5 Soil and water conservation for climate-resilient agriculture

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Introduction

Limited soil moisture is one of the most critical environmental factors affecting crop production and food security in the semi-arid zones of East and Southern Africa (ESA) (FAO, 2019). Inadequate or increasingly erratic rainfall is compounded by high runoff from farmers' fields, estimated at between 25% and 30% of the rainfall received under conventional tillage practices (Swai *et al.*, 2007). The high levels of runoff are caused partly by inappropriate tillage practices among smallholders and a lack of vegetation cover over the soil. Many soils are therefore degraded and infertile due to the leaching of nutrients, erosion by water and wind, and continuous cropping, with farmers unable to obtain maximum potential yields.

These negative impacts can be reduced by introducing good physical soil and water conservation practices. Reducing surface runoff by modifying tillage practices or changing land management methods helps to reduce soil erosion, prevents the formation of rills, gullies, and soil crusts. Good soil and water management can also increase soil organic matter, improve soil structure, replenish soil nutrients, increase water infiltration and water-use efficiency, conserve soil moisture, and increase efficiency of nutrient uptake by crops.

Using soil and water management practices together with agroforestry can provide win–win solutions and allow for sustainable intensification, allowing farmers to produce more food from their available land, while conserving their resources. Sustainable yield increases contribute to food security and incomes, and build resilience to climate change.

Africa RISING has validated and disseminated good soil and water management practices in Babati, Kiteto, and Kongwa districts of Tanzania, with promising results including sustainable yield increases, reduced land degradation, and increased community resilience through diversified options for production and income generation (Kizito *et al.*, 2016). These experiences can be replicated elsewhere in ESA. This chapter presents three interventions that can be used separately or in combination, depending on the context of the region:

- integrating strips of forage grasses and legumes
- rainwater harvesting through tied ridges and ripping techniques
- constructing banks and ditches as part of an agroforestry system.

For areas of high rainfall intensity, sandy soils, or steep slopes, a combination of the different interventions will provide complementarity and

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result in improved productivity of the farming system without compromising the integrity of its natural resources (Figure 5.1).

Integrating strips of forage grasses and legumes in farming systems

Description of the technology

Lack of feed resources for livestock limits milk production throughout ESA, with the adoption of forage technologies remaining low among smallholder farmers (Lukuyu *et al.*, 2009). Introducing forage crops (grasses and legumes) as soil and water conservation interventions can benefit farming systems in several ways, especially where farms are located on steep slopes.

Africa RISING has disseminated a system in which single or intercropped forage grasses, such as Napier grass, and forage legume cover crops, such as desmodium (*Desmodium* species) and lablab (*Lablab purpureus*), are planted on terraces or as strips across the slopes of the fields (Figure 5.2). The distance between terraces or strips is determined by the length and steepness of the slope. The forage strips are perennial, and they reduce soil losses during the cropping season, increase water infiltration, and reduce soil erosion by limiting the volume and speed of runoff water. The legumes also help to improve soil fertility (see Chapter 3 of this book).

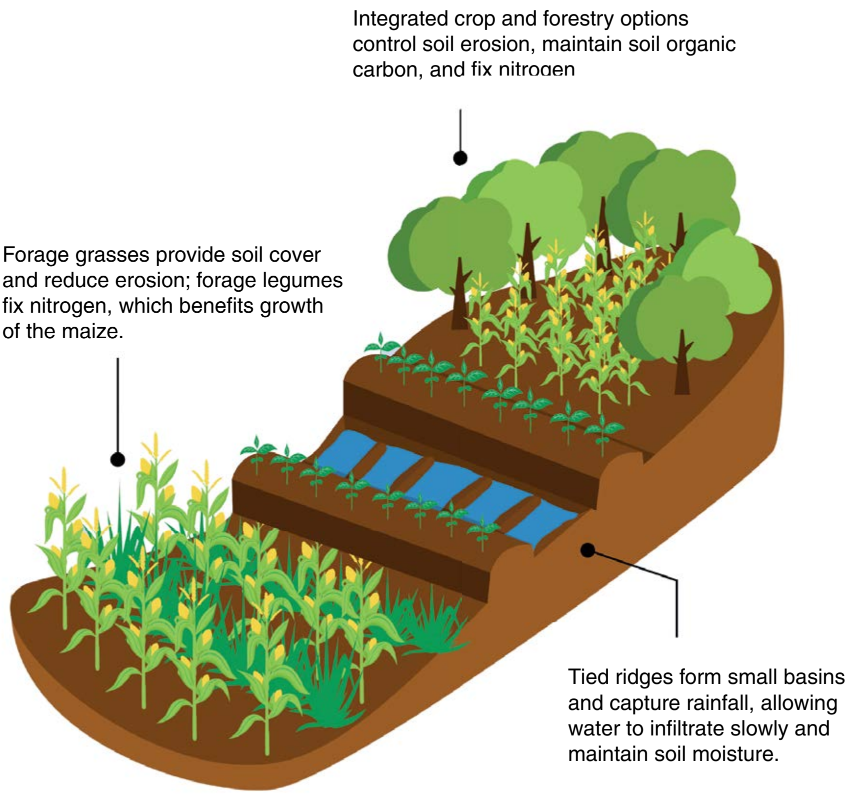

Figure 5.1. Conceptual illustration of validated soil and water conservation interventions in ESA. At the lowest part of the farm, forage grass strips are planted along the contours to slow water runoff and reduce erosion. In the middle section, tied ridges form micro-basins for water to pond and then infiltrate into the crop root zone. On the highest land, an integrated crop and forestry system helps to retain soil, water, and nutrients within the landscape. Source: Kizito (original artwork, 2020); open access.

Figure 5.2. A forage grass strip within a maize farm in Seloto Village, Manyara region, northern Tanzania. (Photo courtesy of Fred Kizito, 2016.)

Benefits of the technology

Figure 5.3 summarizes the benefits of forage grasses and legumes as soil and water conservation measures. The roots of the grasses and legumes help to hold the soil in place and stabilize the contour strip. The forage legumes (e.g., desmodium or lablab) also act as cover crops and provide ground cover beyond the contour strip, smothering potential weeds. Desmodium is particularly valuable in areas prone to infestation with witchweed (*Striga hermonthica*), a parasitic weed that can devastate maize yields. Desmodium stimulates suicidal germination of the striga seed, hence eliminating it from maize fields. The 'push-pull' effect is also useful (Napier grass attracts and desmodium repels the stem borer moth away from the maize plants). In addition, extracts of lablab can repel some foliage insects, while flour made from the seeds can be applied to soil to deter *Coleopteran* pests, reducing the need for chemicals (Reicosky, 2018).

With fewer weeds, farmers spend less time weeding. Desmodium and lablab provide nutrient-rich forage for livestock, while cowpea (*Vigna unguiculata*) also provides nutritious food for the household; all three legumes increase soil nitrogen through biological fixation. Fodder crops can also be sold, providing a diversified income source.

The ground cover from forage grasses and legumes also reduces raindrop impact by 60% compared with a sole maize crop. The reduced runoff, increased soil infiltration, and reduced soil evaporation significantly increase soil moisture and benefit crop water uptake, resulting in higher yields. When farmers plant improved maize varieties, average yields increase from 0.8 t/ha for conventional farmer practice to 1.2 t/ha for contour farming, 3.5 t/ha for forage strips, and 4.7 t/ha for a combination of contours and forages.

Research conducted in Babati on the effect of forage grass–legume intercrops on a slope of 10% demonstrated that runoff levels were reduced by 60–120 mm per annum. There was higher soil moisture storage of about 25 mm of water over a depth of 50 cm (30% higher) in areas with forage legumes compared with the control areas with no forage legumes (Figure 5.4). The perennial forages reduced erosion by lowering runoff; and increased productivity, biomass, soil moisture storage, and net income (Table 5.1). In the validation trials summarized in Table 5.1, management for Napier sole was slightly different in that the Napier with desmodium and Napier with lablab was always able to smother the weeds with complete groundcover. The combination of Napier with lablab seemed to offer the best co-benefits, and this is recommended for farmers, especially if lablab planting material is available and suitable for the local agroecosystem. It should be noted that farmers more often look at the tangible or visible outcomes such as yield. However, there is sometimes a time lag before the impact of the technology on yield becomes apparent. For example, in this case, although the combination of Napier and lablab on contours reduced erosion by 60% and increased moisture storage by 58%, it increased yield by only 25%. It is also possible that after overcoming soil moisture limitation, another factor may be more limiting (see Chapter 4, Liebig's Law of the Minimum).

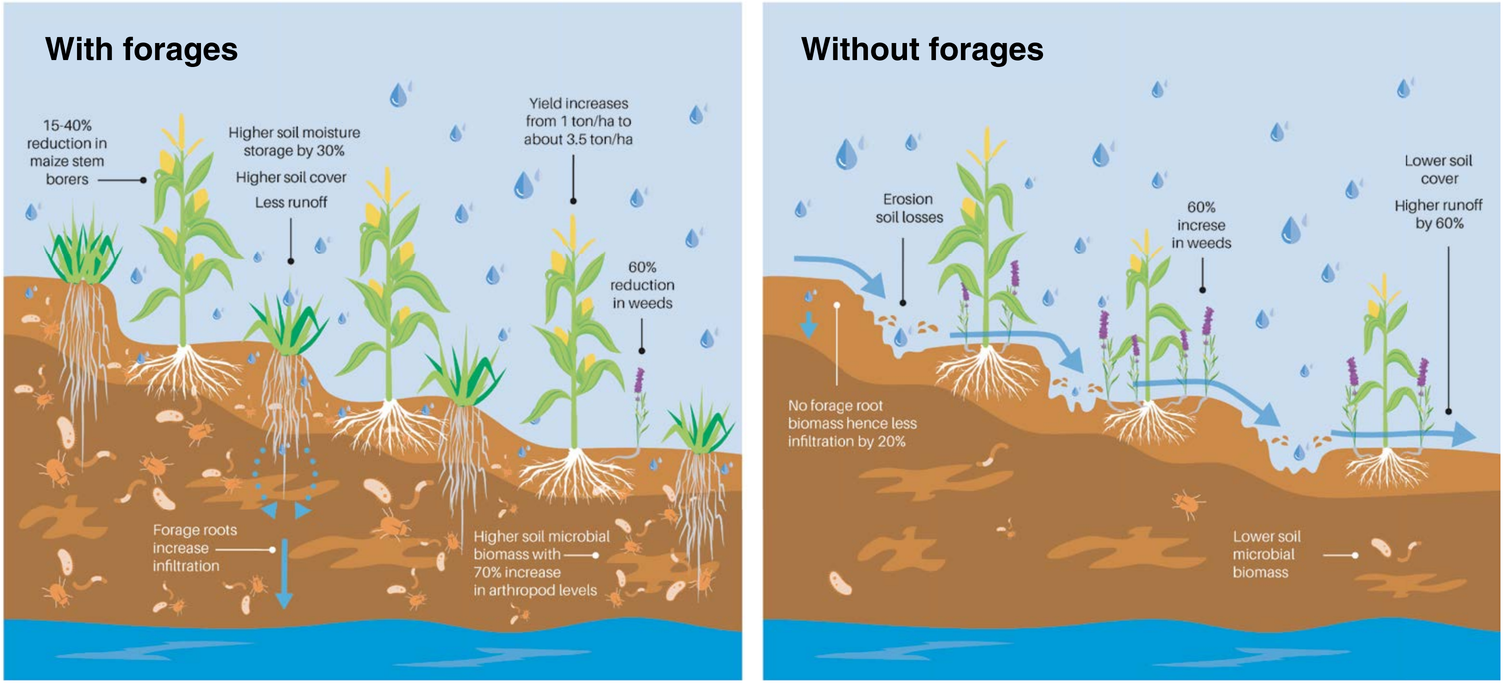

Figure 5.3. Agroecological benefits of integrating forage grasses and legumes in a cropping system. Source: Kizito (original artwork, 2020); open access.

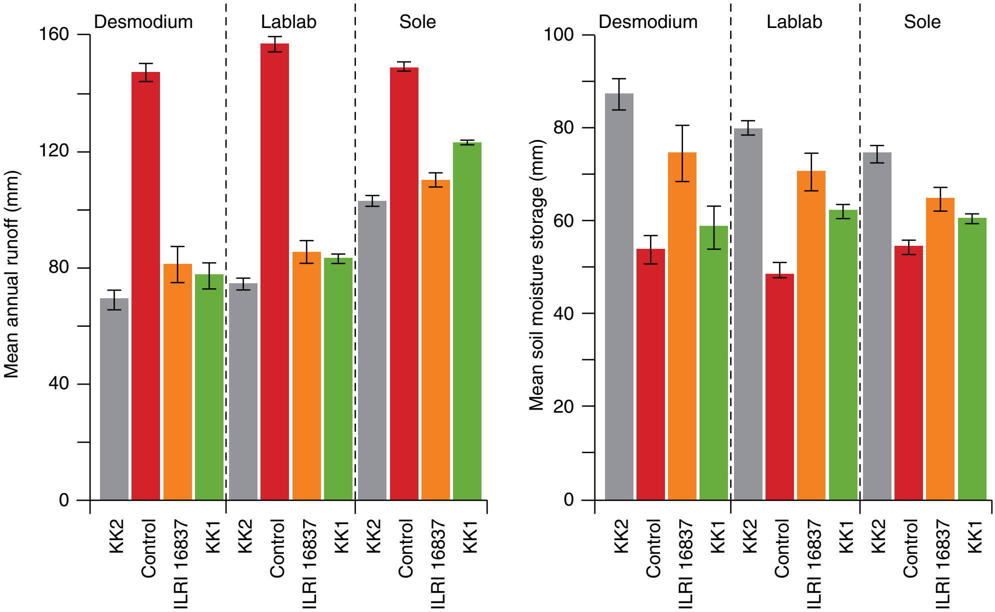

Figure 5.4. Mean annual runoff and mean soil moisture storage for forage grass and legume combinations along contour strips with a 10% slope in a maize farm (2014–2015). Horizontal axis: KK1 represents Kakamega 1, KK2 is Kakamega 2; these and ILRI 16837 are Napier grass accessions from the International Livestock Research Institute. Source: Kizito *et al*. (2016); reproduced with permission.

Table 5.1. Benefits of forages for soil and water conservation in Long village and Seloto village, Babati, Tanzania

Forage arrangement (only KK2 considered against baseline)	Annual rainfall (mm)	Increase in maize yield (%)	Increase in biomass (%)	Reduction in erosion (%)	Increase in soil moisture storage (%)	Increase in net income (%)[1]
Sustainable intensification domain		Productivity		Environment		Economic
Control (baseline)	Long 1100	n/a[2]	n/a	n/a	n/a	n/a
Napier on contour (sole)		15	10	25	31	10
Napier + desmodium on contour		22	15	45	57	15
Napier + lablab on contour		25	18	60	58	30
Control	Seloto 850	n/a	n/a	n/a	n/a	n/a
Napier on contour		13	15	35	42	14
Napier + desmodium on contour		20	25	40	47	20
Napier + lablab on contour		28	20	55	65	30

1 Both farm labor and on-farm inputs were considered in the calculation of net income. Net income includes yield income less the costs of seeds, labor for planting, and management.
2 n/a = not applicable.

Farmers' responses

Farmer testimonies underscore the value of introducing forages to increase productivity, with the forage often given to stall-fed cows (Figure 5.5). For example, Anton Leonce of Seloto village, Babati, Tanzania, stated: "I feed my cows with the maize crop residue, which I supplement with the fresh fodder from the Napier grass that is intercropped with the maize. I have a full-time supply of feed for my cows, while my soil and farm continue to be protected by these forage grasses. When I cut a few stalks of Napier grass from the upper band, it takes about five or six weeks to grow back to its previous biomass level. I then go to the mid-slope bands and harvest them, then I harvest the lower bands. By that time the upper band has fully regrown and is ready for cutting again."

Figure 5.5. Stall-fed cows in Tanzania. (Photo courtesy of Nils Teufel, 2012.)

Focused group discussions with 34 respondents (15 men and 19 women) in Bermi, Sabillo, and Seloto communities in Babati district, northern Tanzania, revealed additional insights on landscape and community-level perspectives (Table 5.2). A comparison scoring matrix ranked the indicators using the five domains of the Sustainable Intensification Assessment Framework (SIAF) (Feed the Future, 2021) in order of merit and importance within the context of forages in farming systems. There were interesting differences in the overall ranking of the indicators between men and women. The overall rank was agreed by group consensus after joint discussions. The reasons behind each of the rankings revealed subtle but important details on decision-making at the household level.

Women generally ranked nutrition as the most important aspect in the household, followed by social cohesion. They said that people need to be healthy to perform work effectively, and that it is essential to work together as a group to realize the full benefits of community development. This links to household nutrition and infant well-being in that women are more likely than men to prioritize food essentials in the home.

In the case of men, group dynamics was scored as the least important. They said that it is difficult to achieve at community level. This may be a result of power struggles among the group but could also point to the fact that men felt that

Table 5.2. Technology ranking for Bermi, Sabillo, and Seloto communities (ranking score ranged from 1 = least important to 5 = most important)

Indicator	Score (women)	Reason for choice	Score (men)	Reason for choice
Nutrition	5	Healthy people can work better	2	Cash can buy food
Social cohesion	4	Working together supports community development	1	Group working can be difficult but having sufficient income means labor can be hired
Income	3	Provides cash for household needs	5	Everything depends on income
Fodder biomass	2	Sufficient fodder means cows give milk for household needs	4	Good to have surplus fodder to sell
Soil fertility	1	Fertile soil means a better harvest	3	Important for good production

money helps other factors to fall in place, although this may not always be the case. For example, men valued income as the paramount factor, and they preferred to have sufficient income to hire labor. However, social cohesion goes beyond just seeking labor as a factor.

Another interesting variation observed between men and women was the way things are valued. For example, forage biomass was viewed in the context of milk production for nutrition by women, but along the value chain for fodder quantity for sale by men. Men did not rank or prioritize nutrition; they cited that sufficient money permits them to buy what they want to eat. However, an increase in income does not necessarily result in better household nutrition.

The rankings from men and women on soil fertility also reveal that men are more likely to prioritize soil fertility than women. This was related to the labor demands associated with achieving soil fertility and making contours, as well as land tenure, because on the whole, men have more secure land tenure. This in turn points to the need to promote labor-friendly technologies that will promote easier uptake, adoption, and scaling for technology dissemination.

Although forage grasses and legumes have numerous merits, they also have disadvantages, such as a high labor requirement for initial establishment and reinforcement of contours, and a reduction in the area of land that can be planted with food crops. The benefits associated with the land equivalent ratio of introducing this technology therefore need to be evaluated. Using a dual-purpose forage that can be used as food and feed can provide a solution, if labor is available.

Opportunities for application of the forage strips technology

The technology has the potential for further dissemination and wider applicability. Forage crops are particularly suited to farming communities in ESA, many of which are based on agro-pastoralism. Planting forage grasses and legumes protects the environment, and provides feed for livestock and food for humans, if dual-purpose legumes are grown. The technology is not well suited to areas where there are free-grazing cattle, since they will be attracted to the forage strips. It may also not be applicable where soil cover is desired (e.g., conservation agriculture) or where contour bunds are used instead of forage strips. In this case, forage strips can be planted on the contour bunds to maximize the benefits associated with soil and water conservation.

How to get started

When establishing the best distance between strips, it is important to consider the length and steepness of the slope, soil type, rainfall intensity, vegetation cover, and labor availability. Table 5.3 suggests parameters that are applicable to ESA agroecosystems similar to those in Babati.

Farmers should also follow the principles of good agricultural practice:

- Prepare land well to remove weeds and plough across the slope.
- Procure improved seeds or planting materials from reliable suppliers and plant soon after the first rainfall of the season.
- Plant forage grass as a cutting at a planting depth of about 10 cm (for Napier) with a planting hole structured as a trough to capture rainfall and ensure good establishment.
- Plant across the slope following a contour pattern, with a spacing of 1.5 m from one Napier grass stalk to the next across the slope.
- Plant forage legumes (lablab, desmodium, or cowpea) as seeds at a planting depth of about 2–5 cm between the forage grass stalks (Napier) at the halfway mark, which

Table 5.3. Thresholds for strip distances within landscapes

Slope category	Slope gradient	Distance between strips (maize-based cropping)	Type of erosion
Flat to gentle undulations	0 to <5%	>50 m	Sheet erosion
Moderate to steep slopes	>5% to <20%	>20 m but <50 m	Gully erosion
Very steep slopes	>20% to <40%	15–20 m	Mass movement, severe rain splash, and sheet erosion

is about 75 cm from one Napier grass stalk to the next.

- Periodically inspect the forage grass or legume contour to ensure that no weeds are emerging.
- After six or seven weeks, implement partial coppicing by pruning about 50% of the leafy biomass from the Napier grass, and feed it to livestock (or sell it).
- Do not harvest the leaves of the forage legumes (lablab, desmodium, or cowpea) as these establish at a much slower rate than the forage grasses. The leaves will provide soil cover and improve water infiltration into the root zone. Seeds can be harvested and the residue used as feed for livestock, or incorporate the leaves and stalks in the soil before planting the forage legume the next year.

Rainwater harvesting using tied ridges and ripping techniques

Description of the technology

Crops grown in semi-arid zones (with annual rainfall of 300–800 mm) are likely to experience water stress, which shortens the period of growth of leaves, flowers, and seeds. This results in reduced grain yields, adversely affecting household food security and incomes. 'In-situ' rainwater harvesting (IRWH), which maximizes uptake of rainwater by plants, is an appropriate technology for these zones.

IRWH technologies include tied ridging (Figures 5.6 and 5.7) and ripping (Figure 5.8). These IRWH techniques conserve rainwater in farmer's fields for optimizing crop production in semi-arid areas characterized by inadequate and erratic rainfall. They are effective in delaying crop moisture stress by improving soil moisture retention, enhancing infiltration, and reducing water loss from surface runoff (Hatibu *et al.*, 2006; Swai *et al.*, 2007; Vohland and Barry, 2009). These facilitative effects ultimately result in increased soil water content that promotes root growth and optimizes nutrient transport to the root surface for easier plant uptake and improved growth, which translates to increased crop yields.

In-field tied ridges effectively store rainwater on the soil surface and reduce soil erosion (Figure 5.7). The ridges constructed in one season can be left in place to provide residual tied

Figure 5.6. Increased growth of maize planted on tied ridges (right) compared with farmer practice (a flat seedbed, left). (Photo courtesy of Elirehema Swai, 2016.)

Figure 5.7. Tied ridges increase rainwater infiltration, and reduce runoff and soil erosion. (Photos courtesy of Jonathan Odhong, 2017, left, and Regis Chikowo, 2018.)

Figure 5.8. Oxen-drawn ripper (left) and rip lines ready for sowing (right). (Photos courtesy of Elirehema Swai, 2016.)

ridges. There is a large demand for labor for ploughing, and for ridge and ridge tie construction in the first season, but in the subsequent seasons, the ridges can be easily re-shaped to their original size, ready for planting. Tied ridging is best suited to fields with a slope gradient of less than 7%.

The aim of ripping is to increase water infiltration and reduce runoff. It is different from normal plough tillage because the soil is not turned over, so some of the crop residue is left on the surface (Figure 5.8). As a result, the soil is less exposed and less vulnerable to the impact of splash and sheet erosion, and to water loss through evaporation and runoff. Ripping can help to maintain soil moisture and prevent the crop suffering from water stress during dry spells. Ripping can be used on slopes with gradients of more than 7%, and can be combined with physical barriers, like strips, as described below.

The choice of tied ridging or ripping depends on site conditions, including the degree of slope, although Africa RISING research indicates that tied ridging is associated with greater yield increases than ripping. However, most IRWH technologies do not work well on sandy soils that do not easily retain water. Here, the benefits may not outweigh the additional labor costs.

Benefits of the technologies

Africa RISING validation work conducted in Malawi and Tanzania confirmed the benefits of the IRWH technologies. Tied ridging increased maize grain yield by 61% and ripping increased maize grain yield by 36% (Table 5.4). These yield increases resulted in economic gains of 58% for tied ridges and 28% for ripping. The results were due in part to soil moisture retention increases of 87% for tied ridging and 53% for ripping. Additional research shows that use of the oxen-drawn ridger (Figure 5.9) and ripper (also known as the Magoye ripper) increased sorghum grain yield in semi-arid areas of Tanzania from 1.1 t/ha under conventional tillage with an ox-plough to 3.2 t/ha under ripping (Majule *et al.*, 2013).

Another maize productivity study was undertaken across several trial sites in semi-arid areas of southern Malawi in a split-plot experimental design, where water management (tied ridges or ridges only) were trialed on the main plots and fertilizer management on the sub-plots. Some sub-plots had no fertilizer applied to the maize, some received 50% of the recommended

Table 5.4. Benefits of in-situ soil and water conservation technologies (2013/2014 and 2019/2020 cropping seasons) in semi-arid areas of central Tanzania

	Productivity (maize yield)		Moisture retention		Soil loss (erosion)		Economic gain	
IRWH technology	t/ha	% change	Moisture %	% change	t/ha	% reduction	Gross margin	% change
Conventional tillage + 20 kg/ha phosphate at planting	2.4	n/a[1]	7	n/a	18.3	n/a	687	n/a
Tied ridging + 20 kg/ha phosphate at planting	3.8	58	13	86	2.2	88	1,089	58
Ripping + 20 kg/ha phosphate at planting	3.2	33	11	57	12.6	31	882	28

[1]n/a = not applicable.

Figure 5.9. Oxen-drawn ridger. (Photo courtesy of Elirehema Swai, 2016.)

levels of nitrogen fertilizer (50% fertilizer) and others were applied with the recommended nitrogen fertilizer rate of 70 kg/ha (100% fertilizer). The results clearly indicated that in the mostly nutrient-depleted soils, growing maize with no fertilizer on tied ridges alone did not result in significant yield gains. However, the benefits of fertilizer application at both 50% and 100% were greater on the tied ridges. Overall, tied ridges enhanced the effectiveness of rainfall and increased the returns to fertilizer investments compared with open ridges. This highlights the importance of fertilizer use and shows the synergy of integrating tied ridges for soil water management and fertilizer application (Figure 5.10).

Farmers' responses

Africa RISING assessed farmers' perceptions of the benefits of using tied ridges by administering a questionnaire to 50 farmers in Mlali village, Kongwa district, during the 2015/2016 cropping season. Of these farmers, 30 had tested the technology in their own plots and 20 had participated in validation trials. More than 40% of farmers noted an increase in maize grain yields and recognized that this was due to improved soil moisture status. Although land preparation for tied ridges demands more labor than traditional practices, farmers noted that fewer weeds grew in fields with tied ridges.

In 2019, an Africa RISING team evaluated men and women farmers' perceptions of the labor involved in using tied ridges for staple cultivation. This was done in four villages in Kongwa district, Tanzania. Farmers identified land preparation and weeding as the most labor-intensive tasks in maize production. With respect to household labor arrangements, land preparation often involves men, with women and children generally responsible for weeding. When comparing land preparation methods, respondents found the establishment of tied ridges demanded more drudgery than for flat cultivation. Perceptions about changes in women's workload for weeding were mixed. Some women rated weeding as less labor intensive with ridges. They perceived that the ridging has a stronger effect on the suppression

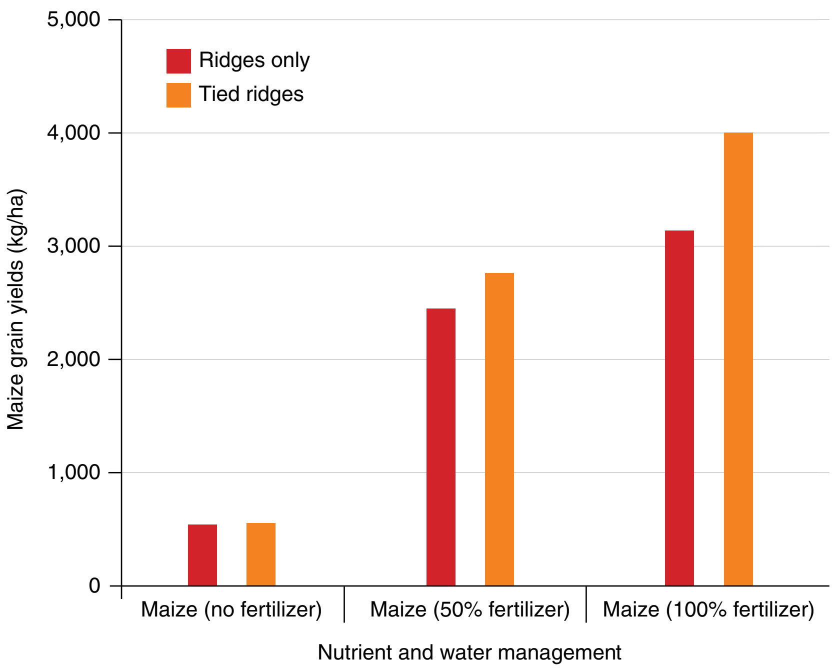

Figure 5.10. Mean maize productivity across five sites comparing maize yields on open ridges with yields on tied ridges (with fertilizer). Source: IITA (2020) CC BY 4.0.

of weeds. Others described how weeding the ridges demanded more time and skill to avoid damaging the mounds. Practitioners should assess the labor benefits and burdens of soil and water conservation practices for women when compared with men. Suitable assessment tools include activity profiles and drudgery scores (see Chapter 1 of this book). Where inequitable labor burdens become visible, it can be useful to reflect on them with farm household members, and potentially balance them through the gender and youth balance tree exercise.

Opportunities for application of IRWH technologies

IRWH technologies are appropriate throughout ESA in regions of inadequate and erratic rainfall. Due to the high labor demand (25 to 35 labor days per hectare), farmers with access to animal traction (oxen or donkeys) are more likely to adopt these technologies. Sufficient forage is required for animals to maintain effective draught power. Animal-drawn rippers are constructed locally. Tied ridging and ripping are not appropriate for well-drained sandy soils.

How to get started

Tied ridges

- Tied ridges must be made at planting time to capture as much rainwater as possible.
- Install ridges across the slope based on the recommended row spacing of the crop using the hand hoe or oxen-drawn ridger. Ridges of about 25–45 cm height maximize the amount of water that can be retained following a rainstorm.
- Install cross ties along the ridges by scraping up soil from the bottom of the furrows at intervals of 1—2 m. These should be 50–75% of the height of the ridges (to allow excess runoff to drain away).
- Allow for flexible ridge management; ridge ties must be broken during flooding periods (when there is continuous rain for more than seven days).
- Plant the crops on the ridges. During the growing season, maintain the ridges and ties, particularly following a rainstorm.
- When tied ridges have collapsed, they can be rebuilt while weeding.

Ripping

- Smallholder ripping is best implemented using the oxen-drawn ripper and should be undertaken before the onset of the rainy season.
- Install rip lines across the slope to capture maximum surface runoff. The oxen-drawn ripper achieves a depth of 20–30 cm.
- Plant seeds in the rip lines at the appropriate spacing.

Contour farming with fodder crops

Description of the technology

Contour farming with fodder crops adopts the principles of contour farming with the addition of planting fodder crops (trees/shrubs or grasses) on the ridges. The fodder crops help to stabilize the banks, and add value as both additional crops and soil conservation structures. Farmers plant banks of vegetation along the contour lines at the top of a field, and within the field, to catch water runoff. It is a landscape-based technology that controls soil erosion and rehabilitates land for crop production. It involves construction of *Fanya chini* terraces (banks below ditches) along the upper field edge to capture water entering the field, and *Fanya juu* terraces (banks above ditches) to capture runoff within the field. Food crops are grown in the alleys between the *Fanya juus*. Fodder trees (e.g., *Gliricidia sepium*), grass fodder (e.g., Guatemala grass, *Tripsacum* spp) and/or cover crops such as sweetpotato can be planted on the banks to stabilize the ridges (Figure 5.11).

The banks and ditches intercept and slow runoff water, thereby preventing the formation of rills and gullies, and reducing soil erosion. They conserve water and increase infiltration, making more water available for plant growth. The stabilizing crops of grass or trees provide biomass (as green manure or manure from

Figure 5.11. Fanya juu (bank above ditch) contour planted with *Gliricidia sepium* in Laikala village, Kongwa district, Tanzania. (Photo courtesy of Jonathan Odhong, 2017.)

livestock fed on the leaves) to improve soil organic matter content. They also provide a diversified income source and sequester carbon.

While the technology reduces the land area available for planting maize by about 10%, it does provide a potential additional income source from sales of fodder (or livestock products). It also helps to improve soil fertility. In addition, after the first few years, the yields of maize should improve sufficiently to balance out the loss of land area. This technology also contributes to climate change mitigation through carbon sequestration into plant biomass.

Benefits of the technology

Land rehabilitation benefits: Research in semi-arid areas of East Africa indicates that contour farming improves land productivity and builds climate resilience mainly through conservation of soil and water resources. Contours reinforced with hedgerows of *Senna siamea* reduced soil loss by 94% and runoff by 78% in semi-arid areas of Machakos, Kenya (Young, 1997). During six years of contour farming on a depleted soil in Kongwa, Tanzania, the Africa RISING team noted a slow but progressive increase in soil fertility. After six years, all the indicators of soil fertility had improved significantly (Table 5.5).

Crop productivity: Table 5.5 also shows an increase in crop yield associated with improved soil fertility. Cumulative maize grain yield increased by 120%, while biomass yield increased by 249% after six years. The biomass yield included produce harvested from the contour-reinforcing crops. *Gliricidia sepium* and Guatemala grass provided additional benefits as fodder and fuelwood (Figure 5.12).

Economic benefits: Gross margin increased by 431% (Table 5.5), with diversified income sources including wood fuel and fodder. These additional crops provide a safety net for farmers during years of adverse weather, when food crop productivity may fall.

The total gross revenue for all crop components was used to calculate the gross margin presented in Table 5.5 after deducting associated

Table 5.5. Change in chemical properties of the topsoil (0–20 cm), yields, margins, and calories after six years of contour-based farming at Mlali village, Kongwa district, Tanzania

Parameter[1]	Control (n=3)[2]	Contour (n=9)	Change (%)
Soil pH (water)[3]	4.39	5.40	23
Total nitrogen (%)	0.04	0.07	75
Phosphorus (mg/kg soil)	13.09	24.50	81
Organic carbon (%)	0.53	0.68	28
Sulfate (mg/kg soil)	13.71	19.93	45
Maize grain yield (t/ha)[3]	3.11	6.82	120
Cumulative biomass yield (t/ha)[3,4]	9.44	32.91	249
Cumulative gross margin (US$/ha)[4]	649	3,445	431
Calories (kcal/ha)[5]	11,243	24,701	120

[1]Recommended (adequate or medium) levels of soil chemicals according to Landon (2013): Soil pH: 5.5–7.2, total nitrogen: 0.2–0.5%, organic carbon: >2%, phosphorus: 5–15 mg/kg (Bray-1 test method), sulfate: 6–12 mg/kg).
[2]Control plot with no contour planting (farmer practice).
[3]Cumulative value over three growing seasons (2018–2020).
[4]Above-ground biomass of maize (grain, stover, and cobs) in the control plots; and maize, grass, and *Gliricidia* in the contour plots.
[5]Calorie yield based on maize grain yield.

Figure 5.12. Fuelwood from coppiced *Gliricidia sepium* in Laikala village, Kongwa district, Tanzania. (Photo courtesy of Jonathan Odhong, 2017.)

costs for labor, land, and inputs. Gross margin is a recommended variable for profit margin analysis of technologies, as it is also used to analyze the sustainability of technologies using the Sustainable Intensification Assessment Framework described by Musumba *et al*. (2017). The gross margin analysis accounted for total revenues from the different crop components and the total variable costs of all farm operations, including land rent, input costs, and labor for crop management operations, including the cost of establishing the contours.

Table 5.6 shows the gross income (revenue before deducting any costs) from the various crop

Table 5.6. Gross income from the different crop components at Mlali village, Kongwa district, Tanzania

Site	Year	Gross income (US$/ha)			
		Maize	Guatemala grass	*Gliricidia sepium*	Total
Lowland site (n=3)	2018	1,027	141	767	1,936
Upland site (n=6)	2018	1,109	198	587	1,894
Lowland site (n=3)	2019	n/a[1]	88	767	856
Upland site (n=6)	2019	243	92	587	922
Lowland site (n=3)	2020	410	62	767	1,239
Upland site (n=6)	2020	1,092	67	587	1,746

[1]n/a = not applicable.

components. The results illustrate the resilience and risk mitigation benefits of crop diversification, especially during adverse growing conditions caused by weather extremes. The poor results for maize in 2019 occurred during a severe drought. In that year, the fodder grass and trees provided a better income than maize.

Scaling up agroforestry interventions

A shortage of quality tree seed and seedlings presents a challenge to increasing the scale of agroforestry interventions throughout ESA. To address this challenge, Africa RISING staff taught farmers how to establish community nurseries and produce tree seedlings for use in research and demonstration sites. This approach was very successful, with a five-member farmer group at Mlali village producing over 20,000 seedlings of various trees and shrubs during the 2016/17 growing season. Around 70% of the seedlings were planted in Africa RISING sites or donated to Kongwa District Council to help them meet the national tree-planting target of 2 million seedlings per year. The remaining 30% of the seedlings were sold, generating over 2 million Tanzanian Shillings (US$ 1,200). Part of the money generated contributed to the costs of nursery operations (e.g., watering and collecting forest soils) while the rest was shared among the group members (see Box 5.1).

Farmers' responses

Farmers have accepted the contour-based technology well. Out of 825 farmers attending a 'training of trainers' program organized by Africa RISING adoption partner the LEAD Foundation in 2019, 92 (11%) have already established the system, planting 2,570 seedlings of *G. sepium* (see Box 5.1). These farmers are located in six districts in the Dodoma region of Tanzania, and their farms now provide learning sites, disseminating the technology more widely. One farmer, who adopted the technology early on, observed an elevation in the water table after four years. He was able to dig a well (Figure 5.14) and use the water to grow off-season vegetables, providing food for three months after the maize harvest. This represented a significant benefit to the family's nutrition and income. A combination of factors, including runoff from upland sites and improved infiltration, may have contributed to the increased water availability. Two additional farmers observed increased maize yields and reduced erosion on their fields. Seedlings of *G. sepium* and fodder grass planted on the contours in 2017 are already providing fuelwood for household use and fodder for livestock.

Initial reluctance on the part of farmers to adopt the technology may need to be overcome. This may be due to the high labor demand for the initial construction of the banks and ditches, and for planting the fodder crops. There are also high initial costs associated with buying quality tree seeds or seedlings. Farmers need to have secure, long-term access to and tenure of the land for the labor investment to be fully repaid. Yields of food crops may also decrease initially, due to an approximately 10% reduction in land area available for these crops. Alternative high-value crops, including fruit trees, may be more appropriate in some locations, and participatory analysis of trade-offs and risks is therefore important. The potential for conflict with downstream farmers

Box 5.1. Farmer Maile's tree nursery

Moshi Maile is a member of the Mlali village tree nursery group. He has successfully commercialized his knowledge of tree nursery management after being identified as a key producer of cashew nut seedlings in Kongwa district. Since 2020, he has received cashew nut seeds from the district agriculture and irrigation officer, which he plants and raises as seedlings at his own cost (Figure 5.13). The sale price is Tanzania shillings (TZX) 500 per seedling and he is also paid TZX 300 per seedling for his services. So far, he has sold 9,000 tree seedlings, earning TZX 7.2 million. He also produces over 10,000 seedlings per season of various tree species, including *G. sepium*, for the LEAD Foundation and the Tanzania Forest Service district office. Income from tree nursery activities in 2021 have helped him to cover the first-year costs of his daughter's course in community development at Uyole College in Mbeya, Tanzania.

Another group member, Abinely Mgomba, used his portion to cover school fees for two children, buy five goats to diversify his livelihood options, and pay the labor costs of planting a woodlot on 0.8 ha to provide fuelwood and timber for the household.

Figure 5.13. Moshi Maile and his wife with their cashew nut seedlings. (Photo courtesy of Anthony Kimaro, 2021.)

(in case of water overflow from the ditches) should also be assessed.

The best results are achieved when the technology is applied by the majority of the farmers in one area. Tree management is a knowledge-intensive practice, requiring an understanding of how to maximize the positive interactions with crops (e.g., reduced soil erosion) and minimize the negative ones (e.g., competition). Poor management (e.g., inappropriate spacing, pruning, pollarding, and thinning) may result in a reduction in the cropping area and crop yield. Availability of quality tree seeds and seedlings of appropriate species may also present a challenge, since the supply system for tree germplasm in many ESA countries is not well established. Farmers may need to receive training on how to collect quality tree seeds and raise seedlings in community nurseries (see box).

Opportunities for application of contour-based technology

Soil erosion and drought are widespread constraints to sustainable agricultural production in semi-arid areas of ESA. These problems are aggravated further by the impacts of climate change, extensive grazing, and high reliance on fuelwood from native forests for cooking by the majority of small-scale farmers in the region. The beneficial effects of integrating trees and grass fodder in contour farming address land degradation challenges while generating useful products and building resilience to climate change. Fuelwood supply from natural forests is declining rapidly with the increasing population in ESA, and while being demanding of labor in the establishment phase, the technology reduces the need for labor in collecting fuelwood, can

Figure 5.14. Water retention ponds helped to recharge groundwater in Mlali, Tanzania. (Photo courtesy of Anthony Kimaro, 2018.)

provide a new source of income, and confers long-term benefits once fully established. Plantations, woodlots, and crop residues are increasingly becoming important sources of wood fuel to mitigate the problem of declining supply from native forests in semi-arid parts of ESA. These conditions provide an entry point to increase awareness and application of technologies that integrate crop production and wood or fodder supply with soil enhancement.

How to get started

- Establish contour lines using an A-frame. Extension staff can help with this. The distance between successive contour lines is determined by the slope length and gradient. Or use the formula W=200/S as a guide to determine the distance between contour lines, where W is the inter-hedgerow spacing (m) and S is slope in percentage (%) (Young, 1997). The recommended intra-row spacing on the *fanya juu* bank is 3 m for fodder trees and 1 m for forage grass (or other cover crop) when they are intercropped.
- The choice of plant types and species, and their combinations for bank re-enforcing is guided by the priority needs of the farmer (fruits, fodder, fuelwood, timber, etc.) to ensure the products generated will be relevant and attractive.
- No weeding or thinning is conducted on the *fanya juu* banks, to encourage the stability of the banks. Trees can be pruned to minimize any shading effects on crops, with the cuttings providing fuelwood, but it must be done to avoid reducing bank stability.
- Tree and shrub species with multiple stems and good coppicing ability are preferred for an annual supply of fodder and wood. Guidelines on the type of tree species to plant and for which purpose can be obtained from forest extension officers (or see Mbuya *et al.*, 1994). Online resources and smartphone applications include 'Potential natural vegetation of East Africa' (World Agroforestry Centre, 2020). Tree seeds can be obtained from national tree seed agencies, forestry institutions, and non-governmental organizations, as well as from local farmer- or community-based nurseries.

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