benefit the poor and the environment.

Pro-poor Rewards for Environmental Services in Africa (PRESA)

Pro-poor Rewards for Environmental Services in Africa (PRESA) project is coordinated by the World Agroforestry Centre (ICRAF) - works at sites in Kenya, Tanzania, Uganda and Guinea to facilitate fair and effective agreements between stewards and beneficiaries of environmental services.

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Acknowledgements

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Introduction

A major requirement in watershed management is establishing soil and water conservation technologies. Many of these have existed over a long time, but information to support selection of those that are appropriate for ecological and socio-economic conditions, has not been readily available to farmers and field officers. This technical manual presents a compilation of twenty technologies that have potential for watershed management within the tropical landscape especially in Africa. It presents simple descriptions of the technologies and instruction for establishing them, where they are appropriate and potential costs. A summary at the end supports users to decide on technologies that are appropriate for their conditions.

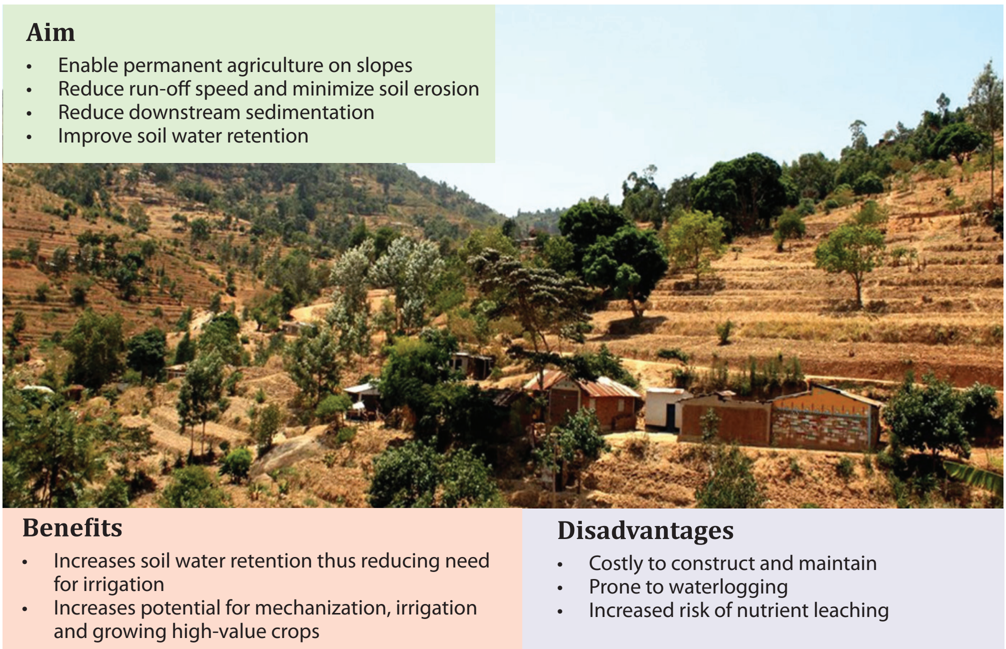
FIELD LEVEL PRACTICES

1) Bench terraces

Bench terraces consist of a series of beds which are more or less level running across a slope at vertical intervals, supported by steep banks or risers (walls or bunds). The flat beds created by bench terraces enable the cultivation of crops on medium to steep slopes[1].

Where suitable

1. Semi-arid to humid regions of rainfall, 700 mm or more.
2. Medium to steep slopes (12- 47%). Bench terraces are not recommended for slopes less than 12%[2]. Small farm size (less than 4 ha)
3. Soil depth of greater than 50 cm
4. Areas with no gullies, nor stones



www.projectsurvivalmedia.org | Joe Lukhovi

Figure 1-1: Bench terraces constructed along a slope in Lukenya, Machakos County in Kenya[3]

[1] UNEP DTIE, 1998

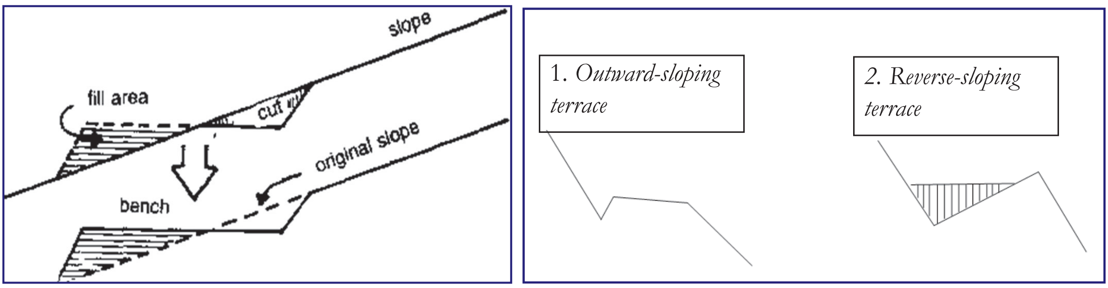
[2] Altshul et al., 1996

[3] Lukhovi, 2012

Design and construction

Terraces draining in one direction should be at least 100 m or more. The length can be slightly increased in arid and semi-arid regions. The width of the bench (flat part) is determined by soil depth, crop requirements, and tools to be used for cultivation[4]. Optimum width of terrace benches ranges from 2.5 to 5 m for manually constructed ones and from 3.5 to 8 m for machine built and tractor-cultivated ones.

Terraces should drain runoff along the horizontal gradient of the slope, either in outward or reverse direction. The outward gradient can range from 0.5% in arid or semi-arid regions to 3% in humid regions with clay soils. Maximum gradients can be 5% for reverse terraces. In high rainfall areas (more than 1000 mm annually), it is necessary to make additional drainage provisions off the terraces – although this has a risk of causing erosion on very steep slopes. These additional drainage channels should be trapezoidal in shape and planted with grass to prevent erosion. Machine construction is possible on slopes of 12 - 36% while manual construction can be used on slopes of 12 - 47%[5].



a) The cut and fill procedure used to construct bench terraces (b) Types of bench terraces in cross section

Figure 1-2: Bench terrace construction[6]

Cost

Terracing is costly. The cost increases with increasing width of the bench and steepness of the slope. Where labour is expensive, machine-built terraces can be cheaper[5].

[4] Hatibu and Mahoo, 2004
[5] Ngigi, 2003
[6] DENR and IIRR, 1992

2) Check dams

A check dam is a small temporary or permanent barrier constructed of rock, gravel bags, sandbags, fiber rolls, or reusable products, placed across a gully, channel or drainage to lower the speed of flows from storm events. Check dams ease the slope of a gully by providing periodic steps of fully strengthened material that collect and hold soil and moisture at the bottom of the slope[7]. Check dams enable growing of tree seedlings, shrub and grass in gullies by protecting them from being washed away by flowing water.

Where Suitable

1. Dry regions with annual rainfall of 700 mm or less
2. Slopes of less than 2%
3. Small streams, long gullies or small open channels that drain 4 ha of land or less.
4. Areas with a local supply of stones or the means to transport them
5. Productive land prone to gully and rill erosion

Aim

- Interrupt runoff to reduce flow speed and erosive activity
- Reduce effective slope of channel
- Filter sediment

Benefits

- Low cost and relatively easy to construct
- Reduces erosion and increases sediment deposition
- Allows percolation to recharge aquifers

Disadvantages

- Effective only in channels draining 4 ha or less
- Ineffective with large storm events
- Extensive maintenance with periodic sediment removal
- Difficult to dismantle if temporary

Figure 2 1: Stone check dams constucted along a gully in Zefie watershed, Amhara region in Northern Ethiopia[8].

[7] Mati, 2002

[8] Pfeifer, 2012

Design and Construction

Check dams are built using rocks arranged in sequence such that the base of the previous dam is at the same height as the top of the second dam. Stones with a diameter of 10-35 cm are suitable, easily maneuvered by a single person, but large enough not to be dislodged by flowing water. Shale and sandstone should be avoided as they wear away easily. Permanent check dams are built with stones, bricks and cement.

Rock check dams should have a notched, "V" or "U" shape with the center portion at least 15 cm lower than the sides to prevent normal runoff from going around the dam, and eroding the sides of the channel[9]. The check dam height is often about ¼ of the base width.

The foundation of the dam should extend below the soil surface to bedrock or for at least 30 - 50 cm to prevent water from undercutting the check dam structure. Lateral trenches should be dug into the sides of the gully to extend the check dam into the sides to stabilize the dam.

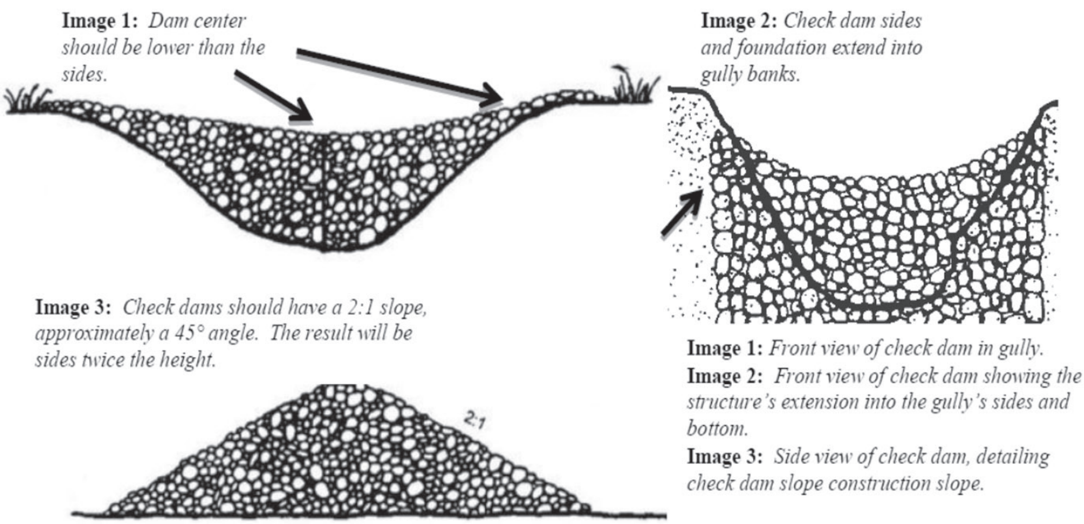


Figure 2-2: A stone check dam profile[9]

Cost

The cost of a check dam is about $200-400 for a temporary structure and about $1,000 – 3,000 for a permanent structure depending upon the materials used, and the length and height of the obstruction desired[10]. Periodic inspection and maintenance is required.

[9] Ruffino, 2009
[10] Ruffino, 2009

3) Contour bunds and hedgerows

Contour bunds are stone or earthen walls built across a slope to prevent runoff. Making furrows parallel to the contours ensures that rainfall and runoff are spread evenly over a field[11]. The earthen bund is formed by excavating a channel and creating a small ridge on the downhill side. Thus contour bunds resemble narrow channel terraces, which in Kenya are referred to as "*fanya chini*" terraces[12]. Hedgerows of nitrogen-fixing trees/shrubs, grasses, fruit trees or other crops can also be planted in rows along the contour.

Where suitable

1. Areas with relatively low annual rainfall (500 - 800 mm)
2. Light textured soils of 1.5 to 2 m depth
3. Gentle to moderate slopes (0.5-3%)
4. Areas with no gullies or rills
5. Large land areas (contour hedgerows cover at least 10% of cultivated land)

Aim

- Reduced runoff and soil erosion
- Increase soil water retention capacity

Advantages

- Improves soil structure and water infiltration
- Hedgerows provide wood and leafy biomass

Limitations

- Increased risk of soil erosion if contours improperly laid out
- Competition for space, light, soil nutrients and moisture between hedgerows and crops
- Hedgerow may attract pests

Figure 3-1: Contour hedgerows along contour bunds in Kenya[13]

[11] Thomas, 1997

[12] Mati, 2005

[13] Black, 2014

Design and construction

Soil is excavated up-slope of the bund to a depth of 50 cm. Contour bunds should drain in one direction and can be manually or machine constructed. The length of a bund across a slope should be between 400 to 500 m. The height of a bund should be at least 25 cm and have an approximate spacing of 1-2 m. In arid areas, the distance between bunds can be increased to 5-10 m. Hedgerows grown to stabilize bunds should be spaced at 4 to 8 m across the slope.

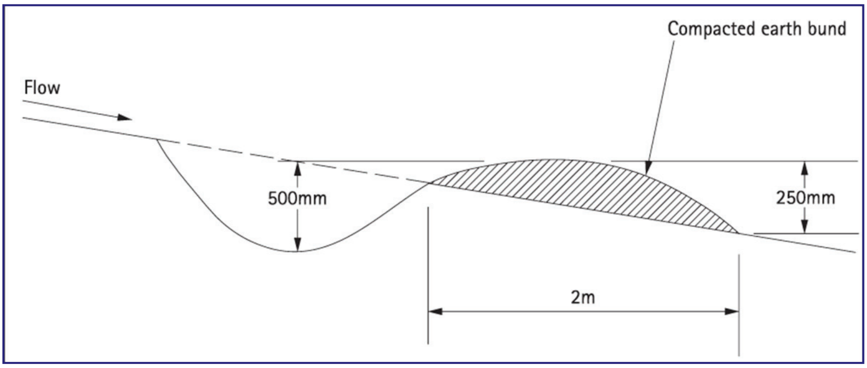


Figure 3-2: Cross section of a contour bund[14]

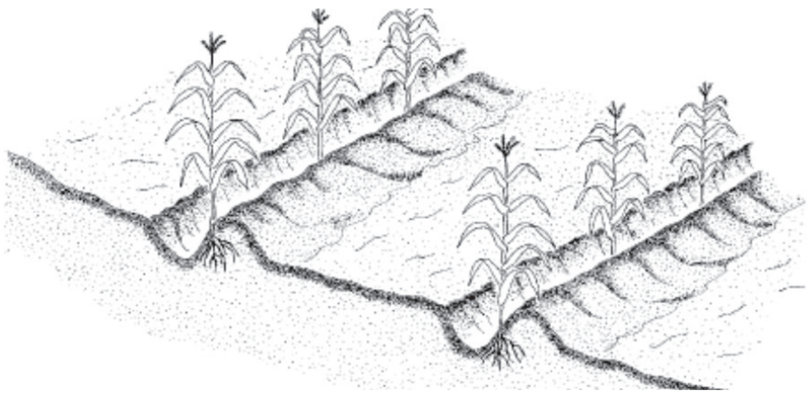


Figure 3-3: Crops planted along contour bunds[15]

Cost

Contour bunds are inexpensive to construct since they can utilize locally available materials[16]. However, contour hedgerows require high labor maintenance and are thus unpopular.

[14] Reij, et al 1996
[15] Duveskog et al., 2003
[16] Reij, et al 1996

4) 'Fanya juu' terraces

Fanya juu terraces (juu is Swahili word for 'up') are constructed by excavating soil and throwing it up-slope to make an embankment. The embankment forms a runoff barrier and the trench (ditch) is used to retain or collect runoff. The embankments are usually stabilized with fodder grasses. Crops, such as bananas, pawpaws, citrus and guava, are grown in the ditches[17]. Through gradual redistribution of soils within the field, the terraces level off.

Where suitable

1. Low annual rainfall areas (less than 700 mm).
2. Moderate slopes (less than 20%)
3. Deep soils (more than 60 cm)
4. Hilly areas that are subject to widespread erosion.

Aim

- Soil erosion control
- Water harvesting

Advantages

- Improved soil structure
- Increased crop yield

Disadvantages

- High labor demand
- Un-stabilized bunds are very susceptible to erosion

Figure 4-1: A fanya juu terrace in Kapingazi watershed in Embu, Kenya[18]

[17] Malesu et al., 2007

[18] Photo credit: F. Mokua

Design and construction

The '*fanya juu*' trench is 60 cm wide by 60 cm deep, and the bund 50 cm high by 150 cm across[19]. In arid regions the trenches can be enlarged to 150 cm deep and 100 cm wide. Distance between bunds can be from 5 m on steep slopes to 20 m on gentle slopes[17]. Stone terrace walls can be built to reinforce the bunds on very steep slopes to allow surplus water to pass between the stones without damaging the terrace. Excess water can be drained from the trenches using cutoff drains.

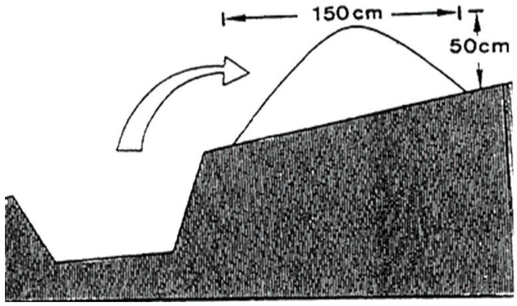


Figure 4-2: Construction of the *fanya juu* terrace[20]

Figure 4-3: Banana trees planted in a *fanya ju*u ditch in Kapingazi watershed in Embu, Kenya[21]

Cost

Labor required for construction is estimated at 150 to 350 person days/ha for terraces and cutoff drains. Fanya juu terraces require regular maintenance of the embankment[5]

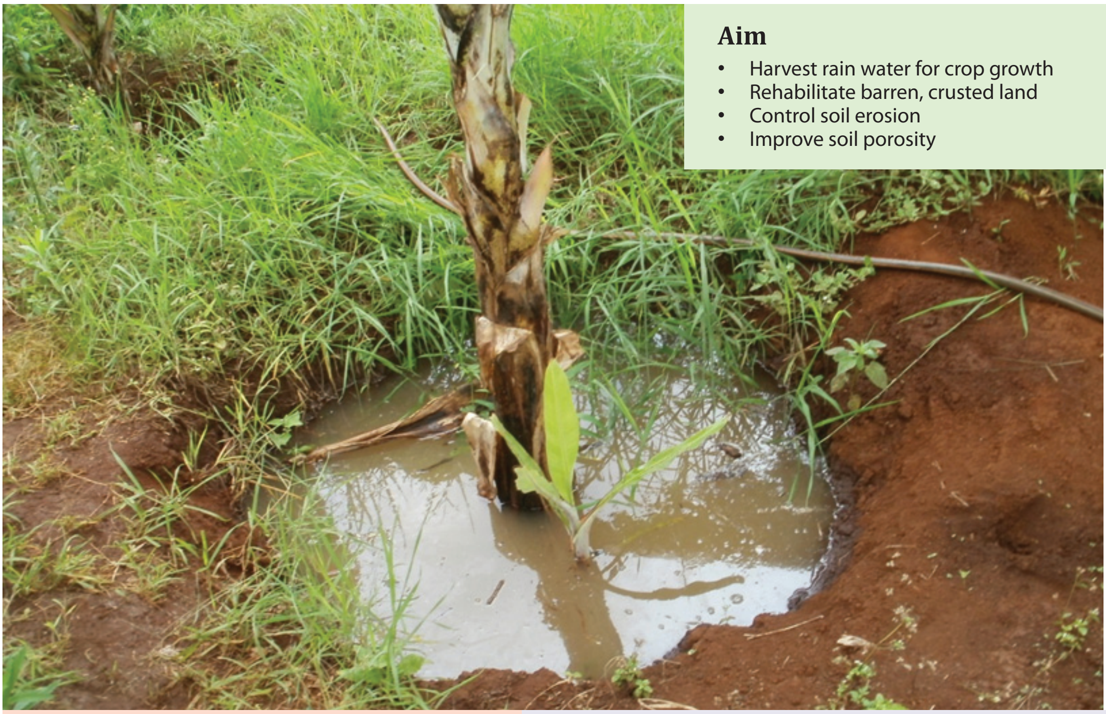
[19] Itabari & Wamuongo, 2003
[20] Critchley et al., 1999
[21] Photo credit M. Makela/PRESA

5) Planting Pits / Zai pits

Planting/zai pits are holes dug to collect and retain runoff to allow infiltration into the soil. They are usually fertilized with plant debris or compost. Zai pits are primarily used to cultivate crops for example sorghum, maize, millet, cowpeas, sweet potatoes, groundnuts and bananas[5, 20].

Where suitable

1. Arid to semi-arid areas (annual rainfall of 200-750 mm)
2. Gentle slopes (less than 5 %)
3. Soils of limited permeability e.g., silt and clay, where tillage is difficult



Aim

- Harvest rain water for crop growth
- Rehabilitate barren, crusted land
- Control soil erosion
- Improve soil porosity

Advantages

- Flexible and easily adaptable design and technique
- Improves groundwater recharge

Disadvantages

- High labor requirements for construction and maintenance
- Prone to water logging in very wet years

Figure 5-1: A banana tree planted in a Zai pit in Kapingazi watershed in Embu, Kenya[21]

Design and construction

Zai pits are 5-15 cm deep, 15-50 cm wide and 80-100 cm apart. In dry areas the size of planting pits can be enlarged[12]. Compost or manure is placed in the pits before planting to improve soil fertility. It is not necessary to follow the contour when constructing pits.

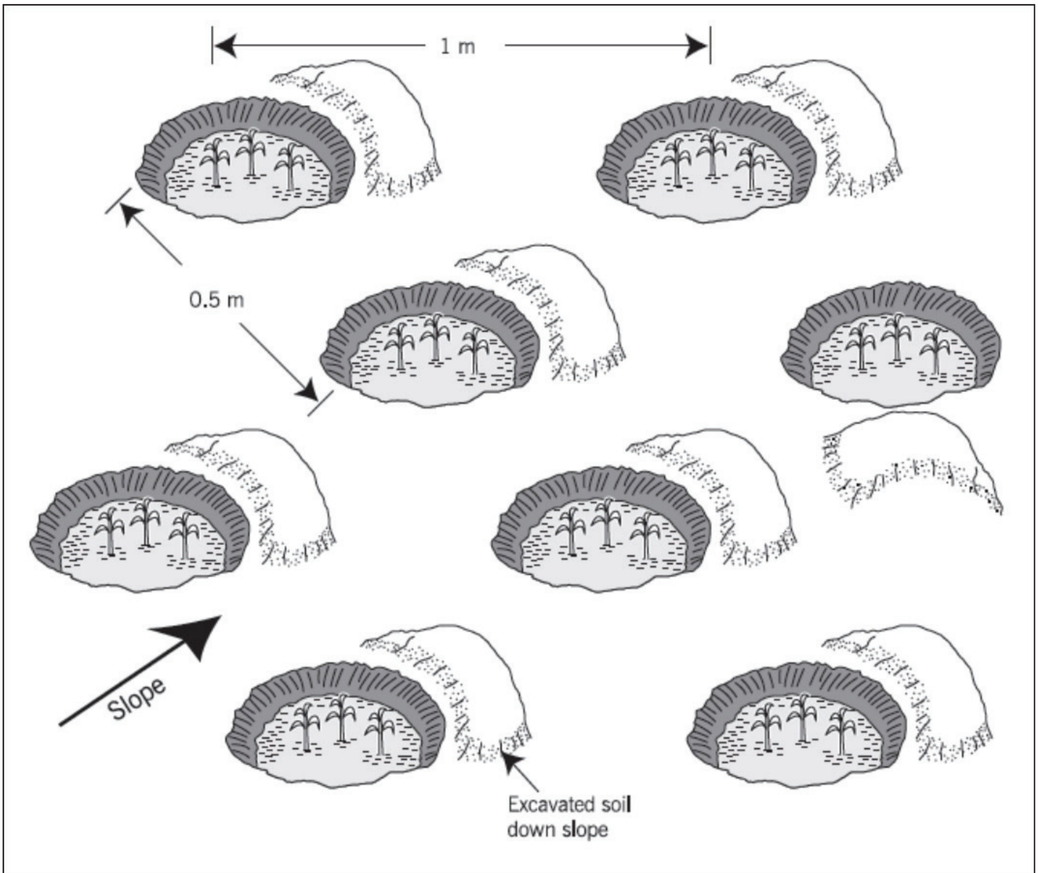


Figure 5-2: Layout of zai pits constructed on a gentle slope[17].

Cost:

Labour for pit construction entails 30-70 person days/ha for digging the holes and 20 person days/ha for fertilization with manure or compost[17]. Pits are easy to maintain, occasional repairs may be needed after heavy storms[5].

6) Katumani Pits

Katumani pits are small, interlocking mini-catchments using a pitting and ridging technique coupled with planting native grasses and legumes[1,22].

Where suitable (as for Zai pits)

Aim: Rehabilitation and cultivation of degraded land

Advantages

- Enables crop cultivation over a wide moisture regime including high water demanding crops e.g. bananas and maize
- Stabilizes soils

Disadvantage

Labor intensive

Figure 6-1: Preparation of Katumani pits for crop production in Katumani community, Machakos County in Eastern Kenya[23].

Design and Construction

Pits are crescent-shaped, about 15 cm deep and 20 cm wide with downslope embankments of about 30 cm height[12]. Pitting can be extended down the slope as convenient and necessary. Cow peas, or other ground cover crop, can be sown on the ridges to stabilize them during the first growing season.

[22] Itabari et al., 2004
[23] Domfeh, 2013

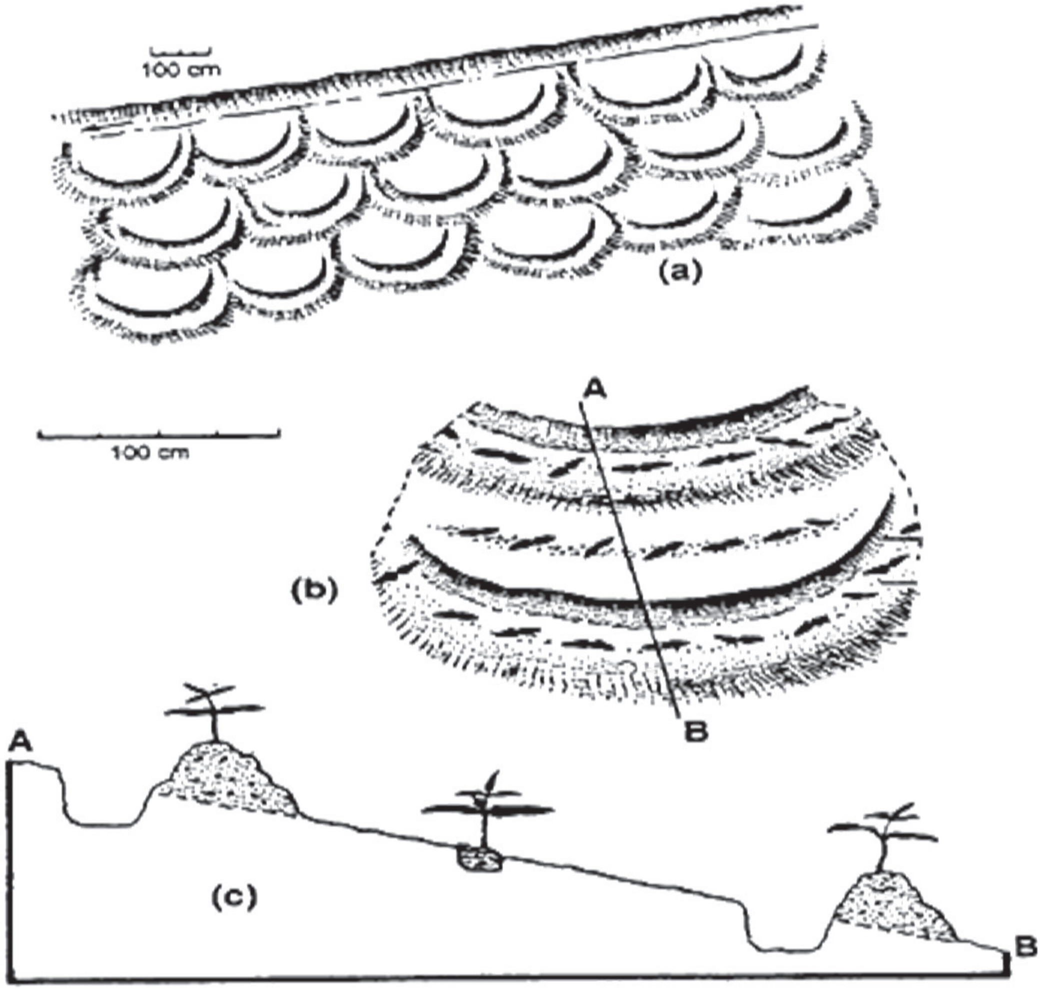


Figure 6-2: Cross sectional views of Katumani pits in plan (a and b) and cross sectional views[24]

Cost

Costs are primarily related to labor costs of about $100 to $150/ha. To establish a ground cover crop, fertilizers may be needed, especially where severe loss of topsoil has occurred[1].

[24] Institute of Water and Sanitation Development, 1998

7) Stone lines

Stone lines are stones placed along contour lines to slow down runoff. With time, the soil builds up on the upslope side of the stone line and a natural terrace is formed[11].

Where suitable

1. Gentle to moderate slopes (less than 10%)
2. Low annual rainfall areas (200 - 750 mm)
3. Stony areas

Aim

- Slow down runoff
- Induce a natural process of terracing
- Rehabilitate eroded and abandoned land

Advantages

- Increased infiltration and soil moisture
- Reduced erosion

Disadvantages

- Labor intensive
- Rodents and reptiles may hide under stone lines

Figure 7-1: A close view of a stone line in in Turasha watershed in Naivasha, Kenya[25]

Design and construction

Stone lines are 35-40 cm wide and approximately 25 cm high. Construction includes a shallow foundation trench of 5-15 cm made along the natural contour with larger stones on the down-slope side of the trench and smaller stones are used to build the rest of the bund. The stone lines can be reinforced with earth, or crop residues. Stone lines are spaced 15 - 30 m apart; spacing may be reduced for slopes greater than 10%[26, 11].

[25] Photo credit: E. Obwocha
[26] Critchley, 1991

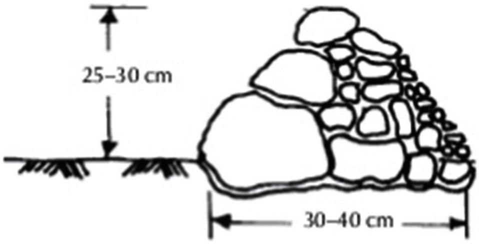


Figure 7-2: Cross section of a stone line[27]

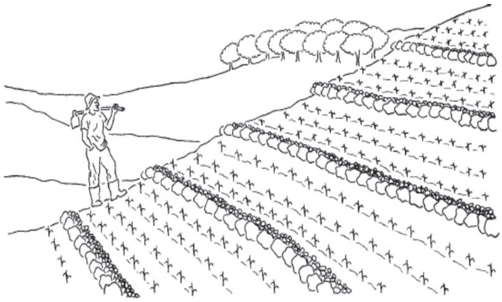


Figure 7-3: Stonelines along a contour[15]

Figure 7-4: Stone lines across a slope in Kibungo, Ulugurus, Tanzania[21]

Figure 7-5: Stone lines across a slope[28]

Cost

Stone lines are easy to design and require very low maintenance, although construction is labor demanding. The structure is also permeable, thus does not require spillways to drain excess runoff[11].

[27] Awulachew et al., 2009
[28] TNAU, 2013

8) Trash lines

Trash lines are formed by placing crop residues in lines across the field slope to form a semi-permeable barrier to soil erosion that allows passage of excess runoff[26]. The lines are temporary, usually seasonal[29] and the trash can be moved into the field to exploit trapped soil fertility gains[30].

Where suitable

1. Semi-arid areas (400 - 750 mm)
2. Slopes 2-30%

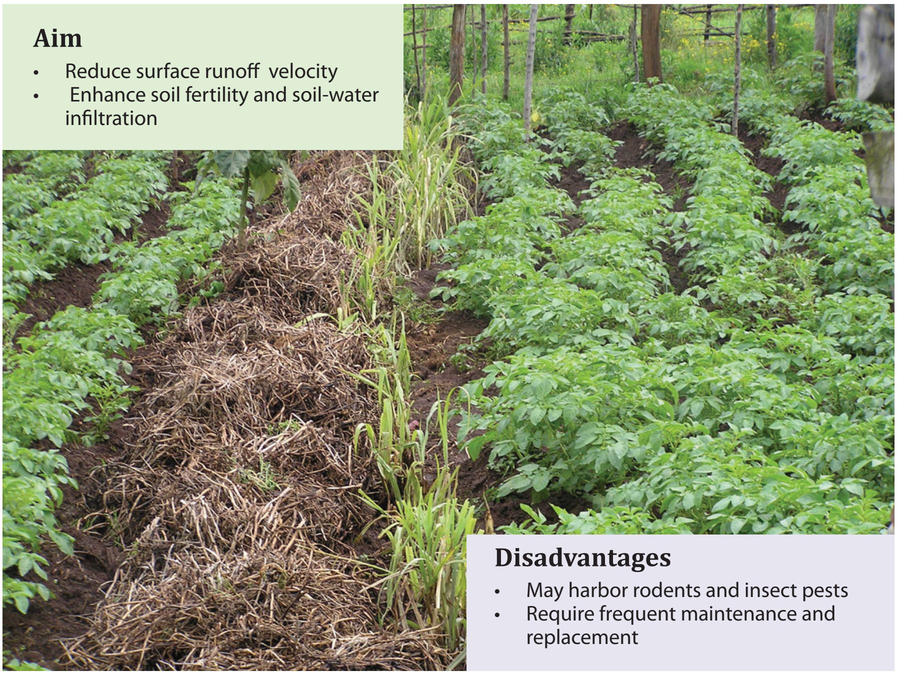


Figure 8-1: Trash lines on- farm in Turasha watershed in Naivasha, Kenya[25]

Design and construction

Trash lines (typically ± 50 cm wide and ±30 cm high) are constructed mainly from sorghum and millet stovers which, compared to maize decompose slowly and are of low palatability to livestock[2]. Spacing between trash lines is 5 - 10 m, depending on the slope. Trash lines can be left in place for four seasons before they are ploughed into soil.

[29] Wakindiki et al., 1998
[30] Tengberg et al., 1998

Figure 8-2: Making a trash line in Kabale, Uganda[31]

Figure 8-3: Trash lines on a gentle slope[32]

Cost

Trash lines are have low establishment cost although maintaining the grass can be labor-demanding[31].

[31] WOCAT, 2012
[32] Photo credit: Berhanu Fentaw, Addis Ababa, Ethiopia (Reproduced from WOCAT, www.wocat.net)

9) Grass strips

Grass strips are dense strips of grass panted up to a meter wide, along a contour. With time, silt builds up above the strip and benches are formed. Grass strips can be planted along ditches to stabilize them, or on the rises of bench terraces to prevent erosion. They are a popular and easy way to terrace land, especially in areas with relatively good rainfall [12, 33].

Where suitable

1. Fairly gentle slopes (0 - 6%)
2. Areas where grass is needed for fodder
3. High rainfall areas.

Aim: To create barriers to reduce soil erosion and runoff

Advantage	**Disadvantage**
Fodder or mulch supply	• High labor demand for maintaining and controlling grass from becoming a weed • Reduced land area for crop production • Planting materials might not be available locally

Figure 9-1: Grass strips planted along a slope in Malewa watershed in Naivasha, Kenya[25]

Design and construction

Spacing between grass strips depends on the slope of the land. It can be 20-30 m on gentle slopes and 10-15m on steep land. Grass strips can be planted along ditches to stabilize them, or on the rises of bench terraces to prevent erosion. The grass needs to be trimmed regularly, to prevent shading and spreading to cropped areas. Various grass species are used, e.g., Vetiver, Napier, Guinea and Guatemala depending on what is locally available[15, 34]. Vetiver grass is drought-resistant and good for reducing erosion.

[33] Stone, 1994

[34] Roothaert et al.,1997

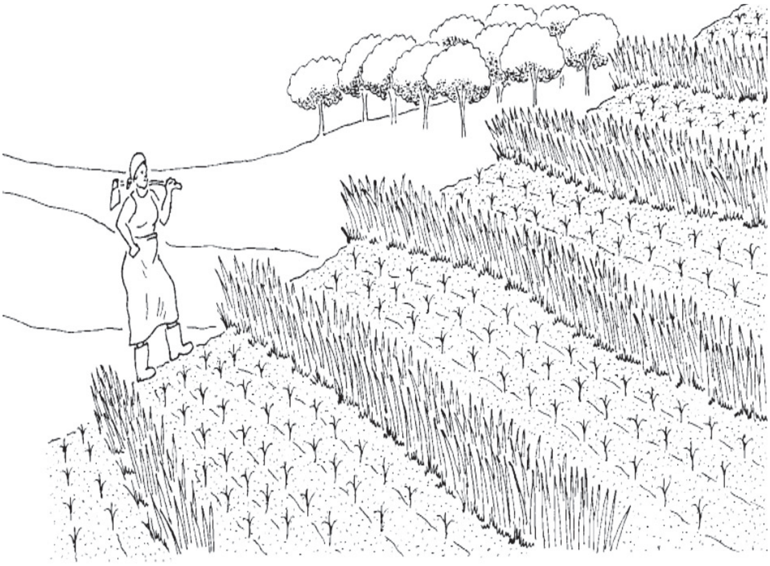


Figure 9-2: Grass strips along the contour[15]

Figure 9-3: Grass strip in Kapingazi watershed in Embu, Kenya[35]

Costs

Grass strips are a cheap alternative to terracing and involve low establishment cost although maintaining the grass can be labor-demanding.

[35] Photo credit: PRESA

10) Grassed waterway

Grassed waterways are broad shallow natural or constructed channels for transporting large water flows down slope and across farmlands without causing soil erosion. The channels are cultivated with vegetative cover (usually grass) to slow down the water flow and minimize channel surface erosion. They can be used as outlets to prevent rill and gully formation, or as outlets for water released from contoured and terraced systems and diverted channels[36].

Where suitable

1. Slopes of less than 20%
2. High rainfall intensity where excess run-off is frequent
3. Soils with low infiltration rates
4. Cultivated fields with terracing systems
5. Areas with a water body downstream threatened by contaminants from uplands

Aim

- Reduce sediments and pollutants in runoff
- Improve soil aeration and water quality

Advantages

- Prevents flooding
- Retards insoluble contaminants in run off
- Disperse runoff, thereby minimizing gully erosion
- Easy to use with mechanisation

Disadvantages

- Costly to construct (grading slopes and grass establishment)
- Reduces space for pasture or crops
- Unchecked vegetative growth may limit drainage and hinder movement of farm equipment

Figure 10-1: A grassed water way to drain excess runoff in Kapingazi watershed in Embu, Kenya[35]

36 Pfost and Caldwell, 1993

Design and construction

A grassed waterway should be saucer-shaped (Figure 11-2). This shape spreads the water, thus reducing its velocity and erosive force. The side slopes should rise no more than 25%. Side slopes can be flattened to allow easier crossing by farm equipment. The bottom width of the waterway should be 3 m (minimum) to allow construction with a grader or scraper. The bottom of the waterway should be kept level during shaping and seeding of grass, so runoff will be spread evenly over the bottom.

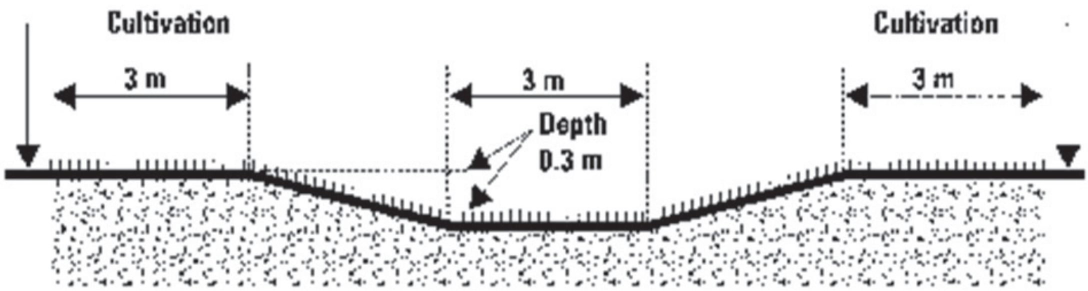


Figure 10-2: Cross-section of a typical grassed waterway[37]

Figure 10-3: Grassed waterway on a farm in Kenya[38]

Cost

The cost of establishing grassed waterways varies depending on the equipment and labor used for grading and planting, the seed and fertilizer used. However in most cases, where no additional structures are made, grassed waterways are cheap to construct. Grass can be harvested from waterways and used as fodder or hay[39].

[37] ARD, 2002
[38] Knoop et al., 2012
[39] FAO, 1989

11) Retention ditches

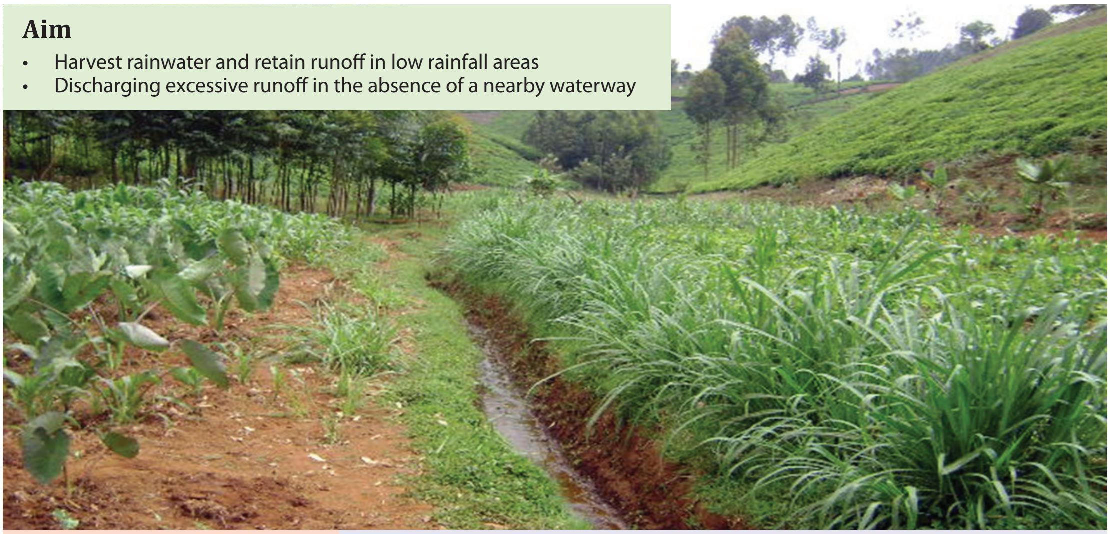
Retention ditches are designed to catch and retain incoming runoff and hold it until it infiltrates into the ground. They can be an alternative to waterways in high rainfall areas, but they are most often used in semi-arid areas to harvest water[11].

Where suitable

1. Semi-arid areas
2. Permeable, deep and stable soils
3. Flat or gentle sloping land

Aim

- Harvest rainwater and retain runoff in low rainfall areas
- Discharging excessive runoff in the absence of a nearby waterway



Advantages

- Improve soil moisture.
- Enables growth of a wide variety of crops in dry areas

Limitations

- May overflow and collapse during heavy rainfall seasons causing gully erosion
- High labor demands for construction, regular maintenance and de-siltation

Figure 11-1: Retention ditch to hold runoff in Malewa watershed in Naivasha, Kenya[25]

Design and construction

The ditches are dug to about 30 - 60 cm depth and 0.5 - 1 m width across the direction of the slope. In very stable soils it is possible to make the sides nearly vertical, but in most cases the top width of the ditch needs to be wider than the bottom width. The soil is thrown to the lower side of the slope to prevent it falling back in and form an embankment. On flat land, ditches are spaced at about 20 m and have closed ends so that all rainwater is trapped. On sloping land ditches are spaced at 10 - 15 m intervals and may have open ends to discharge excess water[40].

[40] FAO, 2000

Figure 11-2: Retention ditch for holding rainwater for irrigation[41]

Figure 11-3: Farmers in Mulala division, Makueni, Kenya being trained on how to establish retention ditches to harvest rainwater[42]

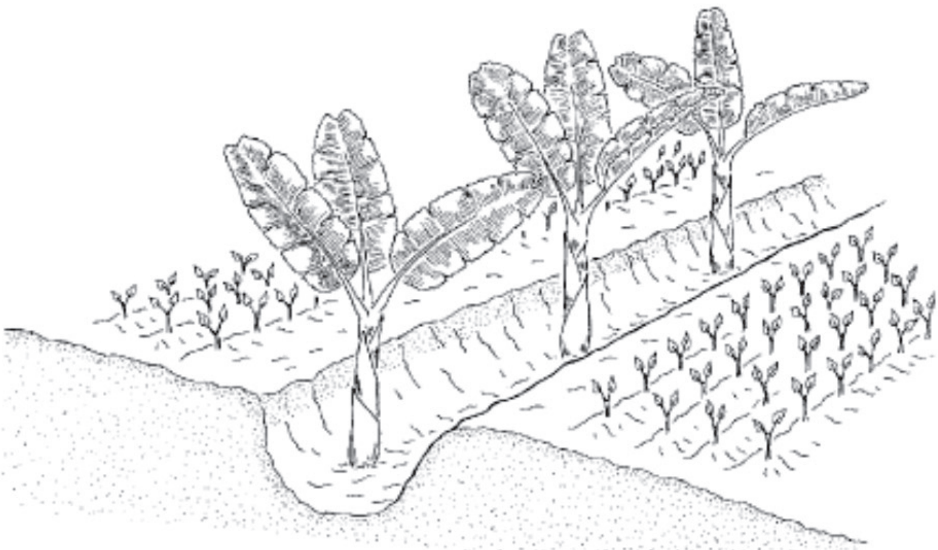


Figure 11-4: Retention ditch planted with banana trees[15]

Cost

Retention ditches require regular maintenance and de-siltation of the channels. They are demanding to construct and thus have high costs of labor.

[41] Hushållningssällskapet, 2012
[42] Africa Harvest Biotech international, 2014

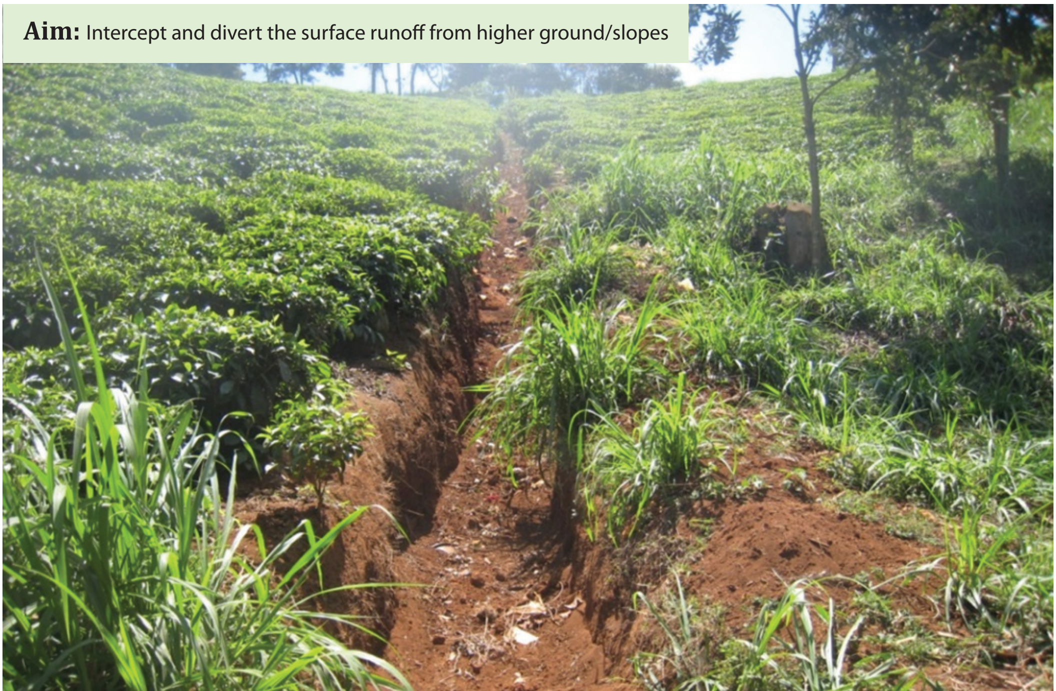
12) Cut-off Drains

Cut-off drains are also referred to as diversion ditches or catch drains. They are dug approximately along the contour of a slope to intercept surface runoff and carry it safely to an outlet such as a canal or stream. They are used to protect cultivated land, compounds, and roads from uncontrolled runoff, and to divert water from gully heads. Poorly maintained drains pool water causing concentrated damage may threaten slope stability. Wherever possible the cut-off drains should be diverted to a natural watercourse.

Where suitable

1. Draining water from relatively small areas of land (less than 15 km^2)
2. Medium to deep soils (20 - 120 cm)
3. Hilly to steep slopes
4. Relatively high rainfall areas (1000 - 2000 mm a year)

Aim: Intercept and divert the surface runoff from higher ground/slopes



Advantage

Reduce downstream siltation

Limitations

- Tendency to silt up quickly
- Constant maintenance

Figure 12-1: An earthen cut-off drain in tea plantation in Kapingazi, Embu Kenya[21]

Design and Construction

Siting of cut-off drains should take into consideration changes to the natural flow patterns of water. Cut-off drains have a trapezoidal cross-section. They have a width of 30 – 40 cm and a gradient of 15 - 50% to facilitate draining of runoff. The excavated soils should always be deposited on the downhill side of the drain and should be properly stabilized so it is not washed away during rains. The risk of silting can be reduced by making sure there is a continuous downhill gradient at the base of the drain and that there is a clear outlet at the end. Grass should be planted along the sides of the drain to protect them from erosion. The inside wall and bottom may be lined with cement.

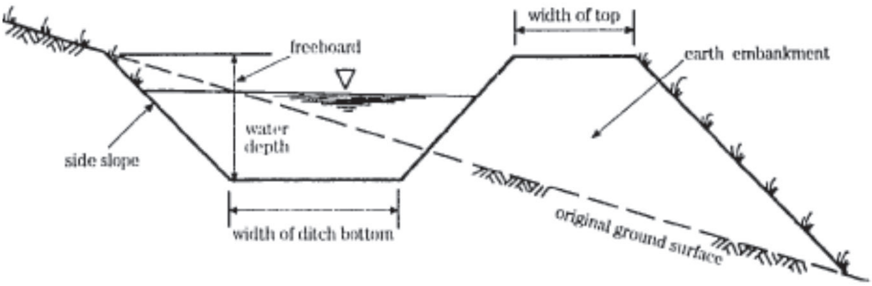


Figure 12-2: Cross section of a trapezoidal cut-off drain[43]

Figure 12-3: Concrete lined cut-off drains in Kapingazi, Embu Kenya.[35]

Cost

Digging of the ditch costs vary but for the case of Kenya, the cost was estimated at about US$ 4.20/ha[31]. Earth cut- off drains, are relatively cheaper to install in any field than cement lined cut-off drains.

[43] FAO, 1988

13) Mulching

Mulching is the covering of soil between crop rows or around trees with materials, rougher than the surface of the soil to protect it from splash erosion and formation of crust[27]. Different materials are used, including organic mulch (from e.g. grass, straw, hay, bark, leaves, husks sand, sea shells, pine needles, gravel, and stone) and synthetic mulch (from e.g. newspaper, plastics, glass, crushed brick, plastic and rubber).

Where suitable

1. Drought and weed prone areas
2. Low to medium annual rainfall areas (Mulching is not suitable in wet conditions)
3. Soils with good drainage

Aim:

- Retain soil moisture
- Suppress weeds
- Prevents soil erosion

Advantages

- Enhances soil structure and microbial activity
- Reduces need to weed
- Increases soil organic matter

Limitations

- Plant material may sprout and become weedy
- Crop residues are also needed as fodder
- Dried material may be a fire hazard.
- May create conditions for increased pests and diseases
- Difficult to spread on steep slopes

Figure 13-1: Organic mulching in Kapingazi, Embu[35]

Design and construction

Mulch is often spread in strips on seedbeds or around planting holes. Large pieces of crop residues should be cut into smaller pieces before application. Crop mulches work best if a layer of 2.5 to 10 cm depth is evenly spread. Mulch should be placed no closer than 15 cm from the base of a tree. Fine mulching material should be spread more shallowly to allow aeration. Crop residues, such as maize stalks can be left on the ground after harvesting to act as much. The mulch may be covered with a layer of soil to protect it against wind[44].

Figure 13-2: Mulching of kale in Kenya[45]

Cost

Cost varies depending on the choice of mulch material used.

[44] Photo credit: Moof Africa 2013

[45] Tengnas, 1994

14) Cover crops

Cover crops are usually creeping plants which cover the ground surface between widely spaced perennial crops such as fruit trees and coffee, or between rows of grain crops such as maize. Often cover crops are combined with mulching. Legume plants such as beans and peas, are often used as cover crops to also boost soil nitrogen content. Tap rooted plants with longer growth cycles such as pigeon peas are used as cover crops in areas with hard pans[46].

Where suitable

Areas with high annual rainfall of more than 500 mm to avoid competition for water between the cover crop and the main crop.

Aim

- Protect soil from erosion and direct heat from the sun
- Improve soil fertility
- Produce additional crop in the available space

Advantages

- Improves soil structure and soil fertility
- Reduces soil surface crusting
- Suppresses weed growth

Limitations

- Can compete with the main crop for growth resources
- May provide conditions for increased of pests and diseases
- May require additional farm labor and inputs
- Legumes (if used) are rather sensitive to diseases

Figure 14-1: Cover crops and mulching in Kapingazi, Embu[35]

[46] Kang, 1996

Design and construction

Cover crops should be planted soon after tillage - at the same time as sowing of the main crop, or after the main crop has established, to avoid competition for growth resources. To minimize competition with the main crop, cover crops should be of a low yielding variety. Cover crops may require frequent thinning to allow circulation of air, light and avoid rotting of roots. Over 100 species of cover crops are in use around the world such as *Mucuna pruriens utilis*, *Pueraria phaseoloides*, *Centrosema pubescens*, *Setaria* spp., *Stylosanthes* spp. and *Glycine* spp.

Figure 14-2: Sweet potatoes planted as cover crops in Kapingazi, Embu[35]

Cost

Likely costs for cover crops will be incurred from purchasing seeds; and managing of the cover crop. Fertilizers and labor costs are relatively high.

LANDSCAPE LEVEL PRACTICES

15) Agroforestry

Agroforestry is a practice where trees or woody shrubs are deliberately managed in combination with agricultural crops and/or livestock in agricultural fields or landscapes. Agroforestry trees serve many purposes including enhancement of soil fertility, organic matter content and structure, land restoration, control of soil erosion, provision of fruits, fodder, medicine, timber, fuelwood, gums, resins and latex products[40, 44, 46, 47].

Where suitable: It is suitable across a wide range provided the right trees are selected for the right ecological and socio economic conditions.

Aim

- Reclaiming eroded and degraded lands
- Sheltering crops and livestock from extreme weather
- Restoring land cover

Advantages

- Provides multiple tree products and services
- Sequesters carbon and reduces pressure on forests
- Modifies environment which enhances crop growth
- Improves soil structure and fertility

Disadvantages

- Trees can be costly to establish and manage
- Trees can attract birds, primates and other crop pests
- Trees can compete with crops for growth resources

Figure 15-1: Agroforestry in Kapingazi, Embu Kenya[35]

[47] ARD, 2014

Agroforestry can take on many designs in terms of tree species retained on farm, how these are arranged in the field and what silvicultual management practices are applied. The distribution and density of trees or shrubs varies widely. For soil and water conservation trees or shrubs are often grown in linear arrangements along contours, but irregular tree distribution has also been found to be effective as runoff speed is reduced by woody surface roots and litter cover. Perennial root networks also tend to hold soil together, thus reducing their ability to become dislodged and washed away. Trees have been however observed to increase soil erosion in some instances where tree roots created downslope channels.

High rainfall areas have multistory trees grown in relatively higher density (e.g. the in banana and coffee home gardens in Tanzania Uganda and Ethiopia and cocoa growing areas in Latin America) compared to those in drier areas which tend to be more widely spaced (e.g. parklands with trees such as Faidherbia, Parkia etc.

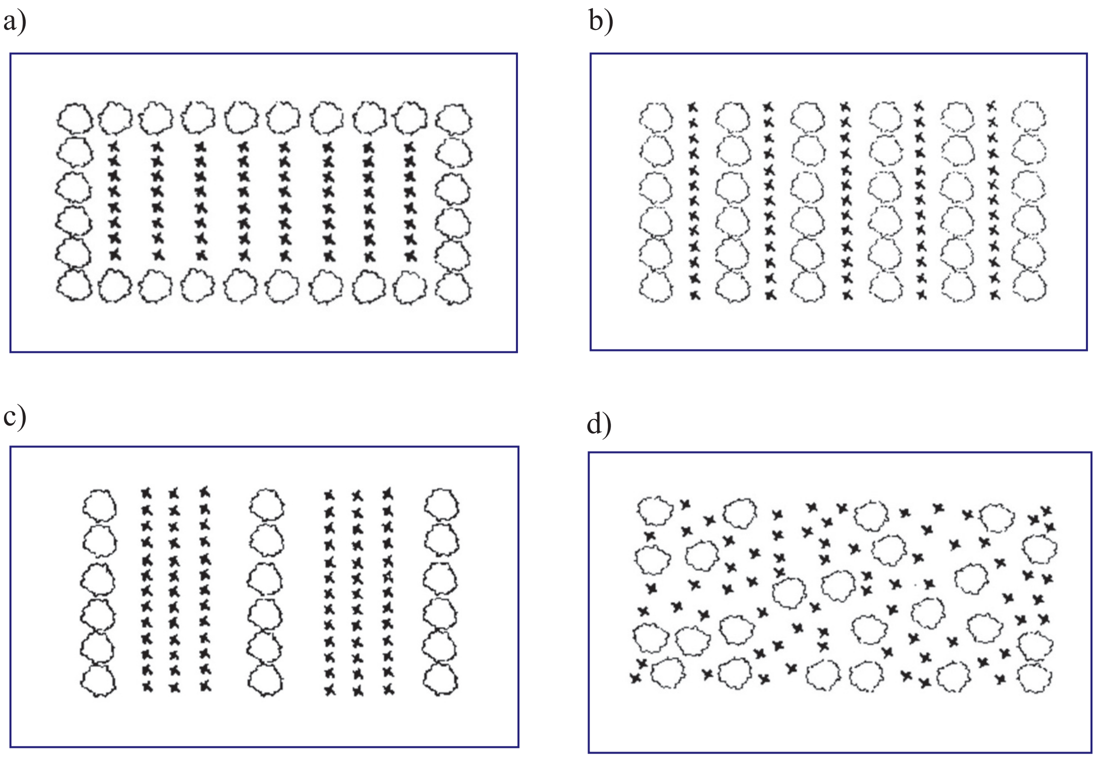


Figure 15-2: Examples of tree arrangement in agroforestry systems a) Trees along borders of fields; b) Alternative rows of plant components c) alternative strips or alley cropping; d) Random mixture[46]

16) Wind breaks /shelter belts

Windbreaks are a form of agroforestry where strips of trees, shrubs and/or grasses planted to protect fields, homes, canals, and other areas by providing a semipermeable barrier to wind. They are placed on the windward side of the land, and are most effective when oriented at right angles to the incident winds. An "ideal" windbreak consists of a central core of a double-row of fast and tall growing species such as *Eucalyptus* spp., *Casuarina* spp., or neem (*Azadirchta indica*), and two rows each of shorter spreading species such as *Cassia* spp., or *Leucaena* spp. on both sides of the central core. *Agave* spp. are also used, especially on the outer rows (away from crop fields). Since the trees change their shapes as they grow, it is usually necessary to mix several species of different growth rates, shapes and sizes in multiple rows[44]. Commonly, windbreaks also consist of multistory strips of trees and shrubs as boundary trees or live fences to provide a barrier to wind.

Where suitable

1. In large-scale farming areas where land tenure is secure (Boundary planting of trees and live fences is usually sufficient as windbreaks in small-scale farming areas)
2. In areas with high wind speed (more than 35 km/h) [44]

Aim: Protect crops from physical damage by direct wind

Advantages

- Can also define boundaries
- Reduce water loss from crops and soil surface
- Can provide other tree products

Disadvantages

- Takes up space that would otherwise be for crop production
- Competes with adjacent crops for growth resources
- Some species can become weeds such as *Prosopis* spp
- If poorly designed, trees may fall on crops

Figure 16-1: Windbreak trees sheltering crops in a farm in Kapingazi, Embu Kenya[35]

Design and construction

A windbreak should be planted at right angles to the incident wind. It can either consist of a single line of trees with a spacing of 1.5 - 2.0 m, or two lines with a spacing of 4 - 5 m within the line and 2 - 4 m between the lines. In addition to one or two lines of trees, a line of shrubs spaced at approximately 1 m can be planted on the side facing the prevailing wind. Tree species selected for a windbreak should tolerate harsh environments; have a bushy, deep crown but that still allows wind penetration; grow quickly; tolerate pests and diseases; not harbor pests that affect crops; and not have roots that compete excessively with nearby crops for water and nutrients[44].

Examples of tree species that can be used as windbreaks:

Acacia albida, Albizia spp., *Anacardium occidentale, Annona senegalensis, Azadirachta indica, Balanites aegyptiaca, Calliandra calothyrsus, Calodendrum capense, Cassia siamea, Casuarina* spp., *Cupressus lusitanica, Ekebergia capensis, Eriobotrya japonica, Eucalyptus* spp., *Gliricidia sepium, Gmelina arborea, Grevillea robusta, Hakea saligna, Juniperus procera, Macadamia tetraphylla, Mangifera indica, Markhamia lutea, Morus alba, Olea europaea, Prosopis* spp., *Prunus africanus, Psidium guajava, Spathodea campanulata, Syzygium cuminii, Trichilia emetica, Vitex* spp., *Ziziphus* spp.[44].

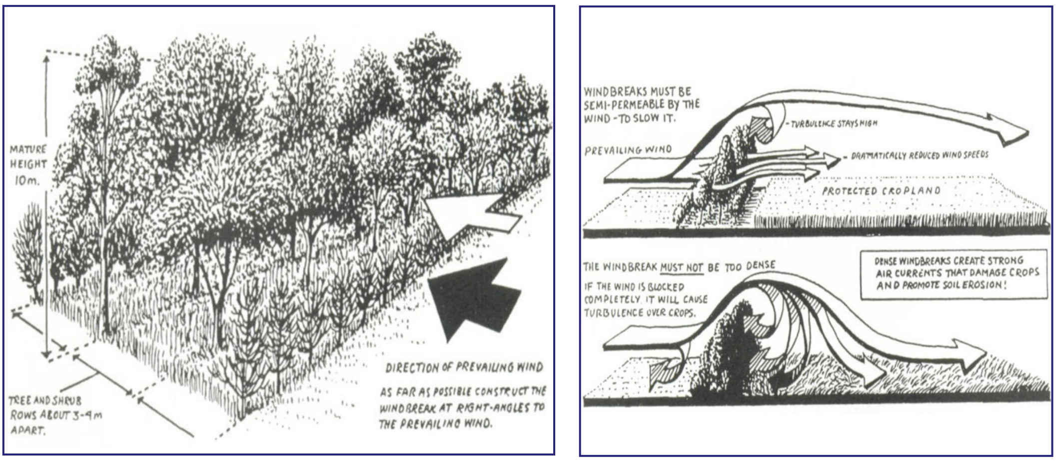


Figure 16-2: a) An illustration of a multi-storey windbreak b) Windbreak design[44]

Costs and management

Wind breaks establishment is labor intensive. The main cost is in purchasing of planting material, as well as labour for land preparation and planting. Establishment costs also include protection of young windbreak trees against livestock and fire, weeding and replacement of dead seedlings. Later the trees in the windbreak may need pruning or pollarding (cutting of branches at raised level) to maintain a suitable density and to minimize shading on adjacent crops. Dead trees or trees that have been blown over must be replaced.

17) Woodlots

Woodlots are usually small afforested plots established and managed by individuals or communities. Vegetables or crops are often intercropped in the woodlot in the establishment stages and discontinued when tree canopies close. Woodlots improve soil structure at the plot level and may contribute to control of soil erosion and wind speed at the landscape level. They are commonly grown on degraded land.

Where suitable

1. Where light-demanding crops (e.g. maize, tea, sugarcane) are dominant and segregation of trees is more cost effective.
2. Where alternative sources of fuel wood are limited
3. Poor or waste areas that is not fit for other use.

Aim: Protect crops from physical damage by direct wind

Advantages	**Disadvantages**
• Utilises of idle land • Provision of other tree services e.g. carbon sequestration, apiary farming	• Reduced water table level if species of high transpiration rate threaten • Long waiting time to reap benefits • Risks from drought, fire and pests • Requires skilled labor to establish and manage

Figure 17-1: A woodlot in a farm in Nyando, Western Kenya[35]

Design and construction

Establishment can be from seedlings or by direct sowing. The initial spacing can be very dense: 0.5 by 0.5 m, if there is a demand for thin poles, or firewood. Gradual thinning will then enable the trees to grow to the desired size. Initial intercropping with crops or vegetables facilitates weed control. If the trees compete with adjacent crops, deep ploughing or digging a trench 50 - 80 cm deep will reduce the penetration of tree roots into the rooting zone of the crop. Species with good coppicing (regrowth of shoots from the stump after) ability are preferable to eliminate the cost of repeated establishment. Management at establishment stages consists of:

- Weeding: carried out 2-3 times in the first 2 years.
- Beating up: young plants are monitored regularly in order to replace weak, dead, and diseased or pest infested ones.
- Protection: enclosures to prevent grazing animals; protection from fire including fire lines (wide lines cleared of all debris), fire watch towers and patrols; boundary buffer strips of e.g. root/tuber crops around the woodlot[44]; patrols and clear boundary markers to minimise illegal harvesting from communities or neighbors

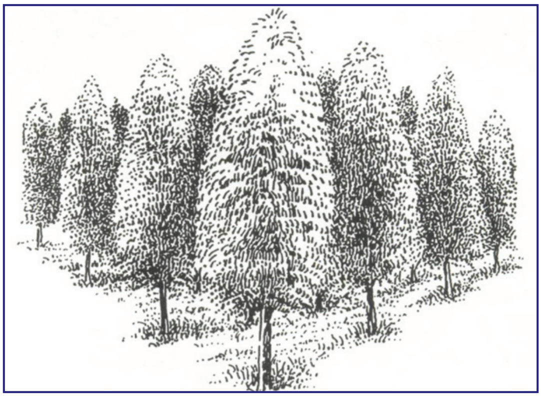


Figure 17-2: a) Eucalyptus woodlot in alongside a road in Nyando, Western Kenya[35] b) A good Eucalyptus woodlot design[44]

Examples of species suitable for woodlots

Eucalyptus has been the main tree species used for woodlots throughout Africa[40]. Fast-growing and coppicing species are best, e.g. *Eucalyptus* spp., *Acacia mearnsii, Markhamia lutea* and *Cassia siamea*. Non coppicing species are also used such as *Pinus* spp. *Cupressus lusitanica*, *Grevillea robusta*, *Terminalia* spp, *Maesopsis eminii*, *Casuarina* spp. *Albizzia* spp. etc.[44]

Cost

Establishing and managing woodlots individually can be costly. For example grevillea woodlots have been estimated to cost US$ 160 per hectare at establishment, and US$ 90 per hectare per year for management[44].

18) Riparian vegetative buffer strip

Riparian buffers are vegetated areas next to water resources that protect water resources from sediment and nonpoint source pollution transported by surface runoff (riparian vegetation remove up to 90% of unused nitrogen from croplands) [48]. They consist of a complex assemblage of plants (including grasses and/or trees) and other organisms adjacent to water ecosystems[49] e.g., along stream banks, floodplain, and wetlands, as well as sub-irrigated sites[50]. The design of riparian buffers should be matched with site topographic conditions to maximize the area of the buffer interacting with water flow.

Where suitable

1. They are limited to small areas (drainage area of less than 4 ha)

Aim: Filter and absorb pollutants including sediments from surface runoff originating from adjacent agriculture fields to in order to protect water sources

Advantages

- Strengthening and stabilizing stream banks by vegetation roots
- Cooling stream temperatures though shade
- Enhancing organic matter decomposition
- Providing habitat for biodiversity
- Enhancing infiltration, replenishing groundwater

Disadvantages

- Reduced water table level if species of high transpiration rate threaten
- Long waiting time to reap benefits
- Risks from drought, fire and pests
- Requires skilled labor to establish and manage

Figure 18-1: A buffer stream of a restored forest and natural vegetation in Kenya[52]

[48] Dillaha et al., 1989

[49] Lowrance et al., 1985

[50] Welsch, 1991

[51] USDA, 2000

[52] Renouf et al, 2012

Design considerations

The length of the buffer strip (parallel to flow direction) can vary. A vegetation plan is usually required which will ensure dense deep routed vegetation that is resistant to saturation and drought. The buffer width influences its effectiveness and is determined by site characteristics associated with topography, hydrology, geology, land use, the value of the water resource and adjacent land [51, 53].Effective vegetative buffer strips are comprised of three zones: a streamside portion, a middle zone, and an outer zone. The streamside and middle zones should include mature trees as well as shrubs and grasses, and the outer zone should be mainly comprised of grasses[53].

Zone 1: 'streamside zone' is the innermost zone, closest to the adjacent receiving water body. It is wooded, with trees or shrubs; mature trees are preferred. No management allowed except bank stabilization and removal of problem vegetation. Neither livestock access nor timber harvesting are recommended. The function of zone 1 is bank stabilization, habitat, shade, flood prevention. Minimum width is 4 m to 7.5 m.

Zone 2: the 'middle zone', like Zone 1, is typically wooded, ideally with mature trees. In some cases Zone 2 can be a managed forest, in which selected, minimal timber harvesting is allowed, primarily for maintaining the health of the stand. No livestock access is recommended. Function of the zone: removal of nutrient, sediments and pollutants from surface and groundwater, habitat. Minimum width is 15 m to 18 m.

Zone 3: the 'outer zone' is composed of grasses and herbaceous plants. The zone slows surface runoff, trap sediments and pesticides. In areas with existing riparian forest buffers (i.e., Zones 1 and 2), if the adjacent up-slope land is grassland, forest, or other area that does not produce sediment, nutrients, pesticides, or other pollutants, then zone may not be necessary. The recommended minimum width ranges from 6 m to 65 m.

Costs

The costs associated with buffer practices will vary with location which include land being taken out of production and costs associated with planting, establishing, and maintaining the buffers. Riparian buffers are sensitive to proper design according to slope and maintaining sufficient vegetation density. Thus, they require routine maintenance, which may be expensive.

[53] Mecklenburg, 1996

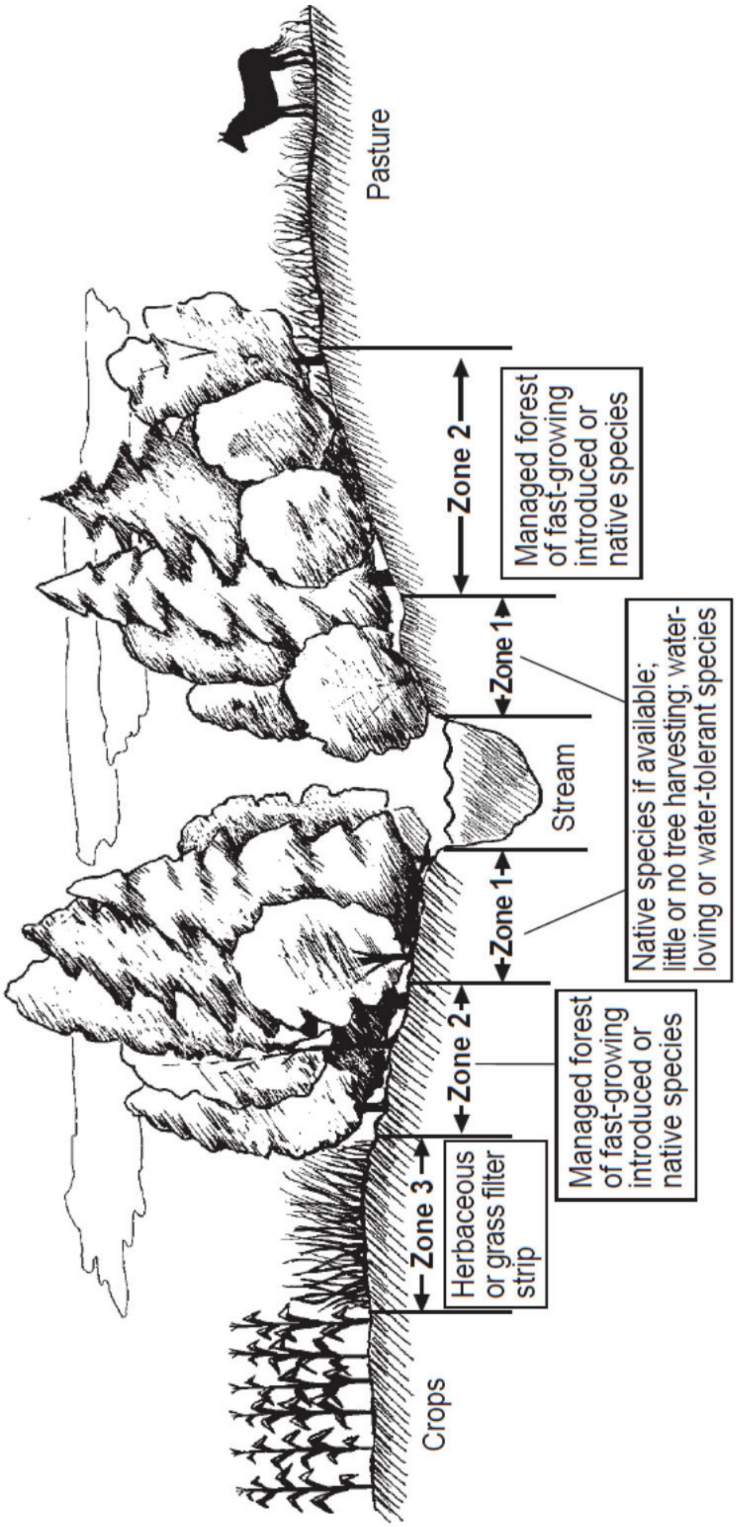


Figure 18-2: Illustrated riparian vegetative buffer zones[54]

[54] USDA-NRCS, 2003

BUNDLED PRACTICES

19) Conservation agriculture

Conservation Agriculture (CA) is an approach that emphasizes the protection of the upper 0 - 20 cm of soil, considered to be the most active zone but also the most vulnerable to erosion and degradation[55]. CA operates on three principles: minimum mechanical soil disturbance, permanent organic soil cover and crop rotation to diversify crop species grown in sequences and/or associations[56].

Where suitable

Applicable to all agricultural landscapes and land uses

Aim

- Prevent degradation of agricultural land
- Sustain land productivity

Advantages

- Improves water infiltration into soil
- Builds up soil organic matter and nutrients
- Reduces soil compaction

Limitations

- High initial costs of specialized planting equipment
- Requires high management skills

Figure 19-1: Soya bean crop as a cover crop in a conservation agriculture field[57]

[55] Mutua et al., 2014

[56] Dumanski et al., 2006

[57] Photo credit: Concern Worldwide/flickr 2011

Design and construction

CA is based on interventions such as mechanical soil tillage are reduced to an absolute minimum, and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with, or disrupt, the biological processes. Different requirements under the three major principles are presented below.

Minimum soil disturbance or Direct seeding or planting: Top soil is not ploughed or turned, but is sub-soiled using a sub-soiler and then ripped using a ripper to make furrows for seed placement. Alternatively, planting can be done using a hand operated jab planter, a hand hoe, a dibbler or muro, or an animal drawn direct seeder, tractor drawn zero-till or direct planter[58].

Maximum soil cover: This can include use of live cover crops such as cowpeas, beans, soybeans, dolichos lablab, mucuna and sweet potatoes or dead vegetative material, mainly from crop residue. Agroforestry tree species (crop friendly) can also be used to provide aerial soil cover. Leguminous cover crop add nitrogen to the soil and decomposing vegetation and the roots of cover crops improves the soil structure and make the clumps and lumps in the soil more stable therefore making them harder to break and wash away.

Crop rotation: Crop rotation is the practice of growing two (or more) dissimilar type of crops in the same space in sequence. Several crops are planted in rotation or as intercrops (crop mixes) rather than planting a single crop in a season or year. Crop rotations include legumes, deep-rooted crops and high-residue crops. Crop rotation improves soil structure as some crops have strong deep roots which can penetrate deep into the soil breaking hard pans, and can tap moisture and nutrients from deep in the soil. Others have shallow roots and tap nutrients near the soil surface and also bind the soil together[65]. When leguminous crops are part of the rotation, they fix nitrogen into the soil and their biomass adds nitrogen through decomposition. Crop rotation helps in control of some weeds, pests and diseases. Growing a mix of grain, beans, vegetables and fodder provides a diversity of diet and a potential source of income.

Cost

The cost of implementing CA differs depending on inputs used (e.g. for seed purchase, fertilizers). The organic matter of the soil increases under CA, so will the soil fertility leading to increased fertilizer efficiency. The labor is well distributed within the production cycle and thus reduces requirement of labor compared to the conventional tillage[59].

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[58] Derpsch, 2005

[59] FAO, 2005

20) Conservation tillage

Conservation tillage (CT) is a tillage system that conserves water and soil while saving labor and traction need. It involves tillage operations that leave at least 30% of the soil surface covered by plant residues in order to increase water infiltration and cut down on soil erosion and runoff. CT is an intermediate form of CA since it keeps some soil cover as residue from the previous crop, but some tillage is usually done. Soil can be amended using crop residues and fertilizers. Inputs can be applied only on cultivated spots[4, 5, 60.] In CT weeds are best controlled with herbicides.

Where suitable: Areas where infiltration is more limiting than total amount of rainfall

Aim

- Minimize soil disturbance
- Improve the infiltration and water holding capacity of soil
- Improve the soil organic matter

- Conserves water by mulching

- Carryover of the pests and diseases from the crop residues

Figure 20-1: A farm under conservation tillage[60]

Design and construction

CT practice involves breaking or ripping of crust, plough pans or sub-soiling of land. This can be done using animal-drawn sub-soilers, rippers, ridgers, planters, and weeders[11]. CT includes no-till, strip-till, ridge-till and mulch-till. Each method requires different types of specialized or modified equipment and adaptations in management.

[60] Photo credit: Conservation Tillage Workshop 2012. http://www.ok.gov/conservation/News/Conservation_Tillage_Workshop_2012.html

Zero tillage (no-till, minimum tillage, or direct seeding): No-till leaves the soil undisturbed from harvest to planting. This system involves opening a narrow slot only wide and deep enough to obtain proper seed coverage and with at least 30% mulch cover. Planting spots are created using spots coulters, row cleaners, disk openers, in-row chisels, or roto-tillers and weeds are controlled entirely by herbicides.

Strip Till: is a system of cultivating crops in narrow strips of about 20 cm wide where the crop is planted with the rest the field left untilled (for example maize and cotton).

Ridge-till involves planting row crops on permanent ridges about 10 - 15 cm high. The previous crop's residue is cleared off ridge-tops into adjacent furrows to make way for the new crop being planted on ridges. Maintaining the ridges is essential and requires modified or specialized equipment. A ripper is a chisel-shaped implement pulled by animals or a tractor. It breaks up surface crusts and opens a narrow slot or furrow in the soil, about 5 - 10 cm deep.

Mulch-till: This involves cutting the roots of weeds and other plants and leaving the crop residues on the surface or mixed into the top (few centimeters) of the soil. The cutting is usually done with a tined (pitch folk) implement with blades or sweeps to uproot or undercut the weeds. Equipment used for planting must have special furrow openers to avoid clogging with trash.

Figure 20-2: (a) A no-till planter being used on a farm to plant maize in Bungoma, Kenya.[61] (b) Crops in a zero-till farming system[62].

Cost

The cost of labor varies; however cost of planting equipment and herbicides has to be taken into account.

[61] Mutua, 2014

[62] Garg et al. (undated)

SUMMARY: Quick decision guide for selecting soil and water conservation technologies for small holder farmer

		BENEFITS								TRADEOFFS				
	TECHNOLOGIES	Reducing runoff velocity	Improving soil moisture retention	Controlling soil erosion	Diversifying farm income	Controlling flood and waterlogging	Improving soil fertility	Improving soil structure/ stabilization	Enhancing water harvesting	Increased Labor constraints	Hindered farm operations (especially with farm machinery)	Increased competition (water, sunlight, nutrients)	Increased niches for pests (birds, slugs, rodents, etc.)	Decreased production area (Loss of land)
1	Bench terraces	High impact	High impact	High impact	Low impact			High impact	Medium impact	High risk	High risk			High risk
2	Check dams	High impact	High impact	High impact	Low impact	High impact		High impact	High impact	High risk	High risk			High risk
3	Contour bunds	Medium impact	High impact	High impact	Low impact	High impact		High impact	Medium impact	High risk	High risk			Medium risk
4	Graded drainage ditch / Fanya Juu	High impact	High impact	High impact	Low impact			High impact	Medium impact	High risk	High risk			High risk
5	Planting Pits (Zai) pits)	Medium impact	High impact	Low impact	Low impact		High impact		Low impact	High risk	Medium risk			Low risk
6	Katumani Pitting	Medium impact	High impact	Low impact	Low impact		High impact		Low impact	High risk	Medium risk			Low risk
7	Stone lines	High impact	High impact	Medium impact	Low impact				Low impact	High risk	High risk		High risk	Low risk
8	Trash lines	High impact	High impact	Medium impact	Low impact		High impact		Low impact	Medium risk	Low risk	Low risk	High risk	Low risk
9	Grass strips	High impact	High impact	High impact	Low impact		High impact		Low impact	Medium risk	Low risk	High risk	High risk	Low risk
10	Grassed waterway	High impact	High impact	High impact	High impact		High impact	High impact	Low impact	Medium risk	Low risk		Low risk	High risk
11	Retention ditches	High impact	High impact	Low impact			High impact		High impact	Medium risk	High risk			High risk
12	Cut off drains	High impact	High impact	Low impact		High impact			High impact	High risk	High risk			High risk
13	Mulching	High impact	High impact	High impact	High impact	Low impact	High impact			Low risk	Low risk	High risk	High risk	Low risk
14	Cover crops	High impact	Medium impact	High impact	High impact	Low impact	High impact			Low risk	Low risk	High risk	High risk	Low risk
15	Agroforestry	Low impact	High impact	Medium impact	High impact		High impact			Medium risk	Medium risk	High risk	High risk	High risk
16	Windbreaks/ shelter belts	Low impact	High impact	Medium impact	High impact		High impact			Medium risk	Medium risk	High risk	High risk	High risk
17	Woodlots	Low impact	High impact	Medium impact	High impact		High impact			Medium risk	Medium risk	High risk	High risk	High risk
18	Riparian vegetative buffer strip	High impact	High impact	High impact			High impact	High impact						
19	Conservation agriculture	Medium impact	Medium impact	High impact	High impact		High impact			Low risk	Low risk	Low risk	Low risk	Low risk
20	Conservation Tillage	Medium impact	Medium impact	High impact	High impact		High impact			Low risk	Low risk	Low risk	Low risk	Low risk

KEY	
High impact	(dark green)
Medium impact	(striped green)
Low impact	(light green)
High risk	(red)
Medium risk	(hatched orange)
Low risk	(dotted pink)
No known impact	(white)

* This can be complemented by a computer-based program[63] developed by Kahiga et al, 2015 for the Upper Tana River basin

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About this book

Selecting the right soil and water conservation technology for the right place is a key problem farmers in soil erosion prone areas face in their operations. Investing in establishing and implementing these technologies requires some skills that farmers can easily adopt and apply. This book lines out 20 soil and water conservation technologies that are suitable for a number of areas in Africa. It presents these technologies in a simple format with illustrations to show how it can be established, what it can be expected to achieve, areas where it is suitable, costs involved, advantages and disadvantages. The book is compiled from review of literature and reports accumulated by ICRAF through working in various landscapes in Africa especially under the Propoor Rewards for Environmental Services project. It is expected to support farmers and extension agents as a quick and simple reference providing enough detail about technology options in order to support decisions technology selection especially in watershed management.

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