A Compendium of Carbon Enhancing Technologies, Approaches and Practices for African Soils

Compiled by:
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World Agroforestry
CTCN CLIMATE TECHNOLOGY CENTRE & NETWORK
UN environment United Nations Environment Programme

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Contents

Tables

Figures

Pictures

Maps

Acronyms

AF	Agroforestry
APC	Africa Plantation Capital group
BCR	Benefit/cost ratio
CA	Conservation agriculture
CAWT	Conservation agriculture with trees
CBO	Community-based organization
CCAFS	Climate Change, Agriculture and Food Security
CCS	Carbon capture and storage
CSIRO	Commonwealth Scientific and Industrial Research Organization
CEE	Central and Eastern Europe
CGIAR	Consultative Group for International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Center
CSIRO	Commonwealth Scientific and Industrial Research Organization
CO2	Carbon dioxide
CR	Crop residue
CS	Carbon sequestration
CTCN	Climate Technology Centre and Network
C/N ratio	Carbon to nitrogen ratio
EcoHSS	Ecosystem Health Surveillance System
FAO	Food and Agriculture Organization
GHG	Greenhouse gas
GMO	Genetically modified organism
ICRAF	World Agroforestry Centre
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IDRC	International Development Research Centre (Canada)
IRR	Internal rate of return
IITA	International Institute of Tropical Agriculture
JICA	Japan International Cooperation Agency
LDSF	Land Degradation Surveillance Framework
MRV	Measuring, reporting and verification
MT	Minimum tillage
NAMA	Nationally Appropriate Mitigation Action
NARS	National Agricultural Research System
NDC	Nationally Determined Contribution
NDE	National Designated Entities
NGO	Non-governmental non-profit organization
NPP	Net primary productivity
NRCS	Natural Resources Conservation Service
NT	No-till
N2O	Nitrous oxide
OA	Organic agriculture
REDD+	Reducing Emissions from Deforestation and Forest Degradation plus enhancing forest carbon stocks
SF	Social forestry
SLM	Sustainable Land Management
SOC	Soil organic carbon
SOM	Soil organic matter
SWC	Soil and water conservation
TA	Tillage agriculture
TOAM	Tanzania Organic Agriculture Movement
TLUD	Top lit updraft
UNEP	United Nations Environment Programme
WWF	World Wildlife Fund

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Introduction

This compendium is about sustainable practices of soil carbon sequestration in agriculture. Soil carbon is a depleting resource globally, and particularly in Africa. Increasing carbon storage in soils is a solution to improving soil fertility and improving agricultural productivity as well as to decreasing CO2 and mitigating climate change – the important challenges encountered by countries nowadays. Agriculture is a prominent topic in the national priorities related to climate change, both in adaptation and mitigation, as expressed by countries in their Nationally Determined Contributions (NDCs) submitted in the context of the United Nations Framework Convention on Climate Change. In March 2017, the analysis found that, most NDCs committed to emission reduction in agriculture and listed agriculture as a priority for adaptation. These priorities included a number of agricultural sub-sectors such as livestock, manure and grassland; croplands, fertilizer management and agricultural residues. Examples of cropland mitigation and adaptation strategies included carbon sequestration, agroforestry, and conservation agriculture.

While several sustainable practices and technologies have been used to enhance soil carbon, the learning resources are not easily available at a single place. There was a demand from the African National Designated Entities (NDEs) for learning resources on soil carbon enhancing technologies, practices and approaches compiled at a single source. This compendium is a collection of pertinent practices intended at enhancing soil carbon and having potential for application in several African countries. The compendium briefly distills out most pertinent points for a general understanding and then points to the relevant literature for detailed reading of an interested reader.

Although the contents of the compendium might be of interest to a much broader readership, the intended readers of this compendium are soil and agricultural practitioners, especially those working in Africa. Other users can be staff of extension agencies, non-governmental organizations (NGOs) and community-based organizations (CBOs).

This compendium is organized into ten modules. Each module describes one of the following topics:

- ✓ Module One: Basics of carbon sequestration in soils;
- ✓ Module Two: Application of biochar for soil carbon sequestration;
- ✓ Module Three: Conservation agriculture with and without trees;
- ✓ Module Four: Agroforestry, social forestry, and plantation management;
- ✓ Module Five: Pasture management and use of cover crops;
- ✓ Module Six: Cross-slope barriers;
- ✓ Module Seven: Mulching of crop residues, green and brown manuring, and managing agricultural waste;
- ✓ Module Eight: Concepts and principles of organic agriculture;
- ✓ Module Nine: Area closures and reserves; and
- ✓ Module Ten: Advanced approaches to monitoring soil carbon stock.

How to use this compendium

The modules in this compendium are largely not linked to one another and can be read on their own. However, it is advisable to read Module One first as it explains the basic concepts of carbon sequestration.

Why is it important to sequester soil carbon?

According to a 2014 report by leading climate scientists, convened by the U.S. National Academy of Sciences and the U.K.'s Royal Society, the atmospheric concentration of carbon dioxide has increased by 40 percent since pre-industrial times. More than half of this increase has occurred since 1970, and of all greenhouse gases in the atmosphere, carbon dioxide plays the most significant role in warming the Earth (White 2014).

The UN Intergovernmental Panel on Climate Change (IPCC) issued its starkest warning yet on the urgency of tackling global warming in its "Special Report on Global Warming of 1.5C", saying that only twelve years are remaining to keep warming within that limit (Hao 2018). The IPCC forecast, with "high confidence", that 1.5C", would be reached between 2030 and 2052. The report says it will be necessary to remove 100 to 1,000 gigatonnes of carbon dioxide from the atmosphere during the 21st century to keep warming ' to below 1.5C target. In other words, to keep the world below the target of 1.5C, global greenhouse gas emissions in 2030 would have to be 55% lower than today (Global Carbon Project 2009, cited in World Bank 2012).

Using estimates from 2005, 2007 and 2008, the researchers found that agricultural production provides the lion's share of greenhouse-gas emissions from the food system, releasing up to 12,000 megatonnes of carbon dioxide equivalent a year — up to 86% of all food-related anthropogenic (human) greenhouse-gas emissions. Next is fertilizer manufacture, which releases up to 575 megatonnes, followed by refrigeration, which emits 490 megatonnes. The researchers found that the whole food system released 9,800–16,900 megatonnes of carbon dioxide equivalent into the atmosphere in 2008, including indirect emissions from deforestation and land-use changes (Gilbert 2012).

Overall, one-third of global greenhouse gas emissions come from agriculture (IPCC 2007, Gilbert 2012). Furthermore, agriculture contributes 50% of global methane (CH4) emissions and 60% of global nitrous oxide (N2O) emissions, two of the most potent greenhouse gases (Soventix South Africa 2014). If no proper action is taken, by 2050, climate change could cause irrigated wheat yields in developing countries to drop by 13%, and irrigated rice could fall by 15%. In Africa, maize yields could drop by 10–20% over the same time frame (CGIAR, cited in Gilbert 2012).

Reducing agriculture's carbon footprint is central to limiting climate change. Improved agricultural practices and forest-related mitigation activities can make a significant contribution to the removal of carbon dioxide from the atmosphere at relatively low cost.

Low carbon technologies and innovations in farming practices can reduce emissions into the atmosphere and lower their effects on climate change. Different technologies to improve carbon sequestration are already applied in Asia, Africa, Australia, Europe and North and South America.

Nearly 90% of the climate technical mitigation potential of agriculture comes from soil carbon sequestration. Many agricultural mitigation options, particularly those that involve soil carbon sequestration, also benefit adaptation, food security, and development. These options involve increasing the levels of soil organic matter which lead to better plant nutrient content, increase water retention capacity and better structure, eventually leading to higher yields and greater resilience (FAO 2009, cited in Cantab 2009).

To manage climate, a combination of approaches is needed, including soil carbon sequestration, better agricultural practices, soil management, afforestation and reforestation, land restoration, carbon capture and storage (CCS). In general, there are five areas of activities within agriculture and forestry sectors, which need a change, to reduce carbon footprint (FAO 2012). These include:

1. **Preparing land:** Most scientists agree that tillage removes substantial quantities of carbon from the soil and thus contributes to greenhouse gas emissions and carbon footprint. The conventional tillage, which is still practiced in most parts of Africa, is also blamed for very low yields and high labor inputs. It is suggested that tillage should be minimized as much as possible;

2. **Deforestation:** Prevention of deforestation and tree restoration have the largest carbon stock impact;

3. **Irrigating land:** Implementing solar power rather than electricity or diesel to power pumps will lower irrigation costs and carbon footprint;

4. **Applying nutrients:** Manufacturing, transport and application of chemical fertilizers produce huge amounts of greenhouse gas emissions. Making use of organic fertilizer or replacing a part of chemical fertilizer with organic manure improves soil quality while decreasing greenhouse emissions;

5. **Transport and food miles:** The bulk transport of produce with packaging being performed at its destination will result in reductions of fuel consumption and lower the carbon footprint.

Module One: Basics of Carbon Sequestration in Soils

Objectives

This module is about carbon sequestration, its benefits and relation to soil carbon. The module introduces different approaches to sequester carbon and explains the main challenges to promoting carbon sequestration practices.

Where does atmospheric CO2 come from?

Atmospheric CO2 comes from natural and anthropogenic activities. Carbon dioxide is released naturally, through the combustion and decomposition of plants and animals. Human activities that lead to carbon dioxide emissions come mainly from energy production and use (fossil fuels such as gas, oil), industries, transport, deforestation and agriculture.

What does "carbon sequestration" mean?

Carbon sequestration is the process of capturing and storing atmospheric carbon dioxide, which can be geologic or biologic (USGS 2018).

Soils are the largest carbon sinks (World Bank 2012). Terrestrial carbon sequestration is the process through which carbon dioxide (CO2) from the atmosphere is absorbed through photosynthesis and stored as carbon in vegetation, biomass and soils. In case of ocean sequestration, the storage of carbon happens in aquatic environments (Balansay 2018). The efficiency of oceans and lands as carbon dioxide sinks has declined because current emissions are outpacing the growth in natural sinks (Global Carbon Project 2009, cited in World Bank 2012).

Geologic carbon sequestration is the process of storing carbon dioxide in underground geologic formations or as a solid material. This technology is still under development, and not discussed further in this compendium.

Soil and carbon sequestration

There are three forms of carbon in the soil: elemental, inorganic and organic (Schumacher 2002, cited in World Bank 2012).

Soil organic matter (SOM) is the main contributor to soil fertility. It is the source of food for soil fauna. It promotes healthy crops, supplies resources for microbes and other soil organisms, and regulates the supply of water, air and nutrients (such as Nitrogen, Phosphorus and Sulphur) to plants.

Soil organic matter also reduces the soil's susceptibility to compaction, erosion, desertification and landslides. Soil erosion is the removal of top soil (the upper 0-20 cm of soil) due to natural, animal, and anthropogenic activities. Accelerated erosion is one of the biggest environmental problems today (Lal 2003, cited in World Bank 2012, Mutua et al 2014; table 1.1).

Table 1.1 Estimate of erosion induced carbon emission

Continent	Cross-erosion (X 109 Mg/year)	Soil carbon displaced by erosion (2 to 3 percent of sediment; Gt C/year)	Emission (Gt C/year)
Africa	38.9	0.8–1.2	0.16–0.24
Asia	74.0	1.5–2.2	0.30–0.44
South America	39.4	0.8–1.2	0.16–0.24
North America	28.1	0.6–0.8	0.12–0.16
Europe	13.1	0.2–0.4	0.04–0.08
Oceania	7.6	0.1–0.2	0.02–0.04
Total	**201.1**	**4.0–6.0**	**0.8–1.2**

Source: Lal (2003) in World Bank 2012.

When soil organic matter decays, it releases carbon dioxide (CO2) into the atmosphere. When soil organic matter forms, CO2 is removed from the atmosphere (Mutua et al 2014).

There are two ways to manage soil organic matter in a better way (European Communities 2009):

- Slowing down decomposition rates by reducing tillage intensity. If the rate of decomposition is faster than the rate at which organic matter is added, soil organic matter levels will decrease.
- Increasing the amount of organic matter in the soil. This can be done through adding organic materials in the soil, for example, by using cover crops or compost amendments.

Soil organic carbon (SOC) is the most important building component for a healthy soil. It is the single largest component of soil organic matter and a key factor in greenhouse gas mitigation. Soil organic carbon supports the soil's structure, improving the physical environment for roots to penetrate through the soil.

SOC content is determined by the following factors (FAO 2012):

- The crop rotation pattern,
- The input rates of organic matter,
- The chemical composition of organic matter inputs,
- The soil type and texture (hence by the degree of protection or bonding of the stable carbon fraction within the soil),
- The previous land use, and
- The climatic conditions.

Lack of carbon sequestration is a result of (FAO 2012):

- Soil disturbance,
- Mono-cropping,
- Specific crop rotations,
- Poor management of crop residues, or
- Soil sampling extended deeper than 30 cm.

Increasing soil organic carbon can reverse soil fertility deterioration and increase yields. For example, the estimated increase in grain productivity in Africa, Asia, and Latin America due to increase in soil organic carbon is 24 to 40 million tons per year (Lal 2011, cited in World Bank 2012)

To increase global soil carbon, White (2018) suggests following eight steps, presented below (box 1.1).

Box 1.1 Eight steps to increase global soil carbon

1. Stop carbon loss – Protect peat lands through enforcement of regulations against burning and drainage.
2. Promote carbon uptake – Identify and promote best practices for storing carbon in ways suitable to local conditions, including through incorporating crop residues, cover crops, agroforestry, contour farming, terracing, nitrogen-fixing plants, and irrigation.
3. Monitor, report and verify impacts – Track and evaluate interventions with science-based harmonized protocols and standards.
4. Deploy technology – Use high-tech opportunities for faster, cheaper and more accurate monitoring of soil carbon changes.
5. Test strategies – Determine what works in local conditions by using models and a network of field sites.
6. Involve communities – Employ citizen science to collect data and create an open online platform for sharing.
7. Coordinate policies – Integrate soil carbon with national climate commitments to the Paris Agreement and other policies on soil and climate.
8. Provide support – Ensure technical assistance, incentives to farmers, monitoring systems, and carbon taxes to promote widespread implementation.

Source: White 2018.

The rate of increase in SOC stock after adoption of improved management practices attains a maximum level of sequestration rates in 5 - 20 years (FAO 2012).

What are major initiatives for harnessing carbon sequestration?

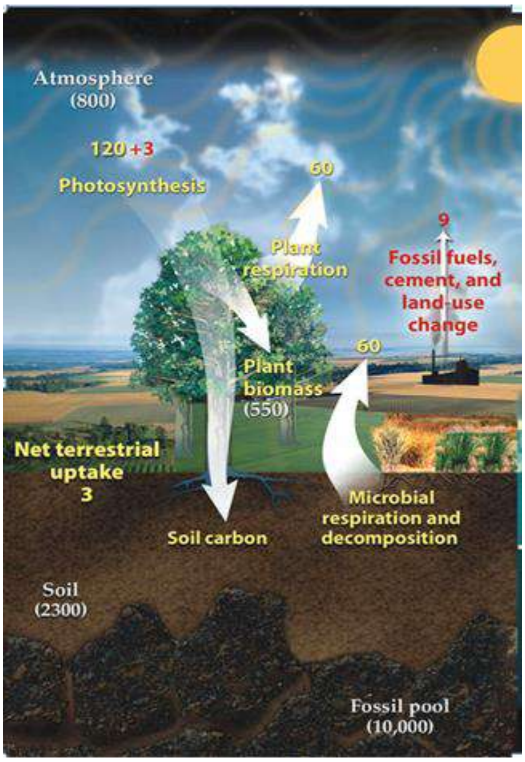
The interest in carbon capture and sequestration has emerged in North America, Europe, and Asia since the early 2000s. Nowadays, there are several international initiatives on carbon sequestration (table 1.2, picture 1.3).

Table 1.2 International soil carbon initiatives

Policy Title	Focus	Agency(ies)
4 per 1000: Soils for Food Security and Climate (picture 3.1.1)	Efforts and commitments to increase soil organic carbon by four parts per thousand (0.4%) per year.	French Ministry of Agriculture and other international partners
Regenerative Development to Reverse Climate Change	Funding to support regenerative agriculture programs in 52 member nations in the Commonwealth of Nations (the former British empire).	The Commonwealth of Nations
Land Degradation Neutrality Fund	Innovative financial market for investing in profit-generating sustainable land management and restoration projects globally in support of the UN Sustainable Development Goal q5.3 for assuring land degradation neutrality.	UNCCD, UNEP, Mirova
Climate Smart Agriculture	Goal of food security and development, by enhancing agricultural productivity and climate adaptation and mitigation.	FAO, World Bank, Dutch Government

Source: Global Development and Environment Institute (GDAE) 2018.

Picture 1.1 Four per 1000 per year



Carbon in topsoil (40cm = 16 inches): 860 gigatonnes

Adding an extra 3.4Gt of Carbon in topsoil per year:

3.4/860 = 0.004 = 4 per 1000

Source: Global Development and Environment Institute (GDAE) 2018.

Which soils are most suitable to enhancing carbon sequestration?

Different soils have different potential to sequester carbon (World Bank 2012). Sustainable land management practices need to be adopted to enhance carbon sequestration on any soil. These practices include: application of biochar, use of mulches, crop residues and cover crops, agricultural waste management, crop rotation, no-tillage or minimum-tillage agriculture, manuring, crop-slope barriers, pasture management, agroforestry and afforestation (see more detail on each of these practices in the modules to follow).

In general, carbon sequestration potential depends on water, temperature and soil texture. The wetter a soil is, the less oxygen is available for organic matter to decay and the organic matter accumulates (European Communities 2009).The research of European Communities (2009) explains that humid and semi-humid tropics are best fit for enhancing carbon sequestration. Organic matter decays more rapidly at higher temperatures. Soils in warmer climates tend to contain less organic matter than those in cooler climates.

Fine-textured soils tend to have more organic matter than coarse soils. These soils hold nutrients and water better, thus providing good conditions for plant growth. Coarse soils are better aerated, and the presence of oxygen results in a more rapid decay of organic matter.

How to sequester carbon in soils?

Hoff 2017 states there are eight ways to sequester carbon.

1. Planting trees: afforestation, reforestation and agroforestry

Trees have potential to absorb CO2 from the air and store it in wood, bark, leaf and root. A single hectare (2.5 acres) of forest can take up somewhere between 1.5 and 30 metric tonnes (1.6 and 33 tonnes) of CO2 per year, depending on the tree species, their age and the climate.

This technology is relatively easy to implement but it is quite land intensive. The most areas which are most fit are those with sufficient water supply for trees and not suitable for agriculture (Hoff 2017).

Worldwide forests currently sequester 2 Gt CO2 per year. There is a potential to increase this amount by a gigaton or more, through afforestation and reforestation. Box 1.2 presents the largest tropical reforestation project in the world. The practices of agroforestry (AF), social forestry (SF), and plantation management are further discussed in Module Four.

Box 1.2 The largest tropical reforestation project in Brazil

The project in the Brazilian Amazon is using a new technique for planting trees that results in more, stronger plants–and hopes to cover 70,000 acres in new forests.

Since 2017, Conservation International is leading the implementation of a six-year project in the Brazilian Amazon. The short-term plan is to plant 73 million trees on the area of 30,000 soccer fields that have been cleared for pastureland.

The new planting technique is called *muvuca* which means “a lot of people in a very small place”. The *muvuca* strategy demands that seeds from more than 200 native forest species are spread over every square meter of burnt and mismanaged land.

In any given hectare, as many as 2,000 locals are actively working together to reforest the land–typically private farmland but also government-owned protected zones and indigenous territories. Pay is issued evenly among participants, and families can earn about $700 per hectare reforested. The finances are typically managed by a local NGO in the field, with support from project sponsors.

A couple million trees have been already planted, and it’s a win-win situation for all involved parties.

Source: Townsend 2017.

2. Other vegetation

Grasslands, coastal vegetation, peat lands also take up and store CO2. In particular, with mangroves sequestering roughly 1,400 metric tonnes per hectare; salt marshes sequestering 900 metric tonnes; and sea grass sequestering 400 metric tonnes (Hoff 2017).

Apart from carbon sequestration benefits, this technology protects coastlines from erosion, provides habitat and protects water quality. However, coastal ecosystems also release methane, a potent greenhouse gas. Thus, further research is needed to understand whether this technology is beneficial in a long run. The areas which are best fit for this technology include coastlines where native habitat was degraded (Hoff 2017).

3. Biochar

Another way to enhance plants' ability to store carbon is to apply biochar. The estimated carbon capture potential of biochar is about 1-4 Gt CO2 per year. Biochar can improve soils but greenhouse gases produced by transportation and other inputs for the application of biochar shall not exceed the value of carbon storage (Hoff 2017).

Biochar is further discussed in Module Two.

4. Carbon farming

The purpose of carbon farming is to grow plants to trap CO_2 through practices such as minimized tillage, planting longer-rooted crops and incorporating organic materials into the soil to encourage the trapped carbon to move into and stay in the soil. The estimated carbon sequestration potential from this technology is about 1-13 Gt CO_2 per year (and more with trees). Agricultural lands with sufficient water supply are the best fit for this technology (Hoff 2017).

Agricultural approaches, which go along with carbon farming - such as conservation agriculture (including minimized tillage), pasture management, cover crops, cross-slope barriers, mulching and organic agriculture - are further discussed in Modules Three, Five, Six, Seven and Eight of this compendium.

5. Bioenergy and bury

This technology starts with converting biomass into a usable energy source such as liquid fuel or electricity. Thereafter, rather than sending the CO_2 released during the process into the air, as conventional facilities do, it traps it in material such as concrete or plastic or injects it into rock formations that trap the carbon far below the Earth's surface.

The potential of this technology to capture carbon has been estimated at 1-20 Gt CO_2 per year. In addition, it provides electricity and fuel. However, because this technology requires many inputs, it is yet not clear whether the entire process is carbon negative in a long run. Furthermore, this technology can compete with food production and the mechanisms for storing captured carbon are still under development (Hoff 2017).

6. Fertilizing the ocean

Plants that live in the ocean absorb considerable amounts of CO_2 each year. Their ability to do so is limited by the availability of iron, nitrogen and other nutrients. Researchers are looking at approaches for fertilizing the ocean or bringing nutrients up from the depths to enhance plants' ability to store carbon. The estimated potential to capture carbon is 1-4 Gt CO_2 per year. However, this technology is still experimental, has high energy needs and its impact on aquatic ecosystems in unknown (Hoff 2017).

7. Rock solutions

CO2 is naturally removed from the atmosphere every day through reactions between rainwater and rocks. Some climate scientists propose enhancing this process through artificial measures such as crushing rocks and exposing them to CO_2 in a reaction chamber or spreading them over large areas of land or ocean, increasing the surface area over which the reactions can occur.

The estimated potential of this approach to capture carbon is <1-18 Gt CO_2 per year. But it is an expensive and energy-intensive technology. The greenhouse gas emissions may exceed its storage, unless this technology is used in the areas where water and rocks are plentiful (Hoff 2017).

8. Direct air capture and storage

A carbon-trapping facility was opened in Switzerland. Known as direct air capture and storage, this approach uses chemicals or solids to capture the gas from thin air and stores it for the long haul underground or in long-lasting materials. The estimated potential of this technology to capture carbon is 3-16 Gt CO_2 per year. This technology is being tested. It is energy intensive, so the net benefit in carbon is yet unknown. There is a possibility that it can be carbon beneficial in the areas where underground geological formations are favorable (Hoff 2017).

Furthermore, there are a lot of innovations being developed in different parts of the world. For example, an artificial plant factory was launched in China. The photosynthesis of plants is used to achieve carbon fixation. The results show that the production increased by 20%-25% and the plants fixed a considerable amount of carbon (Zhang et al 2017).

Challenges to promoting carbon sequestration and healthy soils

Logan et al (2007) identify four main challenges to promoting carbon sequestration and healthy soils, such as:

- Developing a policy driver to incentivize deployment;
- Defining a flexible and adaptable regulatory framework;
- Funding demonstration projects; and
- Achieving public acceptability.

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Module Two: Application of Biochar

Objectives

The module discusses the benefits of biochar, its potential to sequester carbon as well as its relation to soil. The module also explains how biochar is made, where it can be applied, and what key considerations for deployment of this technology are.

What does "biochar" mean?

Biochar is a charcoal produced from plant matter, used as soil amendment and stored in the soil as well as a means of removing carbon dioxide from the atmosphere. Biochar is made by the pyrolysis of biomass (*pyro* means fire and *lysis* means decomposition). It is made by heating organic material under conditions of limited or no oxygen.

Not all biochar looks or behaves the same (Anand 2015). The type of organic matter (or feedstock) that is used and the conditions under which a biochar is produced greatly affect its relative quality as a soil amendment (Hunt et al 2010).

The biochar pH rate matters (table 2.1). Soil pH is a measurement of the alkalinity or acidity of soil and is measured on a scale of 1-14. A measure of 7 on the scale is neutral while anything below 7 is considered acidic and anything above 7 is considered alkaline. Soil pH plays an important role in plant growth. Soil pH determines how easily nutrients become available to plants in the soil (Mutua et al 2014).

Table 2.1 Biochar feedstock and its pH

Biochar feedstock	**pH**
Rice Husk	8.78
Prosopis Julifora	9.02
Rice pellet	9.63
Coconut	9.34
Mixed fuel wood	8.34
Rice straw	9.62

Source: Anand 2015.

Biochar and carbon sequestration

Biochar has the unique ability to sequester carbon and thereby reduce atmospheric carbon. As stated in Module One of this compendium, the carbon capture potential of biochar has been estimated at <1-4 Gt CO2 per year (Hoff 2017).

Using agricultural waste (see more in Module 7) for biochar production could cost-effectively prevent the release of 331 megatonnes of carbon dioxide equivalent per year (MtCO2e/year) from decaying biomass. This is equal to the emissions from 70 million passenger vehicles per year. Reaching this scale will require operations converting half a billion tonnes of crop waste to biochar each year. That's about 2-3 times the scale of current global charcoal production for fuel and almost all of this currently comes from wood (Nature4Climate 2018).

Making biochar sequesters approximately 50 per cent of the carbon that would otherwise be released. For comparison, composting sequesters 10 or 20 per cent, and burning the waste sequesters about 3 per cent. Apart from carbon sequestration potential, biochar has the potential to assist with soil productivity, bioenergy and agricultural waste (table 2.2).

Table 2.2 Biochar benefits

Benefit	How to achieve it?
Carbon sequestration	Creating biochar sequesters approximately 50 per cent of the carbon that would otherwise be released (Godbey 2016).
Soil productivity	Biochar has the potential to increase the world's agricultural productivity by improving degraded soils. Biochar has the potential to change "slash and burn" to "slash and char" agriculture. For example, instead of abandoning nutrient depleted tropical soils, the productivity of the soil can be improved with the use of biochar. This is a far better practice than cutting rainforest again and again (Godbey 2016).
Creation of bioenergy	The process produces bioenergy such as syngas and bio-oils. This bioenergy can be "upgraded" to transportation fuels like biodiesel and gasoline substitutes to replace fossil fuels.
Management of agricultural waste	Agricultural wastes are usable resources for pyrolysis bioenergy production. Not only is energy obtained in the charring process, but the quantity of waste materials is significantly reduced. Similar opportunities exist for urban and industrial wastes (Hofstrand 2009).

Source: Hofstrand 2009 and Godbey 2016.

Where has biochar application been practiced?

It's believed that ancient South American cultures burnt agricultural waste to cover soils 1500 years ago to increase soil productivity. But the term 'biochar' was coined by Peter Read in 2005 (Godbey 2016).

Nowadays, there are many initiatives that promote biochar production and application in Africa (boxes 2.1-3).

Box 2.1 Sustainable wood fuel systems in coastal regions in Tanzania

In 2018, CTCN-UNEP pioneered a stakeholder approach to sustainable woodfuel systems in the coastal regions of Tanzania. The main activities included:

- Context analysis, priority interventions by stakeholders,
- Co-learning with participation of 16 men and five women,
- Grassroots trainings with participation of 76 males and 42 females,
- Co-designing a proposal for scaling up business models.

The lessons learnt are:

- Bioenergy-biochar systems have multiple benefits, such as: energy security, improved livelihoods and gender equity, resource recovery, improved agricultural productivity and climate change mitigation and adaptation,
- There is a need for gender-responsive demand-driven development for scaling up existing technologies for sustainable biomass production,
- There is a need for knowledge dissemination and capacity development on charcoal and biochar systems,
- There is a need for enabling policy framework including standards and regulations for climate smart charcoal and biochar production.

Source: Presentation of Mary Njenga et al, ICRAF, Nairobi, December 2018.

Box 2.2 Biochar application in West Africa

A farming technique practiced for centuries by villagers in West Africa, which converts nutrient-poor rainforest soil into fertile farmland, could revolutionize farming across Africa.

A global study, led by the University of Sussex, which included anthropologists and soil scientists from Comell, Accra, and Aarthus Universities and the Institute of Development Studies has for the first time identified and analyzed rich fertile soils found in Liberia and Ghana,

They discovered that the ancient West African method of adding charcoal and kitchen waste by highly weathered, nutrient poor, tropical soils can transform the land into enduringly fertile, carbon-rich black soils, named by researchers as ‘African Dark Earths’.

From analyzing 150 sites in northwest Liberia and 27 sites in Ghana researchers found that these highly fertile soils contain 200-300 percent more organic carbon than other soils and are capable of supporting for more intensive farming.

Source: Presentation of Mary Njenga et al, ICRAF, Nairobi, December 2018.

Box 2.3 Biochar initiatives in Africa

The Africa Biochar Partnership (ABP) which is an open continental platform for advancing the cause of Biochar Systems in Africa was launched on March 1st, 2016 in Nairobi - Kenya at the International Workshop on Biochar Systems for Africa, organized by the "Biochar Plus" project in collaboration with "Biochar for Sustainable Soils" project (see more @ http://www.ecreee.org/news/launch-africa-biochar-partnership-0).

The **sub Saharan African Soil Regeneration Initiative (ASRI)** aims to scale up regenerative, climate smart agriculture (CSA) and grazing practices across Africa with emphasis on the smart use of biomass and nutrients.

International Biochar Initiative (IBI) provides a platform for fostering stakeholder collaboration, good industry practices, and environmental and ethical standards to support biochar systems that are safe and economically viable.

Source: EOCWAS 2016, presentation of Mary Njenga et al, ICRAF, Nairobi, December 2018.

The application of biochar is rapidly gaining its popularity. Biochar application is supported by FAO and Biochar International. There is increasing number of scientific trials and farmers' experiments on charcoal application in Latin America, South Asia, and Sub-Saharan Africa while UK and Australia are more careful in advocacy of charcoal application as there is no long-term evidence of its benefits proven by the scientists.

Which areas are most suitable for the application of biochar?

This technology is most beneficial in the degraded lands of African tropics (e.g. Moltsen 2016).

How to make biochar?

There are different ways to make biochar. Picture 2.1 illustrates TLUD gasifier used in rural Kenya. These gasifiers do not only produce biochar, but are also used as kitchen stoves.

Picture 2.1 TLUD gasifier improves livelihoods of 150 farmers in rural Kenya

Top Lit Updraft (TLUD) Gasifier

Reproduced by

uses 43% less wood than (net)

uses 32% less wood than (gross)

emits 41% less CO_2 than

emits 79% less PM2.5 than

Three-stone open fire

	MASS BALANCE	GASTOV (n=5)		Three-stone (n=5)
IN	Firewood (g)	1007 ± 17*a	844.56±174.6*b	1475 ± 159.9
OUT	Biochar yield (g)	198 ± 32.24 *(16.4%)*	*NA*	NA

Source: presentation of Njenga et al, ICRAF, Nairobi, December 2018.

Picture 2.2 illustrates pyrolytic cooking systems, used to produce biochar in Uganda.

Picture 2.2 Pyrolytic cooking systems: two – chamber gasifier in Uganda

Two-chamber

uses 36% (RH) to 40% (CS) less wood than

emits 24% (CS) to 33%(RH) less CO_2 than

emits 67% (CS) to 82% (RH) less PM than

emits 8%(CS) to 28% (RH) less CO than

Three-stone fire

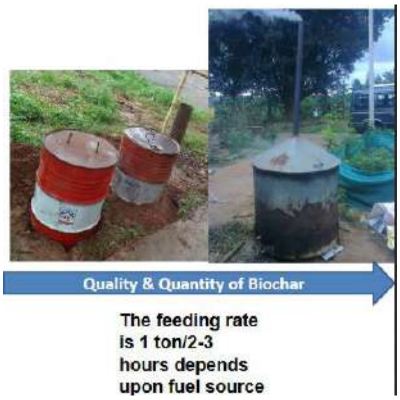
	MASS BALANCE	Gasifier x Rice Husks (n=6)	Gasifier x Coconut shells (n=6)	Three-stone (n=4)
IN	Firewood (g)	2412 ± 162	2229 ± 244	3771 ± 297
IN	Crop residue (g)	600	1500	NA
OUT	Biochar yield (g)	342 ± 15 *(55 - 60%)*	555 ± 61 *(33 - 41%)*	NA

Source: presentation of Njenga et al, ICRAF, Nairobi, December 2018.

Picture 2.3 illustrates low-cost biochar makers at household and farm levels in India.

Picture 2.3 Low-cost biochar maker in India

Biochar maker at household level



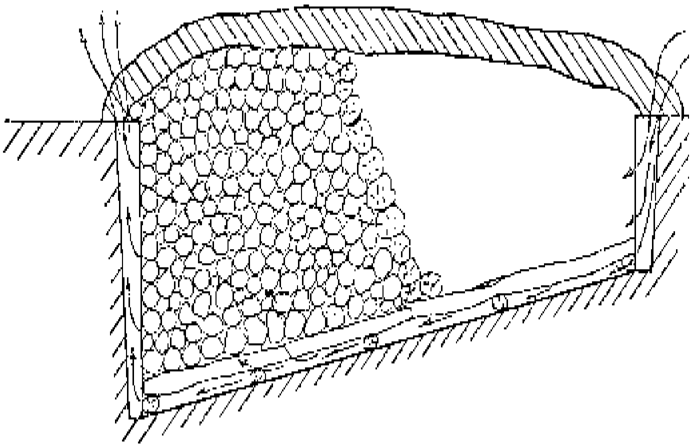
Biochar maker at field scale

Source: Anand 2015.

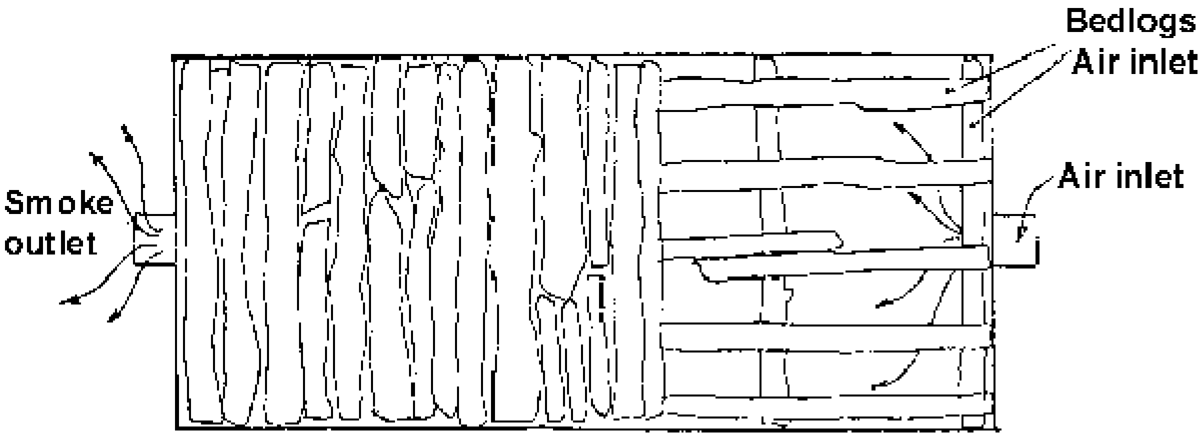
Yet another way to produce biochar is to use a pit method (picture 2.4, FAO 1983).

Picture 2.4 Pit method to make biochar

Charcoal Pit - Longitudinal section



Charcoal Pit - Plan view - without earth cover



Source: see more in FAO 1983.

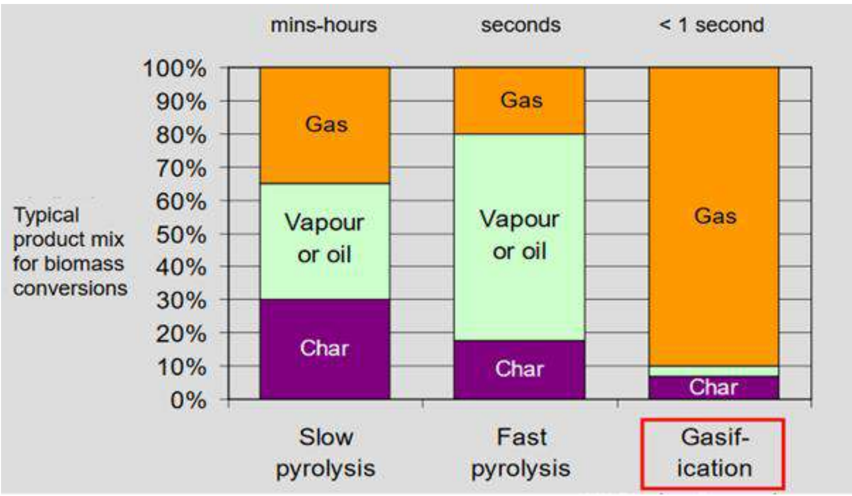
Different soils require different biochar application practices. The practical aspects of biochar application in various soil management systems are explained in great detail in the manual by Major (2010).

What needs to be considered?

1. **The process of making biochar matters**

The conversion process has an effect on the level of gasification. Thus, fast gasification is to be avoided (figure 2.1, Anand 2015).

Figure 2.1 Biochar conversion process



Source: Anand 2015.

2. **Biochar making and land grabbing**

Biochar making may exacerbate land grab in Africa (African biodiversity Network et al 2009). Land grab for biochar production can be avoided by using agricultural waste instead. Biochar production with right policies may improve carbon capture, soil fertility and lift communities from poverty, like it has happened in the Sunderbanks Delta, West Benegal, India, when women from small households had an opportunity to earn from selling biochar made in low-cost TLUD gasifier cook stoves (Anand 2015).

3. Scientific basis

The long-term impacts of biochar addition to soils are yet not fully understood. Studies show great variation in short-term results, which depend on the different soil types, the type of biomass which was used, burn temperatures, and crops grown with biochar. A spokesperson for the Australian Science Onstitute CSIRO, which received substantial government funding for biochar research, stated serious reservations about advising farmers on biochar use, in the absence of further research, and expressed concerns about farmers already experimenting with biochar (African Biodiversity Network et al 2009).

Further reading

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Module Three: Conservation Agriculture With and Without Trees

Objectives

This module is about conservation agriculture with and without trees; its benefits and potential to sequester carbon. The module discusses how and where to practice conservation agriculture as well as the key considerations for deployment of this approach.

What does "conservation agriculture" mean?

"Conservation agriculture (CA) is a concept for saving agricultural resources so as to achieve acceptable profits together with high and sustained levels of crop production while concurrently conserving the environment" (FAO 2007).

"CA is a system that optimizes yields and profits, to achieve a balance of agricultural, economic and environmental benefits. It is the integration of ecological management with modern scientific agricultural production" (Mutua et al 2014).

Conservation agriculture emphasizes:

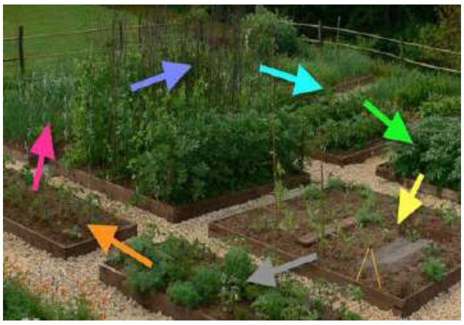
a) Soil as a living body, essential to sustain life on earth.

b) The protection of the upper 0-20 cm of soil is important since it is most vulnerable to erosion and degradation.

Conservation agriculture is based on the following three principles or tenets (Mutua et al 2014; Nature4Cliamte 2018a):

1. Minimum soil disturbance,
2. Crop rotation (picture 3.1), and
3. Maximum soil cover (see more in Module 5).

Picture 3.1 Crop rotation



Source: Presentation of Eng. Alex R. Oduor and Eng. Maimbo Malesu, ICRAF, Nairobi, December 2018.

These three principles of conservation agriculture have a number of benefits (table 3.1).

Table 3.1 Benefits of three principles of conservation agriculture

Principle	Practice	Biophysical benefits	Farm benefit
Minimum soil disturbance	Minimum tillage or zero tillage	-Improved soil physical properties (texture and structure, aeration, soil moisture regime), -Improved biological properties (microbial activities and organic matter).	-Reduced erosion, -Enhanced soil fertility, -Enhanced productivity, -Enhanced profitability.
Permanent soil cover	Live mulch and crop residue		
Crop rotation / intercropping	Crop rotation, intercropping, or both		

Source: Presentation of Eng. Alex R. Oduor and Eng. Maimbo Malesu, ICRAF, Nairobi, December 2018.

What is conservation agriculture with trees?

Conservation agriculture with trees (CAWT) is "the inclusion of trees to support the CA system in order to combine the best of CA and the best of agroforestry leading to a working model under different social, economic, biophysical, institutional and policy conditions" (Mutua et al 2014).

Conservation agriculture with or without trees and its carbon sequestration potential

Conservation agriculture: About 350 million hectares – up to 25 percent of the world's cropland – could be planted with cover crops. Practicing conservation agriculture could sequester up to 372 megatonnes of carbon dioxide equivalent per year (MtCO2e/year). That's comparable to the emissions from 79 million passenger vehicles per year (Nature4Climate 2018a).

Conservation agriculture with trees: Trees could be planted in croplands across 608 million hectares worldwide. Holding warming to below 2 degrees C would need the application of agroforestry systems across 322 million hectares, an area about the size of India (Nature4Climate 2018b).

Planting trees in agricultural lands could store 439 megatonnes of carbon dioxide equivalent per year (MtCO2e/year). That's comparable to the emissions from 94 million passenger vehicles per year (Nature4Climate 2018b).

Benefits of conservation agriculture with or without trees

CA prevents further soil degradation and ensures more stable yields in a long run while reducing production costs (e.g. inputs for tillage) and increasing labor productivity (FAO 2001). CAWT has even more benefits than CA (table 3.2). Apart from a higher rate of carbon capture, CAWT provides fodder, fuel, construction materials, agricultural implements, biomass, nutrients, fencing and fruits.

Table 3.2 Benefits of conservation agriculture with or without trees

Benefits without trees	Benefits with trees
1. Carbon storage. 2. Controlled weeds. 3. Higher sustained yields (30-200%) at lower costs. 4. Environmental conservation. 5. Increases soil organic matter and nutrients, thus reducing the need for chemical fertilizers. 6. Improves soil structure and its ability to absorb and hold more moisture for crop growth. 7. Reduces time and labor requirement by up to 60% thereby allowing even the elderly farmers to still practice CA. 8. Reduced time spent working on the farm hence creating an ample time for one to engage in social activities or other employment.	1. Carbon storage through tree biomass. 2. Soil improvement. 3. Enhancing soil structure and water infiltration and penetration through mulching and their rooting systems. 4. Weed suppression through mulching and upper canopy cover. 5. Nitrogen fixation and nutrient cycling through inclusion of deep rooted and leguminous trees and shrubs leading to improvement in crop yields. 6. Biodiversity conservation through leaves falling from the trees which are used as feed by soil micro-organisms. 7. Maintaining vegetative soil cover through mulching and upper canopy thereby reducing soil erosion. 8. Providing shelter belts against wind thereby controlling erosion. 9. Fodder, fuel, construction materials, fencing, nuts and fruits.

Source: Mutua et al 2014.

Where is conservation agriculture with or without trees practiced?

Conservation agriculture with and without trees is mainly practiced in Latin America (e.g. Brazil, Argentina), the USA, Europe and Australia. It is now being seen as a possible solution for restoring soil fertility in Africa too (box 3.1).

Box 3.1 Conservation agriculture with trees in Niger

In the 1980s, during a national famine, local farmers in the Maradi district in Niger were required to practice forest-managed natural regeneration through a food-for-work program. The project encouraged farmers to protect and manage seedlings and regenerate tree stumps in their croplands, focusing on trees with agronomic benefits such as nitrogen fixation.

The efforts led to widespread recovery of tree cover, with a corresponding drop in soil erosion and an increase in soil fertility. As a result, crop yields surged. The economic benefits of the project were estimated at $56 per hectare per year. The project spread rapidly, and is now practiced on more than five million hectares in southern Niger.

Similar programs are happening in many other areas, including Ethiopia, Indonesia, Senegal and Timor-Leste.

Source: Nature4Climate 2018b.

Which areas of Africa are most suitable for conservation agriculture?

Conservation agriculture can be beneficially practiced in steep-sloping, high rainfall tropical regions; to less extent in flatter temperate areas (FAO 2001). The choice of species, management practices, climate and soils are important to consider (Cheesman et al 2016).

As regards conservation agriculture with trees, it can be applied to croplands worldwide (Nature4Climate 2018a and 2018b).

How to practice conservation agriculture?

To practice CA, farmers need to focus on the following areas of farm management (Mutua et al 2014, FAO 2018):

- Build-up of soil organic matter and reduced nutrient loss,
- Minimum soil disturbance – zero tillage and direct planting - to prevent loss of soil organic matter and nutrients,
- Nu burning of crop residue or fallow vegetation,
- Maintaining and managing a permanent soil cover,
- Farm planning and crop rotations design,
- Choice of cover crops,
- Crop and cover crop residues stay on the surface,
- Permanent crop and weed residue mulch protects the soil
- Lime and minimum fertilizers are surface-applied where necessary,
- Specialized equipment for seedling and mulch management,
- No uncontrolled grazing.

Furthermore, specific equipment may be needed to practice minimum tillage.

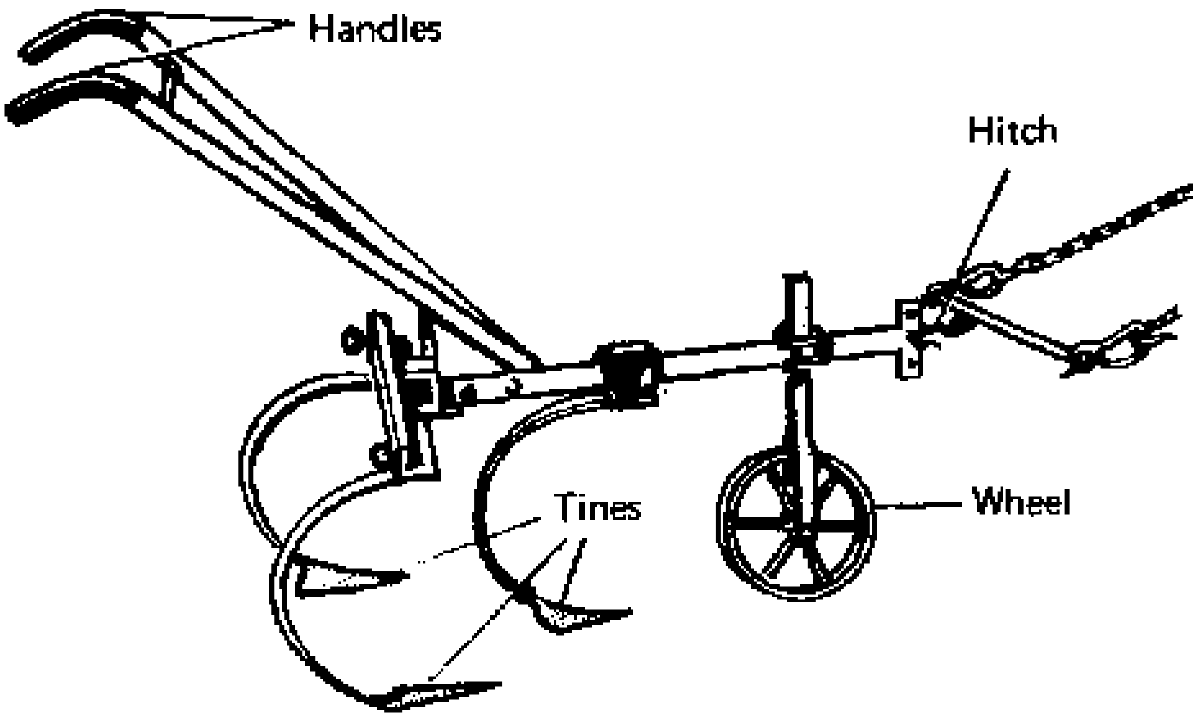
Minimum tillage equipment

The application of minimum tillage equipment is limited to the area where the crop is going to be planted leaving the rest of the area undisturbed (Mutua et al 2014). Pictures 3.2-5 illustrate minimum tillage equipment (see more in the manual by Mutua et al 2014).

Picture 3.2 Tractor-drawn minimum tillage

Source: Presentation of Eng. Alex R. Oduor and Eng. Maimbo Malesu, ICRAF, Nairobi, December 2018.

Picture 3.3 Minimum-tillage animal-drawn tines

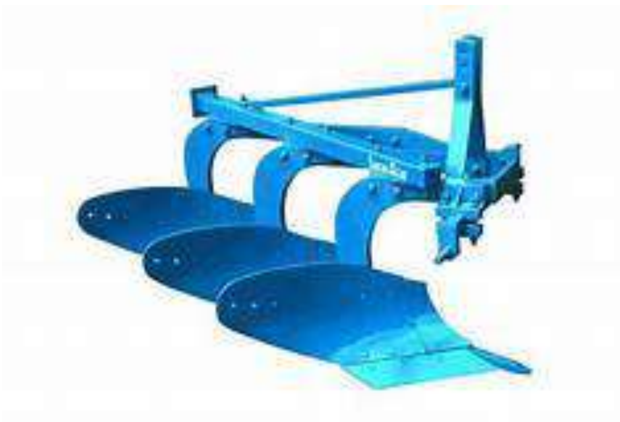


Animal-drawn cultivator

Source: Presentation of Eng. Alex R. Oduor and Eng. Maimbo Malesu, ICRAF, Nairobi, December 2018.

Picture 3.4 Equipment for minimum tillage

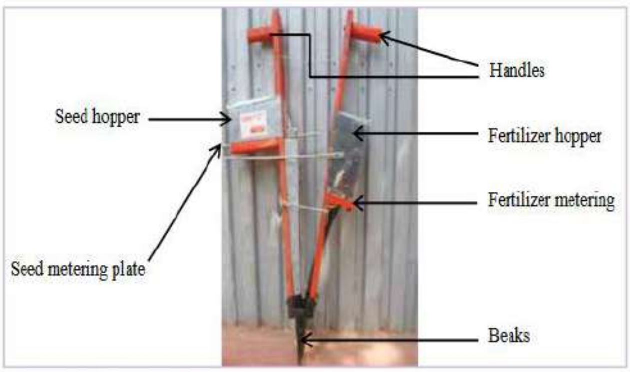
VS



Source: Presentation of Eng. Alex R. Oduor and Eng. Maimbo Malesu, ICRAF, Nairobi, December 2018.

Picture 3.5 Jab planter – direct seeding equipment

A trainer demonstartes to a farmer how to use a jab planter.



Various parts of a jab planter

Source: Mutua et al 2014.

Laser Land Leveler

In arid areas, where irrigated agriculture is practiced, CA can be started by precision land leveling. Laser land leveling is a simple operation to prepare the land before sowing to maximize water and nutrient saving. It can bring massive returns such as increasing yields, saving water and reducing greenhouse gas emissions (box 3.2).

Box 3.2 Benefits of laser land leveling in South Asia

- Laser land leveling considerably lowers irrigation time for rice by 47-69 hours per hectare per season and for wheat by 10-12 hours per hectare per season,
- It increases yields by an average 8% for both crops,
- It saves electricity about 755kWh per hectare per year for rice –wheat systems,
- It is cost effective. As demand increases, service provides rent out equipment and farmers collectively share the costs,
- It reduces greenhouse gas emissions from saving on energy, reducing cultivation time and increasing input efficiency.

Source: A study by researchers from the International Maize and Wheat Improvement Centre (CIMMYT), Borlaug Institute for South Asia (BISA) and the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), 2015.

Picture 3.6 Laser land-leveler


A laser land leveller ensures an even surface like a table top. Photo CIMMYT-India
(view original)

Source: CCAFS 2015.

A laser land leveler is a machine equipped with a laser guided drag bucket, which ensures a flat table-top like surface (picture 3.6). An even land means irrigation water reaches every part of the field with minimal waste from run-off or water-logging.

How to practice conservation agriculture with trees?

The ICRAF manual of Mutua et al 2014 provides details on each of the four steps for practicing CAWT. These steps are briefly introduced below:

Step 1: Tree propagation.

Step 2: Nursery establishment and management.

Step 3: Field preparations and transplanting.

Step 4: Management of agroforestry tree species, including activities such as watering, fertilizing, controlling weeds, mulching, gapping, thinning, pruning, coppicing and pollarding.

What needs to be considered?

The shift to CA has been achieved where (FAO 2012):

- ✓ Farmers have been informed of the system and convinced of its benefits by experience;
- ✓ Training and technical support to early adopters have been provided; and
- ✓ Adequate support policies (e.g. funding through carbon sequestration contracts with farmers) have been implemented.

According to Mutua et al 2014, the key challenges hindering the adoption of conservation agriculture are:

- ➢ Changing to CA involves a fundamental change in mind-set. Farmers are skeptical about trying new ideas due to the fear that a new way of doing can put their food supply at risk,
- ➢ Farmers need knowledge about what type of cover crops and trees have economic benefits and, at the same time, improve soil fertility; when and how deeply to plant; what equipment is needed and how to get access to and use this equipment,
- ➢ Keeping a permanent crop cover is difficult, especially in drier areas,
- ➢ Seed availability is a problem, particularly seeds for cover crops,
- ➢ CA equipment is relatively new and unavailable locally. It is also expensive compared to conventional equipment,
- ➢ Limited access to information and knowledge.

Costs and benefits of conservation agriculture in Latin America

The financial benefits for farmers in Latin America who have adopted CA have been striking (FAO 2001). By the tenth year net farm income had risen on the CA farms from under US$10000 to over US$30000, while on conventional farms net farm income fell and even turned negative. In addition to monetary income, 18 farmers who participated in this research experienced:

1) Less soil erosion and improvements in soil structure and increase in soil fertility and yields;
2) Reduced time between harvesting and sowing crops;
3) Cost saving from decreased need for inputs; and
4) Benefits from diversification.

Further reading

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Module Four: Agroforestry, Social Forestry, Plantation Management

Objectives

This module comprises three sections. Each section is focusing on one of the three approaches, such as: agroforestry, social forestry, and plantation management. The module explains the benefits and the potential of each of these three approaches to sequester carbon. The module also discusses how and where these approaches can be practiced, and what key considerations for their deployment.

4.1 Agroforestry

What does "agroforestry" mean?

FAO defines agroforestry (AF) as "a collective name for land-use systems and technologies where woody perennials (e.g. trees, shrubs, palms, bamboos) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence." (FAO 2017).

ICRAF defines agroforestry as "a farming system that integrates crops and livestock with trees and shrubs. The resulting biological interactions provide multiple benefits, including diversified income sources, increased biological production, better water quality, and improved habitat for both humans and wildlife. Farmers adopt agroforestry practices for two main reasons. They want to increase their economic stability and they want to improve the management of natural resources under their care." (Mutua et al 2014).

What are the benefits of agroforestry in terms of soil carbon?

There are wide variations in CO2 storage from agroforestry depending on tree species, their age and climate. The average carbon sequestered by AF practices has been to be 9, 21, 50, and 63 $MgCha^{-1}$ in semiarid, sub-humid, humid, and temperate regions accordingly. In tropics, for small agroforestry systems, it has been found to be ranging from 1.5 to 3.5 $MgCha^{-1}yr^{-1}$. In degraded soils of the sub humid tropics, agroforestry practices have been found to increase top soil carbon stocks up to $1.6MgCha^{-1}yr^{-1}$ (Murthy et al 2013).

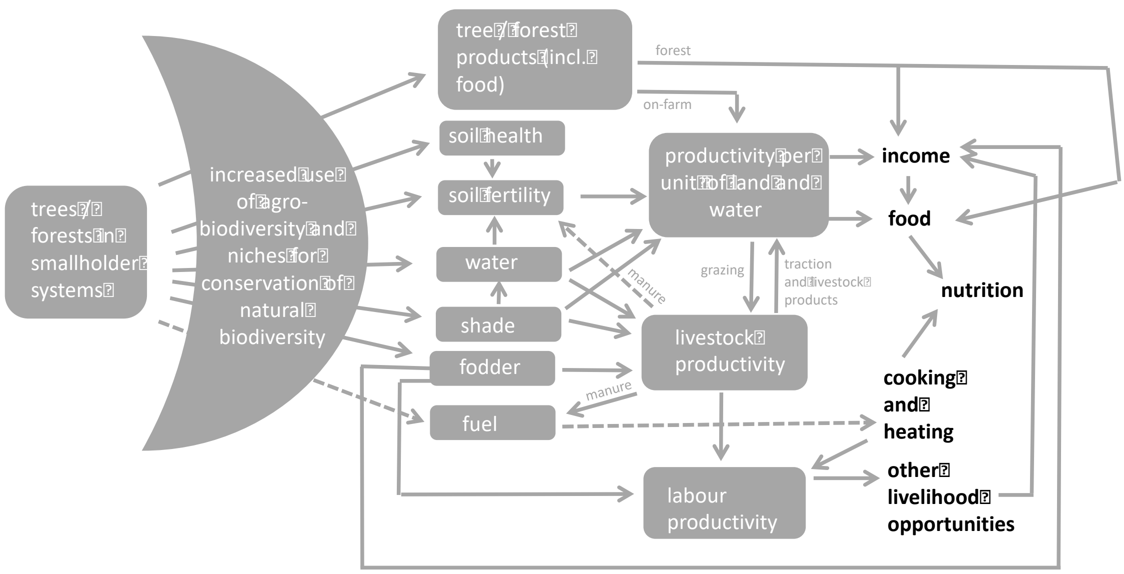
Agroforestry has environmental, economic, agricultural, social and other benefits (table 4.1, picture 4.1).

Table 4.1 Multiple benefits of agroforestry

Environmental	Economic	Agricultural	Social	Other
Increased carbon stock	Higher income due to provision of non-wood products and timber	Soil fertility; controlling soil erosion,	Gender equality, e.g. due to income opportunity for women to sell fruits	Air quality
Climate adaptation	Reduced vulnerability	Trees in agroforestry practices catch, store and release water	Food security	Shade
Climate change mitigation	Increased productivity	Increased nitrogen inputs due to nitrogen fixing trees		Aesthetic value

Source: Kiptot and Franzel 2011, Murthy et al 2013, FAO 2017.

Picture 4.1 Major ways in which trees and forest resources impact smallholder livelihoods



Source: Presentation on Fergus Sinclair (ICRAF), ICRAF, Nairobi, December 2018.

Agroforestry can improve people's livelihoods. For example, agroforestry practices in Niger, being implemented on 5 million ha of land, resulted in 15-30% of crop yield increase as well as improved nutrition and income (box 4.1).

Box 4.1 Agroforestry in Niger

5 million ha, impacting 2.5 million people in southern Niger

$200 per year and only 10-25% of harvested product sold

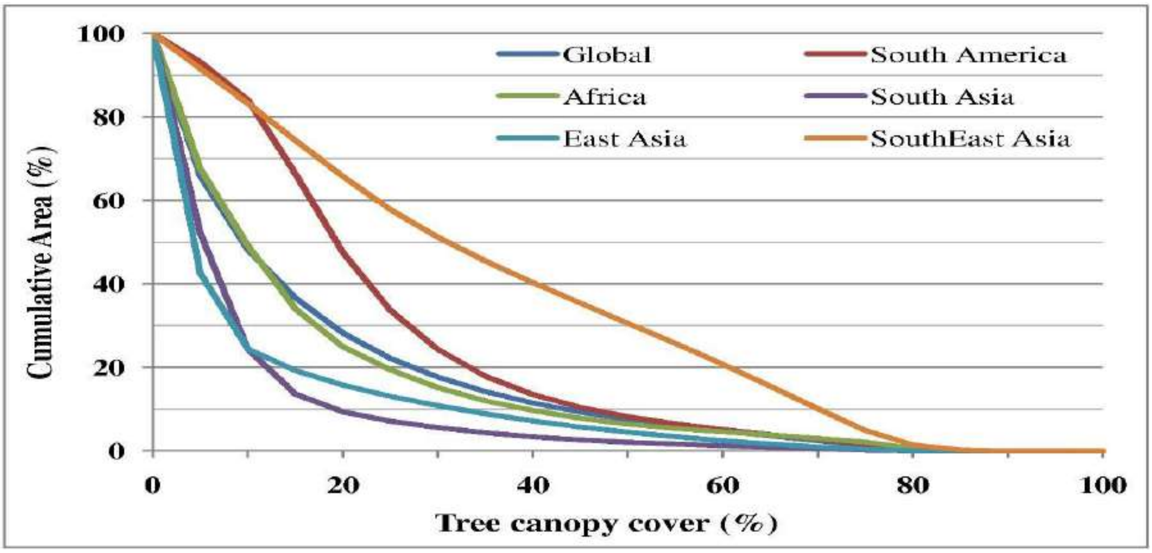
Crop yield increased 15-30% depending on tree species, location and crop type

Source: Presentation on Fergus Sinclair, ICRAF, Nairobi, December 2018.

Where is agroforestry practiced?

Globally, agroforestry is practiced in over 1 billion hectares in developing countries, and to a lesser extent in the industrialized countries (Nair et al 2010, Cole 2018; figure 4.1). Millions of farmers practice agroforestry in East Africa.

Figure 4.1 Agroforestry and its extent



Source: Zomer et al., 2016, presentation of Fergus Sinclair, ICRAF, Nairobi, December 2018.

Which areas of Africa are most suitable for agroforestry?

Various agroforestry systems can be practiced in diverse ecological conditions, and especially in humid tropics (Murthy et al 2013).

How is agroforestry implemented?

There are three main types of agroforestry systems (FAO 2017):

- **Agrisilvicultural** systems are a combination of crops and trees, such as alley cropping or home gardens.
- **Silvopastoral systems** combine forestry and grazing of domesticated animals on pastures, rangelands or on-farm.
- The three elements, namely trees, animals and crops, can be integrated in what are called **agrosylvopastoral** systems and are illustrated by home gardens involving animals as well as scattered trees on croplands used for grazing after harvests.

The common agroforestry practices are described in table 4.2.

Table 4.2 Common agroforestry practices

Practice	Description
Home/kitchen gardens	These are trees planted on home compound or near homesteads. They provide shade, shelter, fruits, fodder, beauty and other products (*Ficus benjamina, Terminalia mentally, Araucaria angustifolia, Cupressus pyramindansis, Ashok),* fruit trees (Mangoes *(Mangifera indica),* avocado *(Persea americana),* cashew nuts *(Anacardium occidentale*), citrus *(Citrus spp),* oranges, lemons, macadamia *(Macadamia tetraphylla), Jackfruits,* mulberry, pawpaws, white supporter, *Annona sps. Syzigium sps.*) and high value medicinal trees (*Neem, Albizia coriara, Moringa oleifera).*
Woodlots	These are trees planted more often than not on the less fertile portion of the farm for firewood and timber production: *Grevillea robusta, Markhamia lutea, Casuarina equissetifolia, Melia volkensii, Prunus africana, Gmelina alborea and Terminalia brownie.*
Improved fallows and rotational fallows	Tree species for improved fallows include: *Gliricidia sepium, Tephrosia vogelii, Tephrosia candida, Calliandra calothyrsus, Leucaena trichandria, Sesbania sesban.*
Trees dispersed on cropland	In this case, multipurpose trees are scattered haphazardly or according to some systematic patterns in the field. Some of the tree species for this technology include: *Faidherbia albida, Tamarindus indica, Melia volkensii* and *Acacia spp*.
Boundary planting, shelter belts and life fences	These comprise trees and shrubs planted along and around the farm for protective purposes or boundary marking. Some of the tree species for this technology include: *Hekea saligna, Markhamia lutea, Melia azadirach, Acacia sps, Jatropha curcas, Croton megalocarpus and Pithlobium dulce.*
Hedgerow planting	This entails growing of food crops between hedgerows of planted shrubs and trees preferably leguminous or fertilizer and fodder trees to

Practice	Description
	fix nitrogen. Some of the species for this technology include: *Gliricidia sepium, Calliandra calothyrsus* and *Leucaena spp.*

Source: see more in Mutua et al 2014.

What needs to be considered in agroforestry?

According to Current et al (1995), to promote agroforestry, there is a need for:

- Knowledge dissemination (e.g. which trees, how to grow),
- Access to resources and financial incentives,
- Economic profitability (short-term and long-term).

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4.2 Social Forestry

What does “social forestry” mean?

CIFOR (2017) defines social forestry or community forestry as “the management of forests by local communities to achieve various environmental, social and development goals, including climate change mitigation and adaptation, food security, nutrition and livelihood support.”

Community forestry is founded on the belief that local residents should play a meaningful role in decisions affecting surrounding forests (Roberts and Gautam 2003).

What are the benefits of social forestry in terms of soil carbon?

Forests play a vital role in combating climate change. Tropical forests cover about 15 percent of the world’s land surface and contain about 25 percent of the carbon on the Earth’s surface. The loss and degradation of forests accounts for 15 - 20 percent of global carbon emissions. The majority of these emissions are the result of deforestation in the tropics (FAO 2016).

In addition to environmental benefits, any kind of forestry has a number of economic and other benefits:

- Employment and income generation from care for forest and use of forest products;
- Timber, fuel, construction material, food, and shade;
- Recreation, better health and thus reduction in health care needs.

Where is social forestry practiced?

Social forestry or community forestry is practiced in: USA, Australia, Canada, and in several countries of Africa, Latin America, South Asia and Southeast Asia.

Which areas of Africa are most suitable for social forestry?

Social forestry projects are most likely to be successful in humid and semi-humid tropics (CIFOR 2017).

How is social forestry implemented?

Social forestry practices, being a sustainable solution to forest depletion, are gaining its popularity. With the support of international community, social forestry projects are successfully implemented in Africa, Southeast Asia and Central and Eastern Europe, (boxes 4.2-3).

Box 4.2 Social forestry in Africa

Social forestry is gaining momentum in Africa as governments consider different measures that can increase tree cover to provide buffer against the increased frequency and intensity of extreme weather events. In 2018, heads of forestry organizations and policy makers from 20 sub-Saharan African countries discussed up scaling social forestry. Social forestry offers cost effective and sustainable solution to forest depletion in many African countries. Capacity development in social forestry is being undertaken by the Japan International Co-operation Agency (JICA)

Source: ICRAF News 2018.

Box 4.3 Social forestry in Southeast Asia (Indonesia, Vietnam, Laos)

Covering 50% of Southeast Asia's land area, forests are crucial in mitigating climate change and enhancing communities' resilience to adverse events. Social forestry has become an important feature of forest management in the region. As efforts to combat climate change get underway, social forestry practices are seen as one way of channeling incentive mechanisms such as REDD+ (Reducing Emissions from Deforestation and Forest Degradation plus enhancing forest carbon stocks).

Source: CIFOR 2017.

The economic viability of social forestry: case of Karnataka in India

The study in Karnataka in India showed that social forestry projects are economically viable and socially desirable. The project reported a high profit with the IRR (internal rate of return) exceeding 16 per cent. If benefits were to fall short by 50 per cent, the project would still report profits with the IRR exceeding 12.5 per cent (Ninan et al 2001).

What is required for promoting social forestry?

CIFOR 2017 identifies three areas for promoting social forestry, such as:

1. Good governance and competing demands for forest products and land,
2. Building on local community realities and knowledge is key to the efficient and effective design of social forestry projects as these correspond to local needs,
3. Financial and policy incentives are required to realize climate mitigation and adaptation synergies.

The key guiding questions for consideration are:

- Who has decision-making authority? (CIFOR 2017),
- Who is involved locally and how they are selected? (CIFOR 2017),
- Who pays and who benefits? (Moeliono et al 2017).

The community forestry projects in Australia adopted the best experiences of similar projects elsewhere (USA, Canada, Scotland, Italy, Nepal, and India). The key points of these experiences are briefly presented in (box 4.4).

Box 4.4 Emerging community forestry in Australia

Community-based forest management is relatively new in Australia. To succeed, community forestry projects adopt the best practices from elsewhere in the world. In brief the identified key principles for success are:

- Holistic approach that addresses the need to balance multiple objectives, including improving rural livelihoods, conserving biodiversity, increasing agricultural production, promoting carbon storage, and increasing provision of multiple ecosystem services, The success of community forestry depends on whether the community forest reflects community values, targets community objectives and delivers community benefits,
- Livelihoods and community engagement are fundamental to success,
- Community forestry initiatives that come from the 'grassroots', rather than being government-led are usually more resilient and successful,
- It is important to develop the best practices and guidelines to enable diverse and improved modes of reforestation to be applied at a landscape scale (social and natural sciences as well as practical issues).
- Best practices and guidelines are critical for encouraging secure investments in restoration.
- At a project level, there is a need for appropriate project design, adequate social preparedness, strong and honest leadership, transparency in handling funds, sustainable livelihood and food security measures, adequate institutional arrangements and supportive policies, security of land tenure, support from extension workers, monitoring and evaluation, women's participation and inclusion.

Source: Agarwal 2001, Roberts and Gautam 2003, CIFOR 2017.

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4.3 Plantation Management

What does "plantation" mean?

A plantation is the large-scale estate meant for farming that specializes in cash crops, such as cotton, coffee, tea, cocoa, sugar cane, sisal, oil seeds, oil palms, and rubber trees, rather than staple crops.

Forest plantations are defined as "forest crops raised artificially either by sowing or planting", which are in general areas in which the naturally occurring tree species have been totally replaced by planted trees" (Poore 2009)**.** There are trends of developing plantations in forest margins, which cause degradation of natural forests.

"Plantations/estates are large, self-contained agribusiness farms that are vertically integrated into value chains" taking inputs from local markets but not sufficiently contributing to local economies (Hall et al 2017).

Where are plantations located?

Some of the largest plantations are coffee plantation in Brazil, Paraguay and Bolivia, Tanzania, Kenya; sugarcane plantation in Cuba, Brazil, Peru, Puerto Rico and Philippines; tea plantation in India, Sri Lanka, Indonesia; cocoa farming in West Indies, Ecuador, Brazil, Nigeria, Ghana; rubber plantation in Malaysia, Indonesia, Thailand, Sri Lanka, Cambodia, Myanmar, India; banana plantation in Mexico, Jamaica, Columbia, Brazil, Panama and Costa Rico.

As regards forest plantations, the expansion of forest plantations has been greatest in the southern hemisphere: in South America (principally Argentina, Chile and Brazil), Asia (principally Indonesia) and New Zealand (Kanowski 1997).

Which areas of Africa are most suitable for plantations?

Areas in humid tropics which are unfit for agriculture could be converted into plantations for biomass production purpose so that extra amount of carbon is sequestrated in order to mitigate climate change (Karoshi and Nadagoudar 2012). However, plantations should not encroach or degrade natural forests.

Benefits of forest plantations

The tropical natural forests are recognized as having the greatest long term potential to sequester atmospheric carbon. However, the existing forest may not be sufficient to maintain ecological balance. Therefore, growing plantations for environmental needs is important. Forest plantations positively contribute to CO_2 sequestration, environmental protection or rehabilitation. Smart forest plantations may also improve livelihoods and provide recreational opportunities (Karoshi and Nadagoudar 2012).

Some 90% of forest plantations have been established to provide wood. Forest plantations provide minimum 10% of the world's wood harvest, thus replacing the need to cut natural forests. Furthermore, some plantation forests are established for non-wood products such as essential oils, tannins, or fodder (Kanowski 1997).

The relative benefits and costs of plantation forestry in broader environmental terms, and in terms of its social impacts, are the subject of greater controversy and debate (Kanowski 1997). Nonetheless, forest plantations do positively contribute to carbon sequestration.

Problems with existing plantations

Plantations are the legacy of colonialism. More recently, there has been an increase in plantations in Africa that mimic large colonial estates and state farms. The new plantations are established on the same sites as former state farms and colonial estates as well as in the regions where they have not previously existed (e.g. as it has happened in Ghana) and not necessarily on unutilized land, resulting in land grab and displacement of local communities (Hall et al 2017).

While plantations may achieve improved productivity, they provide very small income through wages (without possibility for accumulation) to local communities and have limited interaction with the local economy. Plantations are "enclave economies' that source inputs (including labor) in local markets and sell the outputs into foreign or national rather than local markets (Ferguson 2006, cited in Hall et al 2017). Thus, existing plantations do not contribute to diversified livelihoods and growth of rural economies; plantations rather deprive local communities of their access to land.

Natural forest may be cut to grow plantations (e.g. as it has happened in Indonesia). Plantations established purely for the production of timber provide a much narrower range of services than the original natural forest for the local people. To improve this situation, smaller plantations are owned by local farmers in India, who then sell their wood to larger companies.

Although few plantations are strict monocultures, it is not only the number of species, but also the identities and relative abundances of species that are of ecological importance. Furthermore, Plantations lack decaying dead wood, which is crucial for natural forest ecosystem; thus new practices of managing plantations are needed (Betts et al 2005).

How to manage plantations in a sustainable way?

1. Need for smart plantations

Existing plantation systems do not necessarily address well the other needs of societies in which they are embedded. A broader conception of plantation forestry and range of plantation objectives are needed, with: a) direct involvement and sharing of the benefits with local people, and especially women; and b) diverse species composition (Hall et al 2017):

2. Smart plantations protect from land grab

A plantation needs large areas of land. It results in the removal of former residents, known as "land grab" (Jacovelli 2014, Hall et al 2017). For example, in Ghana, in the area surrounding the commercial mango farming area, people experienced the most severely constrained access to land, due to the land consolidation involved in the establishment of the medium-scale commercial farms. Likewise, in Zambia, land conflicts were highest around the Magobbo sugar out-grower scheme (Hall et al 2017). Smart plantations address people's needs.

3. Carbon sink performance

Plantations can be an important means to cease any more increase of CO2 in the atmosphere. Carbon sink performance depends on various factors, such as ecological suitability, choice of plant species and management factors.

NPP (net primary productivity) is an important parameter in many forestry models that are used to assess the future mitigation potential of the sector. NPP is defined as the balance between carbon gain through photosynthesis (gross primary productivity, GPP) and losses through autotrophic respiration (Ra). It represents the net carbon uptake from the atmosphere into vegetation. The variation in NPP values within the species is due to factors like altitudinal range, rainfall amount and pattern, and soil factors. Therefore, for optimum NPP, the ecological suitability of species is to be considered (Karoshi and Nadagoudar 2012).

The research shows, that the highest average NPP is recorded in case of *Bamboo* (17.523) followed by rubber (15.970), oil palm (14.500) (*Samanea and Erythrina* (13.350), Coconut (12.150), *Cassia* (10.350), *Eucalyptus* (10.009), *Alnus* (10.000), *Sesbania* (9.433), *Prunus* (9.000), *Leucaena* (8.739), *Acacia* (9.000) and *Casuarinas* (7.550) (see more in Karoshi and Nadagoudar 2012).

The NPP value varies with in the species due to management practices. Management aspect like weeding, fertilization, and application of insecticides is very important in carbon sequestration through forestry projects (Karoshi and Nadagoudar 2012).

4. **Diversity is important for environment**

Most dominating plantation species are: *Acacia, Eucalyptus, Picea* and *Pinus*; and a few others: eg *Araucaria, Gmelina, Larix, Paraserianthes, Populus, Pseudotsuga* or *Tectona*. A mosaic of relatively small blocks of different tree species is more useful and environmentally beneficial (FAO 2017).

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Module Five: Pasture Management and Cover Crops

Objectives

This module is about pastures and cover crops and how these practices relate to soil carbon. The module also discusses how to manage pastures and cover crops and what needs to be considered in the deployment of these approaches.

5.1 Pasture Management

What does “pasture” mean?

Pasture (from the Latin *pascere*, "to feed") is land covered with grass and other plants (e.g. legumes, forbs), which are suitable for grazing animals.

What are the benefits of pasture management in terms of soil carbon?

Healthy, diverse pastures are natural ‘carbon sinks’. The basic principles of healthy pastures that sequester carbon and improve soil fertility are based on:

a) Planting a diversity of native grasses or well-adapted perennial grasses and legumes which eliminate the need for synthetic fertilizers;

b) Using a rotational grazing system. Overgrazing reduces carbon sequestration and productivity. Stocking density and rotation time depend on the season, the weather and the soil health (White 2014; GWA 2018).

Where do farmers manage pastures well?

In many countries, e.g. in USA, Australia, and South Africa.

Which areas of Africa are most suitable for pastures?

To successfully grow annual and perennial pastures, it is important to consider the influence of factors such as soil, climate, pests and grazing. A wide range of grasses and legumes are available for rain-fed (e.g. tropics) and irrigated production systems (semi-arid zones) (GWA 2018).

How to manage pastures well?

An efficient grazing system uses the appropriate mix of grass or legume species for pasture, manages stocking rates, encourages more uniform use of paddocks, and adjusts the timing of grazing (World Bank 2012). The key elements of well-managed pastures are summarized in box 5.1 and table 5.1 below.

Box 5.1 Livestock integration in conservation agriculture system

It is a common practice for small-scale farmers in tropical countries to practice both crop and livestock production from the same farm. In this case, there is a need to include complementary livestock feeding strategies, such as:

-Establishment of plots of permanent forages for direct grazing or for cut-and-carry.

-Controlling the grazing time permitted in a given area, e.g. 15 days per month.

-Reduction of herd size by culling out/destocking some animals to ensure the right density as per resources available.

-Temporary displacement of animals to other areas especially among pastoralist communities.

-On steep land, the use of living contour erosion barriers consisting of grasses and/or palatable leguminous trees.

-Biomass transfer involving cutting, carrying and spreading bushy vegetation to make mulch.

-Conserving forage from periods of surplus to periods of deficit.

-Practicing zero grazing and cut-and-carry, though it demands more labor.

Source: Mutua et al 2014.

Table 5.1 Key elements of well-managed pastures

Elements	Description
Proper soil health and fertility	This ensures a good growth environment for pasture species, both forage and legume.
Manure	Manure can help to improve and maintain soil fertility by providing needed nutrients, (N, P, and K) and organic matter. These nutrients will help promote growth of grasses and legumes while organic matter from manure will help to provide soil structure, protection against erosion and improve natural soil fertility.
Appropriate grass and legume	Choosing the appropriate grass and legume species will help optimize forage management and pasture growth.
Pasture rotation	Pasture rotation is also practiced in order to optimize plant growth and utilization by grazing vegetation at the proper heights and allowing for proper rest and regrowth.
Sacrifice areas	These areas are designated locations for feeding, watering, exercise and relaxation for times when pastures are not accessible due to lack of growth. Generally, these areas have little or no vegetation. It is important that manure not be spread in these areas. They are meant to be sacrificed for animal activities in order to protect the remaining pastures. Runoff from sacrifice areas should also be managed to reduce the risk of water pollution.
Managing erosion	Erosion problems on small farms are often different than large farms. On large farms, most erosion may be sheet or rill erosion running off large fields. On smaller farms, erosion may more often be a gully where animals cross a stream. Or it could be poorly vegetated pastures that provide poor ground cover during precipitation. Fencing, watering and feeding sites, presence or absence of field buffers, and stream crossings can all influence erosion on a small livestock farm.

Elements	Description
Riparian areas	Grazing animals on pasture need to be supplied with adequate water for drinking. Livestock on pasture will tend to congregate near or in riparian areas that have greater access to shade and water. The management and design of these riparian areas is critical for maintaining a proper pasture grazing environment with adequate feed and water availability and promoting optimal environmental quality.

Source: Extension organization 2015.

What needs to be considered?

The keys to success in pasture management are much more than grazing. The success requires adequate institutional arrangements and supportive policies, access to required resources and knowledge and acceptance of new ways of doing by farmers (box 5.2).

Box 5.2 Improving pasture management in Ethiopia and Somali

Over the last ten years, the Horn of Africa has faced seven major drought events. Estimates indicate that during the 2016/2017 drought, over 2 million livestock were lost in Ethiopia's Somali region alone. In these areas, cattle milk production decreased by as much as 80 percent. During the past two decades, FAO and its partners have conducted Pastoralist Field Schools (PFS) in Kenya and Ethiopia to address this challenging context.

Pastoralists learned how to:

- Establish and manage pasture (e.g. fencing, chisel ploughing, weeding, irrigation systems);
- Harvest and store pasture seed;
- Harvest (e.g. harvesting time and practices), bale and conserve hay; and
- Identify new sources of income (e.g. through the sale of seed and hay).

However, the success of the pastoralists was limited by:

- Unreliable weather conditions/patterns;
- Unavailability of certified pasture seed,
- Skepticism among community members that grass can also be grown;
- Scarcity of labor, farm machinery and other inputs (e.g. fencing material, quality seeds);
- Cultural barriers in addressing problems through collective and joint effort across gender and social divides;
- Perceptions restricting uptake of new practices (e.g. some communities do not support the practice of cut and carry but favor animals grazing on the pastures).

While little can be done about weather conditions, a lot can be done to improve pasture management through knowledge dissemination and improved access to seeds and other inputs.

Source: FAO 2017.

Further reading

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5.2 Use of Cover Crops

What does "cover crop" mean?

A cover crop is a crop of a specific plant that is grown primarily for the benefit of the soil rather than the crop yield. The main types of soil cover are (Mutua et al 2014):

- A range of living plant material which provide dense ground cover such as cowpeas, beans, soybeans, *Dolichos lablab, Mucuna* and also aerial ground cover provided by trees.
- Mulch or dead plant materials which include crop residues and pruning from trees and shrubs.
- Crop Residue (CR), the fibrous by-products that result from the cultivation of cereals, pulses, oil plants, roots and tubers.
- A range of tree species (crop friendly) which provide shade, soil cover and biomass.

It is important to distinguish between weed and good vegetation cover (Mutua et al 2014).

Characteristics of a good cover crop

- Grows quickly providing ground cover to protect the soil from direct sunlight and prevent erosion,
- Produces heavy leaf biomass,
- Aggressive enough to compete with weeds and has multiple uses such as being suitable for human food and as animal feed,
- Has multiple uses e.g., edible seed for humans, animal feed, and
- Fixes Nitrogen in the soil.

Some examples of the good cover crops are:

- *Dolichos lablab, Pigeon peas, Mucuna, Canavalia, Stylosanthes*; in semi-arid areas: *Vetches, Lupins,* peas, black oats, and wheat,
- Legumes as a cover crop, which is also a green manure.

Characteristics of weeds

Weed seeds can remain dormant in the soil for a long period, e.g. up to 20 years. Most weeds are capable of reproducing through seeds and stem parts. They also have high genetic diversity. Thus, they have a high level of adaptability to a wide range of conditions.

Weeds can be controlled through cultural methods (e.g. crop rotation, mulches); physical control and chemical control (see more in the manual by Mutua et al 2014).

What are the benefits of cover crops?

The research of Mutua et al 2014 shows that good soil cover is very important because:

- It protects the soil from erosion agents such as wind and water,

- It helps in suppressing weeds by smothering their growth and reducing the number of weed seeds, hence, reducing labor requirements for weeding,
- It increases the soil fertility and the organic matter content of the soil. When leguminous cover crop such as *Dolichos* and *Mucuna* are used, they add nitrogen to the soil,
- It increases soil moisture by allowing more water to sink into the ground and reduces evaporation,
- It stimulates development of plant roots, which in turn improves soil structure, allowing more water to infiltrate into the soil reducing the amount that runs off
- Decomposing vegetation and the roots of cover crops improves the soil structure and make the clumps and lumps in the soil more stable therefore making them harder to break and wash away,
- Soil organisms, earthworms and microorganisms can prosper in the soil cover as well as in the soil.

Box 5.3 Use of cover crops in Spain

The research in semi-arid agricultural environments in the vineyards of Spain has revealed that vegetation cover treatments increased SOC (soil organic carbon) by 1.2% and intra-pedal SOC by 10-60% compared with tillage. The study concluded that there are considerable benefits of using cover crops in rain-fed areas. For example, cover crops in vineyards do not only prevent soil erosion, but also improve soil fertility and reduce the heavy reliance on industrial fertilizers.

Source: Ruiz-Colmenero et al 2013.

Box 5.4 Use of cover crops in Benin

The use of cover crops is not new in Benin. In 1996, the International Development Research Centre of Canada (IDRC), Sasakawa Global and the International Institute of Tropical Agriculture (IITA), and the Ministry of Rural Development in Benin held the workshop bringing together more than 60 people to discuss the constraints and opportunities presented by cover crops in West Africa. The objectives were defined as: information exchange by farmers, identification of major constraints in adopting the practice of cover crops and setting the priorities for action.

After the workshop and demonstration visits to farmers who already make use of cover crops, a facilitation center was established in Cotonou. He center provided information and seeds. The field visits and presentations showed the wide adoption of *Mucuna-fallow* practices in Benin was due to *Mucuna's* dual impacts on soil fertility and weeds. Even farmers with very small land holdings opted to dedicate some of their field to a *Mucuna* fallow, often the most weed-infested portion, with a view to improving it for the following season.

Source: Canada's International Development Research Centre (IDRC) 2000.

Which areas of Africa are most suitable for cover crops?

Semi-arid and rain-fed areas are most favorable areas for having cover crops. However, cover crops aren't suitable everywhere, e.g. in some areas in the tropics that are already double-cropped (Nature4Climate 2018).

How to achieve maximum soil cover?

The aim is to have a protective layer above the soil surface. This is done by inclusion of live cover crops such as *Dolichos lablab, Mucuna,* sweet potatoes and cow peas or spreading of dead vegetative material, mainly from crop residue. Agroforestry tree species can also be used to provide aerial soil cover (Nature4Climate 2018).

What needs to be considered?

To promote the practice of improving vegetation cover, there is a need for:

- Knowledge dissemination;
- Supportive policies;
- Incentives; and
- Access to and affordability of seeds (WLE 2014, Nature4Climate 2018).

Further reading

Mutua, J., Muriuki, J., Gachie, P., Bourne, M. and Capis, J. (2014) Conservation agriculture with trees: principles and practice: a simplified guide for extension staff and farmers. Technical Manual No. 21. World Agroforestry Centre, (ICRAF) Nairobi, Kenya. Available online: http://www.worldagroforestry.org/downloads/Publications/PDFS/TM17693.pdf [accessed Nov 12 2018].

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Module Six: Cross-Slope Barriers

Objectives

This module is about crops-slope barriers. The module explains the benefits of cross-slope barriers and their potential to sequester carbon. It also discusses how and where to practice cross-slope barriers, the costs of establishment and maintenance of cross-slope barriers, and the key considerations for deployment of this technology.

What does "a cross-slope barrier" mean?

Cross-slope barriers are measures on sloping lands in the form of earth or soil bunds, stone lines, and/or vegetative strips for reducing runoff velocity and soil loss, thereby contributing to soil, water and nutrient conservation. This is achieved by reducing steepness and/or length of slope (FAO 2011).

What are the benefits of cross-slope barriers?

Cross-slope barriers have production, economic, ecological, and socio-cultural benefits (table 6.1 box 6.1).

Table 6.1 Benefits of cross-slope barriers

Benefit	Land users/community level	Watershed/landscape level	National/Global level
Production	Increased crop yield (long term) Increased grass/fodder production	Reduced risk and loss of production Access to clean drinking water	Improved food and water security
Economic	Increased farm income (long term)	Less damage to off-site infrastructure Stimulation of economic growth	Improved livelihood and well-being
Ecological	Reduced soil loss (mainly in sub humid areas) Increased soil moisture (mainly in semi-arid areas) reduced soil erosion (by wind/water) Increased infiltration rates Decrease in runoff velocity and control of dispersed runoff	Reduced degradation and sedimentation Improved water quality Increased water availability Intact ecosystem	Increased resilience to climate change Reduced degradation and desertification incidence and intensity Enhanced biodiversity

Benefit	Land users/community level	Watershed/landscape level	National/Global level
	Improved soil cover Increase in soil fertility (long term) Biodiversity enhancement Improved micro-climate		
Socio-cultural	Improved conservation/erosion knowledge Community institution strengthening	Increased awareness of environmental "health" Attractive landscape	Protecting national heritage

Source: FAO 2011.

Box 6.1 Cross-slope barriers increase crop yields in Tanzania

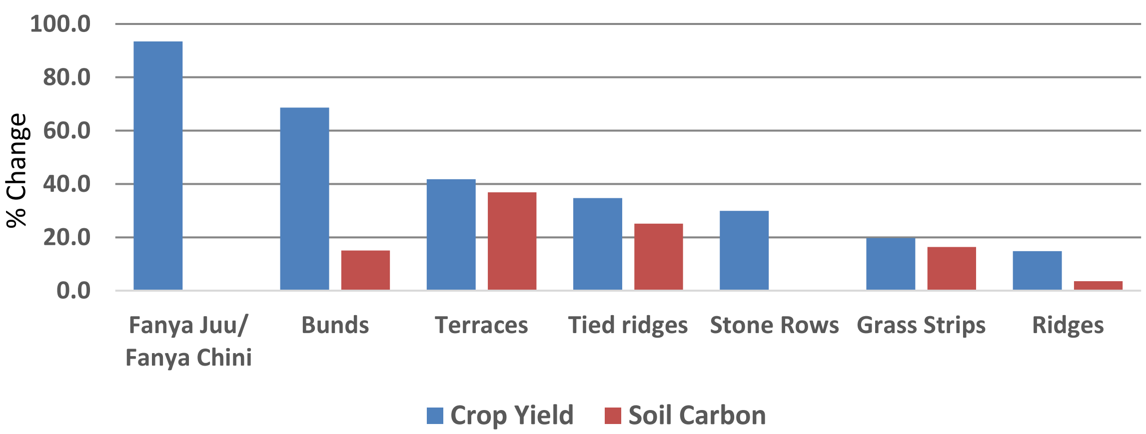
A study in the West Usambara Highlands in Tanzania has shown significant increase in the crop yield for maize and beans by implementing bench terraces, *fanya juu* or grass strips. However, the results clearly showed that cross-slope barriers alone may not significantly increase crop yields unless these are followed by other practices such as manure and fertilizer.

Grass strips and/or the introduction of grass on the risers, can lead to an additional increase in yield which can be either used as fodder for livestock or it can be sold.

Source: Tenge et al 2005, cited in FAO 2011.

Cross-slope barriers have a high climate-change mitigation potential, due to their capacity to sequester carbon (FAO 2011; figure 6.1, table 6.2).

Figure 6.1 Benefits of cross-slope barriers: soil carbon and crop yield



Source: Climate-smart Agriculture Compendium, Rosenstock, Lamanna et al, in presentation of Dr. Christine Lamanna, ICRAF, Nairobi, December 2018.

Table 6.2 Cross-slope barriers: climate-change mitigation potential

Climate change mitigation	Potential
Potential for C sequestration (tonnes/ha/year)	0.5-1.0 tonnes/ha/year
C Sequestration: above ground	+
C Sequestration: below ground	+

Source: FAO 2011; based on expert estimation for duration of the first 10-20 years of changed land use management.

Cross-slope barriers also have a high climate-change adaptation potential (table 6.3).

Table 6.3 Cross-slope barriers: climate-change adaptation potential

Climate change adaptation	Potential
Resilience to extreme dry conditions	++
Resilience to variable rainfall	+
Resilience to extreme rain and wind storms	+
Resilience to rising temperature and evaporation rates	+
Reducing risk and production failure	+

Source: FAO 2011.

Where do farmers practice cross-slope barriers?

Terracing steep lands in Africa is an indigenous technology. Under colonial regimes, large areas of communal lands were compulsorily terraced in the 1950s (e.g. in Kenya, Malawi and Zambia) through the construction of ridges or bunds. Rejected after independence, the techniques made a come-back in the 1970s (FAO 2011; table 6.4).

Table 6.4 Practice of cross-slope barriers

Type	Where Common	Suitable slopes
Terracing	Steep areas	Moderate to Very Steep
Stone Lines	West Africa, stony areas	Gentle to Steep Slope
Earth Bunds/Ridges	Semi-arid areas	Gentle to Moderate Slope
Fanya Juu/Fanya Chini	East Africa	Moderate to Steep Slope
Vegetative Strips	Humid areas	Gentle to Steep Slope

Source: Presentation of Mary Njenga et al, ICRAF, Nairobi, December 2018.

Fanya juu terraces, first developed in the 1950s, and are currently spreading throughout East Africa. The period of rapid spread occurred during the 1970s to 1980s with the advent of the National SWC (Soil and Water Conservation) Program in Kenya. In the West African Sahel, contour stone lines (and vegetative barriers) have been promoted successfully since the 1980s, as water harvesting structures.

Cross-slope barriers are also practiced in Thailand and Vietnam to reduce soil erosion on sloping land.

Which areas of Africa are most suitable for cross-slope barriers?

FAO (2011) identifies four considerations for assessing the suitability of establishment of cross-slope barriers (table 6.5).

Table 6.5 Considerations for establishment of cross-slope barriers

Consideration	Detail
Terrain and landscape	Cross-slope barriers are applicable from gentle to steep slopes. ➢ Bench terraces: moderate to very steep slopes; ➢ Earth bunds: gentle to moderate slopes; ➢ Stone bunds: gentle to steep slopes; ➢ *Fanya juu* terraces: moderate to steep slopes (up to 50%); ➢ *Fanya chini* terraces: moderate to hilly slopes (up to 35%); ➢ Vegetative strips: gentle to steep slopes.
Climate	Cross-slope barriers are suitable for the whole range of arid to humid areas. They are mainly located in sub-humid and semi-arid, partly in humid and arid areas. In sub-humid to humid areas, cross-slope barriers are mainly used for protection against soil erosion, whereas in semi-arid areas, these are mainly used for water conservation purposes; Terraces and vegetative strips can, to a certain extent, cope with extreme rainfall events. **Earth bunds** are not suitable for very wet areas unless graded;

Consideration	Detail
	Vegetative strips are most effective in moist areas and least effective in dry areas; ***Fanya juu* terraces** are not suitable in dry areas unless used for rainwater harvesting
Soils	Not suitable for very shallow and sandy soils – bench terraces must not be built on shallow soils (to avoid risk of landslides).
Land use	Mainly on annual cropland and / or partly on mixed land with tree and shrub cropping. Partly on intensive grazing fodder production: rarely on grazing land.

Source: FAO 2011.

How to establish cross-slope barriers?

Table 6.6 provides details on how to establish different types of cross-slope barriers.

Table 6.6 Specifics of cross-slope barriers

Type of cross-slope barrier	Description
Bench terraces	Bench are commonly developed on steep slopes as a result of constructing cross-slope barriers, and then erosion (water and tillage) progressively causing the bed to level. A bench terrace is defined by a flat or slightly backward or forward-sloping bed. Stone-faced terrace risers are characteristic of areas where stone is available (e.g. the Konso terraces in Ethiopia), otherwise the earth risers are protected by grass. Due to the heavy labor input they are usually constructed to support production of high-value crops such as irrigated vegetables and coffee. Bench terraces are rarely excavated and constructed directly, as this is very expensive.
Earth bunds	Earth bunds (or 'ridges') are soil conservation structures that involve construction of an earthen bund along the contour by excavating a channel and creating a small ridge on the downhill side. Usually the earth used to build the bund is taken from both above and below the structure. They are often reinforced by vegetative cover to stabilize the construction. Bunds are gradually built up by annual maintenance and adding soil to the bund.
Fanya juu	*Fanya juu* ('do upwards' in Kiswahili) terraces are made by digging ditches and trenches along the contour and throwing the soil uphill to form an embankment. A small ledge or 'berm' is left between the ditch and the bund to prevent soil sliding back. In semi-arid areas they are normally constructed to harvest and conserve rainfall, whereas in sub-humid zones they may be laterally graded to safely discharge excess runoff. The embankments (risers) are often stabilized with fodder grasses.
Fanya chini	In a *Fanya chini* system ('do downwards' in Kiswahili) soil is piled below a contour trench. These are used to conserve soil and divert water and can be used up to a slope of 35%. *Fanya chini* involve less labor than *Fanya juu*, but they do not lead to the formation of a bench terrace over time as quickly as the former.
Stone lines and bunds	In areas where stones are plentiful, stone lines are used to create bunds either as a soil conservation measure (on slopes) or for rainwater harvesting (on plains in

Type of cross-slope barrier	Description
	semi-arid regions). Stones are arranged in lines across the slope to form walls. Where these are used for rainwater harvesting, the permeable walls slow down the runoff, filter it, and spread the water over the field, thus enhancing water infiltration and reducing soil erosion. Furthermore, the lines trap fertile soil sediment from the external catchment.
Vegetative strips	Vegetative strips are the least costly or labor-demanding type of cross-slope barriers. Such strips are a popular and easy way to terrace land, especially in areas with relatively good rainfall. The spacing of the strips depends on the slope of the land. On gentle sloping land, the strips are given a wide spacing (20-30 m), while on steep land the spacing may be as little as 10-15 m. Vegetative strips can also provide fodder for livestock if palatable varieties of grass (or densely spaced bushes) are used.

Source: FAO 2011.

Costs and benefits of cross-slope barriers

Table 6.7 presents the establishment and maintenance costs of three types of cross-slope barriers, such as terraces, *fanya juu,* and vegetative strips; and table 6.8 illustrates the production benefits.

Table 6.7 Establishment and maintenance costs of cross-slope barriers

Item	**Establishment costs (USD/ha)**			**Maintenance costs (USD/ha)**		
Costs	Terraces	*Fanya Juu*	Veg.strips	Terraces	*Fanya Juu*	Veg.strips
Labor Cost Pdays*	High	High	Medium-high	Medium	Low	Low
	150-1200 150-600	40-600 40-300	7-80 7-40	10-300 10-150	10-60 10-30	0-30 0-15
Equipment	Low-medium	Low-medium	Low	Low	low	Low
	10-50	20-60	10-50	0-20	0-10	0-10
Material inputs	Medium-high	Low-medium	Medium	Low	Low	Low
	50-300	10-80	20-100	0-50	0-15	0-10
Total	**210-1350**	**70-740**	**37-230**	**10-370**	**10-85**	**0-50**

Source: FAO 2011, *USD 1-2 per day.

Table 6.8 Production benefits

Crop, location	Yield without SLM (t/ha)	Yield with SLM (t/ha)	Yield gain
Maize, Kenya	2.1-3.4	2.3-3.7 (grass strips) 3.1 – 4.5 (*fanya juu*)	10-45%
Beans, Tanzania	1.5-1.8	2 (grass strips) 2.8 (*fanya juu*) 2.1 – 2.7 (bench terraces)	10-85%
Sorghum, Ethiopia 15% slope 25% slope 35% slope	Non-terraced 0.96 0.67 0,43	Terraced (stone bunds) 2.18 1.83 1.7	127% 173% 197%

Source: Mwangi et al 2001, Tenge et al 2005m Alemayehu et al 2006, cited FAO 2011.

The short-term benefit-cost ratio for different types of cross-slope barriers is not the same (table 6.9). And it can take up to two years until the barriers lead to a positive return (FAO 2011).

Table 6.9 Benefit-Cost Ratio (BCR) of cross-slope barriers

Type	Short term	Long term	Quantitative
Bench terraces	--	++	Internal rate of return, Tanzania 19%
Bunds	-	++	
Stone lines	-	++	
Fanya juu	-	++	14%
Veg.stips	+/-	++	6%
Overall	-	++	

--negative, -/+ neutral, +slightly positive, ++positive

Source: Tenge et al 2005 and WOCAT 2009, cited in FAO 2011.

Vegetation barriers with local grasses tend to have the lowest establishment costs (box 6.2).

Box 6.2 Low-cost cross-slope barriers in Burkina Faso

The analysis of different structural conservation measures in Burkina Faso has shown that:

- The construction of **stone lines** generally leads to the highest establishment costs (140-400 US$/ha),
- The construction of **earth bunds** is slightly cheaper (95-200 US$/ha), whereas
- **Vegetation barriers** show relatively low establishment costs if local grasses are used (approx. 60-70 US$/ha) (Spaan, 2003, cited in FAO 2011).

Source: Spaan 2003, cited in FAO 2011.

What needs to be considered?

There are five factors that need to be considered for establishment of cross-slope barriers (FAO 2011).

1. **Farming system and level of mechanization**

Mainly animal traction (oxen, with plough) and manual labor (hand tools, on steeper slopes where oxen cannot be used), very often a combination of animal traction and manual labor; only partly mechanized (e.g. for transportation of stones).

2. **Land tenure and land use/water rights**

Secure individual land use rights are needed, otherwise the land users are not willing to invest in structural conservation measures. Land tenure is often formally state- or communal-(village) property and individually not-titled.

3. **Skill/knowledge requirements**

A high level of know-how is required for the establishment and the maintenance of terraces and bunds.

4. **Market orientation**

Mainly subsistence (self-supply), partly mixed and partly commercial/market.

5. **Labor requirements**

- ➢ The establishment of terraces and bunds requires high input; sometimes outside labor needs to be hired for the construction of the terraces or the bunds.
- ➢ *Fanya juu* terraces are associated with hand construction, and are well suited to small-scale farms. In Kenya they are often established through self-help groups.
- ➢ Maintenance can usually be done by individuals and is very important for all kind of terraces and bunds.

Table 6.10 summarizes the constraints and solutions to adopting cross-slope barriers.

Table 6.10 Cross-slope barriers: constraints and solutions

Constraint	How to overcome
<u>Production constraint</u> Loss of land for production due to risers of terraces, ditches for *Fanya juu/chini*, vegetative strips. The construction can easily be damaged by cattle interference. Planting vegetative strips fails in the period with highest agricultural activity. If not adequately managed soil and water conservation function can be lost or can even be accelerated. Competition for water and nutrients in the case of vegetative barriers.	Integrating and incorporating vegetative measures in the system, widen the spacing between bunds, make bund area productive (e.g. grass on terraces for livestock), increase productivity of fodder trees on bunds. Controlled grazing, management of the terraces. Need for capacity building and training for appropriate management.
<u>Economic Constraint</u> High investment costs, usually exceeding short term benefits. Shortage of labor, especially for the construction, very high labor input is needed. Some cross-slope barriers can also lead to high maintenance requirement, e.g. soil bunds. Shortage of construction material and hand tools. Lack of market infrastructure.	Credits and financial incentives for initial investments should be easily accessible to land users. Establishment with labor-sharing groups, financial incentives to credit facilities or phasing the establishment over several years to overcome. For maintenance less support is needed but land users should be organized (individually or in groups) to undertake maintenance and repairs.
<u>Ecological Constraint</u> Possible water-logging before bund/embankment. Uneven flood water distribution, breakages of terraces. Rodent and other pests hiding in the vegetation. Competition of veg. strips + bunds with crop. Unprotected bunds, which have not been planted with grass, are prone to erosion.	Addition measures such as vegetation/mulch cover. Maintenance and adjustments of the barriers. Provision of appropriate measures, provision of rodent and pest controlling mechanisms. Trimming of vegetation during crop growing period.
<u>Socio-cultural constraint</u> Often traditional system, but not properly maintained, especially when population move away from rural areas.	Incentives for “renovation” of traditional structures (e.g. Konso terraces in Ethiopia).

Source: FAO 2011.

To promote the adoption of cross slope barriers, FAO (2011) identifies the need for the following measures:

- **Awareness:** Land users need to recognize the multiple resource losses due to runoff and erosion on sloping land.

- **Clear land use rights** are needed for investments to be made in structural measures.
- **Access to knowledge** must be ensured for land users; training of land users is essential to establish knowledge and technical skill about appropriate establishment and also maintenance.
- **Micro-credit for financial investments:** The self-financing capacity of farmers needs to be strengthened and credits must be easily accessible also for small-scale land users.
- **Access to material inputs and markets** is necessary for establishment of cross-slope barriers.

Possible options for incentives to construct cross-slope barriers can be transport facilities for stones (for example) or subsidies on inputs such as seedlings for the vegetative strips. Payment for ecosystem services (PES) is another incentive that specifically addresses the benefits of downstream users.

Further reading

FAO (2011) Sustainable land management in practice: cross-slope barriers: 114-119. Available online: http://www.fao.org/docrep/014/i1861e/i1861e07.pdf [accessed Nov 15 2018].

Module Seven: Mulching, Green Manuring and Managing Agricultural Waste

Objectives

This module is about mulching, green manuring and managing agricultural waste in a sustainable way. The module comprises six sections. Next section introduces four practices, such as managing crop residues, green manure, tree residues and animal waste for carbon sequestration and productivity. Thereafter, each section focuses on each practice in detail, explaining how to implement these practices and what to consider implementing them. Last section provides general information on managing agricultural waste and the links to more detailed manuals.

7.1 On-Farm Sources of Organic Carbon

There are four on-farm sources of organic carbon, such as crop residues, green manure, tree residues and animal waste (picture 7.1).

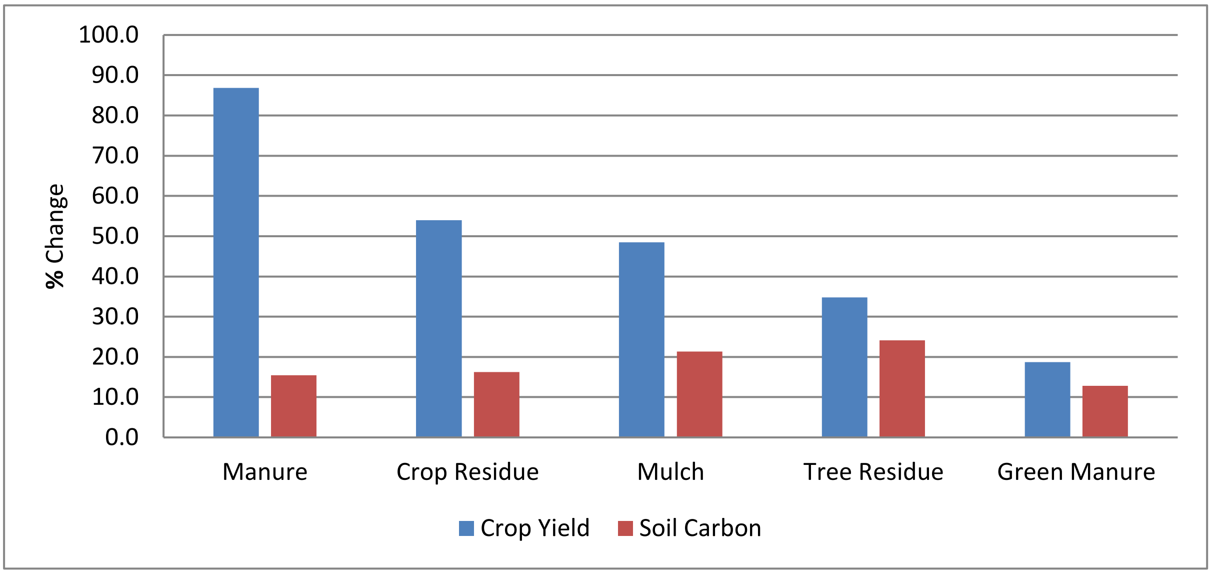
Picture 7.1 Agricultural residues

All crops produce residue: the non-edible or non-marketable portion of the growth.

Source: Presentation of Dr. Christine Lamanna, ICRAF, Nairobi, December 2018.

These on-farm sources of organic carbon not only benefit carbon sequestration, but also improve yields (figure 7.1).

Figure 7.1 On-farm sources of organic carbon



Source: Presentation of Dr. Christine Lamanna, ICRAF, Nairobi, December 2018.

7.2 Mulching of Crop Residues and Residue Incorporation

What does "mulching" mean?

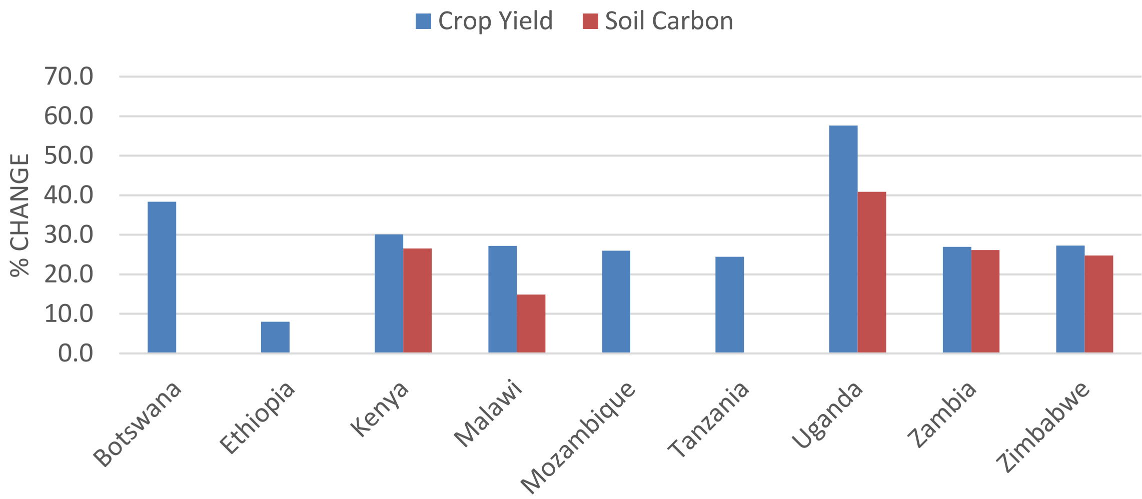
Mulching of crop residues is a process of using crop residues to cover bare soil on the farm. Mulching returns organic materials and nutrients to the soil (Government of Australia 2007).

Agriculture with mulch in the tropics promotes plant health. Mulching improves nutrient and water retention in the soil, encourages favorable soil microbial activity and worms, and suppresses weed growth. When properly executed, mulching can significantly improve the well-being of plants and reduce maintenance as compared to bare soil culture. Mulched plants have improved resistance to pests and diseases.

What are the advantages and disadvantages of mulching?

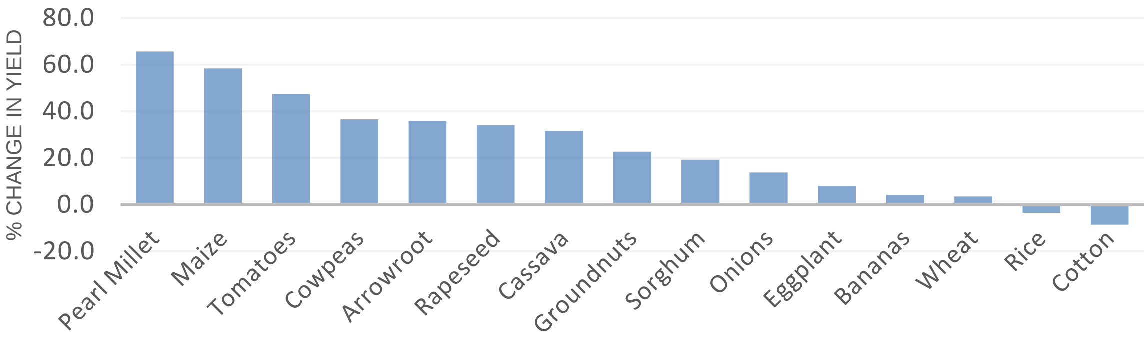
- Mulching with crop residues is one of the most sustainable approaches in sequestering carbon (figure 7.2),
- Soil mulching significantly enhances yields and water and nitrogen use efficiencies (Qin et al 2015; figure 7.3),
- Minimizing weed competition and improving soil structure,
- Economic benefits of mulching: reduces cost of farming in dry lands, reduces water costs, reduces cost of weeding, and improves fertilizer use efficiency (Olila 2015):

Figure 7.2 Benefits of mulching by African countries: soil carbon



Source: Climate-smart Agriculture Compendium, Rosenstock, Lamanna et al, in presentation of Dr. Christine Lamanna, ICRAF, Nairobi, December 2018.

Figure 7.3 Benefits of Mulching: crop yield



Source: Climate-smart Agriculture Compendium, Rosenstock, Lamanna et al, in presentation of Dr. Christine Lamanna, ICRAF, Nairobi, December 2018.

Nutrient composition of crop residues

Crop residues contain substantial quantities of plant nutrients (table 7.1). On a weight basis, the major plant nutrients contained in 1 Mg of crop residue may range from 15 to 60 kg of N. (nitrogen) P. (phosphorous) and K. (potassium). Nitrogen and phosphorus concentrations are generally higher in legumes than in cereals.

Table 7.1 Nutrient composition of crop residues

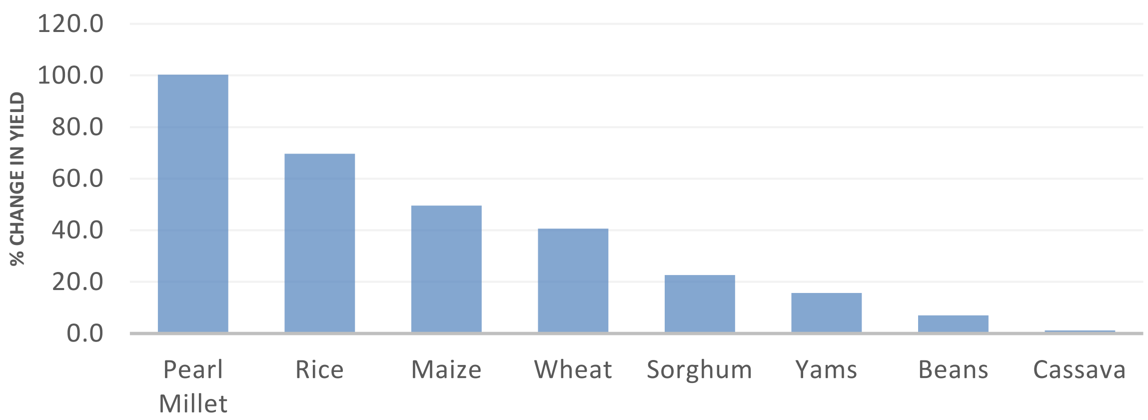
Crop residue	N	P	K	C/N ratio ∗
		(kg/ha/year)		
Cowpea stem	1.07	1.14	2.54	-
Cowpea leaves	1.99	0.19	2.20	-
Rice	0.58	0.10	1.38	105.0
Maize	0.59	0.31	1.31	55.0
Oil palm fiber	1.24	0.10	0.36	-
Sesbania leaves	4.0	0.19	2.0	-
Crotolaria spp.	2.89	0.29	0.72	-
Tephrosia spp.	3.73	0.28	1.78	-
Water hyacinth	2.04	0.37	3.40	18.0
Azolla spp.	3.68	0.20	0.15	-
Typha spp.	1.37	0.21	2.38	-

Source: United Nations University 1984.

∗A carbon-to-nitrogen ratio (C/N ratio) is a ratio of the mass of carbon to the mass of nitrogen in a substance. Plant growth and **carbon assimilation by plants** is limited by nitrogen availability. Mulching enriches the soil providing nutrients, including nitrogen, to plants.

Nutrient composition of crop residues contributes to higher crop yields, especially the yields of pearl millet, tice and maize (figure 7.4).

Figure 7.4 Benefits of crop residue: crop yield



Source: Climate-smart Agriculture Compendium, Rosenstock, Lamanna et al, in presentation of Dr. Christine Lamanna, ICRAF, Nairobi, December 2018.

Where is mulching practiced?

Mulching is generally practiced in tropics, subtropics, and arid zones (Agrisud 2010). For example, in Rwanda, mulch is applied in coffee fields to control soil erosion (Nzeyimana et al 2017). Mulching as traditionally applied by small scale coffee growers in Tanzania (Tibanyenda 2017).

Which areas of Africa are most suitable for mulching?

Mulching is a simple, low-cost, low-tech solution for improving agricultural productivity, resilience, and sequestering carbon.

In Africa, it can be practiced anywhere, and especially in tropics and semi-arid areas. It can be easily adopted by smallholder farmers.

How to implemented mulching?

The method involves applying a layer of mulch on bare soil. It is important to note that mulch should not touch tree trunks and plant stems (Government of Australia 2007).

It is advised to have a mixture of coarse materials such as leaves and straw with denser materials, e.g. grass clippings. This produces the greatest output of nutrients and also allows water to be more easily absorbed into the mulch. As a general rule, coarse mulches which may consist of stalks, leaves and straw should be about 15cm deep. Dense mulch which mainly consists of grass clippings should be about 8cm deep. Mulches made of grass clippings (dense) will break down more quickly and produce more nutrients than those made of woody materials (coarse). However, predominantly wood mulches should be more effective in reducing weed growth (Government of Australia 2007).

Box 7.1 Types of organic mulch used in South Africa

- Wood chips—are a byproduct of the pruning of trees by arborists, utilities and parks; they are a means to dispose of bulky waste.
- Leaves—Leaves from deciduous trees, which drop their foliage in the fall. They tend to be dry and blow around in the wind, so are often chopped or shredded before application.
- Straw—comes from the leftover stems of harvested grain crops.
- Grass clippings—come from mowed lawns, are sometimes collected and used elsewhere as mulch.
- Peat moss or sphagnum peat—is long lasting and packaged, making it convenient and popular as mulch. When wetted and dried, it can form a dense crust that does not allow water to soak in.

Source: Department of Agriculture, Forestry and Fisheries, South Africa (2017).

Different mulching machinery can be used to produce mulch (picture 7.2).

Picture 7.2 Mulching machinery

Source: https://www.youtube.com/watch?v=bj0CIIeMVfs (on the left); https://www.youtube.com/watch?v=NbEYVUZgfXc (on the right).

High-quality mulch can be of low cost too (table 7.2).

Table 7.2 High-cost and low-cost mulch

High cost mulch	Low cost mulch
• Purchased from company • Produced with machinery	• Sourced on-farm, e.g. crop residues, green manures, tree wastes, grass, compost

Source: Climate-smart Agriculture Compendium, Rosenstock, Lamanna et al, in presentation of Dr. Christine Lamanna, ICRAF, Nairobi, December 2018.

What needs to be considered in mulching?

Apart from multiple advantages, mulching might have also disadvantages, if poorly managed (table 7.3).

Table 7.3 Advantages and disadvantages of mulching

Advantages of mulching	Disadvantages of mulching
-Mulching improves nutrient and water retention in the soil, -Encourages favorable soil microbial activity and worms, -Suppresses weed growth, -Mulching reduces evaporation, -Mulch also helps to retain moisture, prevent soil erosion, control weeds and it adds nutrients to the soil.	-Heavy mulching over a period of years may result in a build-up of soil over the crown area of plants, -The cost of some materials can be a drawback to large-scale mulching, -Some mulch is not readily available, -When using sawdust and woodchips as mulch, nitrogen starvation sometimes occurs, -In humid areas, may increase likelihood of fungal disease or water logging, -Trade-off with livestock fodder, -Extra labor

Source: Department of Agriculture, Forestry and Fisheries, South Africa (2017) and presentation of Dr Christine Lamanna, ICRAF, Nairobi, December 2018.

If the mulching material is to be obtained from grown grass, then land is required for this purpose. This might prove difficult and expensive in areas with high demand for land. Also a lot of labor is involved in cutting and carrying the material. To a smallholder, it might not be worth the trouble unless the crop sells at a relatively high price (Tibanyenda 2017).

Residue incorporation as an alternative to mulching

As an alternative to mulching, residues can be incorporated into the soil, before or after composting (table 7.4).

Table 7.4 Advantages and disadvantages of residue incorporation

Incorporation advantages	Incorporation disadvantages
➢ Returns organic material to soil, sequestering carbon, and enhancing soil fertility, ➢ Increases soil moisture, ➢ Quicker release of nutrients than with mulch, ➢ Increased yields.	➢ Trade-off with livestock fodder, ➢ Higher labor requirements than mulching, ➢ Tilling soil can reduce soil carbon and increase erosion.

Source: Presentation of Dr. Christine Lamanna, ICRAF, Nairobi, December 2018.

7.3 Green Manuring

What does "green manure" mean?

Green manure crops (picture 7.3) are grown exclusively for the benefits and not for harvest or grazing. They are used to improve the soil, for organic matter, nitrogen status, nutrients or to control weeds (EMNZ 2015). Typically, they are ploughed under and incorporated into the soil while green or shortly after flowering (Agriculture and Food 2018).

Picture 7.3 Green manure crops

Source: Presentation of Dr. Christine Lamanna, ICRAF, Nairobi, December 2018.

What does “brown manure” mean?

Manuring can be also brown. Brown manuring is a ‘no-till’ version of green manuring, using a non-selective herbicide to desiccate the crop (and weeds) at flowering instead of using cultivation. The plant residues are left standing, helping to retain surface cover and soil structure. As a result, soil organic matter is increased (Agriculture and Food 2018).

A variation of brown manuring is mulching, where the crop or pasture is mowed, slashed or cut with a knife roller and the residue is left lying on the soil surface. This mulch reduces soil moisture loss through evaporation (see more in section 7.2).

Green and brown manure and soil carbon

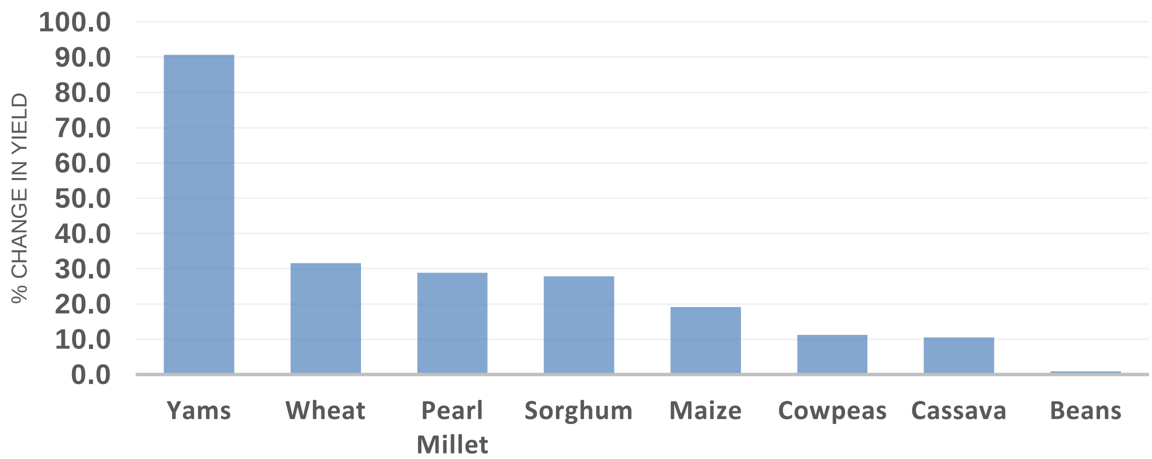
Green or brown manuring for carbon credits is not viable because there isn’t an approved methodology for generating carbon credits from this activity. Good data is needed to calculate the potential carbon sequestration value of this practice (Agriculture and Food 2018). Nonetheless, green or brown manuring still can be one component of a sustainable farming system (FAO 2010; box 7.2, figure 7.5).

Box 7.2 Benefits of green manure

-Improved soil fertility achieved by building SOM and SOC, soil humus and nutrient status, and increasing Nitrogen fixation (e.g. legumes) and buffering capacity to moderate changes in pH.
-Reduced weed burdens: green manures tend to be vigorous plants that can out-compete weeds.
-Provide access to unavailable nutrients from lower soil profile.
-Improved soil structure and providing a protective cover for the soil surface: this increases water infiltration and retention, reduces wind and water erosion risk, and reduces the impact of extreme temperatures.
-Green manure crops provide a habitat for pollinators and other beneficial insects.

Source: EAP 1992, FAO 2010, and Agriculture and Food 2018.

Figure 7.5 Benefits of green manure: crop yield



Source: Presentation of Dr. Christine Lamanna, ICRAF, Nairobi, December 2018.

Which areas are most suitable for green manuring?

To derive benefits from green manuring, soil type, climate and management are to be considered. As regards soil type, green manuring is best suited to cropping soils with loamy to clay surface textures. Clay soils can sequester more carbon as soil organic carbon (SOC). Clay/loam soils can support higher concentrations of organic carbon than sandy soils (Agriculture and Food 2018). As regards climate, higher rainfall supports more biomass leading to higher SOC (areas receiving less than 400 millimeters per year have limited ability to generate SOC; high temperatures will lead to faster rates of biomass and SOC decomposition, with the release of carbon dioxide, methane and nitrous oxide. As regards management, soil disturbance through tillage will encourage SOC loss. Minimum tillage and no-till minimize SOC loss (ibid).

How to choose the best green manure?

Ideal green manure crops should (EAP 1992):

- Be inexpensive to plant;
- Be easily established;
- Produce succulent tops and roots rapidly;
- Generate good ground cover quickly;

- Be capable of growing on poor soils (sands and clays benefit most).

Furthermore, green manure crops are not the same. For example, some green manure crops are better in Nitrogen fixation than other (table 7.5).

Table 7.5 Nitrogen fixation capacity of green manure crops

Plant	Nitrogen Fixation
Alfaalfa	Yes
Field beans	Yes
Buckwheat	No
Crimson clover	Yes
Other clovers	Yes
Fenugreek	No
Lupins	Yes
Mustard	No
Phacetta	No
Fodder radish	No
Rye, Grazing	No

Source: EAP 1992.

How to apply green manure?

- Green manure crops should be tilled in, mowed down almost to the ground, or smothered by organic mulches before they go to seed (EMNZ 2015).
- More-specialized machinery, such rollers and mulchers, may need to be purchased (Agriculture and Food 2018).
- The no-tilling option is the best way to ensure that you get the largest benefit out of the crop and the least amount of damage to the soil biota (EMNZ 2015).
- Excessive tilling, or tilling too deep, can kill off beneficial fungi in the soil and create soil texture problems and some soil fertility issues (EMNZ 2015).
- Green manures can be rotated with other crops and grown during fallow seasons or short seasons. Before green manure goes to seed, it is either cut and left (no till) or incorporated into the soil.
- Green manures can be intercropped with other crops during main cropping seasons. Benefits to both intercrop and next season's crops. Can be combined with crop residue retention.

What needs to be considered in green manuring?

If not properly managed, green manuring may cause undesirable results, such as (EAP 1992):

- Tilling in a heavy non-leguminous crop with a high C/N ratio can result in a depressed nitrogen uptake by the following crop.

- In areas of low rainfall, green manure crops may deplete soil moisture to the point that the succeeding main crop will suffer from drought.

- Depending on the soil, the green manure crop, and the rotation, succeeding crops may not benefit from the expense, time, and energy devoted to green manuring.

- On land of high market value, giving over the entire cropping season to green manure crops is seldom profitable. It is justified when the following crop is fairly permanent and the establishment and good growth of the seedlings or young plants are of prime importance, e.g. for orchards or lawns.

- In addition, with the cost of N fertilizer increasing at 20 per cent plus per year, and the quality of our soils deteriorating under monoculture cropping, green manuring might just be the best method of saving farmland.

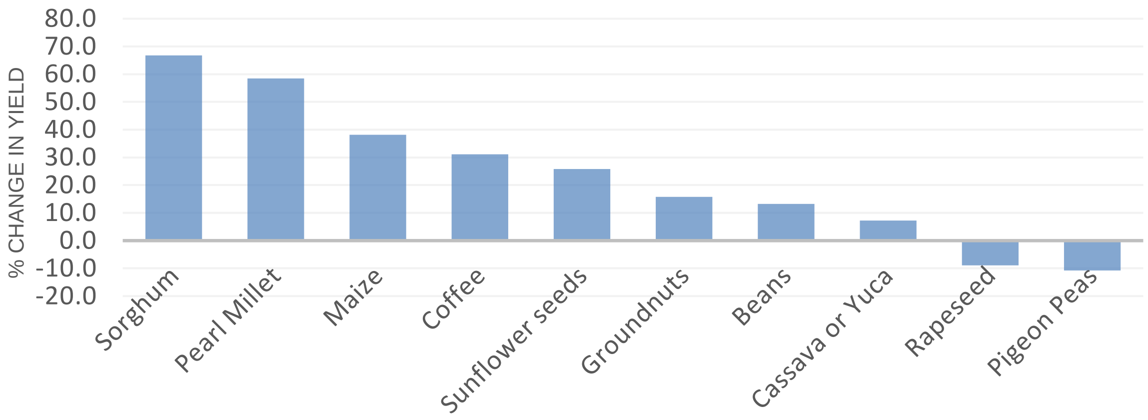
7.4 Agroforestry Residues and Carbon

Tree residues, such as leaves, can also be a rich source of carbon and nitrogen. In agroforestry systems, trees are intercropped with crops. These trees are often nitrogen fixing.

Agroforestry trees often need to be pruned to avoid shading or competition with crops. Pruning residues can be returned to the soil to enhance soil fertility.

Application of agroforestry residues to crops tends to increase yields (figure 7.6).

Figure 7.6 Agroforestry residues: crop yield



Source: Climate-smart Agriculture Compendium, Rosenstock, Lamanna et al, in presentation of Dr. Christine Lamanna, ICRAF, Nairobi, December 2018.

7.5 Animal Waste and Manure

Why to apply animal manure?

Animal manure is a rich source of organic carbon, nitrogen, potassium and other nutrients, and is readily available for many farmers.

How to apply animal manure?

Animal manure can be applied to the soil, or incorporated into the soil, after it has been composted.

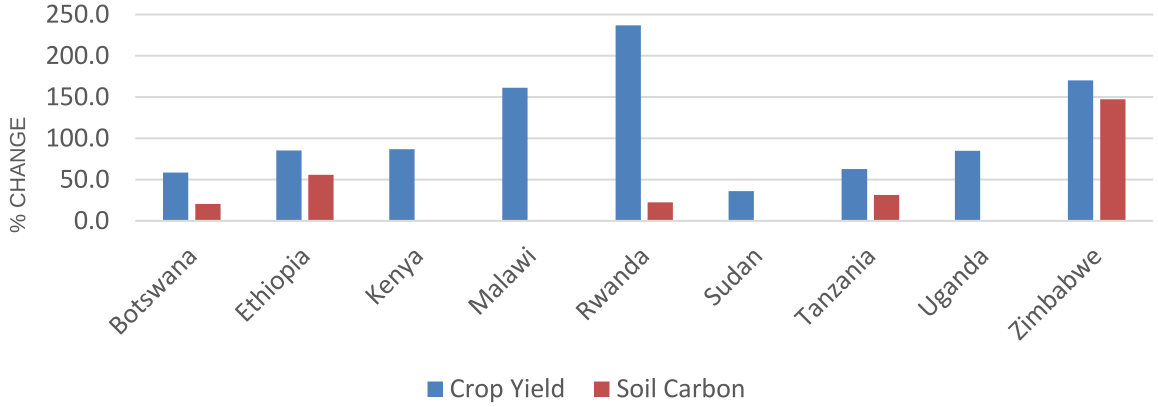
Manure can also be used to create liquid fertilizer by mixing with urine, water, or plant materials.

In *kraaling,* animals are kept on fallow fields to directly deposit manure. The kraal is then prepared for planting and the animals moved to a new fallow field.

Benefits of animal manure

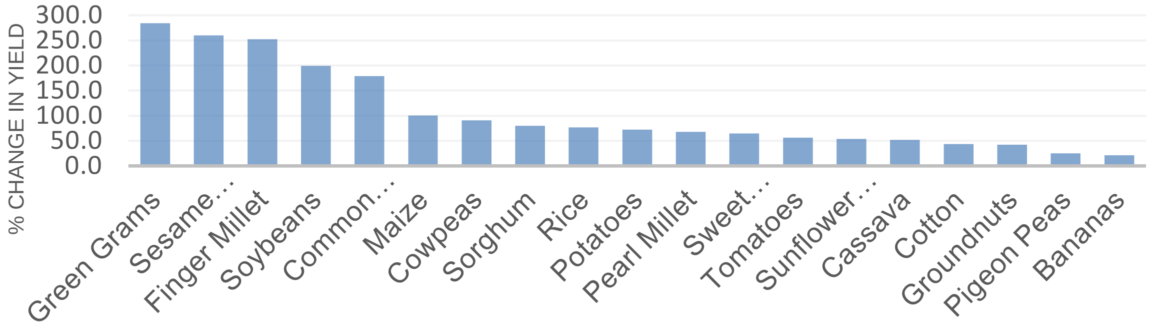
- Returns organic material to soil, enhancing soil fertility,
- Sequesters carbon and reduces GHG emissions from manure (figure 7.7),
- Increases soil moisture,
- Reduces soil erosion,
- Increase crop yields (figure 7.8).

Figure 7.7 Benefits of manure by African countries: soil carbon and yield



Source: Presentation of Dr. Christine Lamanna, ICRAF, Nairobi, December 2018.

Figure 7.8 Benefits of animal manure: crop yield



Source: Presentation of Dr. Christine Lamanna, ICRAF, Nairobi, December 2018.

What needs to be considered in animal manuring?

- If not managed properly, animal manure can pollute soil and water,
- Animal manure may increase exposure to diseases,
- Management can be labor intensive.

7.6 Managing Agricultural Waste

What does "agricultural waste" mean?

United Nations defines agricultural waste as: "waste produced as a result of various agricultural operations. It includes manure and other wastes from farms, poultry houses and slaughterhouses; harvest waste; fertilizer run-off from fields; pesticides that enter into water, air or soils; and salt and silt drained from fields".

Agricultural waste includes natural waste, animal waste, and plant waste (Kalamkar 2017).

Agricultural waste and soil carbon

Agricultural wastes are suitable raw materials for the production of activated carbon (Hofstrand 2009).

Where is agricultural waste well-managed?

USA, Canada, Europe, Japan, and Australia.

How to manage agricultural waste well?

Agricultural waste management comprises several stages, such as: production, collection, transfer, treatment and storage, and utilization or disposal (Soleimani and Kaghazchi 2007, Obi et al 2016).

The treatment process includes composting, recycling and incineration (Kalamkar 2017). Composting is a method of decomposition of the organic matter present in the agricultural waste into humus. Recycling is a process which transfers waste into new products. Incineration is a method of burning the dry refuse in the incinerator (ibid).

The technology of incineration matters (picture 7.4).

Picture 7.4 Uncontrolled and controlled incineration

Source: Kalamkar 2017.

The internet location of two guidelines on proper management of livestock and farm waste are listed below:

1. Farm Waste Management (https://www.epa.vic.gov.au/~/media/Publications/IWRG641.pdf)
2. Livestock Waste Management - EFP Reference Guide (http://ardcorp.ca/wp-content/uploads/2017/11/EFP-Reference-Guide-Chapter-3.pdf)

What needs to be considered in managing agricultural waste?

- Functional policies, regulations as well as access to knowledge and credits are required for proper waste management,
- If not managed properly, agricultural waste can pollute the environment (Kalamkar 2017),
- The degradation of water quality can impact adjacent waterways and ground water both onsite and offsite (ibid),
- Nitrates can be found in fertilizers and agricultural waste runoff, can seep into groundwater (ibid),
- Water contaminated with nitrates is hazardous to humans (ibid).

Further reading

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Guidelines:

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Module Eight: Organic Agriculture

Objectives

This module is about organic agriculture. It explains what organic agriculture is; its benefits and potential to sequester carbon. The module also discusses how and where to practice organic agriculture, and what key considerations for deployment of this technology are.

What does "organic agriculture" mean?

FAO (1999) defines organic agriculture (OA) as "a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity. It emphasizes the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using, where possible, agronomic, biological, and mechanical methods, as opposed to using synthetic materials, to fulfill any specific function within the system."

There is a need for sustainable farming. The modern farming has proved to be unsustainable because of (Conserve Energy Future 2017):

- Loss of soil fertility due to excessive use of chemical fertilizers and lack of crop rotation.
- Nitrate run off during rains contaminates water resources;
- Soil erosion due to deep ploughing;
- More requirement of fuel for cultivation;
- Use of poisonous biocide sprays to curb pest and weeds;
- Cruelty to animals in their housing, feeding, breeding and slaughtering;
- Loss of biodiversity to monoculture;
- Native animals and plants lose space to exotic species and hybrids.

What are the benefits of organic farming?

- Organic soils are very useful in terms of adapting to climate change (Chait 2018). They have a great buffer capacity concerning droughts and floods and withstand erosion (FAO 2014, Neubert 2016).
- Organic agriculture reduces non-renewable energy use by decreasing agrochemical needs (FAO 2014).
- Many management practices used by organic agriculture (e.g. minimum tillage, returning crop residues to the soil, the use of cover crops and rotations, and the greater integration of nitrogen-fixing legumes), increase the return of carbon to the soil, raising productivity and favoring carbon storage. A number of studies revealed that soil organic carbon contents under organic farming are considerably higher. The more organic carbon is retained in the soil, the more the mitigation potential of agriculture against climate change is higher (FAO 2014).
- Organic farming reduces the exposure to pesticides and chemicals, contributes to water conservation, animal health and welfare, and biodiversity. The use of

genetically modified organisms (GMOs) within organic systems is not permitted during any stage of organic food production, processing or handling. The hidden costs of agriculture to the environment in terms of natural resource degradation are reduced due to organic farming practices (Despain 2017).

Some evidence, however, suggests that organic farming may generate higher greenhouse gas emissions per product than conventional ones, which depends on a product produced. More specifically, the studies of Oxford University has found that organic milk, cereals, and pork generated higher greenhouse gas emissions per product than conventional ones but organic beef and olives had lower emissions in most studies (University of Oxford 2012).

Where is organic farming practiced?

- The markets for organic products are strongest **in North America and Europe,** which as of 2001 are estimated to have $6 and $8 billion respectively of the $20 billion global market (WorldAtlas 2018).

- As of 2007 **Austral-Asia** (Australia, New Zealand, and neighboring islands in the Pacific Ocean) has **39% of the total organic farmland**, including Australia's 1,180,000 hectares. US sales are 20x as much (WorldAtlas 2018).

- **Europe** farms **23 % of global organic** farmland (6,900,000 ha), followed by Latin America with 19 percent (5.8 million hectares). Asia has 9.5 percent while North America has 7.2 percent. Africa has 3 percent. African nations are among the countries with the fewest organic farms by are (WorldAtlas 2018).

- In **China**, there is **a growing market for "green food"** which, according to government grading standards, is produced without certain pesticides and fertilizers and with biological methods. Chinese farmers also produce organic food for export (e.g. tea to the Netherlands, soybeans to Japan) (FAO 2014).

The countries with the most developed organic farming in Africa by area are Uganda, Tanzania, Ethiopia, and Tunisia. Other top African countries for organic farming are Egypt, Sudan, DR Congo, South Africa, Madagascar, and Ghana (table 8.1, boxes 8.1-2; WorldAtlas 2018).

Table 8.1 Top African countries in organic farming

Rank	Country	Organic Area (ha)
1	Uganda	231,157
2	Tanzania	186,537
3	Ethiopia	164,777
4	Tunisia	137,188
5	Egypt	82,167
6	Sudan	54,845
7	DR Congo	51,838
8	South Africa	43,170
9	Madagascar	30,265
10	Ghana	28,161

Source: WorldAtlas 2018.

Box 8.1 Organic farming in Uganda

In Africa, Uganda is the top country for organic farming due to the government support that it receives. The Ugandan government strictly prohibits the use of synthetic inputs such as fertilizers, pesticides, and drugs. The objective of the prohibition is to promote sustainable agricultural growth for the long-term improvement of the people's lives. The country is popular for its organic exports. The effects of organic farming in Uganda include reduced agricultural chemical runoff, improved food security, and increased organic exports.

Source: WorldAtlas 2018.

Box 8.2 Organic farming in Tanzania

Organic farming in Tanzania is championed by the Tanzania Organic Agriculture Movement (TOAM). It has resulted in fertile soils, great ecosystems, and a healthy population. TOAM came into being in 2005. Since then, its role has been to facilitate and coordinate organic farming in Tanzania. Growth of organic farming in Tanzania is also attributed to the growing support received from the consumers and stakeholders. Organic farmers focus on protecting the environment, health of consumers, and soil. Some of the methods used in organic farming include the use of organic manure, intercropping, and crop rotation. Consequently, approximately 186,537 hectares of Tanzanian land is under organic farming. Hence, Tanzania is the second top African country for organic farming.

Source: WorldAtlas 2018.

How to practice organic farming?

The explicit goal of organic agriculture is to contribute to the enhancement of sustainability over the long term (FAO 1999, FAO 2014). To achieve sustainability, a number of agricultural practices are implemented, such as: use of organic fertilizers, micro-dosing, use of beneficial insects, crop rotation, buffers and cover crops. These practices are briefly described below.

1. **Use of organic fertilizers and pesticides (Biernbaum 2003, Only Organic 2018)**

Organic fertilizers and amendments: There are naturally occurring fertilizers or amendments that are acceptable for certified organic production. They can be categorized as either mineral derived, animal derived or plant derived.

Animal Manure: A traditional source of soil organic matter has been animal manures.

Green Manures: Another source of organic matter and nutrients is growing plants on the land and then plowing them into the soil to decay and release nutrients for the next crop.

Compost: A third primary source of organic matter and nutrients, particularly for smaller plots of land or gardens is compost. Compost is the end product of biological breakdown of organic matter. While composting improves soil organic matter, the trade-off of composting is, however, the generation of carbon dioxide.

Organic pesticides: Some organic farmers introduce beneficial insects such as ladybugs, soldier beetles, green lacewings, big-eyed bugs and beneficial nematodes that eat harmful insects (Only Organic 2018).

2. **Micro-dosing**

Micro-dosing involves applying a small, affordable amount of fertilizer with the seed at planting time or as top-dressing three to four weeks after emergence. This can be done by filling a soda bottle cap with fertilizer and applying it directly to the root of the crop. Same ways other inputs such as pesticides and water, can be applied.

Micro-dosing is a highly efficient technique that minimizes the application of and over-reliance on inputs. It is often viewed as an affordable option for poor smallholder farmers as the small quantities of fertilizer required reduces the investment cost (ICRISAT 2014).

Box 8.3 Micro-dosing in Zimbabwe

> Crop yields in the semi-arid areas of Zimbabwe have been declining over time because of poor soil fertility due to mono-cropping, lack of fertilizer, and other factors. ICRISAT has promoted conservation agriculture and micro-dosing techniques.
>
> Farmers adopting the Dube technology have realized yield gains of 15 to 100 percent across different agro-ecological regions.
>
> The Dube technology is simple to implement. To prepare for planting season, farmers dig holes. Though the holes dug 15 cm deep by 15 cm wide look ordinary, they are not. Dube sprinkles fertilizer, using a soft drink bottle top as a measure. Then farmers throw three hybrid maize seeds into each basin and cover it halfway with dry soil. When the first rains fall, water collects in the basin, providing moisture for the plant for many weeks until the next rains come.
>
> Training was the key to the adoption of micro-dosing. The findings show that the training in micro-dosing raised the probability of adoption by 30 to 35 percentage points.
>
> The obstacles included: adequate supply of inputs and the ability to reach female-headed households.

Source: ICRISAT 2018.

3. **Crop rotation**

Organic farmers often do not grow the same crop on the same field year after year. Crop rotation naturally replenishes the soil because as different plants contribute varying nutrients to the soil (Only Organic 2018).

4. **Buffers**

Organic farmers designate the edges of their land as buffer zones. This means the land is managed in accord with organic practices, but the crops grown on them aren't sold as organic because some plants in the buffer may have been exposed to genetically engineered crops or chemicals used in conventional agriculture but barred for organic farms (Only Organic 2018).

5. **Cover Crops**

Cover crops such as clover, rye, and wheat are planted between growing seasons to help replenish the soil with nutrients and prevent soil erosion. They also help maintain populations of beneficial insects. Cover crops can control weeds by smothering and shading them and out-competing them for nutrients (see Modules Five and Seven for more detail) (Only Organic 2018).

Costs and benefits of organic farming

Table 8.2 presents the benefits, costs and specificities of organic farming in relation to yields, biodiversity, climate-change mitigation, soil quality, water quantity and quality, livelihoods, consumers' health and access, and challenges for up-scaling organic farming.

Table 8.2 Costs and benefits of organic farming

Criteria	Benefits	Costs	Specificity
Yields	Stability of yields might be higher under organic management.	Yields under organic management are on average 19 to 25 per cent lower than under conventional management. Higher prices make up for this yield difference (Neubert 2016). A recent study by two Washington State University professors, who found that premiums paid to organic farmers ranged up to 32 percent more than for conventional crops (Despain 2017).	Many cereals show higher yield gaps, while forage crops (like hay or alfalfa) have lower yield gaps.
Biodiversity	On average, organic management results in a 40 to 50 per cent increase in organism abundance in agricultural fields.	Depends on yields	Plants and bees benefit the most, while other arthropods and birds benefit to a smaller degree.
Climate change mitigation	Organic farms typically have lower energy use and lower green-house gas (GHG) emissions than conventional farms.	GHG emissions depend on yield and crop type	
Soil quality	Organic management leads to improved soil quality, as organic soils tend to have higher organic matter, and likely lower soil erosion rates.	The impact on soil quality is unknown when lower organic yields are taken into account.	
Water quality	Fields managed organically have on average lower nitrogen loss and lower pesticide leaching than conventional farms. Organic agriculture also uses more recycled nitrogen and phosphorus, thereby introducing less new nitrogen and phosphorus into our water systems.	Due to lower organic yields, the nitrogen loss per unit food produced might actually be higher under organic management.	Organic systems that apply large amounts of animal manure have a stronger negative impact on water quality than organic farms that use nitrogen-fixing crops as fertilizers.
Water quantity	Organic soils may have higher capacity to hold water.	Unknown as there are very few studies on the water use of organic farms.	

Criteria	Benefits	Costs	Specificity
Farmer livelihood	Organic agriculture is typically more profitable than conventional agriculture.	Organic farmers in low-income countries are usually dependent on export markets and exporting agents and therefore lose some of their autonomy.	In regions with high labor costs, organic agriculture is probably less profitable due to its high dependence on agricultural labor.
Farm worker livelihood	Organic agriculture reduces the exposure of farm workers to toxic agrochemicals.	Organic farm workers are likely exploited in similar ways to conventional farm workers.	Agricultural workers in regions with high rural unemployment rates can benefit from the increased employment opportunities in organic agriculture.
Consumer health	Organically grown foods have lower pesticide residues and are most likely slightly higher in some micronutrient contents. But it is not clear whether the higher micronutrient contents provide any actual health benefits to consumers.		Consumers in countries with weak pesticide regulations benefit the most from consuming organic food.
Consumer access	Organic food is more expensive and therefore less accessible to consumers with low income.		Being a member of a community supported agriculture (CSA) initiative can provide cost savings to organic consumers.
Scaling-up organic farming	The yield gap between organic and conventional agriculture could probably be decreased further, with more research on organic agriculture.	Organic farms currently are highly dependent on nutrient inputs (e.g. animal manure) from conventional farms. It is not clear whether there are enough organic fertilizers to feed everyone in the world.	

Source: Sustainable footprint 2017.

What needs to be considered?

Global

The demand for organic products has created new export opportunities for the developing world. While some consumers express a preference for locally-grown organic foods, the demand for a variety of foods year-round makes it impossible for any country to source organic food entirely within its own borders. As a result, many developing countries have begun to export organic products successfully (FAO 1999).

Typically, organic exports are sold at high premiums, often at prices 20 percent higher than identical products produced on non-organic farms. But entering this market is not easy because of expensive certification and it takes at least two-three years after beginning organic management since the products can be sold as "transitional organic". As a solution, farmers can sell the organic products on local markets, though at a lower price (Sustainable footprint 2017).

Local

It is very difficult to establish organic farming in Africa, although it offers many advantages over conventional cultivation. A key challenge is to generate sufficient biomass for organic soil management in semi-arid areas.

In Africa, animal manure typically accrues in too small quantities. Only pastoralists, who do not belong to the same ethnic groups as the farmers, hold cattle in relevant numbers, and their relationship to farmers is mostly competitive. Reestablishing win-win situations in which crop farmers and pastoralists benefit from one another' manure and plant residues would make a lot of sense (Neubert 2016).

Support is needed at several levels:

- Suitable agricultural policies must foster sustainable land-management approaches,
- Research is still needed to identify the most suitable approaches for smallholders in different agro-ecological regions,
- Loans and credits must be made available for means to transport manure and compost,
- Farmers need devices for minimum tillage (as a substitute for the plough) and for mechanized weed control or even, in breach of orthodoxy, herbicides so they can reduce manual labor intensity,
- Subsidies are needed for the acquisition of suitable seed (plant varieties and tree species), and
- Targeted subsidies must promote soil enhancement.

In places where soils are already degraded, sustainable methods will not be adopted widely unless they are supported by an appropriate agricultural policy.

Land issue

To produce the same quantity of food, organic farming requires more land than conventional farming. This shall not mean cutting down more forest or using up more pasture to create farmland (Sustainable footprint 2017).

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Module Nine: Area Closure and Reserves

Objectives

This module is about the practice of area closure and reserves. The module explains the benefits and potential of these approaches to sequester carbon. The module also discusses where and how these approaches are practiced as well as key considerations for their deployment.

9.1 Area closure

What does “area closure|” mean?

Area closure is defined as “an area delineated to exclude human and livestock interferences” (Yosef 2015). The aim of area closures is to prevent further degradation of the ecosystems, advance re-vegetation or forest regeneration, and restore the overall ecological conditions of the area (Mengistu et al 2016).

Area closure improves ground vegetation cover, which in turn enhances better soil conditions, microclimate conditions and water percolation (Emiru et al 2006, cited in Mengistu et al 2016). Longer time kept area closures can facilitate large numbers of woody species to grow in to higher height, and help woody species to have good population structure (Kibret 2008, cited in Mengistu et al 2016). Area closures may provide forest products including trees that can improve the livelihoods of the rural poor though increasing incomes, improving food security, reducing vulnerability and enhancing well-being in the long run (Mengistu et al 2016).

What are the benefits of area closure?

Area closure has emerged as a viable option to restore ecosystems and sequester CO2 with possibility for qualifying for carbon credit programs (Mengistu et al 2016). This approach contributes to the three pillars of sustainable development, such as environmental, economic and social benefits (table 9.1).

Table 9.1 Area closures and sustainable development

Environmental benefits	Economic benefits	Social Benefits
Increased vegetation cover	Sustainable fire wood from fallen branch	Land user rights secured
Decreased downstream erosion	Grass harvesting through cut and carry	Increased community institutional capacity
Increased biodiversity		Awareness creation
Improved microclimate		Knowledge transfer

Source: Mengistu et al 2016.

Box 9.1 presents the case of area closure in Ethiopia.

Box 9.1 Area closure in Ethiopia

The area closures for 3-5 years in the Central Rift Valley (a total of 60 circular sample plots of each 314 m 2 area) in Ethiopia in 2012 brought changes by rehabilitating degraded lands and eventually brought economic, social and ecological benefits to the local communities.

The aim of area closures in Ethiopia was to prevent further degradation of the ecosystems, advance re-vegetation and forest regeneration, and restore the overall ecological conditions of the area. This was a national initiative that was implemented in the context of Ethiopia's Productive Safety Nets Program (PSNP). The target beneficiaries were chronically food insecure smallholder farmers who rely on the land and natural resources for agriculture and food security.

The linking of area closure with other natural resource management, soil and water conservation and livelihood diversification practices has been the biggest innovation that has contributed to the sustainability, acceptability and broader impact of the practice in terms of environmental, social and economic aspects in addition to climate change adaptation and mitigation benefits. For example, in some instances beekeeping has been linked to area closure as the practice does not result in damage to the closed off area, while beekeeping provides and alternate income and contributes to resilience to climate change through livelihood diversification. This ensures that the practice of area closures contributes to both climate change adaptation and mitigation.

As regards up-scaling, the practice of area closure is suited to highly degraded land (due to human activity) with low productivity.

Source: Mengistu et al 2016.

There are two types of area closure (Mengistu et al 2016):

1. Only closing the area from interferences of human interventions (leaving it to natural regeneration), and

2. Closing off degraded land while simultaneously implementing additional measures such as planting of tree seedlings, mulching and establishing water harvesting structures to enhance and speed up the regeneration process.

Which areas of Africa are most suitable for area closure?

The practice of area closure can be used and is suitable for all areas where severe land degradation has taken place (Mengistu et al 2016).

How to practice area closure?

The practice of areas closure comprises five stages (Mengistu et al 2016):

1) The area to be closed is first identified in participation with development agents, community leaders and community members.
2) Awareness activities are undertaken to make local communities understand the methods and benefits of area enclosures. Development agents in collaboration with community leaders call a general community meeting and discuss the plan and its implementation on degraded land and community members have an opportunity to

voice their concerns and opinions. Both men and women are involved in the community consultations and awareness raising activities.

3) The area to be closed is then demarcated and fenced, in most cases with living fences and guard duties assigned. The demarcation and fencing are conducted largely using labor from the local community on “cash for work” basis and with involvement of the local administration and development agents.
4) There is also a maintenance component for area enclosures which involves activities such as replanting, maintaining of fences, pruning of trees and weeding. Some periodic repairs may be needed to physical structures.
5) Sustainable Land Management (SLM) measures such as terracing, enrichment plantation and over-sowing of grass are among the activities that are often undertaken along with the area closure. These practices enhance growth of natural vegetation and enrich biodiversity.

Degraded land is closed from human and animal interferences for at least 3 -5 years in order to ensure rehabilitation of the land.

Economic benefits of area closure in Ethiopia

In Ethiopia, a cost-benefit analysis conducted on area closure as a practice showed that the practice has a positive net present value (NPV) and that its benefit to cost ratio (BCR) varied between 4.6 to 54.3 through carbon credit program (PWA 2014, cited in Mengistu et al 2016).

What needs to be considered?

1. For sustainable maintenance of the rehabilitated areas and their contribution to the livelihood of to the local communities, setting tangible benefit sharing schemes from the closures, and diversify alternative sources of income are vital (Yosef 2015).

2. Good community engagement and awareness building on the value of area closures both for the environment and for their livelihoods is crucial for success of the practice (Mengistu et al 2016).

3. The key issue for sustainability of the approach is involvement and ownership by people of the process and the results. Extensive community engagement, awareness raising and sensitization is needed on the issue of area closure and its benefits before coming to agreement on where to implement the practice and on how much land (Mengistu et al 2016).

4. Area closures integrated with other natural resource and income generating activities such as water conservation, promotion of wood saving and solar stoves, crop land management, graying land management plans, agroforestry, fodder production and community capacity building show greatest success and sustainability (Mengistu et al 2016).

5. Initial external support to implement the practice is necessary in most cases, as many households cannot afford the costs associated with fencing and additional SLM measure (Mengistu et al 2016).

Table 9.2 Constraint and solution to area closure in Ethiopia

Problem	Solution
The concept of benefit sharing for different community members and groups was a challenge as one group/person realized tangible benefits of area closure while another group/person did not see the value.	To address this, participatory approaches in the identification of land for area closure as part of a broader watershed management plan were used, while sensitization and awareness building on the short and long term benefits of area closures were conducted by development agents. Alternative livelihood options/tangible benefits were proposed.

Source: Mengistu et al 2016.

Further reading

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9.2 Reserves

What do “reserves” mean?

Nature reserve is a protected area of importance for wildlife, flora, fauna or features of geological or other special interest, which is reserved and managed for conservation and to provide special opportunities for study or research.

What are the benefits of reserves?

Reserves bring a number of benefits. First, carbon sequestration due to improved vegetation is one of the key benefits of having reserves. Reserves qualify for carbon credit programs.

Second, reserves provide income from ecotourism and payments for ecosystem services.

Third, reserves may also encourage local support for conservation through the provision of benefits from protected area management or through investment in alternative livelihoods. The legal provisions related to protected area designation can often provide local communities with formal protection, such as land tenure, that would otherwise be unavailable. This can protect traditional lands from external threats such as extractive industries or development (Coad et al 2008).

Where are reserves located?

Australia, Brazil, Democratic Republic of Congo, Egypt, EU (Denmark, Sweden, Estonia, France, Germany, Hungary, Poland, Portugal), United Kingdom, Israel, Japan, Jordan, Kenya, Kyrgyzstan, and New Zealand.

Box 9.2 Establishment of a new reserve in the Democratic Republic of Congo

Conservation groups and the government of the Democratic Republic of the Congo (DRC) have announced the establishment of a new reserve to protect the endangered bonobo, a great ape found only in the DRC’s vast tropical forests

Preserving the region’s vast tropical forests can also protect wildlife by helping to mitigate global warming. If deforested, the region would release as much as 2 billion tonnes of carbon dioxide, equivalent to the emissions of 38 million cars a year for 10 years, says the BCI. In 2006, as many as 16,118 species were threatened worldwide from climate change and other dangers.

Source: Worldwatch Institute 2018.

How are reserves established?

Nature reserves may be designated by governmental institutions, communities or by private landowners, such as charities and research institutions, depending on land tenure.

Box 9.3 New way of establishing community reserves in UK

When most people think of a nature reserve, they imagine wide open spaces. But it can be composed of many small pieces of private gardens, back yards and window boxes.

Felixstowe's Community Nature Reserve is a network of these small green spaces, where local people can grow wildlife-friendly plants, and where they can also create ponds, insect lodges and bird nesting boxes—all with the ultimate aim of stopping the decline in wildlife populations.

Step 1: Talk with people and leaders in your community.

Step 2: Get active on social media.

Step 3: Turn to local media.

Step 4: Involve young people.

Step 5: Celebrate your successes.

Step 6: Continue to engage your community.

Step 7: Help other community reserves.

Source: Cooper 2017.

What needs to be considered?

Reserves require land. Those with high dependency on reserves and little political influence might lose their livelihood, which in turn is likely to influence their attitude towards conservation. To ensure sustainable management of reserves, there is a need for (Coad et al 2008):

1. Livelihoods options as a result of changing access to resources,
2. Land tenure,
3. Policies, and
4. Incentives.

Common problems with protected areas

According to WWF (2018), the common problems with protected areas are:

- **Poor representation of habitats**: Many habitats are not well represented in the current network of protected areas. For example, less than 4% of the ocean is protected. Freshwater habitats are also poorly represented.
- **Lack of connectivity between protected areas:** Some species, especially large animals like cats and bears, need large areas of natural habitat in order to feed and find mates. Few protected areas are large enough to support more than a few individuals of these species, and many are isolated from other areas of natural habitat. To address this, corridors must be put in place between protected areas to allow species to move from one protected habitat to another. The linking of protected areas to form networks or systems is very important for the survival of many species; however, such connectivity remains rare.

- **Lack of funds:** Putting representative protected area networks in place and managing them effectively requires money. However, few countries, including the richest, have managed to define and establish was to provide long-term, sustainable financing for individual protected areas, let alone a network. This funding gap is particularly acute in developing countries and for marine protected areas. There is a clear need to find new and sustainable financial resources to supplement funding for existing protected areas and to support the establishment of new protected areas.
- **Poor management**: The declaration of a protected area is not an end result: a whole series of conditions must be in place for protected areas to be effective. Effective management is essential to ensure that nature is being conserved within a park's boundaries. Management activities include monitoring the health of habitats, ensuring that the rules of the protected area are respected, and working with local people to balance nature protection with their needs and aspirations.
- **Human activities:** Poorly managed or illegal human activates occurring within protected areas in many parts of the world. These include logging, poaching of protected animals, mining, and encroachment by human settlements and agriculture.

Further reading

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Module Ten: Monitoring Soil Carbon Stock

Objectives

The module introduces the approaches and tools to carbon monitoring. It also provides the links to the resources where a reader can find more detailed information on the practical application of the monitoring tools and approaches.

What does "carbon monitoring" mean?

Carbon monitoring comprises methods for systematic assessment of soil and ecosystem health, which not only inform about the status at the time of measurement or changes between the assessments, but also enable advice on rehabilitation measures to recover soil.

Why to monitor carbon?

The organic carbon content in the soil has been identified as indicator of the soil health. Without proper monitoring, the changes in soil carbon cannot be detected.

Monitoring carbon can improve crop modeling prediction in various climate scenarios, guiding more targeted interventions, e.g. what farmers can do to optimize soil health, improve crops and manage agriculture in a sustainable way.

Where carbon monitoring systems are employed?

Signatory parties of the UN Framework Convention on Climate Change (UNFCCC) are required to prepare and report on national GHG inventories on a periodic basis. Industrialized countries are required to estimate and report emissions and removals annually, while low-income countries need to report every 3 to 5 years. Examples of national carbon accounting system and tools are presented in table 10.1.

Table 10.1 Carbon accounting systems and tools

Name	Description and internet location
Australia's National Carbon Accounting System (NCAS)	NCAS estimates emissions through a system that combines satellite images to monitor land use and land-use change across Australia that are updated annually; monthly maps of climate information, such as rainfall, temperature, and humidity; maps of soil type and soil carbon; databases containing information on plant species, land management, and changes in land management over time; and ecosystem modeling—the Full Carbon Accounting Model. http://www.climatechange.gov.au/government/initiatives/national-carbon-accounting.aspx
National Forest Carbon Monitoring, Accounting and Reporting System, Canada (NFCMARS)	NFCMARS is designed to estimate past changes in forest carbon stocks and to predict, based on scenarios of future disturbance rates and management actions, changes in carbon stocks in the next two to three decades. http://carbon.cfs.nrcan.gc.ca/index_e.html
Agriculture and Land Use National Greenhouse Gas Inventory Software (Colorado State University, United States)	The program supports countries' efforts to understand current emission trends and the influence of land-use and management alternatives on future emissions. It can be used to estimate emissions and removals associated with biomass C stocks, soil C stocks, soil nitrous oxide emissions, rice methane emissions, enteric methane emissions, manure methane, and nitrous oxide emissions, as well as non-CO2 GHG emissions from biomass burning. The software accommodates Tier 1 and 2 methods as defined by the Intercontinental Panel on Climate Change. It allows compilers to integrate global information system spatial data along with national statistics on agriculture and forestry and is designed to produce a consistent and complete representation of land use for inventory assessment. http://www.nrel.colostate.edu/projects/ghgtool/software.php
National Carbon Accounting System of Indonesia	Provides monitoring capabilities for greenhouse gas (GHG) emissions/sinks to establish a credible reference emission level. The three major activities linked are the remote sensing program, the modeling and measurement program for GHG accounting and reporting, and the data program. http://www.dpi.inpe.br/geoforest/pdf/group2/04%20-%20National%20carbon%20accounting%20system%20of%20Indonesia.pdf

Name	Description and internet location
New Zealand's Carbon Accounting System	The National Carbon Accounting System for New Zealand's indigenous forest, shrub land, and soils was developed for the Ministry of the Environment by Land Care Research and Scion. It monitors forest definition, land-use change, forest inventory and modeling, and reporting methods. http://www.joanneum.at/carboinvent/workshop/1000_Peter_Stephens_ver_final.pdf
Forest Vegetation Simulator, United States	The Forest Vegetation Simulator (FVS) is a family of forest growth simulation models. The basic FVS model structure has been calibrated to unique geographic areas to produce individual FVS variants. Since its initial development in 1973, it has become a system of highly integrated analytical tools. http://www.fs.fed.us/fmsc/fvs/description/index.shtml

Source: World Bank 2012.

Land Degradation Surveillance Framework at ICRAF

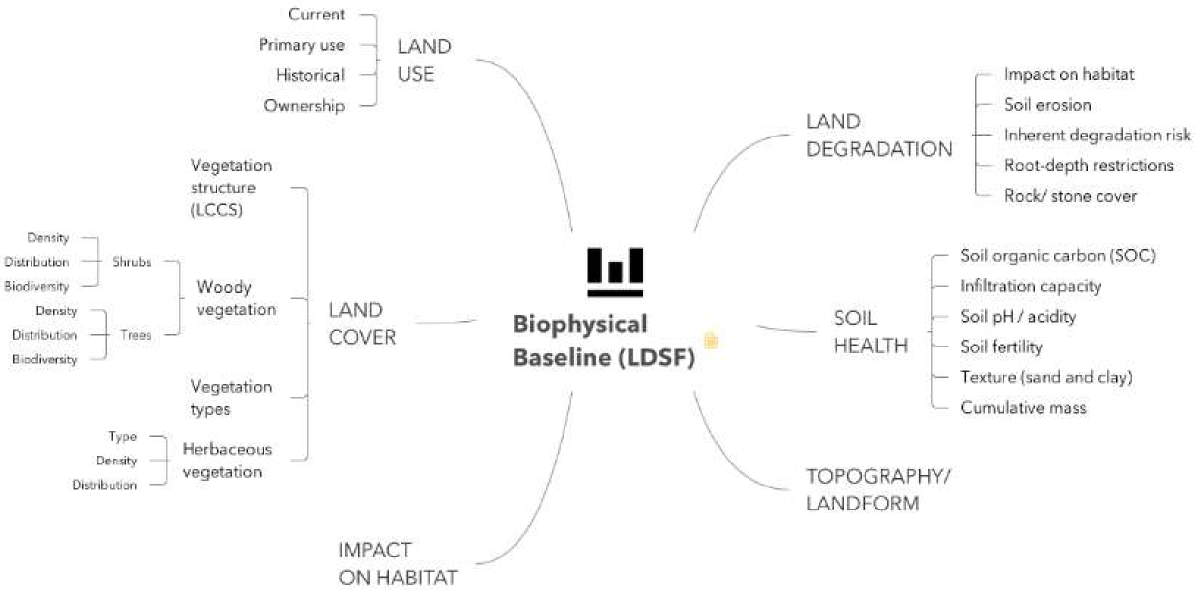
Land Degradation Surveillance Framework (LDSF) is a part of the Ecosystem Health Surveillance System (EcoHSS) developed by the World Agroforestry Centre (ICRAF). The EcoHSS applies a range of statistical modeling and machine learning methods to assess ecosystem health at multiple spatial scales and across social and ecological systems.

The LDSF collects data on biophysical variables across as range of indicators (Figure 10.1) that might hinder successful agricultural practices. This include soil assessment, monitoring and evaluation as well as biophysical baseline at landscape level to advice rehabilitation measure to recover soil

The data can predict soil organic carbon and soil erosion and provide complete picture at a landscape level.

The methodology is designed to provide a biophysical baseline at landscape level, and a monitoring and evaluation framework for assessing processes of land degradation and the effectiveness of rehabilitation measures over time.

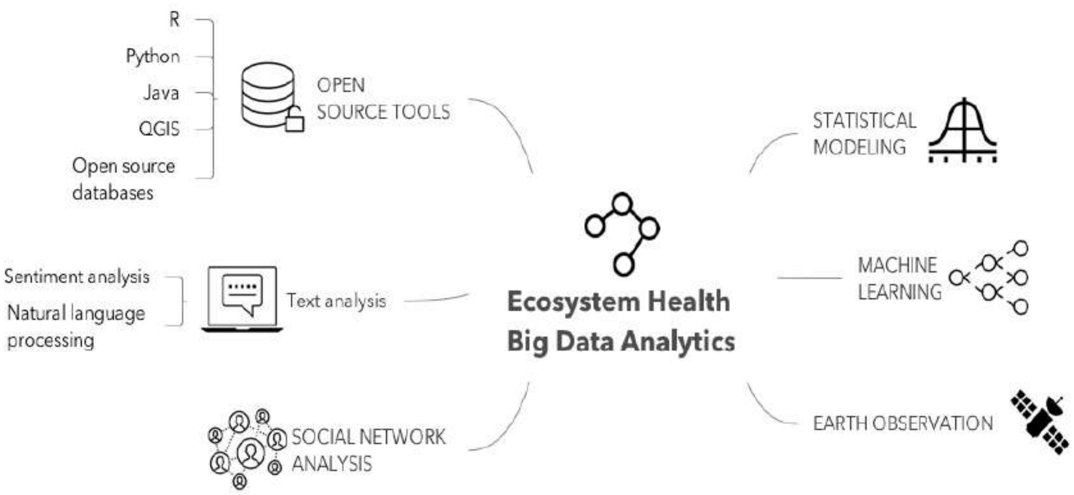
Figure 10.1 Indicators of the Land Degradation Surveillance Framework



Source: http://landscapeportal.org/blog/2015/03/25/the-land-degradation-surveillance-framework-ldsf/

A range of different analytical tools and approaches are used as part of the LDSF, including highly specialized use of earth observation data (Figure 10.2).

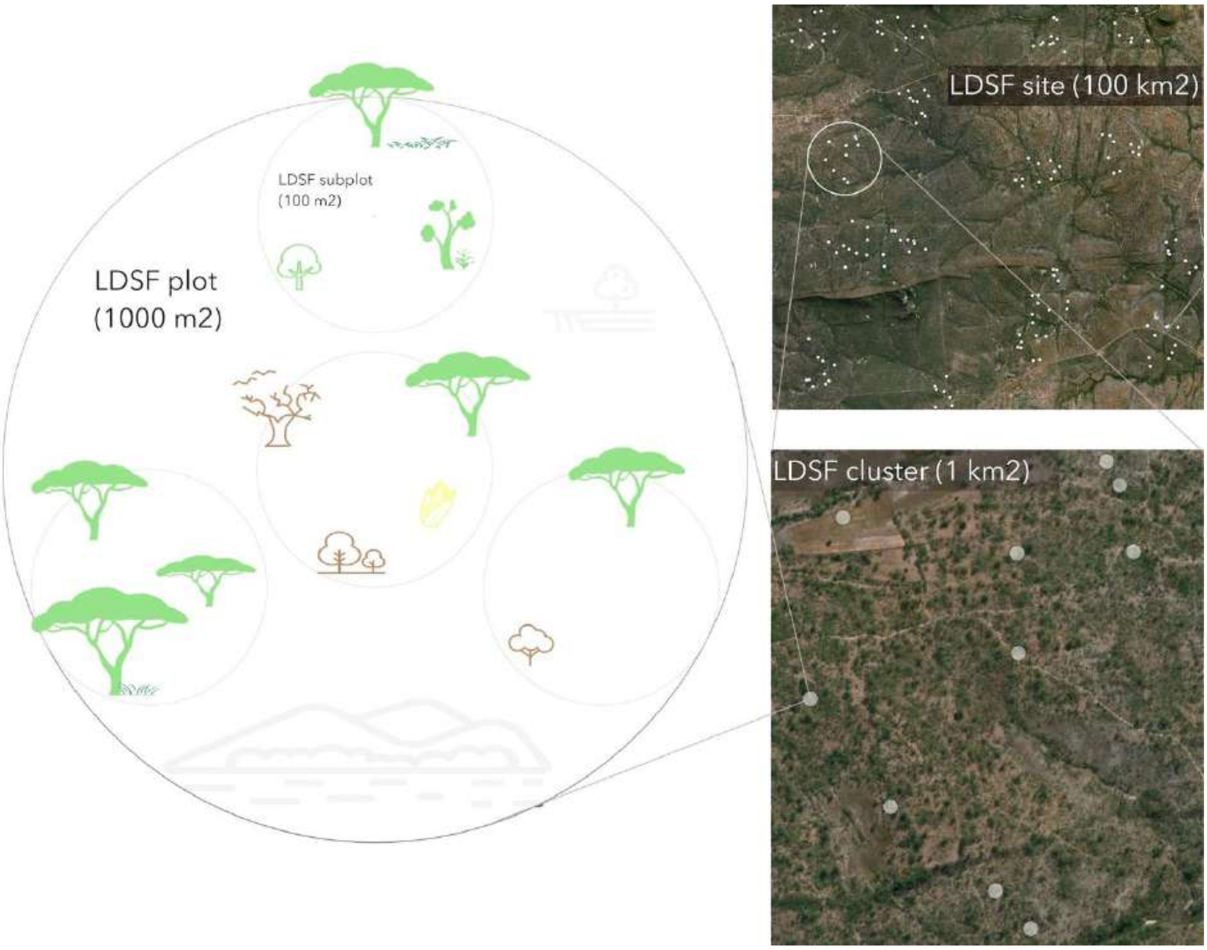
Figure 10.2 Tools and approaches of the Land Degradation Surveillance Framework



Source: http://landscapeportal.org/blog/2015/03/25/the-land-degradation-surveillance-framework-ldsf/

The framework is built around a hierarchical field survey and sampling protocol using sites that are 100 square km (10 x 10 km; picture 10.1). The sites may be selected at random across a region or watershed, or they may represent areas of planned activities (interventions) or special interest.

Picture 10.1 Sampling design



Source: http://landscapeportal.org/blog/2015/03/25/the-land-degradation-surveillance-framework-ldsf/

Mapping outputs are produced at multiple spatial scales, with fine-resolution maps produced at 5 to 10 m or higher resolution, high resolution maps at 20 to 30 m and moderate resolution maps at 250 to 500 m resolution.

The LDSF has been employed in a number of countries across the global tropics (map 10.1).

Map 10.1 Application of the Land Degradation Surveillance Framework

Source: http://landscapeportal.org/blog/2015/03/25/the-land-degradation-surveillance-framework-ldsf/

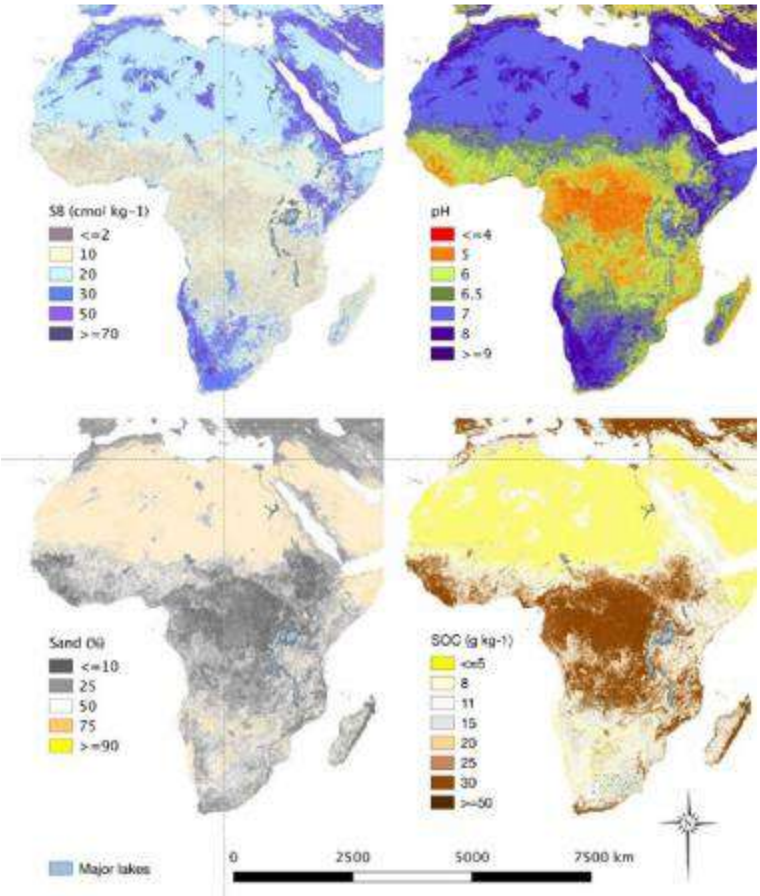
Field and laboratory data collected using the LDSF are stored in open source databases (principally MySQL and PostgreSQL), hosted at the World Agroforestry Centre (ICRAF).

Anyone who is interested in using the LDSF can do so, by collecting and entering data into the system using mobile. For more detail DOWNLOAD THE LDSF FIELD GUIDE! And to share ideas and experiences on landscape level applications of GeoScience, as well as modeling and mapping in general, you can use the Landscapes Portal blog: http://landscapeportal.org/blog/2015/03/25/the-land-degradation-surveillance-framework-ldsf/

Systematic field and lab data collection and analysis methods and rigorous data analytics, applying spatial assessments and maps in real decision contexts, enable identifying the processes of land degradation as well as options for land restoration.

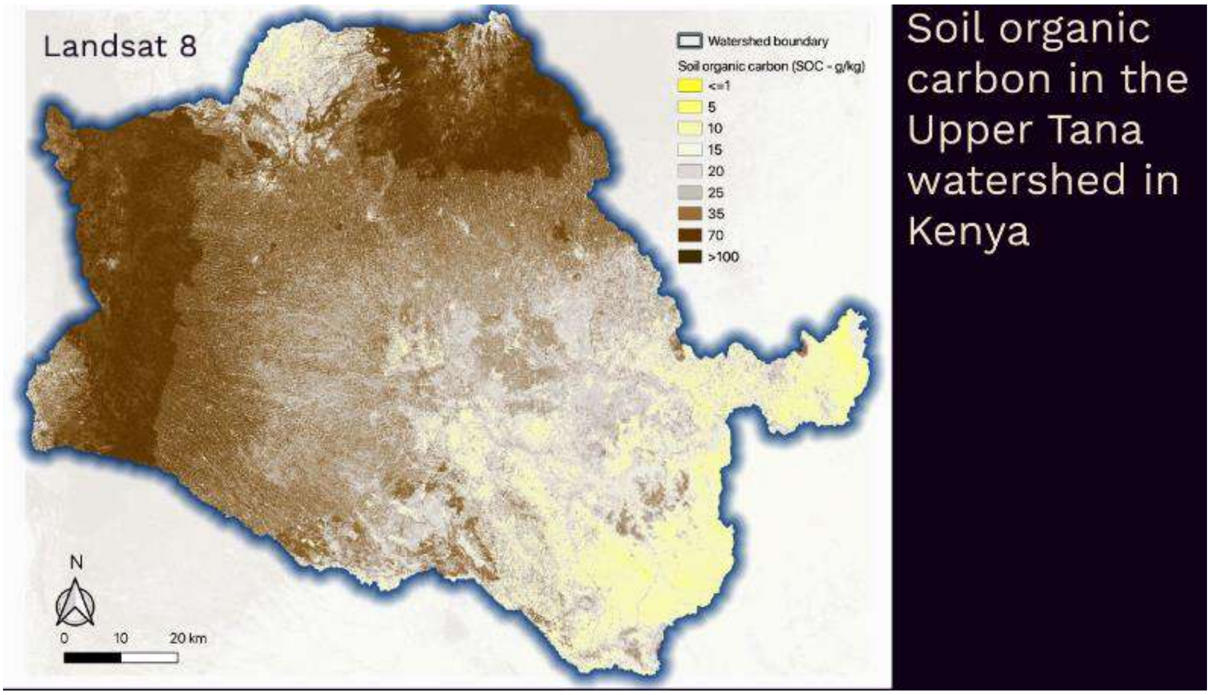
LDSF enables mapping of soil properties and land degradation, assessing carbon and soil erosion as well as targeting interventions to restore soils, improve carbon capture, combat soil erosion, and increase productivity (pictures 10.2-5).

Picture 10.2 Mapping of soil properties and land degradation in Africa using MODIS reflectance



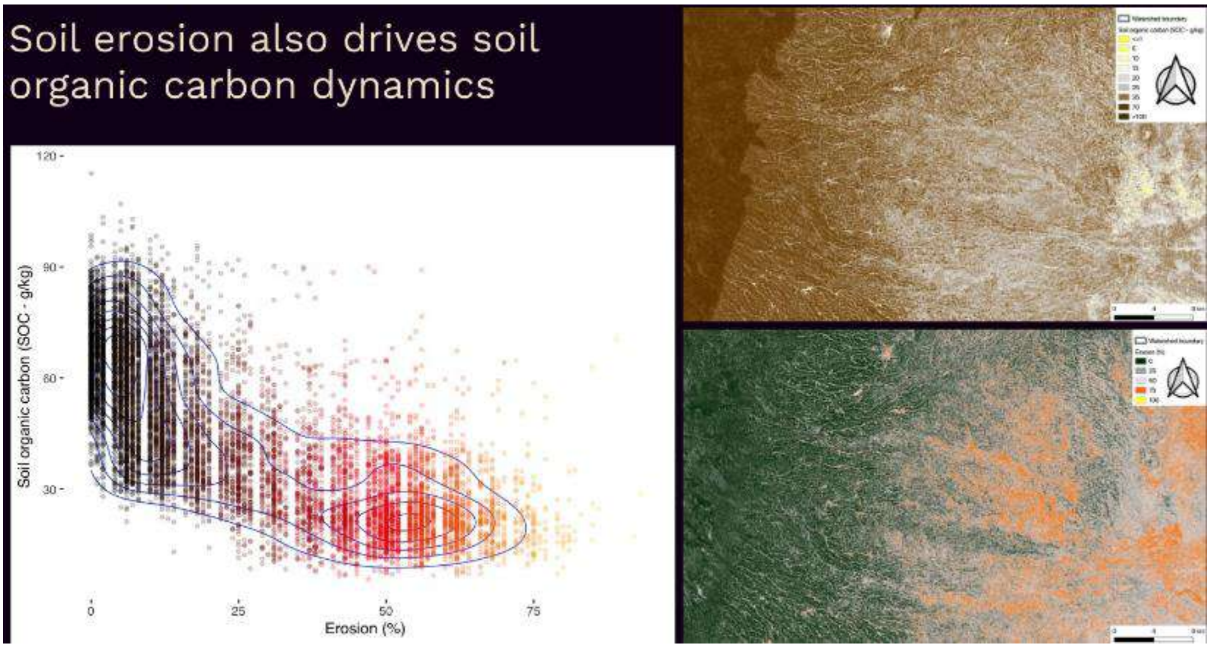
Source: Presentation of Vågen, T. and Winowiecki, L, ICRAF, Nairobi, December 2018.

Picture 10.3 Assessing soil carbon in landscapes at multiple spatial scales



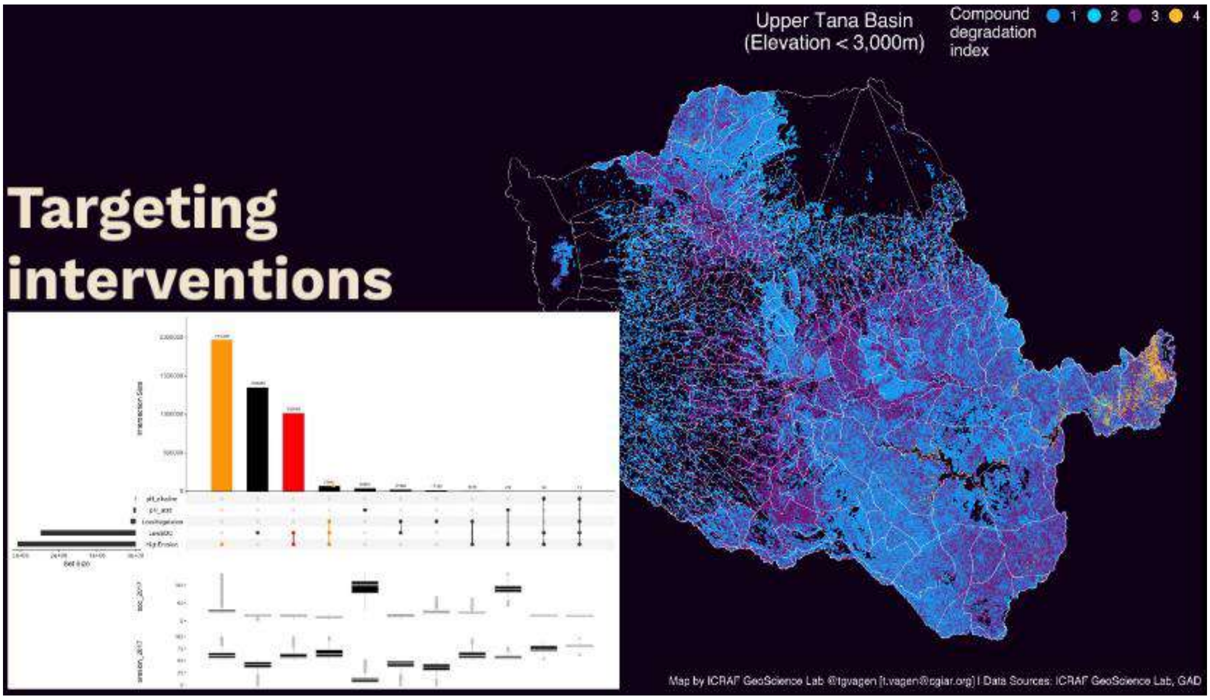
Source: Presentation of Vågen, T. and Winowiecki, L, ICRAF, Nairobi, December 2018.

Picture 10.4 Soils erosion



Source: Presentation of Vågen, T. and Winowiecki, L, ICRAF, Nairobi, December 2018.

Picture 10.5 Target interventions



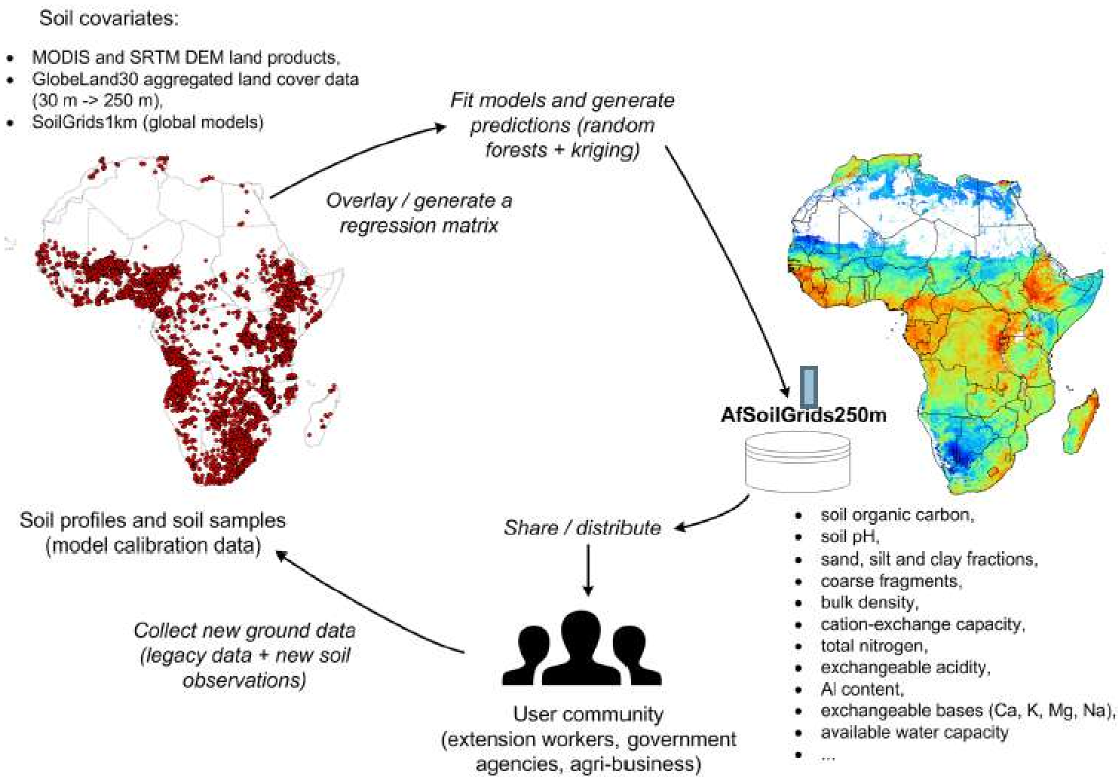
Source: Presentation of Vågen, T. and Winowiecki, L, ICRAF, Nairobi, December 2018.

ICRAF spectral lab network

ICRAF has established a wide spectral lab network, including:

- NARS: Ethiopia (7), Nigeria (3), Tanzania (>6), Ghana, Benin, Cameroon, Cote D'Ivoire (2), Kenya, Malawi, Mali, Mozambique, South Africa, Peru, India
- Private sector: CNLS, Mauritius Sugar, China phosphate mine, Soil Cares, OCP, Amplus Foods
- CGIAR: Africa Rice, CIMMYT, IITA
- International: NRCS, CSIRO, Rothamsted (reference lab for dry spectroscopy calibration), Global Soil Partnership

Picture 10.6 ICRAF's spectral lab network in Africa



Source: Presentation of Ermias Betemariam & Erick Towett, ICRAF, Nairobi, December 2018.

There is a widening range of instruments available (picture 10.7).

Picture 10.7 Instrument developments

Dispersive VNIR FT-MIR Robotic FT-MIR Portable

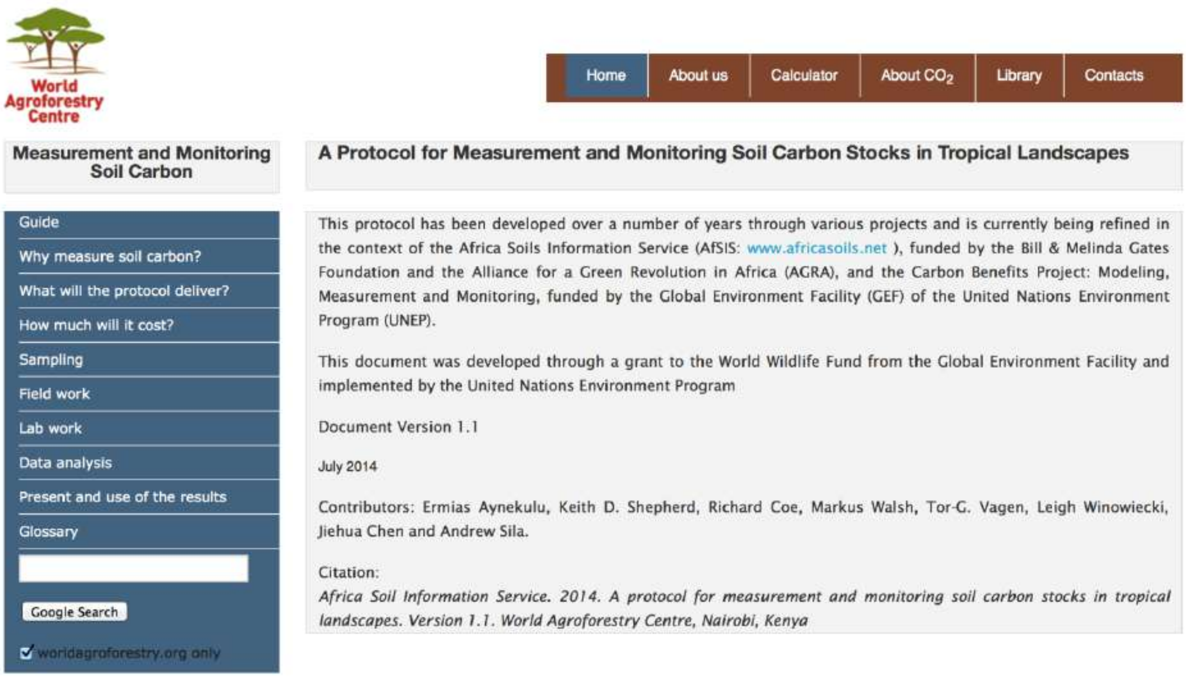
Source: Presentation of Ermias Betemariam & Erick Towett, ICRAF, Nairobi, December 2018.

Measuring, reporting and verification (MRV): land health out-scaling projects

Measuring, reporting and verification (MRV) of climate mitigation actions thought Nationally Appropriate Mitigation Actions (NAMAs) is one major outcome of the Bali convention (United Nations, 2007). MRV gives opportunities to developing countries to claim financial, technical and capacity building support from developed countries to implement their NAMAs. Understanding these benefits, a growing number of developing countries (e.g. Algeria, China, South Africa, Indonesia, Costa Rica) have drafted, adopted and, in some cases, started implementing national climate action plans (Fransen et al., 2008). However, lack of a robust method of measuring NAMAs and the technical gaps pose serious challenges for developing countries (Ellis and Larsen, 2008).

The aim of the protocol (picture 10.8) is to provide practical and cost-effective methods for measurement and monitoring of soil carbon stocks in landscapes.

Picture 10.8 Online- soil carbon measurement protocol



Source: http://www.worldagroforestry.org/soc , in presentation of Ermias Betemariam & Erick Towett, ICRAF, Nairobi, December 2018.

The land health work is rapidly taking off at every level of scale (pictures 10.9-12):

- Continental scale: Africa Agricultural Monitoring System and there are new opportunities to expand into a set of nine major river basins across the tropics; .
- Regional scale Tibetian Plateaux-Mekong transect, the Great Green Wall Project;
- National scale: AfSIS is now moving to support national soil health surveillance systems.
- Project level: the land health surveillance methods are supporting intervention targeting and impact assessment in an increasing number of projects, including SLM in Cameroon, food security in Malawi, rangeland carbon in East and West Africa, the smallholder cocoa project in Cote D'Ivoire, and climate change adaptation and mitigation projects in Kenya and Tanzania. The framework is becoming a standard inclusion in new ICRAF land management projects.

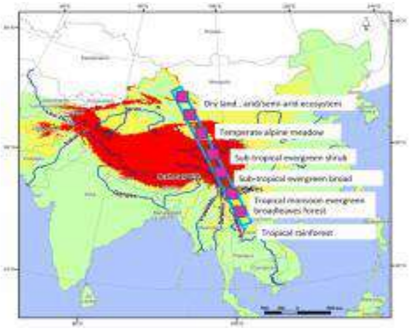
Picture 10.9 Global-continental monitoring systems

Vital signs

Source: Presentation of Ermias Betemariam & Erick Towett, ICRAF, Nairobi, December 2018.

Picture 10.10 Regional information systems

Tibetan Plateau/ Mekong   Evergreen Ag / Horn of Africa



Source: Presentation of Ermias Betemariam & Erick Towett, ICRAF, Nairobi, December 2018.

Picture 10.11 National surveillance systems

Ethiopia

Source: Presentation of Ermias Betemariam & Erick Towett, ICRAF, Nairobi, December 2018.

Picture 10.12 Project baselines

Rangelands E/W Africa

Parklands Malawi

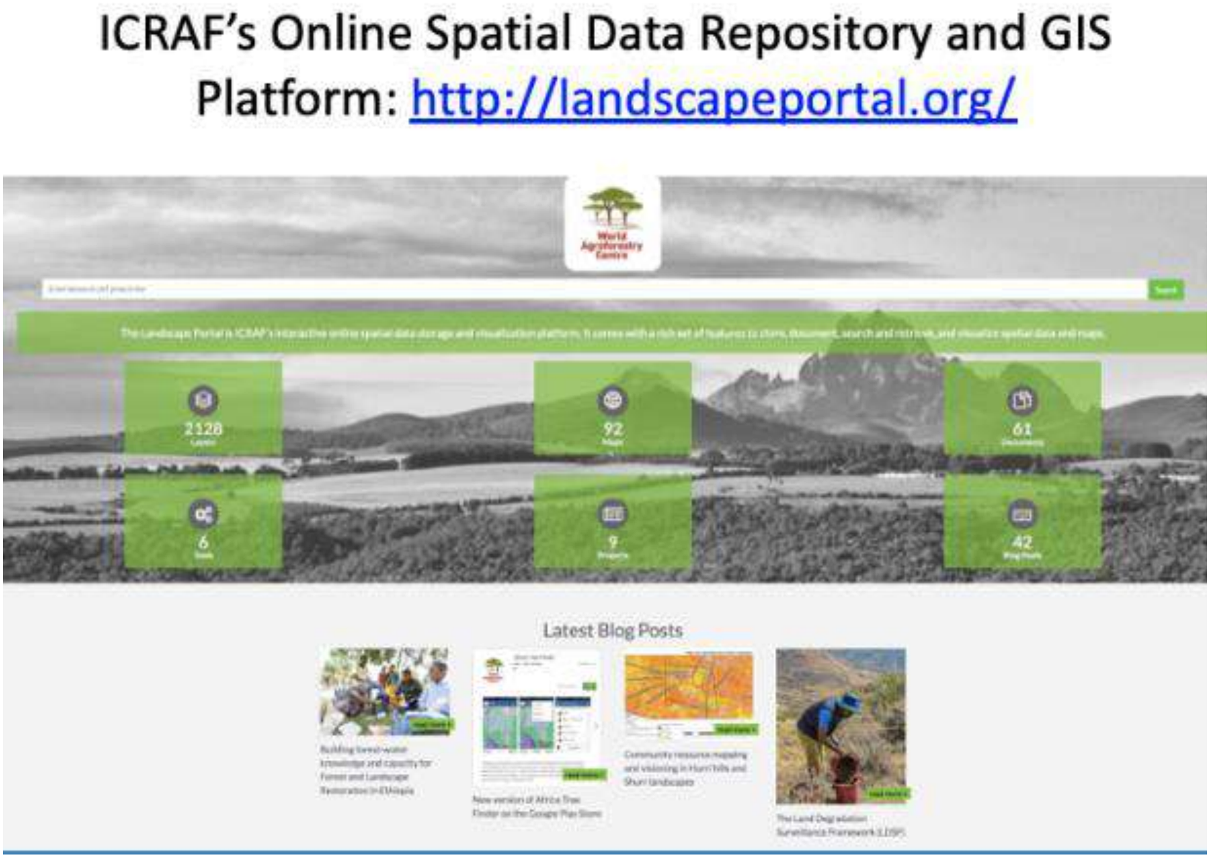
Source: Presentation of Ermias Betemariam & Erick Towett, ICRAF, Nairobi, December 2018.

ICRAF's online spatial data repository and GIS platform

The Landscape Portal is ICRAF's interactive online spatial data storage and visualization platform. It comes with a rich set of features to store, document, search and retrieve, and visualize spatial data and maps. By January 2019, it comprises 2129 layers, 94 maps, 61 documents, 7 tools, 9 projects and 42 blog posts.

Online spatial data repository and GIS platform enable the application of GeoScience in real decision contexts, such as climate change adaptation, hydrological effects of changes in climate and land cover, targeting of agroforestry interventions, provision of soil fertility and surveillance advisory services for smallholder farmers, digital soil and land use/cover mapping, and measuring impacts of interventions, all using open source software.

Picture 10.13 ICRAF landscape portal



Source: http://landscapeportal.org/tools

Online decision-making dashboard

A dashboard is a visual display of interactive information and data in a central online point. Dashboards allow information and data to be quickly and easily communicated to key users and decision makers. Decision dashboards are customized to the context and user. They can include quantitative and qualitative information shown in a range of visualizations that work best for the target audience, such as graphs, charts, photographs, videos, documents, and maps. Designed by users for users, decision dashboards aim to allow trends and links to be drawn between information not often seen together, in order to inform decision-making (example of Malawi, picture 10.14).

Picture 10.14 Malawi Agroforestry and Land Health Dashboard

Source: Presentation of Leigh Ann Winowiecki, Tor-Gunnar Vågen, Mieke Bourne, Muhammad Ahmad, Bernard Onkware, Anthony Njogu, Christine Magaju, ICRAF, Nairobi, December 2018.

Challenges to carbon monitoring

- **Costs of monitoring:** Large data sets required, which is expensive. Strategies to reduce the cost of soil carbon monitoring include lengthening the sampling interval, increasing the efficiency of sampling through stratification, pooled sampling, use of *in situ* analytical methods, and the use of biogeochemical models (World Bank 2012),
- **Accuracy:** There is an increasing demand for soil data at fine spatial resolution. To reduce costs, it is important to define the purpose of data collection before measuring,
- **Dynamics:** One-time data measurement is only a snapshot of reality. Continuity in data collection and analysis is needed to see the full picture,
- **Comparability and up-scaling:** The methods, e.g. at the national level, are to be comparable but appropriate to the local circumstances,
- **Inter-disciplinarity:** Social, biophysical and economic analysis is needed to identify problems and to provide meaningful solutions,
- **Availability:** Several *in situ* soil carbon analytical methods are being developed. However, most of the *in situ* techniques are still in their infancy. The exception is infrared spectroscopy currently being used to develop a spectral library for soils of the world, developed by ICRAF (World Bank 2012).

Further reading

ICRAF's online decision-making dashboard. Available online: http://www.worldagroforestry.org/output/decision-dashbaords [accessed Jan 20 2019].

ICRAF's Land Degradation Surveillance Framework. Available online: http://landscapeportal.org/blog/2015/03/25/the-land-degradation-surveillance-framework-ldsf/ [accessed Jan 20 2019].

ICRAF's LDSF fieldwork guide. Available online: DOWNLOAD THE LDSF FIELD GUIDE HERE! [accessed Jan 20 2019].

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Vågen, T. and Winowiecki, L. (2019) Assessing Soil Carbon in Landscapes at Multiple Scales. ICRAF Presentation. Available online: https://prezi.com/view/xo4wVc3PlqsVVXWEyBCK [accessed Jan 20 2019].

World Bank (2012) Carbon sequestration in agricultural soils, World Bank report 67395-GLB. Available online: http://documents.worldbank.org/curated/en/751961468336701332/pdf/673950REVISED000CarbonSeq0Web0final.pdf [accessed Feb 11 2019].

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