A Basket of Regenerative Agriculture Technologies for the Improvement of Soil Health in Africa

50 Technologies for On-farm Demonstrations

SAA
Sasakawa Africa Association

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Acronyms

AWD	Alternate Wetting and Drying
C	Carbon
CBF	Community-Based Facilitator
CDP	Community Demonstration Plot
CNTA	Centre for No-Till Agriculture
CSA	Climate-Smart Agriculture
EAs	Extension Agents
EM	Effective Micro-organisms
FBS	Fallow Band System
FLP	Farmer Learning Platform
FTC	Farmer Training Centre
MAD	Men Assisted Demonstration plot
MAP	Model Adoption Plot
OM	Organic Matter
PNA	Participatory Needs Assessment
PR	Phosphate Rock
RA	Regenerative Agriculture
RC	Relay Cropping
RS	Rhizosphere Soil
SAA	Sasakawa Africa Association
SC	Strip Cropping
SOC	Soil Organic Carbon
TAP	Technology Adoption Plot
UDP	Urea Deep Placement
WAD	Women Assisted Demonstration plot

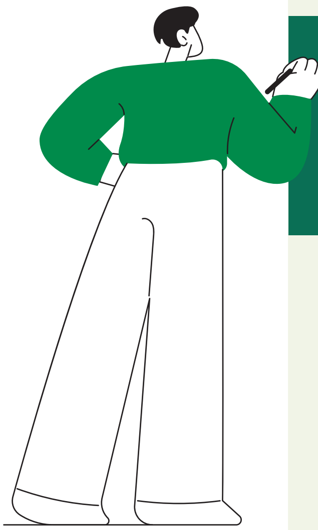
Executive Summary

The term ‘soil health’ refers to the ability of soil to provide vital ecosystem services, including plant growth, food security, biodiversity conservation, water absorption and retention, and environmental resilience. Soil is the most significant carbon sink on land and is vital for climate change mitigation. Sufficient soil organic carbon (SOC) and the absence of toxins are necessary for maintaining healthy and productive soil.

In Africa, different soil types bring different challenges. Ferrallisols and Acrisols make phosphorous unavailable for plant roots. Vertisols have high clay content and crack during dry periods in semi-arid and sub-humid zones. Gleysols are excessively wet and require significant investments in drainage systems. Meanwhile, Arenosols are prone to leaching and wind erosion, limiting crop growth and performance. At the same time, African soils have low SOC, biodiversity, and fertility. It is not surprising, therefore, that these soils are severely degraded.

In Sub-Saharan Africa (SSA), 65% of agricultural land is degraded [1]. Population increase and food, water, and fuel demand have contributed to this issue. As a result, less land is available per person, land use has become more intensive, and traditional practices have declined. The conversion of forests into cropland and the overuse of grazing lands for crop cultivation further contribute to this problem. Forest resources are also being exploited for fuel and timber to generate income for rural households.

To make matters worse, SSA faces a fertilizer shortage, significantly limiting agricultural productivity and increasing fertilizer costs. Only 22 kg of fertilizer is applied per hectare in the region, seven times less than the global average of 146 kg [2]. To help smallholder farmers overcome these unique challenges, we must collaborate and develop adaptable strategies for building capacity, providing fertilizer support, and implementing regenerative agricultural techniques.



Studies have shown that rehabilitating degraded land and improving soil health is a profitable investment. It can generate a return of up to 5 USD for every 1 USD invested and, in some cases, a return of 7-30 USD for every 1 USD [1, 3]. This high return on investment will help to build resilient food systems and regenerate soil health across the region.

This extension guide was created by The Sasakawa Africa Association (SAA), using material obtained from field demonstrations in countries across SSA, including Mali, Uganda, Nigeria, Ethiopia, and Ghana. The guide illustrates a ‘Basket of Regenerative Agriculture (RA) Technologies,’ which extension agents can construct and demonstrate on-farm using SAA’s Farmer Learning Platform models. It consolidates soil health and water conservation practices, and integrated soil fertility and climate-smart technologies. The technologies illustrated use indigenous African knowledge, holistic management, and cutting-edge crop and soil science. They should be deployed alongside Good Agronomic Practices (GAPs), recommended fertilizer types and application rates.

Dr. Makoto Kitanaka
President of Sasakawa Africa Association

Appreciation

We are grateful to Dr. Kofi Boa of Ghana's Centre for No-Till Agriculture (CNTA), Kumasi, Ghana, for training SAA's RA team in conservation agriculture and integrated soil and water management. We also want to thank SAA's RA team for bringing these soil-improving technologies to smallholder farmers. Your work continues to have a major positive impact in Africa.

Introduction

Regenerative Agriculture (RA) is a subset of Climate-Smart Agriculture (CSA). CSA aims to increase agricultural productivity sustainably, adapt to climate change, and decrease greenhouse gas (GHG) emissions. RA takes a holistic approach to farming to enhance the health of soil, water, and ecosystems while increasing biodiversity and improving climate resilience. It encompasses the positive domino effect of soil health and environmental rejuvenation. Both RA and CSA are vital to creating more sustainable and resilient food systems.

What is Regenerative Agriculture?

RA aims to revitalize and restore the environment, prioritizing soil health and biodiversity. It employs methods to encourage natural resource utilization and reduce carbon emissions. In Africa, there are eleven core principles governing regenerative farming, as illustrated in Figure 1. As agricultural practitioners, researchers, and policymakers, your role in implementing these principles is crucial and valued.

The Eleven Core Principles of African Regenerative Agriculture

Figure 1: The eleven core principles of RA most suitable for African soils and agriculture.

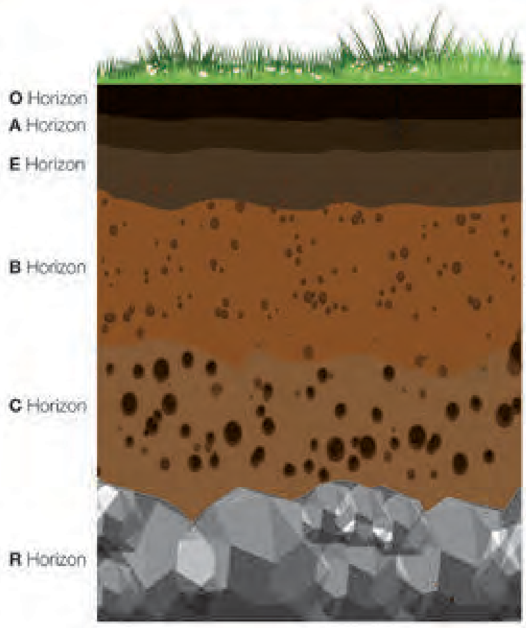
What does regenerated soil look like?

A. Demonstrating soil regeneration

1. The soil profile pit

Soil experts have confirmed that Africa's soils have been highly weathered, eroded, and degraded. For smallholder farmers, the soil profile's first, second, and third layers have been lost through century-old erosional processes. Consequently, farmers are now growing crops in the lower soil horizons (Fig. 2). Lower soil horizons have a limited capacity to supply and retain the nutrients and water needed for plant growth.

The soil profile pit can be set up at a demonstration site at the beginning of RA practices to enable the farmer to monitor the soil's improvement (Fig. 3). A healthy soil profile should have a large organic matter or humus layer and show evidence of microorganisms such as soil insects and earthworms. This is a good indicator of healthy soil (Fig. 4). The profile pit can be protected with a concrete slab lifted during field days or demonstrations for farmer visits at the RA site.



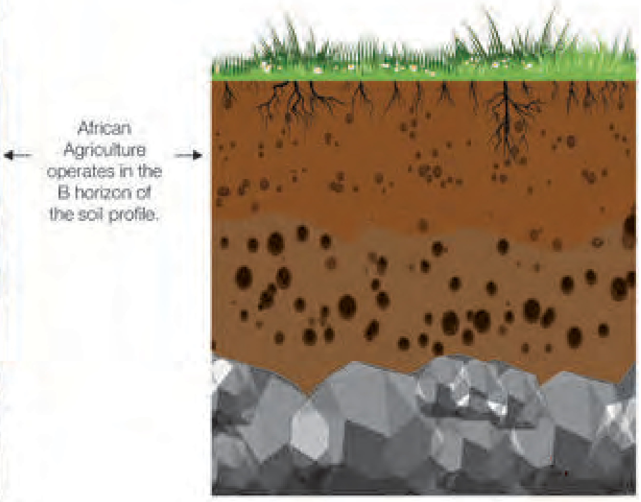


Figure 2: Africa's soils are highly weathered, eroded, and degraded through century-old erosional processes. Agriculture operates in the soil profile's fourth horizon (the B horizon). RA aims to increase the resilience of this soil.

Figure 3: A covered and open soil profile pit for RA demonstrations.

Figure 4: Profile pits demonstrating healthy soil, with a thick layer of organic matter or humus, and an indication of soil organisms such as insects tunneling in the lower soil.

SAA's Farmer Learning Platform Model

SAA's Farmer Learning Platforms (FLPs) aim to simplify technical messages while improving knowledge and technology transfer to smallholder farmers. They do this using a science-based, problem-solving technology demonstration strategy.

The FLPs start with the following stages: i) Participatory Needs Assessment (PNA) (Fig. 5), ii) Establishing Community Demonstration Plots (CDPs), iii) Classifying Technology Adoption Plots (TAPs), iv) Recognizing Model Adoption Plots (MAPs), and v) Continuous training and capacity building of partner Extension Agents (EAs) and Community-Based Facilitators (CBFs).

i. Participatory Needs Assessments (PNA)

The PNA process begins with community consultations involving partner extension service providers and farming communities. The main objectives are to identify the actual needs of smallholder farmers, determine the factors that limit agricultural productivity, and assess the capacity-building requirements of both EAs and farmers.

The appropriate basket of technologies is selected during strategic meetings at the community level in consultation with national EA partners, representatives of farmer-based organizations, and rural opinion leaders. This process ensures a bottom-up approach that enhances the adoption of agricultural technologies.

SAA Ethiopia

SAA Mali

SAA Nigeria

SAA Uganda

Figure 5: SAA personnel conducting pre-season PNA meetings with farming communities in Ethiopia, Mali, Nigeria, and Uganda.

ii. Establishing Community Demonstration Plots (CDP)

The EAs use CDPs as training tools to generate awareness of promising agricultural technologies. These CDPs consist of 15-20 smallholder farmers. The EAs and smallholder farmers help to establish the CDPs and identify productivity-increasing technological packages.

Each CDP is established as four plots in the middle of community gardens. Two demonstration plots are managed by men; these are known as Men Assisted Demos (MADs). The other two are managed by women, known as Women Assisted Demos (WADs), to account for potential gender barriers to adoption (Fig. 6). Using this methodology, the number of farmers per community benefiting from CDP training can range from 60-80. There is also a spillover effect into surrounding communities. SAA fully funds these CDPs.

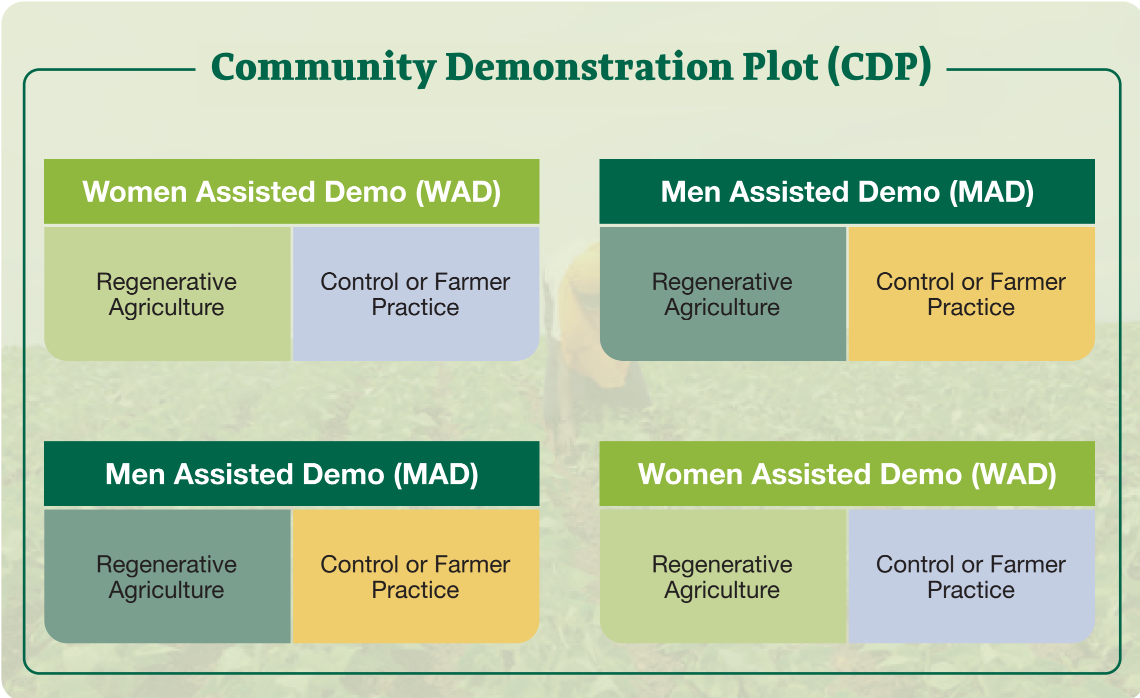


Figure 6: A CDP cluster design for RA demonstrations using a gender-balanced approach.

iii. Classifying Technology Adoption Plots (TAPs)

The smallholder farmers and farmer groups participating in the CDPs are expected to test the demonstrated agricultural technology on small plots on their farms, at their own expense, before deciding whether to adopt and scale. We refer to these small plots as Technology Adoption Plots, or TAPs. They are crucial for driving effective technology adoption and for increasing overall impact.

Out of the 80 CDP-trained farmers in a community, 15 TAP farmers are selected based on the following criteria:

1. They must have adopted at least 30% of the technological package demonstrated in the CDP.
2. The plot size should not be less than 1,000 m^2.
3. The plots should be easily accessible and visible, for example, along village paths.
4. The farmer should allow SAA personnel and EAs to gather relevant technology adoption data.
5. The farmer should be willing to share experiences with other farmers.

TAP farmers, the early adopters.

The TAP farmers (Fig. 7) are known as '**early adopters'** and receive ongoing training from EAs. They are also connected to the other two SAA pillars: Nutrition- Sensitive Agriculture (NSA) for post-harvest and agro-processing techniques, and Market-Oriented Agriculture (MOA) for enterprise selection and marketing channels. At this stage, data collection is vital. SAA has developed a database by documenting these TAPs through continuous data collection, analysis, and interpretation. In addition, the TAP farmers collect data through citizen science to inform our prediction models for scaling technologies across Africa.

Figure 7: A smallholder Technology Adoption Plot (TAP) in Ethiopia, showcasing spatial crop rotation of faba bean and wheat.

iv. Model Adoption Plots (MAPs)

MAPs are run by exemplary TAP farmers identified through a strict selection process (Fig. 8). In each community, two MAPs are chosen from the 15 TAP farmers based on the following criteria:

1. They should be a TAP farmer who adopted 100% of the demonstrated technological package.
2. The plot size should be at least 1ha for Nigeria and Mali and 0.5 ha for Uganda and Ethiopia.
3. They should preferably be a commercial farmer.

Figure 8: SAA personnel in Mali evaluating a MAP run by a commercial farmer growing a drought-tolerant Vitamin A maize variety. The farmer participated in the ISSD-Sahel project to enhance seed access through community seed multiplication in West Africa.

v. Continuous training and capacity building of partner Extension Agents and Community-Based Facilitators (CBFs)

SAA continuously trains national EAs and Community-Based Facilitators (CBFs), who then pass on knowledge to smallholder farmers through at least three different training sessions, as follows:

1. Pre-season training
2. Mid-season training about two months after the first season (Green Field Days).
3. Late-season training to analyze and evaluate the season (Brown Field Days).

Our diligent EAs and CBFs are crucial in our data collection efforts. They gather information on agronomic practices, management skills, production and productivity. They also provide a cost-benefit analysis of the demonstrated technology (Fig. 9, Table 1). This comprehensive data is then stored in our SAA databases for further analysis and interpretation.

Figure 9: SAA staff in Uganda building EA and CBF capacity for collecting and testing soil samples as part of various RA interventions.

Table 1: Number of EAs and smallholder farmers trained in RA using SAA's Farmer Learning Platforms

Year	Ethiopia	Mali	Nigeria	Uganda	Total
Extension Agents trained					
2021	710	280	1,870	1,370	4,230
2022	574	280	960	158	1,972
2023	93	131	112	174	510
Total	**1,377**	**691**	**2,942**	**1,702**	**6,712**
Smallholder farmers trained					
2021	92,000	5,200	192,000	59,700	348,900
2022	18,900	7,600	455,200	40,200	521,900
2023	951	5,168	9,000	10,378	25,497
Total	**111,851**	**17,968**	**656,200**	**110,278**	**896,297**

Principle 1:

Understand the context of your farm operation

Understanding the farm context is an RA principle that emphasizes the importance of site-specificity. Considering each farm's unique context, it enables farmers to set objectives and monitor results to measure regenerative outcomes. As such, it is a foundational step in the effective implementation of RA practices.

WHAT TO LOOK OUT FOR;

i. Soil Health and Type:

- **Soil Testing:** Conduct comprehensive soil tests to determine your soil's health, structure, nutrient levels, and microbial activity.
- **Soil Type:** Recognize the type of soil (clay, loam, sand, etc.) and its water-holding capacity, drainage, and fertility.

ii. Climate and Weather Patterns:

- **Local Climate:** Analyze your region's climate, including temperature ranges, rainfall patterns, and seasonal variations.
- **Microclimates:** Identify any microclimates on your farm that may affect plant growth and soil health differently.

iii. Topography and Landscape:

- **Slope and Elevation:** Assess the slopes, elevation changes, and overall topography to determine water flow, erosion risks, and suitable planting areas.
- **Hydrology:** Map out water sources, drainage patterns, potential water retention, soil erosion, or irrigation areas.

iv. Biodiversity:

- **Existing Flora and Fauna:** Take stock of the current plant species, insects, wildlife, and microbial life on your farm.
- **Habitat Diversity:** Evaluate the variety of habitats on your farm, such as wetlands, woodlands, grasslands, and their interconnections.

v. Farm History and Management Practices:

- **Previous Land Use:** Understand the land's historical use, previous crops grown, and any past chemical inputs or tillage practices.
- **Current Practices:** Review your current farming methods, crop rotations, pest and weed management, and any conservation practices already in place.

vi. Economic and Social Factors:

- **Market Access:** Identify the markets available for your produce and any potential for premium pricing for regeneratively grown products.
- **Community and Labour:** Consider labour availability and skill level, community support, and partnerships with local organizations.

vii. Goals and Values:

- **Farm Vision:** Clarify your long-term goals for the farm, such as increasing sustainability, improving yield, enhancing biodiversity, or restoring ecosystems.
- **Personal Values:** Reflect on your values and how they align with regenerative principles, such as a commitment to environmental stewardship and community health.

Understanding the context of your farm operation is an ongoing process. By continuously observing, learning, and adapting, you can effectively implement RA practices that enhance your farm's resilience and productivity while delivering broader social and environmental benefits.

Figure 10: SAA-Nigeria RA team talk to farmers in Jigawa State, Nigeria, about understanding their farm contexts when practicing RA.

Principle 2:

Minimize soil disturbance

RA is all about improving and restoring soils. To this end, it is essential to understand and follow the principle of reduced soil disturbance. Soil disturbance can be physical, chemical or biological, severely harming the soil ecosystem. For example, physical disturbance, such as tillage and overgrazing, negatively affects the soil's biological integrity.

Benefits of this principle

- No-till or minimal-tillage farming improves carbon sequestration and soil aggregation.
- Crop yields can be improved by increasing soil organic matter, which enhances nutrient delivery.
- Soil micro and macro-organisms can settle and function appropriately in undisturbed soil.
- Minimizing soil disturbance improves soil fertility, maintains pore connections, and preserves soil integrity.
- Because soil pores at the top are related to the soil fabric below, minimizing soil disturbance enhances water infiltration, lowering the chance of surface runoff and soil erosion.
- When natural vegetation is mainly left undisturbed, it can thrive and grow abundantly.

Traditional agricultural systems involve tilling soil multiple times during the fallow period to control weeds and prepare a seedbed for sowing. Residues from previous crops are also removed for easier tillage and sowing. No-till systems offer numerous benefits over traditional tillage, including controlling erosion, reducing fuel use, conserving soil moisture, promoting soil health, and increasing yields (Fig. 11). They also increase organic carbon concentrations, improving the soil's structural stability, nutrient stores, and biological diversity. In the absence of soil tillage, soil macropores also increase, leading to increased water infiltration, slow runoff, and decreased erosion rates. Overall, no-till systems are highly valued for their environmental benefits.

Figure 11: SAA-Uganda RA team with a CBF who practices minimum tillage in Kiboga, Uganda.

B. Demonstrating minimum soil disturbance

2. Jab planters for minimum tillage

A jab planter helps small-scale farmers to reduce drudgery when sowing and applying fertilizer. It is an easy-to-operate dibble instrument used with various soil types, including tilled and stubble soil. The jab planter consists of a seed hopper and fertilizer hopper mounted on wooden components with handles and metal 'beaks' (Fig. 12). A sliding mechanism regulates the seed flow while simultaneously dispensing a precise amount of fertilizer.

3. Mechanized minimum tillage rippers

As tractors are often too expensive for smallholder farmers in Africa, power tillers present a more affordable option for agricultural mechanization. Minimum tillage rippers are a popular choice among small and medium-scale farmers. They can perform almost all farm operations, including minimum tillage and ripping, if used judiciously. Their compact structure also makes them easy to transport (Fig. 13).

Figure 12: SAA RA team members from Nigeria, Ethiopia, and Uganda practice using jab planters at Ghana's Center for Non-Tillage Agriculture (CNTA).

Figure 13: The SAA teams from Uganda and Mali train smallholder farmers to use small power tillers (e.g., Honda) for minimum tillage.

4. Small drillers for constructing permanent planting basins and Zai pits

No-till planting basins and Zai pits are planting structures that help to minimize soil disturbance. They improve water infiltration and the application of inputs such as lime, fertilizer, manure, or compost. However, while planting basins can improve crop productivity, their construction may initially require significant additional labor, which can impact the profit margins of resource-constrained farmers [4]. For this reason, mechanized RA promotes the use of small drillers to reduce the drudgery of constructing and maintaining these structures (Fig. 14,15).

Figure 14: Various mechanized tools, such as small powered tillers weighing only 10kg (e.g., Mantis), and small disk harrows (e.g., Field Tuff), can be utilized in RA for minimum soil disturbance

Figure 15. Small soil drills are suitable for constructing and maintaining permanent planting basins and Zai pits in minimum tillage cropping systems.

5. Fertilizer applicators

Instead of broadcasting, fertilizer applicators inject fertilizer granules directly into the soil, reaching depths up to 6.5 cm (Fig. 16). This approach allows plant roots to absorb the fertilizer quickly and reduces volatilization, especially from nitrogen fertilizers. It also reduces leaching and water contamination while helping to minimize soil disturbance and improve efficiency. In addition, the deep placement of nitrogenous fertilizer increases nitrogen use efficiency in wetland rice and minimizes environmental impact, while the deep placement of urea minimizes loss.

Figure 16. Fertilizer applicator (e.g., ADOVZ)

Principle 3:

Maximize crop diversity

Crop diversification is an RA practice that ensures many species of plant roots exist in the soil simultaneously. Soil organisms interact with the rhizosphere's roots, improving above-ground and below-ground biodiversity. Crop diversification enhances biodiversity through combinations of agricultural techniques, such as:

- Perennial and annual crop planting
- Cover cropping
- Hedgerow planting
- Reduced agrochemical use
- Silvopasture with rotational grazing
- Underutilized crops
- Companion planting
- Intercropping
- Crop rotation
- Relay cropping
- Sequential double cropping
- Strip cropping

Benefits of this principle

- Different species have distinct roles to play in maintaining the balance of an ecosystem. Biodiversity therefore enhances the overall functioning of ecosystems.
- Increasing crop diversity enhances resilience to drought and flooding, reducing the risk of agricultural damage.
- Cover crops, crop rotation and perennial crops increase soil fertility and create ecosystem diversity, which is crucial for agricultural resilience.
- Perennial pastures can improve water quality and increase soil water holding capacity by accumulating organic matter.
- An increase in farm species diversity supports various ecosystem services, including providing food, water and nutrients and improving ecological function.
- It has been observed that crop diversity helps to reduce disease and manage pests. One study indicates that compared to monocrops, crop diversification reduces disease by 73% [18].

C. Demonstrating diversified multiple cropping systems to enhance biodiversity and farm incomes

6. High-value intercrops

One main advantage of intercropping is that resources are converted more efficiently, which increases production. When the intercrops are high value, the farmer's production costs are lower, increasing the net return on investment. Smallholder farmers can improve farm incomes by diversifying into high-value crops, such as vegetables and spices, that fetch more money than staple crops.

Regenerative advantage

Turmeric and ginger are examples of high-value spices that can thrive under minimum tillage (Fig. 17). Nigeria has the largest area under ginger cultivation in the world, while Ethiopia is one of Africa's largest producers of turmeric. Studies have shown significant yield increases for these spices when RA practices, such as minimum tillage and organic manure application, are deployed [5, 6]. Both spices can provide continuous soil cover through the structure of their leaves and foliage. Their root rhizomes have also been found to improve soil enzymes and enhance the health of low-fertility soil.

Figure 17. Dr. Boa of CNTA shows the extent of soil cover provided by turmeric and ginger crops. Turmeric and ginger intercropping generates yield increases when RA practices are deployed.

Intercrops should not compete for light. Therefore, it is advisable to select crop mixtures that cover the soil and are exposed to sunlight at different times of the growing season. Pineapple and carrot, pineapple and papaya, and pineapple and banana (Fig. 18) are high-value crop mixtures that do not compete for light. The combination of shallow and deep root systems also enhance water use efficiency through the upper and lower soil layers.

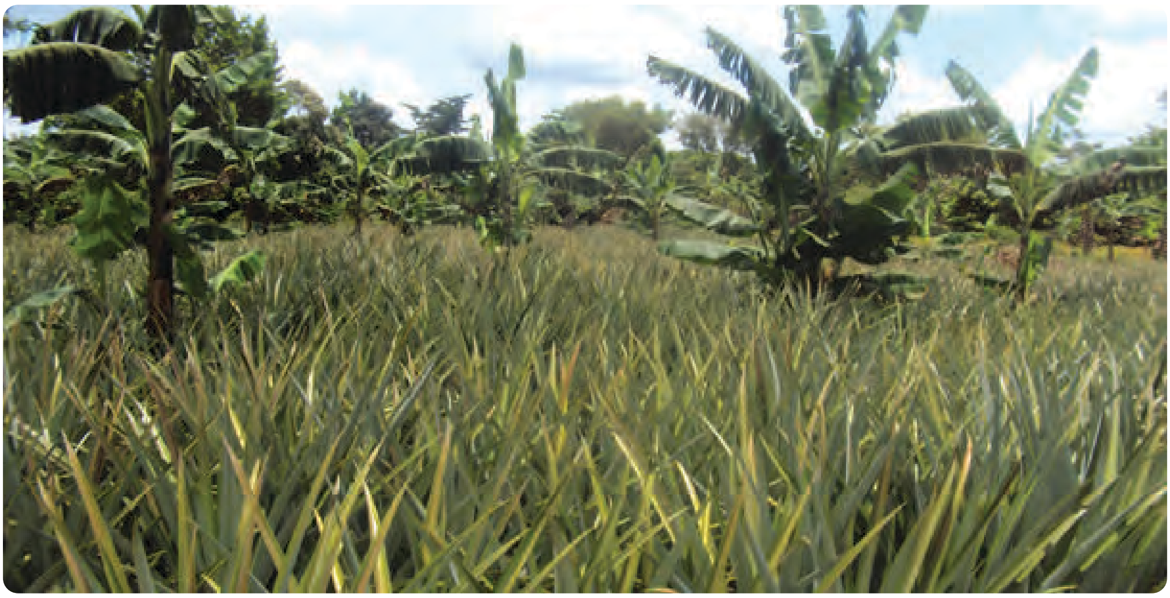


Figure 18. Pineapple and banana intercropping in Kayunga District, Uganda. These high-value crops do not compete for light; they also utilize water efficiently.

7. Perennial and annual intercrops

Intercropping perennials with annual crops enables farmers to grow cash and food crops while utilizing the same labor inputs, meeting household income and food security needs [7].

Regenerative advantage

Under projected climate change scenarios, the yield stability of monocrop farming systems may significantly decrease. Therefore, mixing species through intercropping reduces the likelihood of crop failure (Fig. 19-21). One of the main benefits of intercropping is that it can acquire and/or convert resources more efficiently, which increases production. It has also been observed that intercrop yields stabilize over time compared to monocrops [8].

Figure 19: Christine Kyomugisha, an RA program officer from SAA-Uganda, demonstrates intercropping highland cooking banana with solanum potato in Mubende, Uganda.

Figure 20: Intercropping faba bean with false banana in Ana Sora, Ethiopia.

Figure 21: Intercropping banana with cucumber in Bamako, Mali. The banana provides a climbing device for the cucumber to anchor on during growth.

8. Cereals and legume intercrops

Intercropping also offers land use advantages, with land equivalent ratios of 1.2 and 1.3 [9]. As a result, the yield per plant is increased, often due to 'plastic responses' that allow plants to acquire more resources. This advantage is due to competitive relaxation, which reduces competition over time and space in the mixed crop compared to the monocrop. Per species, the acquisition of resources, including light, water, and nutrients, is therefore significantly improved. Intercrops also suppress pests, diseases, and weeds, reducing growth impediments.

Regenerative advantage

Studies have shown that in low nitrogen input systems, such as those found in Africa, intercropping cereals with legumes leads to improved grain quality in the cereal crop (Fig. 22). This is because there is less competition for nitrogen, light, water, and other nutrients. For example, intercropping maize with groundnut in calcareous soils (soils rich in calcium carbonate) increases the ability of the maize grain to acquire micronutrients such as iron, zinc, and copper [10].

Figure 22: Maize and Cowpea intercrop [11].

9. Relay cropping

Relay cropping (RC) enables smallholder farmers to increase biodiversity in their production systems, harness the benefits of crop diversification, and efficiently utilize natural resources (Fig. 23). It enhances farm incomes by increasing crop productivity, net return per unit area, land use efficiency, nutrient recycling, and weed and pest control. It also reduces fertilizer use. To reap maximum benefits, farmers are advised to use high-yielding cultivars.

Regenerative advantage

RC can regenerate soils by enhancing nutrient cycling and soil health. It does this by assimilating nitrogen into the ground soil when nitrogen-fixing legumes are used, thereby improving soil structure and health through increased organic matter and microorganisms. This system allows farmers to grow two crops yearly, especially in unimodal climates. The yield advantage is higher when leguminous plants are used as relay crops in cereal systems.

RC with host and non-host crop species has been found to reduce pests, diseases, and weed pressure, thereby decreasing synthetic chemicals, environmental pollution and the loss of beneficial pollinator insects. In RC, green manure crops can enhance physical, chemical, and microbial activities when plowing into the soil. Under reduced tillage, green manure improves aggregate stability and increases nitrogen and phosphorous content. It also leads to increased exchangeable cations and microbial respiration. This cropping system has been shown to prevent further soil degradation while improving soil health. In addition, residual soil nutrients that would otherwise be lost during a season can be scavenged by a relay crop. Studies have shown that soil benefits from RC systems can be further enhanced when RC is practiced alongside other regenerative methods, like zero tillage, thereby increasing soil organic carbon (SOC) and the stability of soil aggregates.

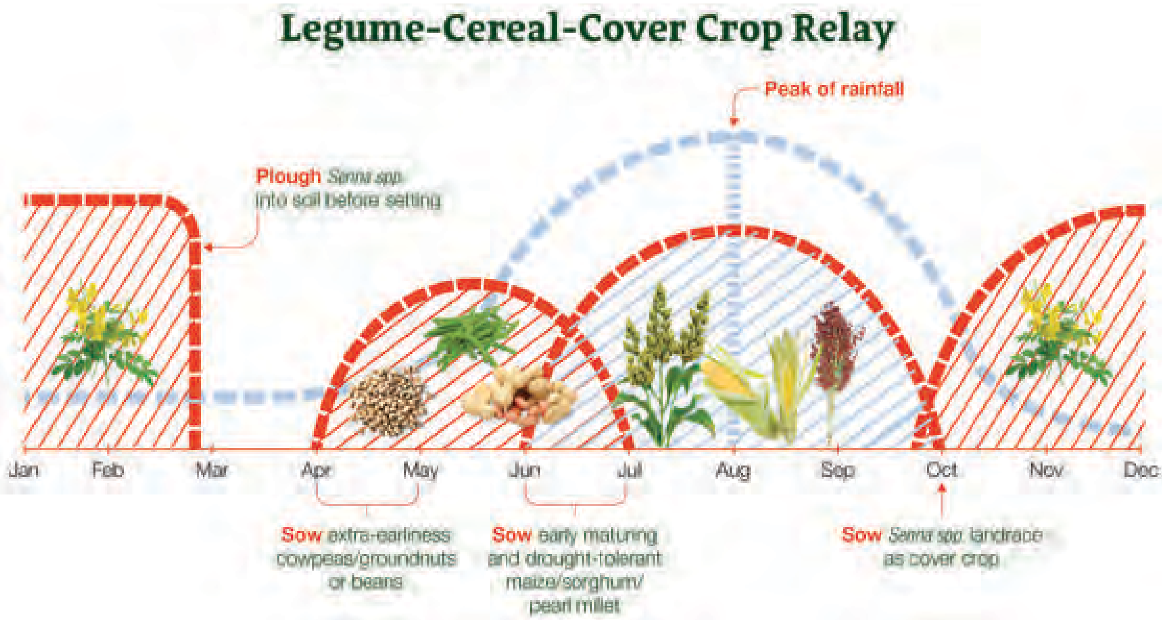


Figure 23: Extension recommendations for annual relay cropping of legume-cereal-living mulch cover crop; developed by SAA for farmers practicing RA in Tiola, Koloni-Boundio, Samanko, and Siranikoto in Mali.

10. Intercropped relay cropping

Our findings indicate that the candidate areas for RC in southern Mali are Tiola, Koloni-Boundio, and Siraninkoto, which have consistently longer growing seasons, higher precipitation, and increased rainy days. Samanko also has higher precipitation and increased rainy days in the growing season. We investigated if farmers in these areas would be open to RC. We found one farmer practicing intercropped RC between May and October during the season. His first crop was cucumber and tomato intercrop, followed by maize and then sweet potato, which served as a cover crop and food crop (Fig. 24).

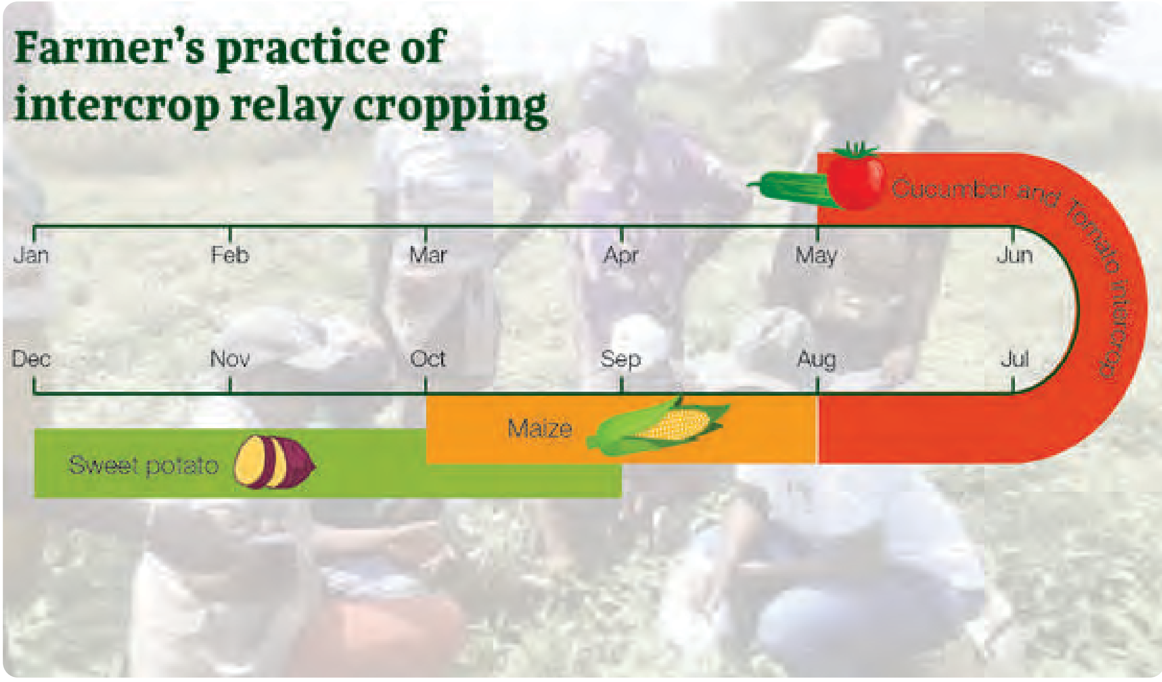


Figure 24: A farmer in Tiola, Mali, explains to SAA's RA team how he utilizes the rainy season to improve income by growing four crops in an intercrop relay sequence. He starts with cucumber and tomato at the onset of the rains in May, moving on to maize at the peak of the rainy season in August. Then, when the maize is senescing, he grows a drought-tolerant sweet potato variety known as fadana, which also serves as a cover crop and food security crop in the dry season.

11. Sequential double cropping

In RC, a second crop is sown before the first is harvested. In sequential double cropping, the second crop is seeded during the first crop harvest. The benefit of sequential double cropping is that there is no competition between the two crops. Depending on the seasonality, the second crop usually has a shorter lifecycle. We found a farmer in Koloni-Boundio practicing sequential double cropping with groundnut and watermelon (Fig. 25), the latter serving as a cover crop and cash crop in the dry season.

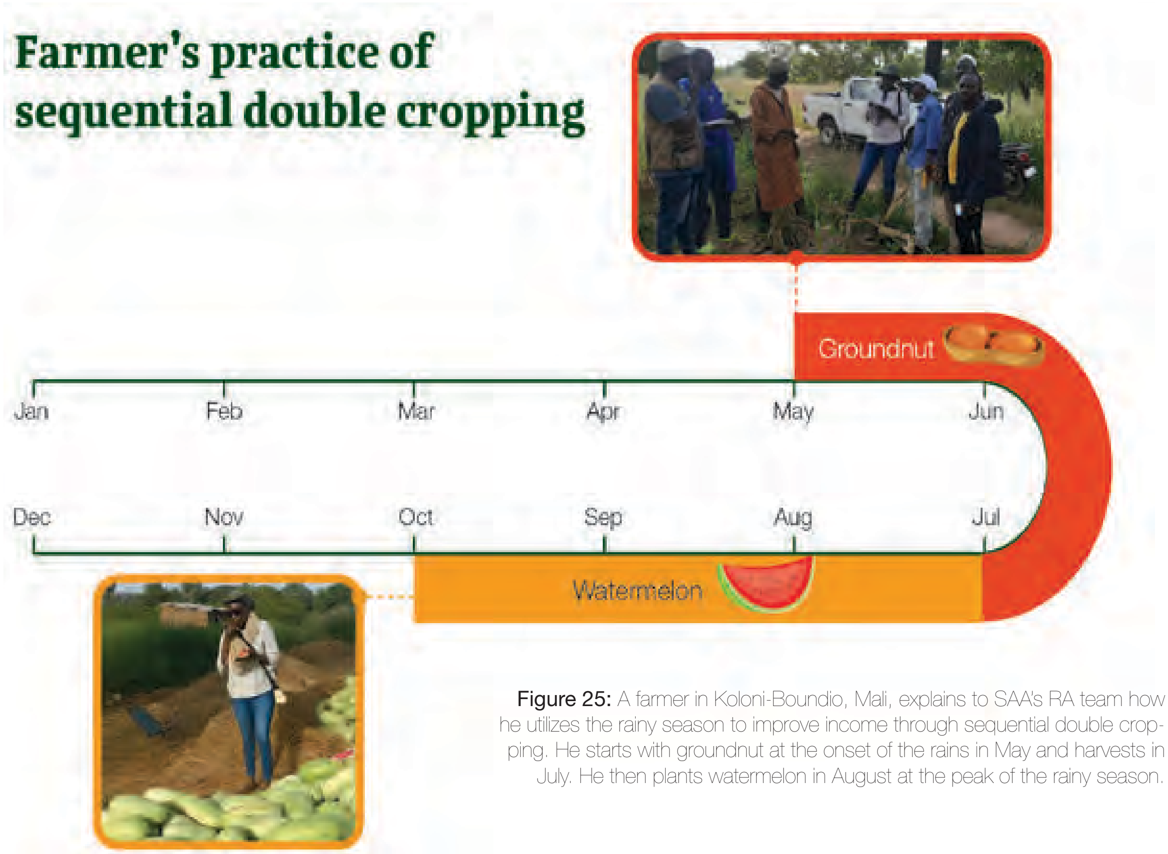


Figure 25: A farmer in Koloni-Boundio, Mali, explains to SAA's RA team how he utilizes the rainy season to improve income through sequential double cropping. He starts with groundnut at the onset of the rains in May and harvests in July. He then plants watermelon in August at the peak of the rainy season.

12. Strip cropping

Strip cropping (SC) is a form of intercropping that involves placing plants in separate strips to efficiently use light, water, and nutrients (Fig. 26). When the strips are changed from season to season, SC allows crop rotation, resulting in pest and disease management, weed suppression, and soil health improvement, which in turn generates increased yields.

Regenerative advantage

SC's main advantage is that it reduces interspecific competition between the root systems of different crops [12]. When SC is practiced on smallholder farms, there is reduced risk, improved food security and income, and enhanced soil productivity.

Figure 26: A demonstration of haricot beans and barley strip cropping at a Farmer Training Centre (FTC) in Ethiopia.

Principle 4:

Keep the soil covered

This principle highlights the significance of soil structure, nutrient availability and water regulation, all of which are influenced by the soil surface. A layer of mineral soil with high organic matter content plays a crucial role in supporting these functions. When the soil surface is covered with living plants, crop residues or agricultural waste, it protects the soil and its resident organisms against weathering and erosion.

Benefits of this principle

- Covering soil protects it against physical damage caused by rain, sunlight, and soil compaction, which can result in erosion.
- Soil coverage enhances the diversity of the soil pore network, improves the water infiltration rate and promotes soil aeration.
- Soil coverage promotes increased activity from micro and macro-organisms in the soil.
- Following herbicide cost increases in Nigeria, the SAA-Nigeria RA team deployed a demonstration model to illustrate the benefits of mulching to farmers (Fig. 27). Mulching builds organic matter, suppresses weeds, retains moisture, reduces the cost of weeding and herbicides, and improves soil fertility.

Figure 27: A CDP by SAA-Nigeria shows mulched and un-mulched plots in the maize-growing Kano State of Nigeria. These plots illustrate the benefits of mulching to farmers.

D. Demonstrating innovative soil cover alternatives under competing uses for crop residues

One of the requirements for conservation agriculture is for each farm to retain at least 30% of crop residues as mulch after harvest. The ultimate goal is to enhance farm sustainability by reducing soil nutrient mining, protecting the soil from erosion, improving water infiltration, and increasing organic matter and soil microbes. Through their interventions in Africa, SAA teams have found that farmers struggle to meet this target, as there is immense competition for harvested crop residues. For example, in Ethiopia crop residues from teff production are used for animal feed, building material, and cooking fuel. In Nigeria and Mali, nomadic pastoralists freely graze their livestock on crop residues during the dry season, nullifying any potential benefits to the soil.

13. Green manure

One way to address the scarcity of crop residues is to supplement crop production with legumes as organic fertilizer. One such application is green manure – a cover crop grown specifically to be incorporated into the soil while still green (Fig. 28). The biomass in the green manure is usually integrated using a plow or disk harrow, with the aim of adding organic matter to the soil.

Regenerative advantage

At current application rates, the average amounts of nitrogen accumulated by green manures can completely replace the nitrogen from mineral fertilizers [13]. When used appropriately, green manures can partially or entirely replace the nitrogen required for subsequent crops that are not legumes. Unlike cereals, legumes often positively impact the grain output of subsequent cereal harvests. While large amounts of fertilizers are used to maximize crop production and quality, excessive use of mineral fertilizers can result in significant nutrient loss from the soil. And this can negatively affect the quality of surface water and ground water.

14. Living mulch

A living mulch is a cover crop mixed with the main crop to fulfill mulch functions, such as controlling soil temperature and suppressing weeds (Fig. 29).

Regenerative advantage

Living mulches can significantly improve soil structure, regulate water content, enhance organic matter, reduce soil erosion, and enrich soil through nitrogen fixation and enhanced macrofauna populations. They can also suppress weed growth, increase water infiltration, and reduce economic risk.

Figure 28: A tractor crimper incorporating climbing beans as green manure before sowing the main crop.

Figure 29: SAA demonstration in Mali showing a cowpea crop as a living mulch in sorghum production to suppress weeds and control soil temperature.

15. Rescue mulching with *Tithonia diversifolia* (Mexican Sunflower)

In RA, we encourage a technique called 'rescue mulching,' using *Tithonia diversifolia*, a shrub in the Asteraceae family. Tithonia is widely found in Africa along farm boundaries and the edges of roadsides or village paths. The technique involves growing this shrub at the fringes of the farm in the rainy season, then using its biomass as mulch during the dry season. We strongly caution farmers not to grow the shrub on fields they use for crops, as it can quickly establish itself as an important weed.

Regenerative advantage

Growing *Tithonia* at farm edges is essential, as the shrubs have deep roots that mop up leached nutrients from the soil and store them in the leaves. When used as mulch during the dry season it decomposes quickly, releasing these nutrients into the ground, thereby reducing soil nutrient mining. The yellow sunflower-like leaves also attract bee pollinators on the farm (Fig. 30-31). *Tithonia* can be ploughed in as green manure; its green leaf biomass is high in nutrients, averaging about 4% nitrogen and potassium and 0.4% phosphorous on a dry matter basis [14]. On a dry weight basis, boundary hedge *Tithonia* can produce about 1kg biomass/m/yr. When applied to the soil as mulch, *Tithonia* decomposes rapidly, releasing nitrogen, phosphorous and potassium and increasing soil microbial load, indicating its significance in improving soil health. Some studies have found *Tithonia* effective in protecting crops from termites, suppressing weeds and controlling pests.

Figure 31: Growing *Tithonia* at farm edges is vital, as its deep roots mop up leached nutrients from the soil and store them in the leaves. The shrub can be cut during the dry season and used as mulch to release nutrients. When used as a mulch, *Tithonia* suppresses weeds and increases soil nutrients as it decomposes.

Figure 30: *Tithonia diversifolia* is widely found along farm boundaries and the edges of roadsides and village paths in Africa. Its yellow sunflower-like flowers attract pollinator bees to farms.

16. Rescue mulching with Napier grass *(Pennisetum purpureum S.)*

Native to Sub-Saharan Africa, Napier grass (*Pennisetum purpureum* Schumach.) grows quickly and is commonly planted in tropical and subtropical locations worldwide. The main use of this versatile forage crop is in cut-and-carry feeding systems for cattle. Farmers who lack mulch for continuous soil cover can grow the grass during the rainy season and then use its biomass as mulch during the dry season (Fig. 32). The grass species continuously regenerates and can offer a constant supply of mulching material.

Figure 32: An SAA-Uganda RA farmer in Kiboga, Uganda, uses Napier grass as rescue mulch. He grows the species on a two-acre piece of land, cuts and lays it on the ground for a few days to dry, then uses it to mulch his banana plantation.

17. Cover cropping with drought-tolerant Indigenous shrub, *Icacina trichantha* (False yam)

All over Tamale in Northern Ghana, *Icacina* thrives in the middle of the harmattan season while all other vegetation and crops have dried up. *Icacina trichantha* is a drought-resistant shrub indigenous to West and Central Africa. It is used as a medicinal plant and for food in some areas. Research on this plant has revealed interesting chemical and pharmacological properties in recent years. Icacina can grow up to two meters high and is characterized by large, fleshy, yam-like tubers. Weighing up to several kilograms, these tubers are consumed in certain parts of Nigeria [15].

Regenerative advantage

Icacina thrives during the dry season when no plant cover can survive. It can be propagated to provide continuous soil cover during drought (Fig. 33), and integrates as green manure to provide continuous soil cover in dry savannahs. Icacina can be sown as a relay crop when the main crop is senescing to give continuous soil cover during the dry season.

Figure 33. Drought-resistant, Icacina foliage has the potential to provide prolonged continuous soil cover in dry savannahs.

18. Cover cropping with the drought-tolerant indigenous shrub *Senna Obstifolia* L. (Sickle pod).

Senna obstifolia, commonly known as sicklepod, is a shrub from the Fabaceae family, widely found in West Africa (Fig. 34-35). It grows up to 2.5 meters tall, showcasing its resilience in harsh environments. It has compound pinnate leaves with rounded tips, produces yellow flowers and reproduces by seed. Senna can be used as a medicinal plant, green manure and fuelwood. Its seeds are dispersed by rainwater and animals. In Mali and Nigeria, SAA has integrated Senna into a relay-cropping or sequential cropping schedule; it is planted as a cover crop between September and October when the main crop is senescing. The aim of this method is to provide prolonged soil cover during the dry season, helping to maintain soil health.

Regenerative advantage

This distribution of *Senna* indicates that the species grows in low-nutrient environments. The combination of its deep tap roots shows it can be used as an effective cover crop. It rescues nutrients leached during the growing season and stores them in its foliage, then releases these nutrients back into the topsoil as green manure. This practice ensures the soil is covered for the longest time possible, while providing multiple ecosystem services such as erosion control, nutrient management, and soil quality improvement. Since the species self-seeds, we recommend that Senna be ploughed into the soil before it produces seed. Between December and February, the plant will likely wither from lack of rain and high temperatures. However, it still offers a cost-effective way for small-scale farmers to cover their soil for the longest time possible during the dry season (Fig. 34), providing them with a sustainable solution.

Figure 34. *Senna obstifolia* (sickle pod) growing as a fallow in Katebougou, Mali. Providing a cover crop during the dry season, the species also produces yellow flowers that attract pollinator bees.

Figure 35. SAA's RA team in Mali observed that Senna remains green after harvesting other crops, recognizing its potential as a cover crop.

19. Natural organic mulches for soil cover and erosion control

Frequent tillage and lack of soil cover accelerate soil erosion rates. Natural organic mulches, such as crop residues, leaf litter, grass, wood chips and twigs, can be used for soil conservation (Fig. 35-38). These mulches can play a significant role in soil erosion control and organic matter growth.

Regenerative advantage

Scientific studies have consistently found that natural organic mulches reduce soil erosion and significantly improve soil quality. They also recover many soil properties lost through over-tillage and other agricultural practices [16, 17].

Figure 36. A tomato garden was mulched with maize stover, and an established plantain field was thoroughly mulched with forest twigs. In RA, we advocate using mulch materials readily available on the farm.

Figure 37. A cabbage field mulched with teff straw in Ethiopia and a leaf litter in Uganda; these materials can be used as a free source of mulch.

Figure 38: In an upland rice field in Siranikoto, Mali, leaf litter is used as natural organic mulch. The farmer shows the difference in soil moisture retention between his mulched and un-mulched rice fields.

Principle 5:

Maintain living roots all year round

Maintaining living roots in soil is crucial for nutrient preservation, plant growth and microbial diversity. Plants convert solar energy into chemically bonded energy through photosynthesis, absorbing it through roots and the soil ecosystem. Without active roots, organic matter in the soil breaks down and releases carbon dioxide (CO_2) into the atmosphere. Therefore, preserving living roots is critical to soil carbon sequestration. Root exudates also enhance soil health and plant growth, while mycorrhizal fungi facilitate water and nutrient absorption.

Benefits of this principle

- Maintaining living roots all year round promotes organic matter accumulation and lowers the danger of soil erosion.
- Nutrient flows are enhanced, and the distribution of organic matter improves soil aggregation and runoff reduction.
- The soil remains living as micro-organisms are fed from root exudates and, in turn, provide nutrients to crops.
- Mycorrhizal fungi convey plant-to-plant signals, allowing un-infested plants to react to possible pest or pathogen infection risks before being attacked.

20. Off-season short fallow periods

'Off-season short fallows' is a regenerative practice whereby fields are left unplanted for short periods between growing seasons, allowing soil to recover, retain moisture and improve its nutrient profile (Fig. 39). This sustainable practice helps farmers manage weeds, pests, and diseases while enhancing soil health. Key benefits include improved soil structure, increased organic matter, and nutrient cycling. Short fallows also help to prevent soil erosion, disrupt weed and pest lifecycles, and offset potential income loss. Cover crops can also provide additional benefits.

Figure 39: Off-season short fallow periods can be implemented to maintain living roots. These roots preserve nutrients, support plant growth, promote microbial diversity and sequester carbon, ensuring a continuous interaction between the atmosphere and the soil rhizosphere.

21. Maintaining living roots after harvest, even from weeds

Leaving living roots in the soil at all times after harvest, even from weeds, has a higher regenerative advantage than leaving the soil bare (Fig. 40-41). Roots play a significant role in the carbon cycle by contributing substantially to the ecosystem's net primary production.

Figure 40: In RA, leaving soil bare after harvest is strongly discouraged.

Figure 41: Maintaining living roots after harvest is an option to maintain continuous soil cover.

Principle 6:

Prevent soil toxicity

Due to their time, labor and cost advantages, chemical methods are used more frequently for weed, pest, and disease control in agricultural and non-agricultural lands. However, despite their effectiveness, agrochemicals have a direct negative impact on soil microorganisms, killing nitrogen-fixing bacteria and disrupting the stability and functioning of the soil ecosystem.

Chemical herbicides are both yield-improving and yield-protecting. Yet they are often mismanaged in developing countries, as many smallholder farmers are unaware of their toxicity and associated risk to human health and the environment. Indeed, despite concerns about their potential negative impacts, herbicides continue to be used across Africa, posing a danger to the environment and, most significantly, soil performance.

RA does not necessarily prohibit agrochemicals, but advocates for their reduction and minimization. The goal is to minimize external inputs such as chemical fertilizers, herbicides and pesticides, as well as adverse external impacts, while utilizing farm resources. This approach follows a circular soil economy, taking into consideration cost, pollution, and soil biology.

E. Demonstrating innovations for reducing chemical inputs in RA

22. Judicious use of herbicides by using aggressive cover crops

In RA, we recommend using herbicides judiciously by first planting an aggressive cover crop like pumpkin (*Cucurbita pepo*), (Fig.42). After the pumpkin has spread on the surface, the farmer only sprays the herbicide along the lines where the crop of choice will be planted. After the crop has been established, the pumpkin crop can be maintained as ground cover or ploughed into the soil as green manure. Another aggressive cover crop that can be used for this purpose is lablab (*Lablab purpureus*), (Fig. 43).

Regenerative advantage

This technique ensures site-specific herbicide application on smallholder farms, significantly reducing the amount of herbicides the farmer needs per hectare. The aggressive cover crop protects soil microorganisms from the toxicity of the herbicide, while providing all the benefits of continuous soil cover. At the same time, nutrient recycling is achieved when the aggressive cover crop's biomass is ploughed into the soil.

Figure 42: Pumpkin (*Cucurbita Pepo*), is an aggressive cover crop that can be used to protect the soil from herbicides.

Figure 43: Lablab (*Lablab purpureus*) is a fodder legume that can be used as an aggressive cover crop to protect the soil during herbicide application.

23. Agrochemical reduction by using intercropping for pest, disease, and weed control

As confirmed by multiple studies, intercropping significantly decreases the incidence of pests, diseases, and weeds, reducing the need for agrochemicals in agriculture [18, 19]. These outcomes are linked to crop mixtures, which have a dilution effect among disease pathogens and pests. In Mali, smallholder farmers intercrop Roselle (*Hibiscus sabdariffa*) and groundnut (Fig. 44-45) to reduce the damage caused by pests. Caterpillars prefer eating the Roselle leaves, leaving the groundnuts untouched. And the loss in terms of the Roselle is minimal since the plant's harvestable part is the flower, which is used to make juice in West Africa.

Figure 44. An SAA Woman Assisted Demonstration in Koloni-Boundio village in Mali showcasing Roselle strip cropping to reduce pest and disease incidence in groundnut.

Figure 45. An SAA SAA Woman Assisted Demonstration in Lira, Uganda, showcasing Malakwang (*hibiscus spp.*) strip cropping to reduce pests and disease in groundnuts. Glow worm beetles attack the Malakwang, while the groundnut remains pest-free.

Regenerative advantage

Mixing species reduces disease and pest pathogens in an ecosystem, creating physical barriers that prevent their spread. The interaction of root exudates between intercrops also hinders the growth of pathogens, leaving them unable to thrive. In contrast, the microclimate created by the intercrops can boost the crops' resistance. Intercropping has been found to reduce the emergence of weeds as well.

24. Push-pull Technology

Push-pull technology is a highly successful pest and weed management method developed by ICIPE and its collaborators. Its aim is to control stemborers and striga weeds in maize farming systems. This integrated agroecological technique utilizes trap plants and repellent intercrops to repel pests, control weeds, and improve soil fertility. The strategy involves intercropping maize with legumes (silverleaf desmodium) and creating boundary hedges of Napier or Brachiaria grass (Fig. 46). Desmodium releases chemicals that drive away stemborer moths, while Napier grass has volatiles that attract female moths. At the same time, these chemicals cause striga, a parasitic plant, to undergo suicidal germination, significantly reducing its soil seed bank.

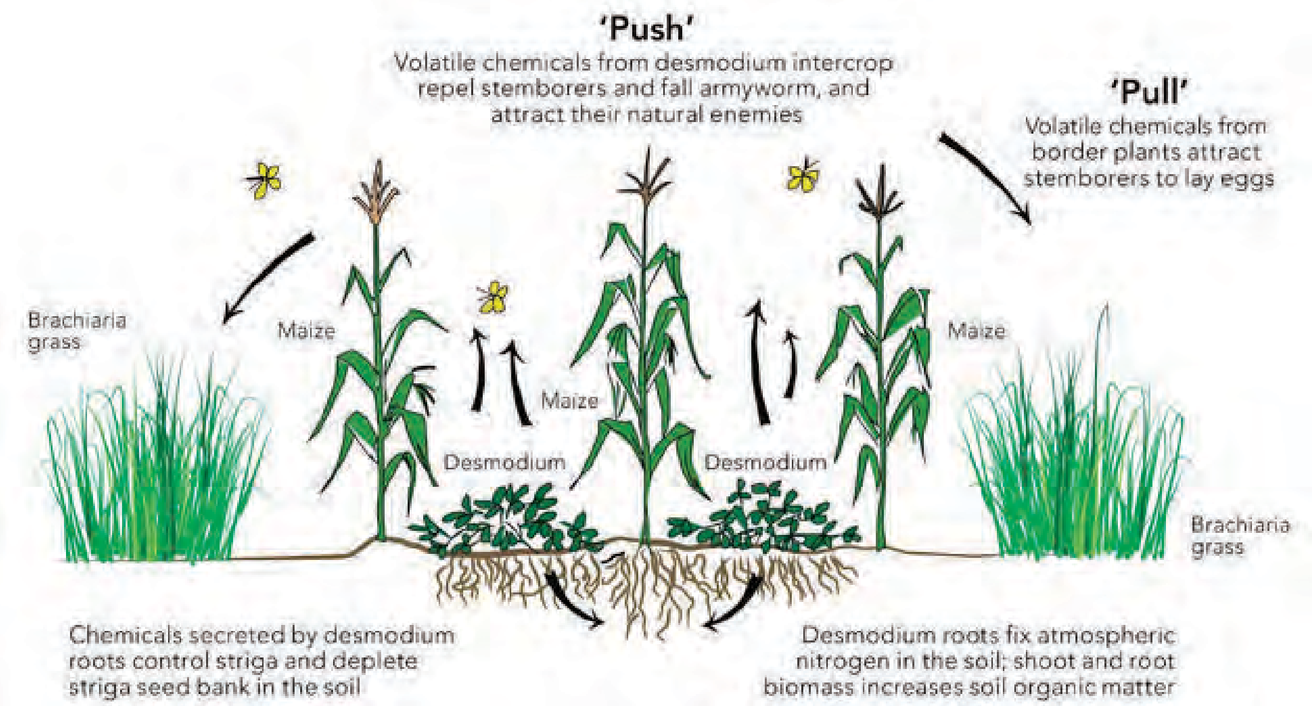


Figure 46: Push-pull technology has been found to significantly decrease pest, disease, and weed incidence, reducing the need for agrochemicals in agriculture.

Regenerative advantage

Push-pull technology offers a regenerative advantage by minimizing the need for chemical pesticides to control stem borers and fall armyworm and reducing reliance on herbicides to manage striga weed. This approach promotes a circular agricultural system where the crops produce fodder for livestock, which provide manure to enhance soil health. Additionally, the technology improves soil fertility, as the roots of desmodium, a leguminous plant, fix nitrogen and boost soil organic matter levels.

Principle 7:

Build soil organic matter with compost

F. Demonstrating Composting Technologies for RA

25. Bokashi

‘*Bokashi*’, a key RA composting technique, is a Japanese term meaning ‘fermented organic matter’. It involves fermenting kitchen waste, including meat and dairy scraps, with an inoculant in a specialized bucket. The inoculant, known as ‘Bokashi inoculant,’ is made of wheat germ, wheat bran or sawdust combined with molasses and Effective Microorganisms (EM). The technique was developed by Dr. Teuro Higa, of the University of Ryukyus, Okinawa.

Bokashi composting is an anaerobic process that requires isolating materials from oxygen. The Bokashi bucket has an airtight lid and produces nutritious ‘Bokashi tea’ for fertilizing plants. However, it must be drained to prevent foul odor. The Bokashi process involves layering waste and allowing it to ferment. The fermented waste can then be used in gardens or traditional compost bins within ten days. The Bokashi bucket should only be opened to add scraps, with the waste pressed into the composter to squeeze out air (Fig. 47). A flat object should be placed on top to shield the material from oxygen.

Regenerative advantage

Bokashi is a low-cost organic amendment practice that has been found to improve soil health. The method allows the use of dairy and meat scraps that are not incorporated in other forms of composting, which results in high nitrogen content in the fermented organic matter [20]. This technique can be used in very small spaces, and the fermented material can be added to a vermicomposting (worm composting) bin.

26. Vermicomposting

Vermicomposting uses earthworms to decompose organic matter, producing a product called ‘vermicast’. To prepare vermicompost, a wooden container is built and sealed with a sheet of polyethylene. A 15-20 cm layer of organic waste is spread on top, with rock phosphate or cow dung slurry sprinkled on the waste material (Fig. 48). Then, the container is filled with organic waste in layers. This material should be allowed to decompose for 15-20 days. Between 500 and 700 earthworms are then added into the container. To conserve sufficient moisture and maintain the earthworms’ body temperature, water should be sprinkled on top every three days. Vermicompost is free from foul odor, black in color, and light in weight.

Regenerative advantage

Earthworm activities improve organic matter biodegradation by 60-80%, resulting in better compost quality, rich in minerals and microbes. Vermicomposting with earthworms improves soil fertility by locking nitrogen in organic matter to make it more available to plants. Earthworms eat organic matter containing large amounts of nitrogen such that after the death of an earthworm, about 0.01g of nitrate is delivered to the soil [21]. Vermicompost is considered an organic fertilizer. It is rich in nutrients and significantly improves soil structure, aeration, and drainage.

A) Mixing rice husk waste with a liquid containing effective micro-organisms (EM)

B) Pouring rice husks waste with EM into a Bokashi bucket

C) Compacting the waste material to remove oxygen

D) Sealing the Bokashi with airtight material

Figure 47: SAA's RA team shows smallholder farmers how to prepare Bokashi using rice husk waste in Kano state, Nigeria.

Figure 48: Smallholder farmers, trained by SAA's RA team in Ethiopia, demonstrate how they prepare vermicompost in earthen and wooden boxes.

27. Microdosing compost with mineral fertilizers

In regions where livestock manure and inorganic fertilizers are scarce, microdosing compost with mineral fertilizers to a localized plant hole is a great alternative (Fig. 49). This technology has been found to improve soil health and crop productivity.

Figure 49: Micro-dosing nutrients (Source, ICRISAT)

Regenerative Advantage

A study in Mali found that applying compost by microdosing makes it possible to achieve a 100% fertilized surface. The technique results in a nitrogen use efficiency of more than 55% [22]. The study also found that applying compost by microdosing at 2.5 t/ha reduced input costs by 27%.

28. Biochar-blended Compost

Utilizing organic waste as a source of carbon and nutrients can restore soil organic matter and nutrient cycling, promoting environmental sustainability and agricultural production. Biochar is produced by heating organic material in a low-oxygen environment below 700°C. It is used as a soil amendment. As we know, composting is a process that involves microorganisms; these microorganisms require specific conditions to grow and thrive. Adding biochar to a composting pile can modify specific physical and chemical parameters, creating a more suitable environment for the microorganisms (Fig. 50). This can help promote microbial growth and improve the composting process.

Regenerative advantage

The combination of biochar and compost has the potential to benefit from biochar's long-lasting physical and chemical properties [23]. Biochar provides stability, water and nutrient retention, and a habitat for soil microorganisms. Compost, on the other hand, supplies labile organic carbon and nutrients. The blend of biochar and compost has been found to improve soil health and quality and enhance crop productivity significantly.

Figure 50: SAA RA team in Mali and Benin train smallholder farmers to prepare biochar-blended compost to improve soil health and quality.

29. Phosphate rock-rhizosphere soil-enhanced compost

Phosphorus is an essential nutrient for plant growth, but around 60-70% of the phosphorus applied to soil in water-soluble forms is unavailable to plants. This is because the phosphorus is converted to an immobile form by specific ions in the soil. For example, Fe, Al and Mn ions can convert phosphorus into complexes that plants cannot use in acidic soils. Similarly, Ca and Mg ions can make phosphorus unavailable to plants in alkaline soils [24]. Understanding this process is crucial for farmers to ensure their plants receive the nutrients necessary for healthy growth.

Regenerative advantage

Adding rock phosphate to organic manure increases microorganisms that make this otherwise unavailable phosphate soluble, increasing its plant uptake while improving compost quality (Fig. 51).

30. Compost teas

Compost tea is a nutrient-rich fertilizer made by brewing compost in water (Fig. 52). It enhances growth and yields in vegetable farming. The process involves using aged compost and aerating the tea with a pump as it brews, enabling beneficial soil microorganisms to thrive.

To make compost tea, dechlorinate 10L tap water and let it sit in the sun and fresh air for several hours. Attach a 20L plastic bucket pump aerator to an external pump. The pump system keeps the tea moving and prevents it from becoming anaerobic, which damages plants. Fill a bucket halfway with loose compost and add some mature compost, without overfilling, plus aged compost to prevent harmful pathogens from spreading. Next, fill the bucket with water, leaving three inches of headroom at the top for easy stirring. Stir the tea with molasses, which will provide food for beneficial soil bacteria. Compost tea should be brewed for two to three days (but no more), allowing the microbes to thrive.

Figure 51: A protocol developed by the Japan International Research Centre for Agricultural Sciences (JIRCAS) for making phosphate rock-rhizosphere soil-enhanced compost for SAA experiments in Mali, Nigeria, Ethiopia, and Uganda.

Figure 52: SAA's RA team, training smallholder farmers to make compost teas in Ethiopia.

Principle 8:

Prevent Soil Erosion

G. Demonstrating soil erosion control practices that prevent loss of soil organic carbon

Over 50% of soil organic carbon (SOC) is held at shallow depths of 0.3 m to 1m of the soil profiles [41]. This proximity to the surface implies that erosional mechanisms can easily sweep away the stored SOC. Soil erosion occurs in three stages: detachment, transportation, and deposition. Climate change has resulted in more frequent and intense storms and rainfall, which has significantly accelerated soil erosion [25]. This section illustrates soil erosion control practices that prevent the loss of soil organic carbon (SOC), which can be demonstrated in farmers' fields.

31. Fallow band System

Wind erosion in the Sahel results in substantial nutrient loss, with windblown nitrogen losses reaching up to three times the amount crops absorb. Fallow band systems (FBS) help mitigate this process by capturing windblown sediments via five-meter-wide fallow strips aligned in a north-south direction (see Fig. 53-54), effectively reducing the loss of nitrogen and other essential nutrients.

Regenerative advantage

The FBS is a low-input technology that controls soil erosion and traps nutrients for crop production. Experiments in Niger have shown higher yields in the fallow bands compared to continuously cultivated fields, and 74% of farmers who adopted the practice still use it currently [26]. Research has shown that a single fallow band prevents the loss of up to 74% of soil and 58% of organic matter (OM) [26].

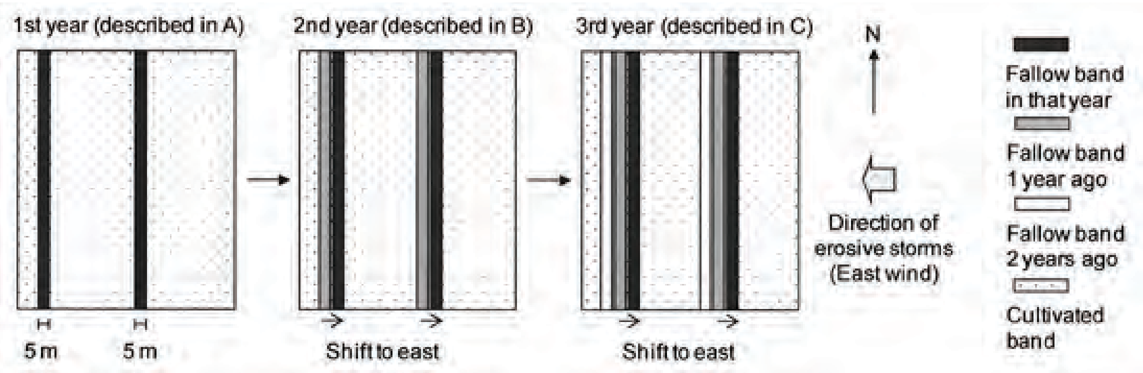


Figure 53: The fallow band system; this diagram shows the size of a fallow band (5 m), how to shift the band seasonally (A, B and C), and how to grow crops from the previous season's fallow band [26].

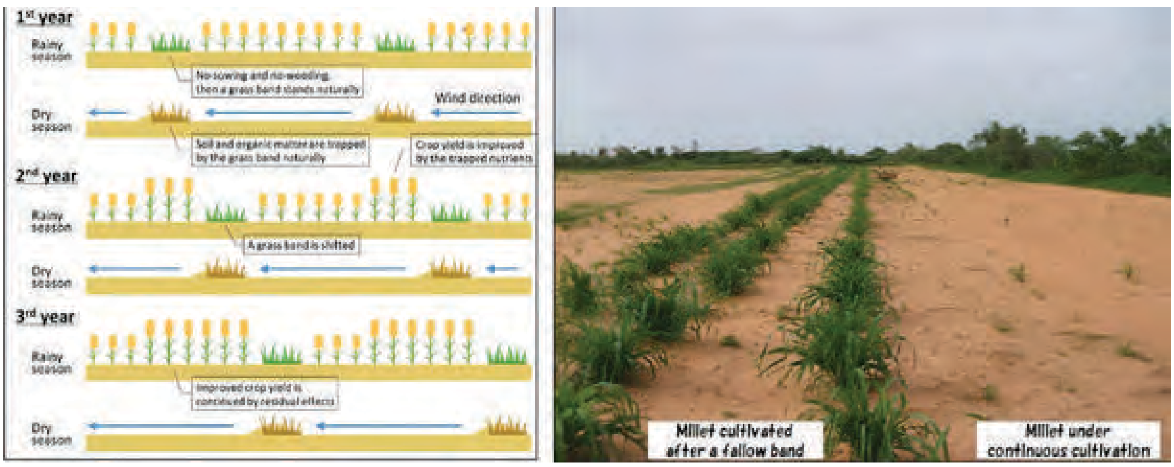


Figure 54: Millet grown on the previous season's fallow band performs better than millet under continuous cultivation [26].

32. Zai pits

A Zai pit is a type of hole dug into the soil to enhance water capture, decrease erosion, and boost agricultural productivity. It is a tillage management practice where holes are dug into the soil for crop cultivation. Zai pits, or planting basins, are typically 60 cm in width, length, and depth (Fig. 55-56).

Regenerative advantage

In regions where the soil is crusted with hard pans, Zai pits can help with soil aeration, increasing permeability and improving plant root development. This technology is instrumental in semi-arid areas with low soil fertility and moisture stress. It has been shown to successfully restore degraded lands, improve soil fertility, and reduce the impact of climate on agriculture. It can be reused for up to five years before major repairs are needed.

Figure 55: Smallholder farmers in Mali digging Zai pits for crop production.

Figure 56: Zai pits or permanent planting basins enhance water capture, decrease erosion, and boost agricultural productivity in semi-arid areas.

33. Stone bunds and trash lines

Stone bunds are a low-cost technique for controlling erosion and checking runoff. Depending on the inclination of the land, stone bunds are constructed with quarry rock or stones, placed along a natural contour to a height of 20–30 cm above the ground, spaced 20–50 m apart. Trash line bunds, meanwhile, are laid with organic material along the slope of the field (Fig. 57).

Figure 57: A smallholder farmer in Mubede, Uganda, has made stone bunds from broken bricks and a grass trash line to control erosion and check runoff.

Regenerative advantage

By slowing water runoff, stone bunds allow rainwater to seep into the soil and spread evenly. They also help create a layer of fine soil and manure particles. Constructed stone bunds contribute to climate change adaptation by protecting the land from heavy rain, improving rainwater harvesting, and conserving biodiversity. In addition, they optimize water and nutrient use efficiency, boosting crop production and economic benefits. In the Ethiopian highlands, stone bunds can reduce sediment loss by 59% [27]. Trash lines, on the other hand, add organic matter to the soil after decomposing, improving soil fertility and controlling runoff.

34. Contour trenches

Contour trench construction involves ditches dug along a hillside or slope perpendicular to water flow, with fields plowed at a right angle to the incline (Fig. 58). The excavated soil forms a berm, which is planted with permanent vegetation or grass to stabilize the soil and trap sediment in heavy rainfall.

Regenerative advantage

Contour trenches reduce the speed of surface water flow, check runoff, and enhance the infiltration of water into the soil.

Figure 58. SAA-Uganda staff monitoring contour trenches constructed in a soybean field in Kiboga, Uganda. The farmer has planted pineapples to stabilize the excavated soil.

35. Long-term demonstration of no-tillage practices to control soil erosion

At CNTA in Ghana, a ten-year-old demonstration plot is used for farmer training to highlight the importance of no-tillage agriculture in controlling long-term soil erosion. The demonstration is constructed on a slopy landscape and consists of three plots. Over the ten years, eroded soil is collected in plastic buckets placed at the end of each plot for educational purposes (Fig. 59-60).

Plot 1:	Farmer's practice, where no soil erosion control measures are taken. Tillage, slashing, and burning of crop residues continue after harvest.
Plot 2:	No tillage, returning at least 30% of crop residues after harvest, plus continuous soil cover with mulch. No soil erosion control measures are taken.
Plot 3:	No tillage, returning at least 30% of crop residues after harvest, plus continuous soil cover with mulch. Soil erosion control measures are taken, including grass and stone bunds.

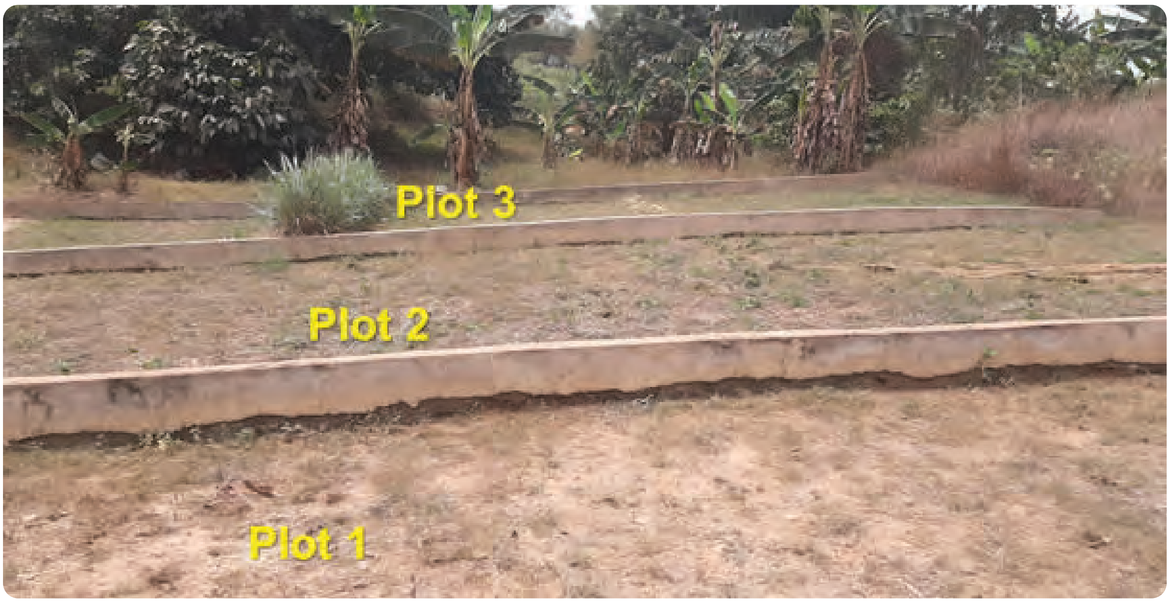


Figure 59: A ten-year demonstration at CNTA in Kumasi, Ghana, shows three plots: 1) Farmer's practice 2) No-tillage and residue return 3) No-tillage, residue return, and soil erosion control using grass and stone bunds. As shown, in Plot 1 the ground has lost topsoil and organic matter.

Figure 60: Plastic containers show the soil lost through erosion in the farmer's practice plot (slash and burn, frequent tillage, and no residue return). Only half a container of soil is lost in each of the no-tillage plots.

Principle 9:

Harvest rainwater

H. Demonstrating innovative water harvesting technologies for RA

In Africa, RA emphasizes using on-farm resources before bringing in external inputs. One technique available to smallholder farmers is rainwater harvesting. Rainwater harvesting is an ancient technique that conserves rainwater at its source, ensuring it is used efficiently without draining away. Rainwater is valued for its purity, softness, and neutral pH.

36. Water harvesting from anthills

Utilizing what is currently on the land is essential for smallholder farmers who want to grow more with fewer resources. One method is collecting water from anthills (Fig. 61-62). Anthills are commonly found in farmers' fields in many parts of Africa.

Figure 61. SAA's regenerative Agriculture team views water harvesting from an anthill at the CNTA in Kumasi, Ghana. Water harvesting can be done from anthills found around the farmer's field.

Figure 62: In Mubende district, Uganda, Mr. Asanasio Ssenkato, a coffee farmer, employs innovative techniques such as anthills to collect run-off from different parts of his 8.5-acre farm.

Regenerative advantage

In RA, termites provide an essential ecosystem service as decomposers. They recycle rotting plant material into fresh soil by dissolving resistant plant fibers. When the soil is covered with crop residues, termites seldom attack the crops since their preference is dead plant material. These ravenous insects are vital to the health of the soil, which they also help to enrich and aerate through their tunneling.

37. Rooftop water harvesting

Rooftop water harvesting involves collecting rainwater from impervious surfaces on houses, storing it in waterproof vessels, and using it for agriculture. This technique can be employed on a temporary basis (after a rainstorm), seasonally (throughout the rainy season), or permanently (throughout the year).

Regenerative advantage

Rooftop water harvesting plays a crucial role in economic and human welfare. Rainwater is often the easiest water to access. It is also the most reliable and least polluted source and can be controlled by individual households (Fig. 63-64).

Figure 63: A small, low-cost rooftop water harvesting structure can be constructed on a farm to collect rainwater for irrigation.

Figure 64: During the rainy season, an SAA RA farmer in Mubende, Uganda, harvests rooftop water from an improvised shed and stores it in low-cost underground reservoirs.The same farmer has constructed six such reservoirs around his farm to collect rainfall runoff, which he uses for irrigation during the dry season.

38. The 'weeping pot' technique

Creative techniques like the 'weeping pot' can mean the difference between food security and starvation in areas where water is scarce. In ancient times, earthenware clay pots were used for water storage. These pots remain functional vessels to this day, despite modern water storage methods. With the weeping pot technique, the clay that is used to make the pot is mixed with sawdust. During the baking process, the sawdust is seared, creating a porous surface. The pot is then buried in the ground, leaving only the open top visible and exposed to the elements. As rain enters, the permeable clay surface allows water to seep slowly into the soil, hence the name (Fig. 65). The weeping pot can be used for domestic vegetable gardens or backyard gardens.

Figure 65: The 'weeping pot' technique releases household wastewater into the soil through the tiny holes created in the pot's surface during the baking process.

Regenerative advantage

The weeping pot technique is a low-cost and effective water-saving method that efficiently maintains soil structure and prevents deep water leakage. It can also reduce soil degradation and salinization. Household wastewater can be poured into the weeping pot to irrigate vegetables at the root zone, preventing evaporation capacity, soil hardening, and salinization, as observed in flood irrigation.

39. Improvised drip irrigation using spent plastic water bottle

When His Excellency Yoweri Kaguta Museveni, the President of the Republic of Uganda, demonstrated drip irrigation using spent plastic water bottles (Fig. 61), he received a backlash from human rights and environmental activists, who claimed it would be an ecological catastrophe. The President argued that it would have saved 40% of the 122 million coffee seedlings, distributed by the Operation Wealth Creation program, that dried up when farmer beneficiaries failed to irrigate during drought. Agricultural experts have since concurred. Dr. Kofi Boa from CNTA has perfected this technique by adding nozzles to the bottles so that farmers can adjust the amount of water released.

Regenerative advantage

A scientific study by Yu et al. [28] observed that improvised drip irrigation using spent plastic water bottles achieves similar results to that of commercial irrigation systems, but represents only 0.8% of the cost (US$20 versus US$2,390) (Fig. 35). The study found that bottles with an opening of 1-2.5 mm are most effective in terms of water use and reduced evaporation, while openings of 3-6 mm are best for soils with high infiltration rates. The author recommends popularizing this system among rural farmers. Notably, the regenerative advantage of this technique enables smallholder farmers to produce more with less and adapt to climate change impacts.

Figure 66: H.E Yoweri Kaguta Museveni, President of the Republic of Uganda, demonstrates drip irrigation using spent plastic water bottles (Source: The Observer, 2017). Dr. Kofi Boa from CNTA demonstrates how nozzles enable farmers to adjust the aperture according to their water needs.

Figure 67: SAA's coffee farmers in Uganda show their improvised drip irrigation system, using spent water bottles.

Principle 10:

Reduce greenhouse gas emissions

I. Demonstrating carbon farming and emissions-reducing RA practices.

40. Carbon farming

According to Lal [29], carbon farming is a deliberate effort to adopt RA practices that create a positive ecosystem carbon budget and sequester atmospheric CO_2 in soil and biomass. The aim is for carbon farmers to generate an additional income stream while using land-generated carbon to address climate change. Some of the practices accepted for carbon farming include regenerative practices that involve mulching with crop residues, cover cropping, agroforestry, complex farming systems that integrate crops with trees and livestock, integrated nutrient and pest management, precision agriculture, sub-drip fertigation, and the cultivation of crops with advantageous root systems and biomass production.

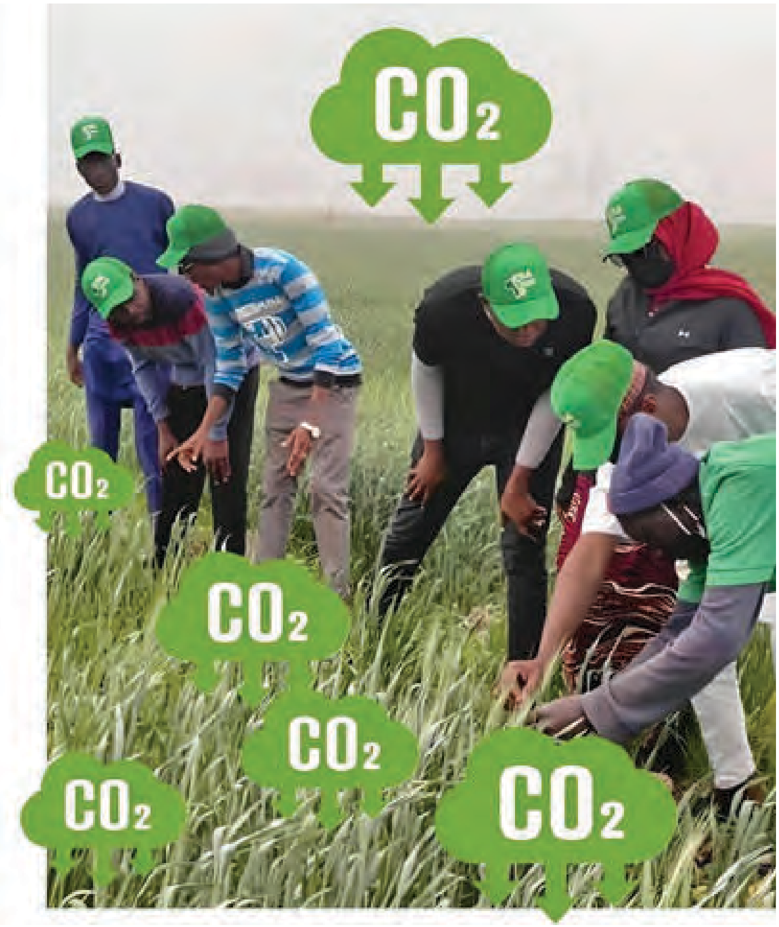


Figure 68. SAA demonstrates decarbonization projects with smallholder farmers in Nigeria, Uganda, Mali, Benin, and Ethiopia. The aim is for RA farmers to generate an additional income stream through carbon credits while using land-grown carbon to address climate change.

41. Agroforestry: Promoting woodlots around RA landscapes

Agroforestry provides four primary ecosystem services and environmental benefits. These are: carbon sequestration; biodiversity conservation; soil enrichment; and air and water quality [30].

Regenerative advantage

In RA, integrating trees and crops enhances soil fertility, reduces soil erosion, improves air and water quality, enhances biodiversity, and sequesters carbon (Fig. 69-70). These benefits are enjoyed at the farm, landscape, and global level. Economic returns for carbon sequestration, through the payment of carbon credits, are currently being explored as part of climate action initiatives.

Figure 69: An SAA community demonstration plot, with agroforestry tree bands on the periphery of a wheat field in Ethiopia.

Figure 70: Shea butter, cashew nut, and mango trees alongside a cotton field in Sikasso, Mali.

42. Alternate wetting and drying to reduce methane emissions in paddy rice cropping systems

Rice is a crucial food source for 60% of the global population, with demand expected to grow by 56% by 2050 [31]. However, rice cultivation results in significant emissions of greenhouse gases, including methane and nitrous oxide, which have substantially higher warming potential than carbon dioxide [32]. Alternate wetting and drying (AWD) is a suitable method for paddy rice production that helps lower rice cultivation's environmental impact. It reduces water consumption by 20-25% and saves around US$30 per hectare by avoiding standing water [33].

Technique

Ten to fifteen days after transplanting rice seedlings, shallow standing water is allowed, and the field can be alternately drained and re-wetted. Water levels are monitored using perforated plastic pipes, with seven to eight pipes recommended for a one-hectare rice field. Irrigation is applied as needed based on the pipe readings. During irrigation, the water level should be maintained between 5-7 cm, then gradually reduced to 2-4 cm (see Fig. 71-72). This process should continue for about two weeks before harvesting, depending on the cultivated rice variety.

Rice fields must have controlled irrigation and drainage facilities, ensuring suitable dry and flooded conditions during dry and wet seasons. This technology does not decrease rice yield. Farmers participating in the program must receive training and technical support in field preparation, irrigation, drainage, and fertilizer use. They must also adhere to all recommended agronomic practices.

Regenerative advantage

A recent study by Echegaray-Cabrera et al. (2024) analyzed the effects of AWD on greenhouse gas emissions from rice fields on the northern coast of Peru. The research demonstrated that AWD treatments significantly reduced methane (CH_4) emissions by 84% to 99% compared to continuously flooded fields. However, AWD increased nitrous oxide (N_2O) emissions by 66% to 273%. Despite the rise in N_2O, the overall Global Warming Potential (GWP) decreased by up to 77%, with AWD showing an efficient water use rate of 0.96 and only a 2% reduction in rice grain yield.

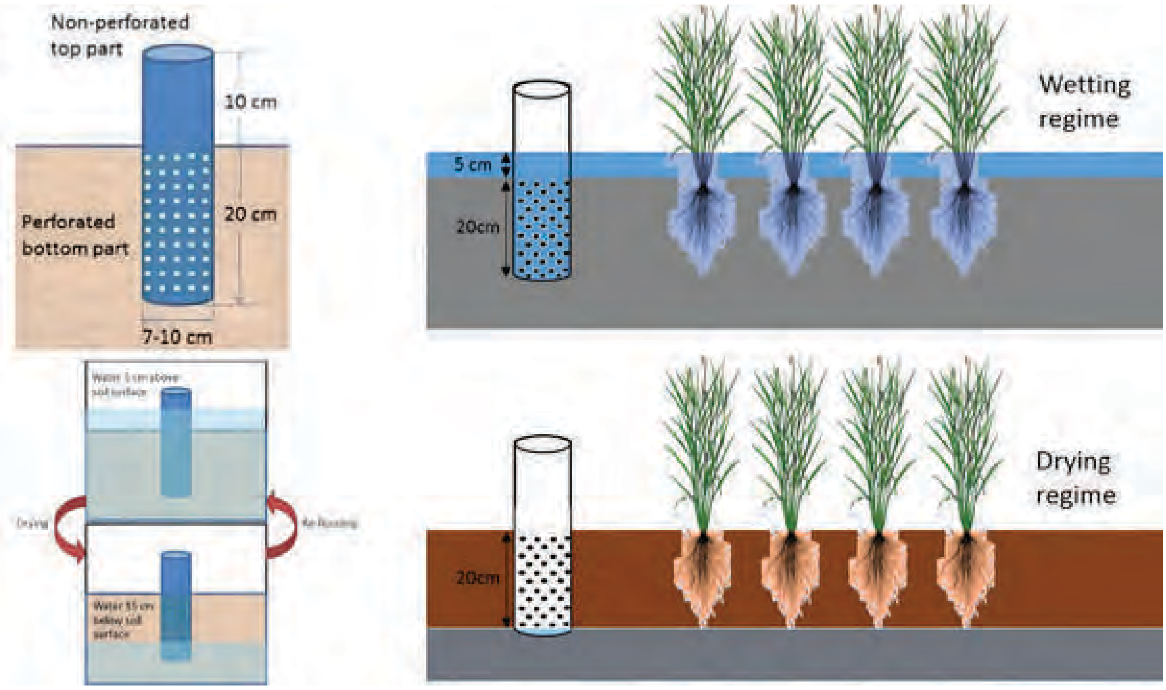


Figure 71: AWD in paddy rice cropping systems, with pipes used to indicate water levels [33].

Figure 72: SAA field staff in Benin install PVC pipes in a paddy rice field, with the assistance of the e-Kakashi AI system. Their aim is to evaluate environmental parameters that influence methane emissions using AWD technology.

43. Urea deep placement (UDP) to reduce nitrous oxide emissions in agriculture

Nitrous oxide (N_2O) is 265 times more potent greenhouse gas than CO_2 and destroys the stratospheric ozone layer of the atmosphere. In 2010, it contributed up to 6% of total anthropogenic emissions [35]. Nitrogen application significantly increases N_2O and NO emissions when the nitrogen fertilizers applied exceed the plant's needs. However, emissions vary greatly depending on fertilizer sources, application methods, irrigation, soil properties, and climate.

To mitigate N_2O and NO emissions, efficient nitrogen management strategies are needed, including selecting the right source, quantity, time and application method. Urea deep placement (UDP) at 7-10 cm retains the N at the soil depth (Fig. 73-74). This increases nitrogen use efficiency and crop yields and reduces emissions by ensuring a continuous nitrogen supply throughout the growing season.

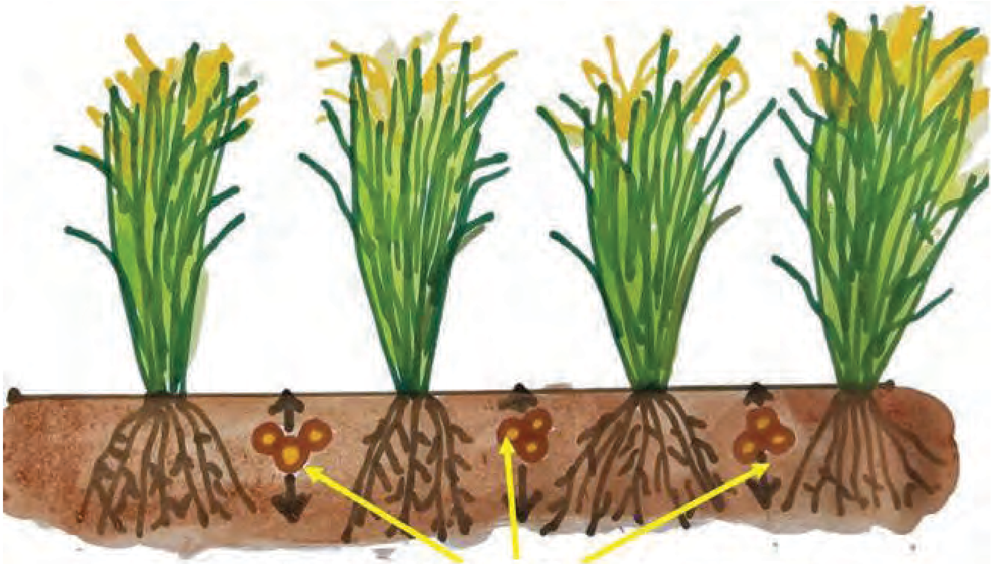


Figure 73: UDP retains nitrogen in the soil root zone, increasing nitrogen use efficiency while reducing nitrous oxide emissions.

Figure 74: SAA builds the capacity of smallholder paddy rice farmers in Nigeria and Benin to apply fertilizers judiciously using UDP technology to reduce N_2O emissions.

Regenerative advantage

A study by Gaihre et al.,2020, found that in direct-seeded rice, UDP can reduce nitrogen emissions in crop production by 95% compared to urea and potassium nitrate [36]. It was observed that UDP was more effective in reducing N_2O emissions, increasing grain yields by 16%, and improving nitrogen use efficiency by 30%. The highest emission factor was observed in urea, while UDP had the lowest, indicating that UDP could mitigate N_2O emissions and improve nitrogen use efficiency in direct-seeded rice.

44. Biochar for carbon sequestration

Biochar is a form of charcoal produced from organic matter via pyrolysis (a process involving high temperatures in the absence of oxygen). It is utilized in agriculture to enhance soil health and sequester carbon (Fig. 75) [37]. Biochar can be made from various biomass sources, including agricultural residues, wood chips, manure, and other organic materials. Biochar is applied as a soil amendment. It is typically mixed with compost or other organic matter before being incorporated into the soil to enhance its effects. The application rate can vary depending on soil type, crop requirements and the farmer's specific goals. Common rates range from 1 to 10 t/ha.

Regenerative advantage

Biochar's porous structure helps retain water, making it available to plants during dry periods. It can also adsorb nutrients, preventing their leaching and making them available for plant uptake. Biochar improves soil aeration and structure, promoting root growth and microbial activity. It also helps regulate soil pH, making it more suitable for plant growth.

Carbon sequestration benefits

By integrating biochar into agricultural practices, farmers can improve soil health, enhance crop productivity, and contribute to carbon sequestration efforts, thereby mitigating climate change [38]. Biochar is highly resistant to decomposition, allowing it to sequester carbon in the soil for many years. This makes it a significant technology for long-term carbon storage. It stabilizes carbon in a solid form, reducing the release of greenhouse gases like CO_2 and methane from the soil. Biochar enhances soil fertility and productivity, reducing the need for chemical fertilizers and contributing to more sustainable farming practices.

Technique

- Ensure the biochar is free from contaminants and produced optimally to maximize its benefits.
- Regularly test soil properties and monitor crop responses to biochar application to optimize usage.
- Mix biochar with compost or manure; this can enhance its effectiveness by providing a balanced nutrient profile and improving microbial activity in the soil.
- Focus on areas with degraded soils or where water retention is particularly needed to maximize the benefits of biochar.

Figure 75: SAA's RA teams being trained to make biochar using rice husk pyrolysis at the Savanna Agricultural Research Institute (SARI) in Ghana.

45. High-quality forage legumes and grasses to reduce methane emissions in livestock systems.

Feeding livestock high-quality forages and supplements can improve digestion efficiency, reducing methane emissions per unit of meat or milk produced. Promoting legumes and grasses that are high-quality, nutrient-rich, and easily digestible can also reduce enteric methane emissions. With high-quality forages, more of the feed is converted into energy and less is wasted. In addition, high-protein legume forages can enhance animal growth and reduce the time to market, thereby reducing overall GHG emissions.

Figure 76: SAA is equipping farmers with the skills to produce high-quality forages, which improve feed, nutrition, and digestion efficiency, and reduce methane emissions per unit of meat or milk produced.

46. Renewable energy integration

Integrating renewable energy into livestock systems, particularly through biogas production, effectively reduces GHG emissions and enhances sustainability. One such technology is biogas production from manure and other organic waste, which can be utilized for energy.

Biogas

Livestock manure is collected in an anaerobic digester, where anaerobic microorganisms break down the organic matter, producing biogas (a mixture of methane and carbon dioxide) and a digestate known as slurry. This nutrient-rich byproduct can be used to improve soil health. The biogas is captured and stored in gas holders for home use cooking and lighting.

Regenerative advantage

Capturing and utilizing methane from manure prevents its release into the atmosphere, significantly reducing GHG emissions. Biogas is a renewable energy source that can replace fossil fuels, reducing the overall GHG emissions from agriculture. The technology efficiently manages manure and organic waste, reducing odor and potential pollution. The digestate/slurry is used as a high-quality organic fertilizer, returning nutrients to the soil and reducing the need for synthetic fertilizers. The onsite use of biogas as an energy source for electricity and cooking is an opportunity for off-grid communities to reduce energy costs and reliance on external energy sources.

Figure 77: SAA-Ethiopia constructed two biogas chambers at farmers' houses as part of the Urban Agriculture Initiative in Lemi Kura sub-city, Addis Ababa. This initiative was supported by Ethiopia's Ministry of Water and Energy and the National Biogas Program Coordination Unit (NBPCU).

47. Solar-assisted composting

Manure use often spreads pathogens and weeds. Solar-assisted composting prevents this from happening. Solar-assisted composting uses solar energy to heat piles of compost. The piles are placed inside transparent solar tunnels. These structures trap the sun's heat, raising the temperature inside and providing a controlled environment for composting, while ventilation helps to maintain optimal oxygen levels. Solar-assisted composting can be implemented on different scales, from small farms to large industrial operations.

Regenerative advantage

Solar-assisted composting reduces GHG emissions and promotes organic waste recycling into valuable compost. Solar heating helps maintain the ideal temperature range (55-65°C) for thermophilic bacteria, accelerating the decomposition of organic matter. These temperatures destroy pathogens and weeds, resulting in safer and higher-quality compost. By ensuring aerobic conditions through optimal temperatures and adequate aeration, solar-assisted composting significantly reduces methane production compared to anaerobic decomposition. Meanwhile, as a renewable and sustainable energy source, solar energy reduces reliance on fossil fuels and lowers the GHG emissions associated with energy use. By integrating solar energy into the composting process, farms and composting facilities can enhance efficiency, reduce environmental impact, and create a more sustainable and cost-effective system for managing organic waste.

Principle 11:

Integrate livestock

J. Promoting efficient use of livestock manures and waste

48. Manure handling and storage

Livestock manure is essential for restoring low fertility, maintaining crop production and boosting animal productivity. However, the correct handling of manure during collection and storage is key to ensuring effective carbon and nitrogen retention and crop uptake. Adding 5-10 t/ha of manure annually can sustain soil organic carbon (SOC) and total soil carbon stocks, while it is essential to invest in livestock housing for proper manure collection. Crop-livestock integration can also enhance productivity and resource efficiency and is vital for soil regeneration.

Cattle manure collection and storage.

Livestock and poultry manure is used in vegetable home gardens.

Fish farming wastewater is used in vegetable gardening.

Poultry manure collection and storage.

Figure 78. The contribution of manure to soil organic carbon and total soil carbon stocks is one of the significant benefits of using manure as a soil amendment.

49. Aquaculture for nutrient cycling in integrated farming.

Aquaculture can create a synergistic system that enhances sustainability, biodiversity, and productivity when integrated into regenerative agriculture. In particular, waste from fish can be used as a nutrient source for plants in nutrient cycling. Aquaponics, where fish and plants are grown together, exemplifies this concept. Combining aquaculture with crop and livestock farming creates a closed-loop system, whereby waste from one process is utilized as an input for another as part of an integrated farming process. In addition, farmers can generate additional income from fish alongside crops and livestock.

Regenerative advantage

Aquaculture systems, such as ponds and wetlands, can create habitats for various aquatic species, promoting biodiversity. Aquaculture can also help with water biofiltration, improving water quality for the entire farm ecosystem. Nutrient-rich water from aquaculture can be used to irrigate and fertilize crops, enhancing soil fertility (Fig. 79); it can also be recycled and reused, reducing a farm's overall water footprint. Adding aquaculture to a farm increases biodiversity and creates a more resilient agricultural system. Meanwhile, aquaculture systems provide habitats for birds, insects, and other wildlife, promoting ecological balance.

Figure 79: The SAA-Uganda RA team interacts with an innovative aquaculture fish farmer in Kole District, Uganda. The farmer maximizes resources by using aquaculture wastewater to irrigate his farm's annual crops.

50. Nutrient-rich rabbit urine as an organic fertilizer

For farmers who raise rabbits, using their urine as a fertilizer is a cost-effective method of improving soil fertility. Rabbit urine is one of the richest nitrogen sources among organic fertilizers. It contains vital elements like nitrogen, potassium, and phosphates, which are all needed for plant growth [39]. It has also been found to contain carbon-organic content, a crucial component of organic fertilizer [40]. As rabbits digest proteins, byproducts like ammonia and other nitrogenous gasses are produced, some of which end up in the animals' dung and urine. As rabbit urine provides the necessary nutrients for healthy plant growth with little environmental harm, it could be a good substitute for chemical fertilizers. There are financial benefits, too, as farmers can raise rabbits for meat and utilize their urine for fertilizer without additional processing.

Figure 80: An SAA RA coffee-banana farmer in Bulambuli District, Uganda, keeps rabbits as a hobby. We told him about the benefits of using rabbit urine and dung to improve soil fertility on his farm.

Regenerative advantage

Rabbit urine is an excellent source of nitrogen that supports healthy plant growth, promotes sustainable farming practices and improves soil quality. It can even act as a natural pest repellent. Regular application of organic fertilizers like rabbit urine improves soil structure, increases water retention capacity, and enhances microbial activity. And by deterring certain pests and insects, rabbit urine reduces the need for chemical pesticides. Furthermore, plants absorb liquid fertilizers, such as rabbit urine, more quickly than solid fertilizers, leading to a faster response in plant growth and health.

COST-BENEFIT ANALYSIS OF REGENERATIVE AGRICULTURE TECHNOLOGIES

What?

Cost-benefit analysis (CBA) is a crucial tool for promoting agricultural technologies. It involves defining and comparing its benefits and costs. It is similar to private business investment appraisal in farming. Social CBA, or economic analysis, assesses costs and benefits from the perspective of the implementing organization or target group. CBA evaluates agricultural technologies, considering technical, social, and environmental aspects, narrowing the decision-making margin, and potentially recommending acceptance, rejection, or identifying problematic components for design adjustments.

Why?

The most straightforward argument favouring a CBA is that decision-making benefits from a clear understanding of costs and benefits. When allocating limited resources to farming, a farmer wants to know if it's worthwhile and if there are better options. As a result, a CBA is a method of considering that farmers who are part of the decision-making process may use a technology without truly understanding its specifics.

Farmers involved in decision-making must conduct a Cost-Benefit Analysis (CBA) to assess the impact of a new technology in a structured way. A thorough CBA process can reveal that agricultural innovations that initially seem attractive may not provide long-term benefits. Farmers want to know if a particular agricultural technology will generate enough revenue to cover the farm's future debts. The net income effect on specific groups must be examined to understand how the project will affect specific groups. These issues are often addressed in conjunction with complementary CBAs.

Scope of CBA

CBA is typically an appraisal tool; therefore, a timeline, a complete set of activities, and objectives must be defined. A CBA is conducted based on incremental analysis, which means that the analysis focuses on the differences between the situation with and without the technology. In CBA, costs and benefits are understood to be incremental. Therefore, analyzing what would have happened without the agricultural technology is crucial. In regenerative agriculture, some technologies' effects may not involve a cash outflow for the farm but may have a broader impact on the environment or soil health. As far as practicable, all effects must be valued in monetary terms, according to CBA. In its most basic form, CBA assigns a value to the identified consequences of the technology project based on market prices.

Time value of money

Regardless of the farmer's timeline for using agricultural technology, costs and benefits occur at different times and often vary yearly. Typically, most costs are incurred in the early years, while benefits arise after the initial investment and may grow over time.

Future costs and benefits are generally valued less than those occurring sooner because farmers people prefer to receive benefits earlier. This preference is due to inflation, risk, consumption preferences, and alternative investment opportunities. Inflation is accounted for using constant prices, and risk is handled separately in CBA through risk analysis. Even after considering inflation and risk, a dollar invested now will grow in value over time. CBA uses the discounting technique to account for the preference for current resources over future ones (the time value of money).

Discount Rate

Discounting makes future costs and benefits comparable by calculating their present value. This involves using a discount rate, an interest rate that

reflects the opportunity costs of capital invested in the project. These opportunity costs represent the benefits forgone from alternative investments, usually indicated by long-term market interest rates. This interest rate is crucial in economic and financial appraisal. In financial CBA, the market rate of interest represents financial opportunity costs, like loan or deposit interest. In economic CBA, an economic rate of account is used as the discount rate, showing the opportunity costs to the country investing in the project, typically applied. The discount factor for each future year is calculated using the formula below.

Discounting Formula

Discount factor =		$1/(1+i)^t$
Where	i =	discount rate in decimals (0.10 for the rate of 10%)
	t =	the future year
Present value (PV) =		Future Value (t) * Discount Factor (t)

Indicators of Profitability

When agriculture is practiced as a business, the feasibility of a technology can be calculated using the following profitability indicators.

- Net present value (NPV)
- Internal Rate of Return (IRR)
- Benefits- Cost Ratio (BCR)

Net Present Value (NPV)

The NPV is, in fact, the most straightforward profitability indicator. It gives the present value of all the benefits and costs of investing in a technology acceptable from a CBA point of view. If the NPV is positive, the investment is expected to make money; if it's negative, it is expected to lose money. In simple terms, NPV helps you decide if an investment is good or bad by comparing the value of money now to the value of money in the future.

Internal Rate of Return (IRR)

Internal Rate of Return (IRR) is the interest rate at which the net present value (NPV) of all the cash flows (both incoming and outgoing) from an investment equals zero. In simpler terms, the rate of return makes the investment break even. Here's an easier way to understand it: If you think of an investment like a project that costs money now but brings in money in the future, the IRR is the percentage rate that tells you how much you're effectively earning on the money you put into the project. A higher IRR means a more profitable investment, while a lower IRR means a less profitable one.

Benefit-Cost Ratio (BCR)

The Benefit-Cost Ratio (BCR) compares an investment's benefits to its costs. It's calculated by dividing the total benefits by the total costs. BCR is a straightforward way to determine whether the money you invest in a project will likely yield good returns.

In simple terms, BCR helps you determine if an investment is worth doing:

- If the BCR exceeds **1**, the benefits outweigh the costs, suggesting the project is **a good** investment.
- If the BCR is less than 1, the costs are more significant than the benefits, suggesting the project is **not a good** investment.
- If the BCR is **equal to 1**, the benefits and costs are equal, suggesting the project will **break even.**

Indicators	Decision	
	Accept	Reject
NPV	NPV > 0	NPV < 0
IRR	IRR > discount rate	IRR < discount rate
BCR	BCR > 1	BCR < 1

Mathematical formulation of indicator of profitability

Net present value (NPV)

$$\sum_{t=1}^{t=n} \frac{(Bt - Ct)}{(1+i)t}$$

Internal rate of return (IRR)

The discount rate/ such that;

$$\sum_{t=1}^{t=n} \frac{(Bt - Ct)}{(1+i)t} = 0$$

Benefits-cost ratio (BCR)

$$\frac{\sum_{t=1}^{t=n} \frac{Bt}{(1+i)t}}{\sum_{t=0}^{t=n} \frac{Ct}{(1+i)t}}$$

In the four mathematical formulations:

Bt = benefits in each year

Ct = cost in each year

Nt = incremental net benefit in each year after stream has turned positive

Kt = incremental net benefit initial years when stream is negative

t = 1, 2…, n

n = number in years

I = interest (discount) rate

Data requirements

To enable smallholder farmers to make informed decisions on the RA technology when choosing competing alternatives. This will be achieved through evaluating two objectives: (i) to identify the RA technologies prioritized by smallholder farmers using a ranking procedure and (ii) to assess the economic feasibility of the prioritized RA technologies using cost-benefit analysis to evaluate the economic feasibility of the technology. The leading economic indicators will include net present value (NPV), the internal rate of return (IRR), and the Benefit-Cost Ratio (BCR). The profitability of the practices will be assessed with incremental benefits, which will measured by increased productivity (yield multiplied by the output price) compared to the control or business-as-usual (BAU) practice.

Table 2: Data requirements for CBA of RA technology demonstrated on farmer's field

Costs								
Name of RA principle	**Name of RA technology**	**Implemen-tation costs/ season**	**Maintenance costs/season**	**All costs incurred at harvest and post-harvest (operational costs)/season**	**Cost of ma-chinery and equipment**	**Cost of inputs**	**Cost of services**	**Cost of labour (man days)**
e.g. Principle 2: Minimize Soil Disturbance	e.g. No till or minimum tillage	All costs in-curred before planting while using the RA technology	All costs in-curred during the growing season while using the RA technology	All costs incurred at harvest and post-harvest while using the RA technology	e.g. hoes, small machines, sprayers, tillers	e.g. seeds, fertilizers, pesti-cides, herbi-cides	e.g., repairs of farm machinery	e.g. ploughing, fertilizer application, sowing, weeding, threshing, spraying, etc.

Benefits				
Increased yield	**Discount rate**	**RA technology life cycle**	**Price of outputs**	**Price of inputs**
Increased yield/ output from implementing the RA technology (Kg) compared to the control (non-RA or business as usual)	The current commercial bank interest rate on investment loans (%)	The period in years from when the farmer implements the RA technology to when he/she stops using it	The current market price of yield/output (cost/kg)	The current market price of inputs (cost/ha)

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