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Kenya Agricultural & Livestock Research Organization

THE KENYA CEREALS ENHANCEMENT PROGRAMME - CLIMATE RESILIENT AGRICULTURAL LIVELIHOODS (KCEP - CRAL) WINDOW

Climate Smart Extension Manual

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The information presented in this manual is for advisory use only. Readers using the manual should verify details that relate to their agro-climatic zones from their area agricultural extension officers.

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FOREWORD

Kenya Agricultural and Livestock Research Organization (KALRO) is one of the key partners in the Kenya Cereals Enhancement Programme - Climate Resilient Agricultural Livelihoods Window (KCEP-CRAL) Programme funded by the European Union (EU) and implemented by the International Fund for Agricultural Development (IFAD). KALRO participation in this programme is based on proven experience and expertise in agricultural research. Within the programme, KALRO handles the research component, conducting on station and on farm trials, develops farmer recommendations together with training materials for extension staff and service providers and conducts the training. The implementation of KCEP-CRAL is in thirteen (13) counties namely Nakuru, Nandi, Trans Nzoia, Kakamega, Bungoma, Kitui, Tharaka-Nithi, Embu, Machakos, Makueni, Taita Taveta, Kwale and Kilifi.

KCEP-CRAL focuses on the three leading rain-fed cereals (maize, sorghum and millet) and associated pulses (beans, green grams, cowpeas and pigeon peas). The programme's overall objective is to contribute to the reduction of rural poverty and food insecurity of smallholder farmers.

Through this manual, the programme will provide a comprehensive guide to extension officers, service providers and lead farmers on how to successfully produce cereals and pulses in Kenya. The manual is a useful training and reference material for extension officers and other stakeholders seeking to enhance the capacity of farmers, increase commercialization for food security and promote gender inclusion and participation along the commodity value chains.

Initial lessons learnt in this project indicate that enhancing the capacity of the extension staff and service providers has improved uptake of new technologies for dry land farming. It has opened up more land for farming through use of conservation agriculture in areas that hitherto were not under agriculture. Besides easing the pressure on previously arable land, farmers in the project areas have been trained to use alternative disease and pest management regimes using Integrated Disease and Pest Management and Push pull technologies for persistent pests of economic importance.

On behalf of KALRO, I am grateful to the European Union for supporting this project through the IFAD and KCEP-CRAL of the Ministry of Agriculture, Livestock, Fisheries and Cooperatives (MoALF&C). I also appreciate the excellent coordination of the whole process by the KCEP-CRAL Secretariat led by Dr Anthony O. Esilaba, MoALF&C and other partners, scientists in participating centres, Knowledge, Information and Outreach Unit team and secretarial staff. It is my hope and desire that in using this manual, the expectations of all stakeholders will be met.

Eliud K. Kireger, (PhD, OGW)

DIRECTOR GENERAL, KALRO

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ABBREVIATION AND ACRONYMS

AR	IPCC's Assessment Reports (4 and 5)
ASALs	Arid and Semi-Arid Lands
ASDS	Agriculture Sector Development Strategy
CC	Climate Change
CCAFS	Climate Change, Agriculture and Food Security
CO2	Carbon dioxide gas
CSA	Climate smart agriculture
CV	Climate variability
EIA	Environment Impact Assessment
FAO	Food and Agriculture Organization of the United Nations
FYM	Farm Yard Manure
GDP	Gross Domestic Product
IFPRI	International Food Policy Research Institute
IPCC	Inter-governmental Panel on Climate Change
KCCAP	Kenya Climate Change Action Plan
MAM	March to May long-rains season
MENR	Ministry of Environment and Natural Resources
MTCO2e	Metric tons of carbon dioxide equivalent
NCCAP	National Climate Change Action Plan
NCCRS	National Climate Change Response Strategy
NDMA	National Drought Management Authority
NPBM	National Performance and Benefit Measurement System
OND	October to December short-rains season
SSA	Sub-Saharan Africa
UNFCCC	United Nations Framework Convention on Climate Change
WII	Weather Index-based Insurance

1 BACKGROUND INFORMATION

Climate change is real and has become an obstacle to achieving sustainable development across the world. Climate change has both positive and negative effects in agriculture depending on the regions of the world. The negative impacts are expected to be more serious in the developing countries, particularly those in sub-Saharan Africa (SSA) such as Kenya. For instance, Kenya has experienced increasing temperatures from 1960's, together with high frequency and intensity of extreme weather events such as El Niño and La Niña. The effects of the negative impacts include declining agricultural productivity and loss of crops, livestock, fish and investments in agriculture due to changing temperatures and rainfall and many other extreme weather events.

Kenya's agriculture is largely rain-fed and therefore is exposed to vagaries of climate change and variability. Agriculture is both impacted by climate change but also contributes to the causes of climate change by being a source of Greenhouse Gases. It accounts for one-third of Kenya's total emissions and is projected to increase from 20 MtCO2e in 2010 to 27 MtCO2e by 2030. Besides climatic change, the agriculture sector is affected by increasing population and demand for natural resources. Farmers need to increase incomes and enhance food security. They face the challenge of increasing overall productivity and market competitiveness of the produce, while preserving an efficient natural resource base.

Agricultural production systems are expected to provide adequate and quality food; income for farmers to sustain a comfortable standard of living; and protect ecosystems both now and for future generations. This calls for climate smart agricultural practices that sustainably increases productivity; resilience or adapted to changing climatic conditions; reduces/removes greenhouse gases; and enhances the achievement of national food security and development goals.

2 CLIMATE CHANGE AND VARIABILITY

2.1 Introduction

2.1.1 What is weather?

Weather is the summary of temperature, rainfall, wind or storms patterns in a specific place on a specific day or over a short period such as a season. When someone says "it is raining a lot today," or "it has been very rainy this season," they are talking about the weather. Weather measurements include temperature, rainfall, wind and cloud conditions that are happening on that day or season. Storms occur when weather conditions are on the extreme such as in heavy rain and strong winds.

2.1.2 What is climate ?

Climate refers to the weather conditions that happen over a long period of time. When climate is measured, it takes into account the average temperature or the average rainfall or wind patterns, and how often storms happen in an area or over a long period of time, many decades or even many centuries.

Climate is a complex natural process that involve the interaction of the air, the water, and the land surface. The Earth's climate is in a state of continuous change, and has changed many times in response to various natural and human causes. The movement of air through the atmosphere that of water through the ocean also affect temperature and rainfall.

2.1.3 What is climate variability?

Climate variability is the natural fluctuation within the climate above and below the set mean parameters. It reflects the different weather conditions over a day, month, season or year. For example, if we consider rainfall in a given period in a particular region, the change may be low, meaning that there is not much difference in quantity or timing of rains from one year to another. In another region, there may be high variability, meaning that rainfall quantity swings from far below average to far above average from year to year, and the timing is unpredictable. Climate variability affects all weather conditions.

Climate variability averages out as climate over years in a steady state (Figure 1).

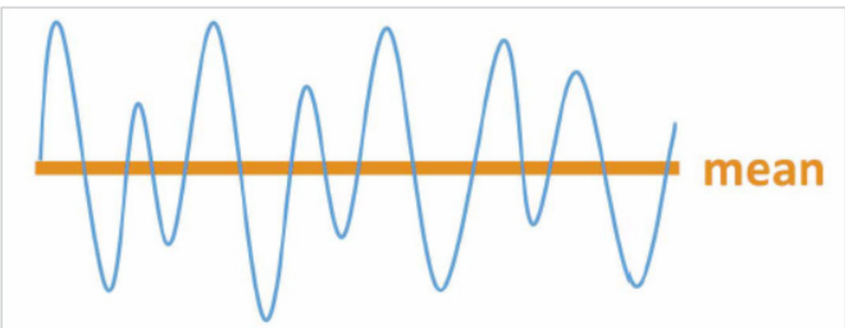


Figure 1: Climate variability around a steady mean

2.1.4 What is climate change?

The main difference between climate variability and climate change is that a trend over a time scale indicates a change in climate. While fluctuations over shorter duration such as days, seasons, years or several years and in cycles is climate variability, a consistent linear tendency will define climate change as patterns shift over decades.

Climate change is detected when the climate, climate variability and the mean exhibit significant measurable changes. For example, on average the climate gets warmer or cooler, or wetter or drier, over decades.

Climate change refers to a broad range of alterations in climatic and weather conditions. It is characterised by changes in average conditions and in the frequency and severity of extreme conditions that have occurred over a long period of time, generally over a period of 30 to 35 years. The conditions that are altered include rainfall, temperature, winds, humidity, snow, and seasons. Climate change averages out to a changing trend over decades (Figure 2).

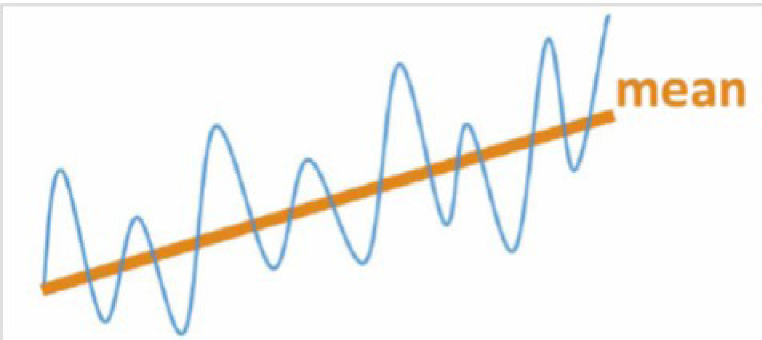


Figure 2: Climate change: Focuses on trend and mean changes

Simply put, climate change refers to changes in long-term weather patterns. It is evident that the globe is warming and the mean surface temperatures have increased.

2.1.5 What causes climate change?

Climate change is mostly caused directly or indirectly by both natural processes and human activities, that lead to the accumulation of greenhouse gases (GHGs) in the atmosphere. These activities include: industrialisation, deforestation, destruction of ecosystems (wetlands, oceans, lakes, and wildlife), agriculture and livestock production, transport, energy production, waste, urbanisation, building, and changes in land use.

The increased concentration of greenhouse gases, makes the atmosphere store more heat from the sun, thereby increasing the temperature on earth. The gases trapped in the atmosphere have increased the earth's heat, leading to temperature rise through greenhouse effect, which results to global warming. The higher the temperature, the more severe the weather conditions become. According to the Fifth Intergovernmental Panel on Climate Change (IPCC), Assessment Report of September 2013, the Earth's temperature has increased by about 0.89°C in the period 1901-2012.

2.1.6 What are greenhouse gases?

Greenhouse gases occur naturally in the atmosphere. These gases have longer wavelengths than visible light, which allows the gases to absorb and emit radiation. The most common greenhouse gases are:

a. Carbon dioxide (CO_2)

b. Methane (CH_4)

c. Nitrous Oxide (N_2O)

d. Hydroflourocarbons (HFCs)

e. Perfluorocarbons (PFCs)

f. Sulfur hexafluoride (SF_6)

2.1.7 What is greenhouse effect?

Greenhouses gases have chemical characteristics that allow these gases to capture, absorb and store heat energy for a long time. The greenhouse effect is therefore the process by which greenhouse gases absorb, reflected long wave radiation (background radiation), and raise atmospheric temperature (Figure 3).

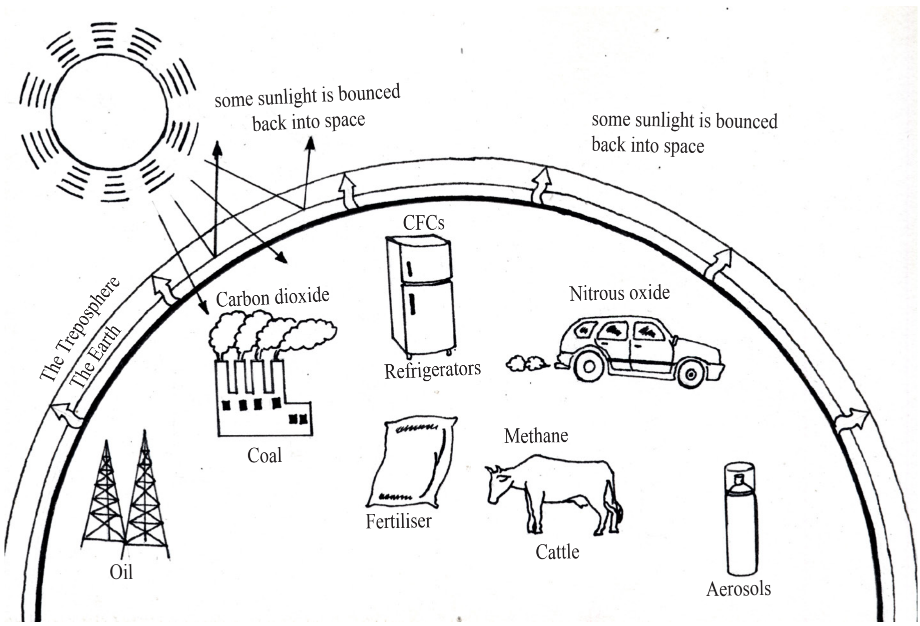


Figure 3: Greenhouse effect

2.1.8 What are the major sources of greenhouse gases?

Greenhouse gas emissions trap heat in the Earth's atmosphere, just as the glass of a greenhouse keeps warm air inside. The main human sources of greenhouse gas emissions are: fossil fuel use, deforestation, intensive livestock farming, use of synthetic fertilizers and industrial processes (Figure 4).

Natural processes such as animal and plant respiration also contribute to increase of greenhouse gasses.

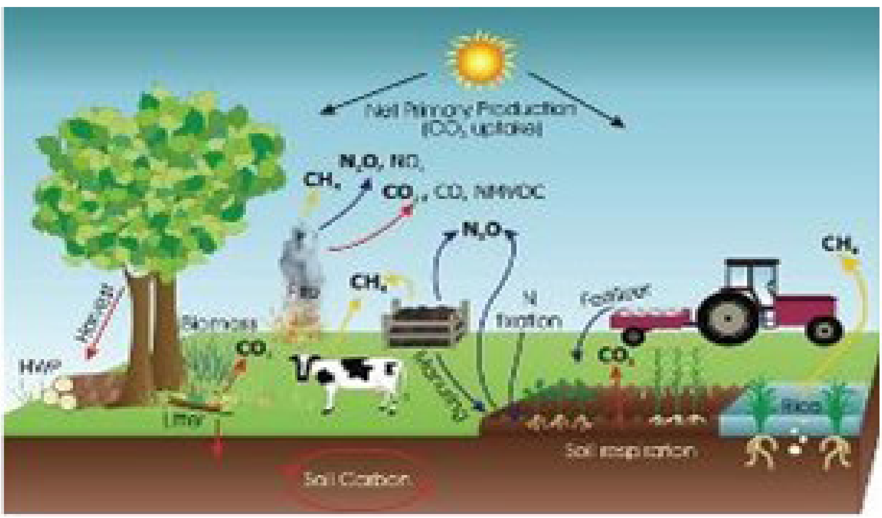


Figure 4: Climate change impacts on agriculture

Direct effect of Climate Change on agriculture

i. Complete crop failure from delayed rains or limited rains or rainfall failure

ii. Reduction of crop and livestock yield

iii. Decreasing availability of water for crop production and drinking and livestock use, drying of water sources

iv. Increasing frequency of droughts leading to crop failures, loss of pastures, loss of livestock and livestock feed supplies

v. Occurrence of frost and abrupt cold temperatures affects crop in various counties

vi. Loss of property and sources of livelihood from extreme weather events such as flash flood, windstorm, hail storms and landslides

vii. Insurgences of new pest and diseases in crops such as the Rice Blast Disease, Grey Leaf Spot of Maize and Army Worm and prevalence livestock diseases and parasites

viii. Loss of seeds and planting materials for next season planting

ix. Land degradation and loss of soil fertility due to erosion of topsoil and runoff sparked by incessant rainfall

x. Damages to key infrastructures like bridges disconnect people from far flung remote areas making them highly vulnerable to food insecurity

xi. Overall degradation of natural resources

xii. Loss of agro-biodiversity and disruption of traditional seed systems

Indirect effects of Climate change on agriculture

i. Increased crop failures and livestock deaths will lead to decreased domestic food production resulting in the increased imports of food

ii. Increase in prices of essential commodities will drive poor farmers to further poverty

iii. Increased incidence of pest and diseases on humans and animals affect their health

iv. Increased drudgery and workload on rural women due to declining access and degradation of natural resources

v. Disruption of the local seed system puts pressure on women who take the lead role in seed saving, seed selection and conservation of crop and varieties

vi. Increased rural- urban migration and fallowing of agricultural land

vii. Crop failures causes increased workload on women who are the care givers and responsible for feeding the family

viii. Reduced agricultural productivity implies lost economic opportunities at the household level and nationally

The negative impacts of climate change and climate variability on agricultural production, can be avoided through using appropriate adaptation measures which includes improved weather and early warning systems, risk management approaches and the Climate Smart Agriculture (CSA).

2.1.9 Impacts of temperature and rainfall changes on Kenya's agricultural sector

According to Farm Management Handbook of Kenya (2009), and the Atlas of Kenya's Changing Environment (2009), Kenya's average annual temperatures increased by 1°C between 1960 and 2003, while in western Kenya it rose by 0.5°C between 1981 and 2004. In the drier parts of Kenya, it went up by 1.5°C, over the same period. These changes in temperature have led to a shift of the upper altitudinal limits of Agro Ecological Zone (AEZ) boundaries by about 90m above sea level (asl). Climate predictions for Kenya (projections from baseline year 2011) show temperature increases by 1ºC by 2020 and 2.3ºC by 2050 in specific regions (Figure 5).

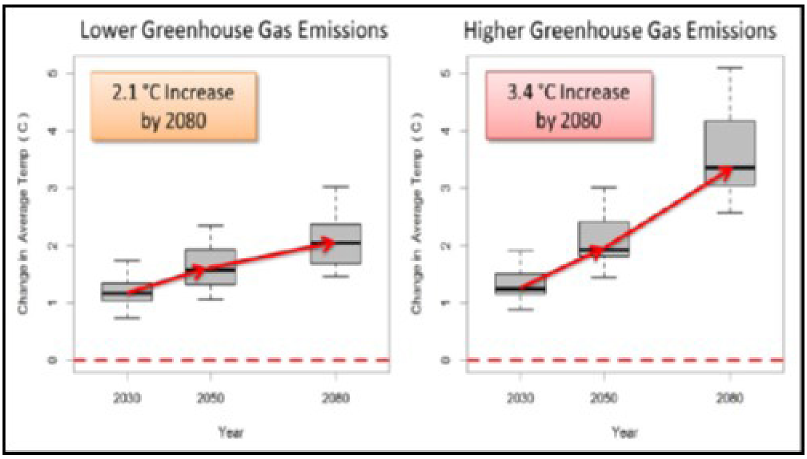


Figure 5: Climate Change impacts of temperatures in Kenya

Although precipitation is projected to increase by most climate models (Figure 6), the timing and distribution of precipitation is also changing with some months projected to decrease.

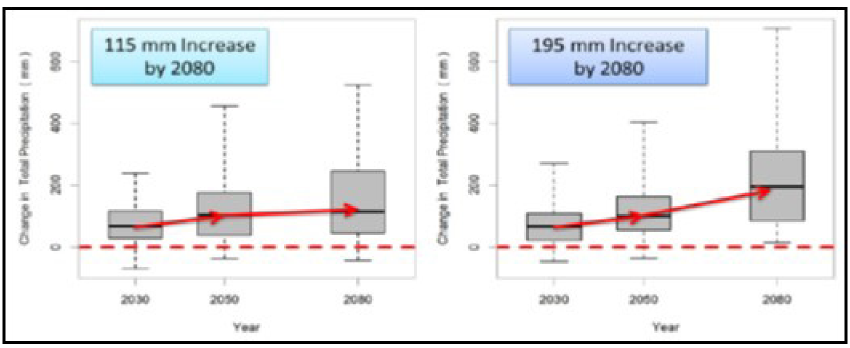


Figure 6: Climate Change impacts of precipitation in Kenya (World Bank)

The indicators of temperature changes linked to climate change include extreme maximum temperature records, warm days, warm nights and increased duration of warm spells. The mean seasonal temperatures, which is critical for crop production have also been affected as illustrated in Figure 7.

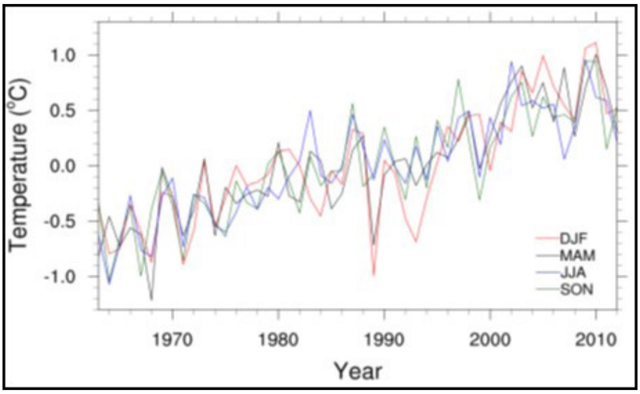


Figure 7: Seasonal temperature changes (1963-2012)

Decreases in the March to May long-rains season (MAM) rainfall season can be linked to rising temperature and have extreme impacts on agricultural production. The MAM rains have become increasingly unreliable. The high inter-annual and intra-seasonal rainfall variability experienced in many areas is accompanied by drought and flood risks.

Climatic changes are creating stress on agricultural livelihoods, while further degrading the environment. For example, recurring droughts have caused heavy losses to livestock, forcing an estimated 30% of livestock owners out of pastoralism over the last 20 years.

2.1.10 Other key terminologies relevant to climate change and variability

Adaptation - Adjustment in a natural or human system in response to actual or expected climatic stimuli or their effects that moderates harm or exploits beneficial opportunities.

Adaptive capacity - The ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Carbon sink - Any process, activity, or mechanism that removes carbon dioxide from the atmosphere. Carbon sinks include the oceans, plants, and other organisms that remove carbon from the atmosphere via photosynthetic processes.

Mitigation - A human intervention to reduce the human impact on the climate system, including strategies to reduce greenhouse gas (GHG) sources and emissions and to enhance GHG sinks.

Resilience - The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the capacity to adapt to stress and change.

Vulnerability - The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate and global change, including climate variability and extremes.

3 CLIMATE SMART AGRICULTURE AS A RESPONSE TO CLIMATE CHANGE AND CLIMATE VARIABILITY

3.1 Introduction

Rain fed agricultural production is heavily dependent on the amount and timing of rainfall, which in many areas is highly variable. On the other hand, small scale farming faces the challenge of increasing production and preservation of the natural resources at the same time. The management of land and water resources is affected by intensive soil preparation by ploughing, deforestation, removal or burning of crop residues, poor land management and inadequate crop rotations. These practices do not maintain vegetative cover or allow correct restoration of organic matter and plant nutrients and therefore leave the soil exposed to wind and rain. Climate variability and change increases already existing agricultural problems and risks. The year-to year variability of rainfall is a significant limitation to the sustainability of rain-fed farming systems.

3.2 What is Climate Smart Agriculture (CSA)?

Climate Smart Agriculture may be defined as:

i. An approach for changing and shaping agricultural development differently under the new realities of climate change.

ii. Agriculture that increases productivity, enhances resilience (adaptation), reduces/ removes GHGs (mitigation), and achieves national food security and development goals in sustainable way. This definition identifies the main goal of CSA as food security and development; while productivity, adaptation, and mitigation are identified as the other three interlinked pillars necessary for achieving this goal.

3.3 Why is CSA needed?

There are several reasons that call for the quick change of present agricultural production system to a more climate-smart and resilient production system in these times of Climate Change and climate associated problems. The following are the six important reasons:

i. The demand for food is increasing and thus more food has to be produced with the same amount of resources such as the land, water and capital.

ii. There is an overall reduction and degradation of natural resource that sustains agriculture production.

iii. Subsistence farmers are highly vulnerable to the impacts of Climate Change and there is an immediate need to adopt a more sustainable approach for adaptation to Climate Change.

iv. There is a need for enhancing food security while lowering effects of Climate Change and reducing destruction of the natural resource base.

v. With the dangers brought about by Climate Change the agricultural production systems have to be more productive, efficient, predictable, stable in their outputs and more resilient to risks, shocks and long-term climate variability.

vi. Awareness and understanding of the farming communities on the potential impacts of Climate Change on agriculture is low and must be quickly increased to build their capacity for adaptation.

Climate Smart Agriculture in anchored on 3 pillars: productivity, adaptation and mitigation as illustrated in Figure 8.

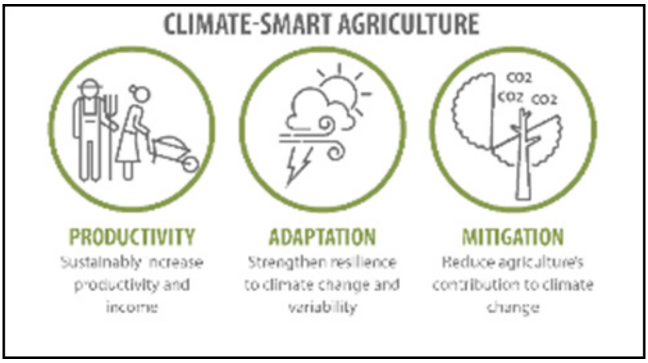


Figure 8: Pillars of CSA

(Adapted from Spore/CTA)

3.3.1 Pillars of CSA

There are three major pillars of CSA. These are:

i. **Productivity:** Climate Smart Agriculture aims to increase agricultural production and incomes while eliminating negative impacts on the environment. Resulting from this effort, there is an increase in food and nutritional security in a sustainable way.

ii. **Adaptation:** Climate Smart Agriculture targets to reduce the exposure of farmers to risks while also strengthening their flexibility by through building their capacity to adjust and grow when they encounter shocks and long-term stresses.

iii. **Mitigation:** Climate Smart Agriculture works to lower or greenhouse gas (GHG) emissions. As a result of this there is reduced emissions in production processes. We also lower deforestation from agriculture as soils and trees are managed to regulate carbon dioxide from the atmosphere.

3.4 Characteristics of CSA Approaches

i. It deals with climate change through taking note of its impacts in planning and developing agricultural systems for adoption.

ii. It incorporates multiple goals i.e. increase in productivity, higher resilience and lower GHG emissions into planning.

iii. It adopts the environmental conservation that is supportive on agricultural production.

iv. It chooses multiple technologies, innovation and management practices that work at the farm level to give the desirable level of production.

v. Being context specific, it employs different interventions for different landscapes. In so doing, it handles each landscape in a unique way.

vi. Takes into account impacts of climate change on gender and engages different stakeholders to identify the most appropriate interventions.

Climate Smart Agriculture has been framed and put forth as the concept for sustainable agricultural development for food security under Climate Change, but its core comprises of sustainable farm based agricultural land management practices (Table 1). Climate Smart Agricultural Practices discussed in this module include; conservation agriculture, water harvesting and conservation measures, integrated soil fertility management, agroforestry, integrated crop management and crop insurance.

Table 1: Examples of CSA practices in Kenya

Practice	Components	How it is climate-smart
Conservation agriculture	• Reduced tillage • Crop residue management-mulching, intercropping • Crop rotation	• Carbon sequestration • Reduction in existing emissions • Resilience to dry and hot spells

Practice	Components	How it is climate-smart
Integrated soil fertility management	• compost and manure management including green manuring • efficient fertilizer application techniques (time, method, amount)	• Reduced emissions of nitrous oxide and methane • Improved soil productivity
Small-scale irrigation	• Year round cropping • Efficient water utilization	• Creating carbon sinks • Improved yields and food security
Crop diversification	• Popularization of new crop varieties • Pest resistance, high yielding, drought tolerant, short season	• Food security • Resilience, improved incomes
Improved livestock feed and feeding practices	• Reduced open grazing, zero grazing • Forage development and range land management • Feed improvement • Livestock breed improvement and diversification	• Improved livestock productivity • GHG reduction • Methane reduction
Others	• In situ water conservation/ harvesting • Early warning systems and weather information • Alternative energy-biofuels, efficient stoves • Crop and livestock insurance • Livelihood diversification (apiculture /aquaculture) • Post-harvest technologies	• Resilience of agriculture • Improved incomes • Reduced emissions • Reduced deforestation • Reduced climate risk • Reduced losses

4 CONSERVATION AGRICULTURE (CA)

4.1 What is Conservation Agriculture?

Conservation Agriculture (CA) is a method of farming system that conserves, improves and uses natural resources more efficiently through sustainable intensification (integration) of locally available resources. The system contributes to environmental conservation as well as to enhancement of and sustained agricultural production. . It can also be referred to as resource efficient agriculture.

4.2 Why Conservation Agriculture and its Principles

Conventional agriculture involves intensive tillage and has been claimed to cause soil degradation, particularly when practised in areas of marginal productivity. The goal of CA is therefore to maintain and improve yields and resilience against crop water stress while stimulating biological functioning of the soil environment.

4.2.1 Minimum soil disturbance

The farmer tills the soil as little as possible or disturbs the soils as little as possible. The soil should only be dug where the seed, fertilizer and manure are to be placed (Figure 9). This is achieved by preparation of permanent planting basins based on the crop recommended spacing or target plant population or special seeders capable of doing this. These activities ensures minimum disturbance of the soil structure, no soil exposure or loosening, slower mineralization of organic matter and little disruption of soil life. The planting basins/hills and rip lines/rows are permanent as the farmer returns to these in subsequent seasons.

Weeds compete with the crop(s) for light, moisture and nutrients. They also push the crops out of their living space; host pests and diseases that attack the crops; reduces crop yields (if not controlled on time). Weeds should therefore be removed from the farm. Weed control without tillage makes use of pre - or post-emergence herbicide. Chemical weed control remains an important option in for minimum tillage practice. Its success is based on proper herbicide selection, timing and of herbicide application.

Benefits of minimum tillage practice

i. Improves water infiltration in the farm

ii. Promotes build-up of soil organic matter

iii. Saves time, energy, and money because less land is tilled

iv. Reduces destruction of the soil structure

v. Reduces soil degradation caused by wind and water erosion

vi. Reduces soil compaction because the crop plant roots are left undisturbed

Figure 9: Farmer opening up

4.2.2 Permanent soil cover

Crop residues, cover crops, tree biomass provides soil cover, or even biomass produced *ex-situ* (Figure 10). Cover crops can be intercropped with main crop to serve the physical attributes of soil cover, biological nitrogen fixation and mineralization from the N rich biomass. Although this could be classified as following the third principle of crop association or crop intercrop, it however needs to be emphasized that farmers who have problems of crop residues due to their multiple uses, can use cover crops to attain maximum soil cover. The cover crops include cowpeas, velvet beans, soya beans, common beans.

Benefits of permanent soil cover

i. Helps reduce direct raindrop impact and so reduces soil erosion.

ii. Helps reduce runoff and helps water to seep into the soil.

iii. Reduces evaporation and so conserves moisture for the crop.

iv. Suppresses weeds emergence.

v. The organic residues improve organic matter content and soil nutrient status.

vi. Provides a beneficial environment for soil organisms, such as worms and millipedes that are important for biological tillage.

vii. Soil temperature is regulated by the crop residues which act as heat insulators. This promotes biological activity and reduces volatilization of mineral compounds from the soil.

viii. Crop residues release trapped mineral nutrients in the stalks through mineralization and are made available to the roots of the main crop. This is cost effective as the amount of fertilizer to be applied will reduce.

ix. Soil aggregate stability and porosity increases.

x. Better conditions for the development of roots and seedling growth.

Figure 10: Maize field with good ground cover from farm retained crop/weed residues

4.2.3 Crop diversification

It is a farming system that allows growing several crops. This is done through embracing crop rotation or intercropping systems.

4.2.3.1 Crop rotation

Crop rotation is the systematic planting of different crops in a particular order over several seasons/years in the same farm unit. The process helps maintain nutrients in the soil, reduce soil erosion, and prevents plant diseases and pests. The length of rotation time between different plants depend on, the rotated crops and the farmer's economic circumstances and locally adopted farming systems. Instead of planting a single crop such as maize, farmers plant several crops in rotation. It is important to include a rotation with legumes. Rotation with legumes is essential in maintaining and improving soil fertility. Rotation also helps in breaking pest and disease life cycles.

Benefits of crop rotation

i. **Replenishes soil fertility**: Nitrogen-fixing legumes that rotated with cereals adds nitrogen into the soil. Such legumes include green grams, field beans and cow peas. Rotation with deeper rooted crops assists to "pump up" leached nutrients to the upper soil zones for use by shallow rooted crops and improves soil quality (more or deeper roots; root exudates) through better distribution of nutrients in the soil profile.

ii. **Reduces pests/diseases**: An effective crop rotation system reduce crop failure due to pests and diseases by breaking the cycle of dominant pests and diseases. It also smothers weeds if cover crops are included in the rotational arrangements.

iii. **Provision of crop residues:** Crop rotations balances production of residues by alternating crops that produce few and/or short-lived residues with crops that produce a lot of durable residues.

4.2.3.2 Intercropping

Intercropping is a system where two or more (multiple) crops are grown (companion planting) in the same farm unit same season/year making use of resources or ecological processes that would otherwise not be utilized by a single crop. The practice is most common in areas where land for cultivation is limited due to high population. An example of companion planting is the inter-planting of maize with field beans or sorghum with cowpea (Figure 11).

Figure 11: Farm showing an intercrop for maize and beans

Benefits of intercropping

i. Greater yield/increased yield and income: Intercropping offers greater financial returns for a farmer, - because of multiple types of produce, which is always for and revenue outcome.

ii. Insurance against crop damage: Intercropping may be the insurance that farmers need, especially when the region is vulnerable to weather extremes. Drought, torrential rain, hurricanes or cyclones and various other weather conditions that affects the yield of a given year or season. Having diverse yields allow the farmer to have some income even if the primary crop gets damaged or doesn't yield as much as expected.

iii. Resource sharing: A complementary sharing of plant resources, such as Nitrogen from N fixing plants.

iv. Natural weed control: Weed suppression, and a reduction in susceptibility to insects and disease.

4.3 Guiding principles for productive conservation agriculture

i. Do not plough or cultivate fields. Ploughing is unnecessary, takes time and money, and robs soil of moisture and structure.

ii. Do not burn stubble/residues from the previous crop, but retain as much of it on soil surface.

iii. Plant seed and apply fertilizer using a conservation agriculture seeders that allows planting through surface residue into narrow slits in the soil.

iv. Farmers can sow on time as no ploughing is needed.

v. Control weeds before sowing with non-selective herbicide. However, remember that this is unnecessary where there is little rain.

vi. New approaches may be needed to manage soil fertility and control pests, diseases and weeds that are different ways than in conventional systems.

vii. Use diverse crop rotations/intercrops to break the cycle of cereal pests and diseases.

4.3.1 Weed control in conservation agriculture

Farmers using CA tillage practices can either depend on hand or herbicides for weed control.

i. Hand weeding: Under hand weeding circumstances, farmers are advised pull out weeds by hand, or slash them with a slasher. One could also use a hoe for weeding, but its use is limited to shallow hoe-slashing to avoid rigorous soil disturbance.

ii. **Herbicide weed control:** Herbicides are quick and easy to apply, and do not disturb the soil. There are non-selective and selective herbicides with each being able to kill only certain types of weeds. It is important to use the right amounts of herbicides, mix them with clean water, and handle them safely. If you one considering using herbicides, get advise on how to use them the right way. Herbicides can be applied using appropriate knapsack sprayers, hand-pulled sprayer, animal-drawn sprayer and tractor-mounted boom sprayer. The following are tips for herbicide use:

a. Read, understand and follow all of the label directions when mixing and applying herbicides.

b. Make sure that the label clearly states that the product can be used in the manner that is intended to.

c. Remember, more is not better. Use the application rate on the label.

d. Herbicides are selective, and only kill certain types of plants, while others are non-selective and kill almost any type of plant. Understand pre-emergence and post-emergence herbicides before use.

e. Some herbicides persist in plants and soils for long periods of time, while others only remain for a short time.

f. Some herbicides have active ingredients that are more likely to move through soils towards groundwater. Others are much less likely to move through soils.

g. There are hundreds of different herbicides on the market. If you decide to use an herbicide to control weeds, be sure to select the appropriate product for your situation.

4.3.2 Economic benefits of conservation agriculture

i. ***Resource saving***: Fewer inputs are required before planting. Reduced ploughing saves farmers energy, labour and time. Farmers who use tractors to plough are able to reduce their fuel use for farm operations by two-thirds. Labour savings mean more time for members of the farm family to pursue other livelihood options, interests and investments.

ii. ***Time savings****:* Time savings allow farmers to plant earlier, perhaps by weeks.

iii. ***Pest and diseases control***: Crop rotation helps break crop disease cycles.

iv. ***Reduces crop failure risks*****:** Diversified crops offers expanded crop sales and lowers risk of no harvest.

v. ***Improved soil water management.*** Improved water infiltration and reduced water loss by evaporation and runoff. This improves yield even with small amounts of moisture. Refraining from ploughing can reduce evaporation loss by the equivalent of 20-30 mm, or between a fifth and a third.

vi. ***Reduction in labour use.*** In the case of animal traction, the reduction in labour when applying conservation agriculture can be as high as 86%. Time required to prepare the land using a tractor is reduced by 58% under conservation agriculture.

vii. ***Reduction in the cost of production*****.** Overall, with equal or slightly higher yields and reduced costs, the farm income increases under conservation agriculture. Production systems that use manual labour or animal traction physical exercise of the farmer is also reduced considerably. Besides a reduction in time required for field activities, the costs for operation and maintenance are also reduced. Ploughing activities are eliminated, farmers do not need heavy machinery or tractors, resulting in lower investment or write-off costs. Generally, the costs for inputs are a bit higher in conservation agriculture compared to conventional tillage, due to cover crop seeds and agrochemicals. Generally, the costs for inputs are a bit higher in conservation agriculture compared to conventional tillage, due to cover crop seeds and agrochemicals.

4.3.3 Environmental benefits of conservation agriculture

i. ***Soil health***. A core benefit is that soil that is little disturbed develops better soil structure. Good soil structure absorbs and retains water for crops more effectively. Nutrients from crop residues enables better nutrient cycling. Crop residues physically protect soil to reduce the wind and water erosion that inevitably diminishes soils left bare by ploughing. Conservation agriculture can reduce soil erosion by up to 96%. Biological activity continues uninterrupted in largely undisturbed soil, and nutrient-rich organic matter is left to accumulate there. All these factors contribute to long-term increases in yield and productivity.

ii. ***Reduced greenhouse gas emissions and water use***. Soil with higher organic matter content sequesters more carbon than does depleted soil. Reduced need for mineral fertilizers also reduces emissions.

iii. ***Cleaner surface water*****.** Improved water infiltration into healthy soil and reduced water erosion of bare ploughing soils keeps water, soil and agricultural inputs such as fertilizer, herbicides and pesticides in the field where they are needed and desired.

iv. ***Reduced loss of genetic biodiversity***. The rotation of crops and cover crops restrains the loss of genetic biodiversity, which is a consequence of mono cropping.

4.3.4 Agronomic benefits of conservation agriculture

Increase in soil organic matter. The constant addition of crop residues leads to an increase of the organic matter content of the soil. Organic matter improves fertilizer use efficiency, water holding capacity, soil tilth, rooting environment and nutrient retention. The increased organic matter content together with soil cover leads to increased water holding capacity of the soil.

4.3.5 Constraints to Adoption of Conservation Agriculture

i. Mistaken perception that soil cultivation (ploughing) is essential for high crop production.

ii. Limited availability of affordable, appropriate seeding machinery and tools that are locally produced and maintained.

iii. Limited knowledge and experience on how to adopt the CA practices.

iv. Perceptions of worsening of weed, pests and disease infestation.

v. Unwelcoming policy and extension environments.

vi. Limited local knowledge and extension expertise on CA.

vii. Pests and diseases build-up. Leaving the previous crop's stubble/residues raises the risk of plant pests and diseases surviving into the following crop, rather than succumbing to the famine that ploughing between crops creates for them.

4.3.6 Meeting the challenges of conservation agriculture

i. Weeding Pressure

Conservation agriculture generally increases weeding burden especially in the first years of implementation. For the resource poor households, lack of adequate labour and herbicides for weed control may prove to be difficult. If weeds are not controlled properly, they take over the field leading to reduced or no yield. It is important to control weeds at the right time, before they become a problem. Do not allow them to compete with the crops, and do not let them grow long enough to produce seeds. One may have to slash weeds even after harvesting the crp in order to prevent them from producing seeds.

ii. Cover crops

- Cover crops are plants/crops planted to manage soil erosion, soil fertility, soil quality, soil water, weeds, pests and diseases. Cover crops may be an off-season crop planted after harvesting the cash crop. Cover crops are chosen and must have multiple purposes and also fits into farmers cropping system. If the area receives little rainfall, select a cover crop that grows quickly, such as cowpea, lablab, lucerne, mucuna, or pigeon pea.
- One may have to weed once to give the cover crop a chance to get established. In addition, you use a post-emergence herbicide after planting maize and the legume to stop weed seedlings from emerging.
- If the rainy season is long enough, consider planting the cover crop as a relay crop. It will spread over the soil and smother weeds after harvesting the main crop.
- Make sure that the cover crop does not interfere with the main crop. For example, avoid growing taller cover crops that might shade the main crop(s). One could also prevent the cover crop from interfering with the main crops by planting it later.

4.3.7 Aspects to be considered in the CA adoption

i. *Conduct a farmer's need assessment*. Conservation agriculture as a farming system will be adapted to suit the needs of farmers. Since these needs depend on a number of factors, situational and problem analysis should be undertaken by the facilitators prior to the introduction of CA.

ii. *Plan for a good crop rotation*. Before starting with conservation agriculture one has to plan for a good crop rotation schedule.

iii. *Prepare the farmers for new habits and cropping timetable*. The focus of conservation agriculture will shift, especially in the first years towards weed control and (cover) crop residue management, and monitoring pest and disease incidence.

iv. *Set farmers realistic expectations*. Conservation agriculture is based on restoring natural occurring processes and therefore needs a conversion period before the new system is established and the natural balances are restored. It is good that starting farmers know each other and they be guided to set realistic expectations.

5 SOIL AND WATER CONSERVATION

5.1 Introduction

Many of the soil and water conservation measures used today, have existed over a long time, but information to support site specific selection of those that are appropriate for the prevailing ecological and socio-economic conditions, has not been readily available to farmers and field officers. This manual presents a compilation of simple descriptions and instructions for establishing them where they are appropriate. An accompanying summary provides useful information for farmers to make informed decisions on technologies that are appropriate for their conditions.

5.1.1 What is soil conservation?

It is the prevention and reduction of the amount of soil lost through erosion. It seeks to increase the amount of water seeping into the soil, reducing the speed and amount of water running off. Erosion is prevented by maintaining enough vegetation to protect the soil surface and bind the soil together and preserve soil structure.

5.1.2 What is water conservation?

This is a way of tapping as much water as possible and storing it in tanks or reservoirs. It allows water to sink into the soil increasing soil moisture levels. It ensures a protective cover of vegetation on the soil surface, slowing down the flow of running water and spreads the water over a large area.

5.2 Principles of soil and water conservation

Both soil and water conservation are essential practices farmers adopt on their farms to limit the loss and degradation of their farmlands. To do this, farmers need to adopt priciplees of soil and water conservation listed below:

i. ***Make effective use of soil water reserves*:** The soil stores water from rainfall providing a reserve that is available to the crop. The amount of water available depends on the soil type and the rooting system of the crop. Sandy soils hold much less water than clay or silt soils, so crops will require watering more often. Deeper rooting crops, such as grasses or cereals will exploit soil water reserves more effectively than shallower rooting crops such as vegetable crops and therefore can be grown in drier periods. Good cultivation practices (e.g. not ploughing too deep or when the soil is wet) that result in a soft, friable soil will also promote deep rooting and efficient use of soil water reserves.

ii. ***Use rainwater effectively*:** Intense rainfall downpours are not readily used by a crop. Harvesting and storage of the rainwater increases the availability of water in the drier seasons.

iii. ***Take measures to avoid run-off*:** Run-off is where water runs across the surface and is not absorbed by the soil from where the crop can use it. Structures such as contour schemes, terracing, pits and bunds can reduce run-off. Run-off is more likely to occur on silt or clay soils where the surface has been subjected to intense rainfall then baked in the sun to form a crust or cap. Adding mulch on the soil to break up the intensity of rainfall, or adding manure, compost or incorporating green manure residues reduce the tendency of the soil to form a crust.

iv. ***Reduce water losses through drainage*:** When water drains out of the soil, not only is it wasted but essential mobile nutrients such as nitrogen are also washed out. This is more of a problem on light sandy soils. Adding organic matter in the form of compost, manures or plant residues will eventually increase the amount of water a soil can retain, but this will only have an effect if it is added over a longer period of years. Most drainage occurs during the heavy rains, especially if the soil is left bare. Growing a cash or cover crop during this period reduces these losses, as the roots lift water and nutrients back from deeper to shallower soil profiles.

5.2.1 Benefits of soil and water conservation

i. Minimizes the risk of crop/production failure during droughts, intra-seasonal droughts and floods.

ii. Reduces water erosion, improves water quality, water infiltration and retention, all of which should lead to higher and less variable yields.

iii. Controlling soil erosion improves crop and pasture yields.

iv. Conserving water makes it available for crops, livestock and domestic use over a longer period.

v. They increase the value of the land.

vi. More and better livestock fodder is available.

vii. Increases water use efficiency.

5.2.2 Common Soil and Water conservation technologies

i. **Field level practices**: Bench terraces, Check dams, Contour bunds and hedgerows, 'Fanya juu' terraces, Planting Pits/Zai pits, Katumani Pits, Stone lines, Trash lines, Grass strips, Grassed waterway, Retention ditches, Cut-off Drains, Mulching and Cover crops.

ii. **Landscape level practices**: Agroforestry, Wind breaks/shelter belts, woodlots, Riparian vegetation buffer strips.

5.2.2 Field level practices

Contour - bunds and hedgerows

Contour bunds are stone or earthen walls built across a slope to prevent runoff (Figure 12) Making furrows parallel to the contours ensures that rainfall and runoff are spread evenly over a field. The earthen bund is formed by excavating a channel and creating a small ridge on the downhill side. The aim of contour bunds and hedgerows is to concentrate moisture into the ridge and furrow area where the crops are planted by trapping run off water from the catchment area between them. This also decreases the risk of erosion. Plants with higher water requirements, such as peas or beans, can be planted on the higher side of the furrow whereas cereal crops requiring less water, such as sorghum or millet, can be planted on the ridges. Hedgerows of nitrogen-fixing trees/shrubs, grasses, fruit trees or other crops can also be planted in rows along the contour.

Where suitable

i. Areas with relatively low annual rainfall (500-800 mm)

ii. Light textured soils of 1.5 to 2 m depth

iii. Gentle to moderate slopes (0.5-3%)

iv. Areas with no gullies or rills

v. Large land areas (contour hedgerows cover at least 10% of cultivated land).

Figure 12: Contour hedgerows along contour bunds in Kenya

(Black, 2014)

Design and construction

Soil is dug up-slope of the bund to a depth of 50 cm. Contour bunds should drain in one direction and can be manually or machine constructed. The length of a bund across a slope should be between 400 to 500 m (Figures 13 and 14). The height of a bund should be at least 25 cm and have an approximate spacing of 1-2 m. In arid areas, the distance between bunds can be increased to 5-10 m. Hedgerows grown to stabilize bunds should be spaced at 4 to 8 m across the slope.

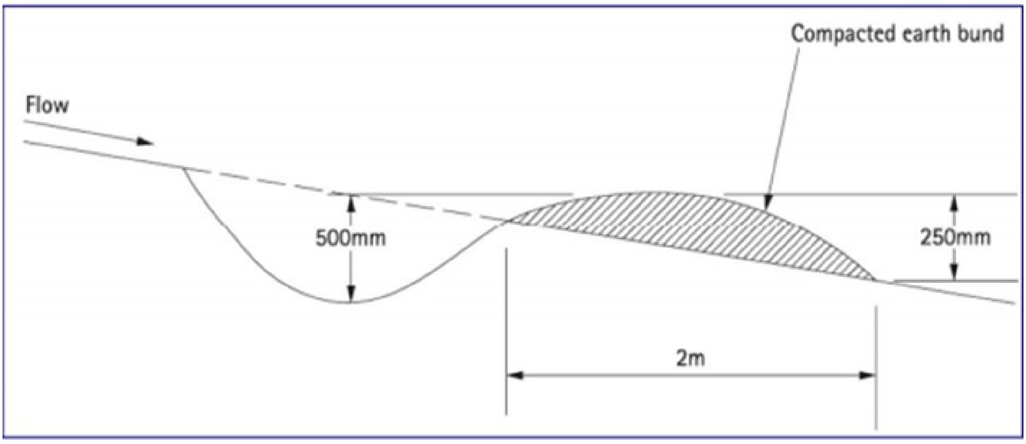


Figure 13: Cross section of a contour bund

(Reij *et. al.,* 1996)

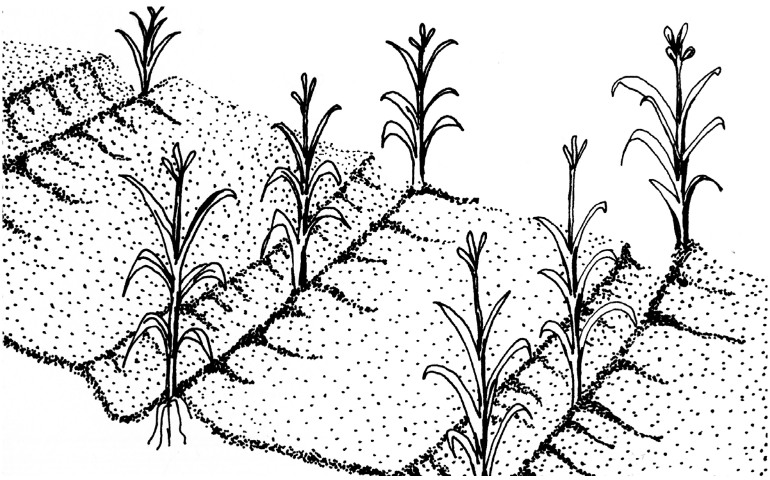


Figure 14: Crops planted along contour bunds

(Duveskog et. al., 2003)

Bench terraces

Bench terraces consist of a series of beds which are more or less level running across a slope at vertical intervals, supported by steep banks or risers (walls or bunds). The flat beds created by bench terraces enable the cultivation of crops on medium to steep slopes (Figure 15).

Where suitable

i. Semi-arid to humid regions of rainfall, 700 mm or more
ii. Medium to steep slopes (12- 47%). Bench terraces are not recommended for slopes less than 12%
iii. Soil depth of greater than 50 cm
iv. Areas with no gullies, nor stones.

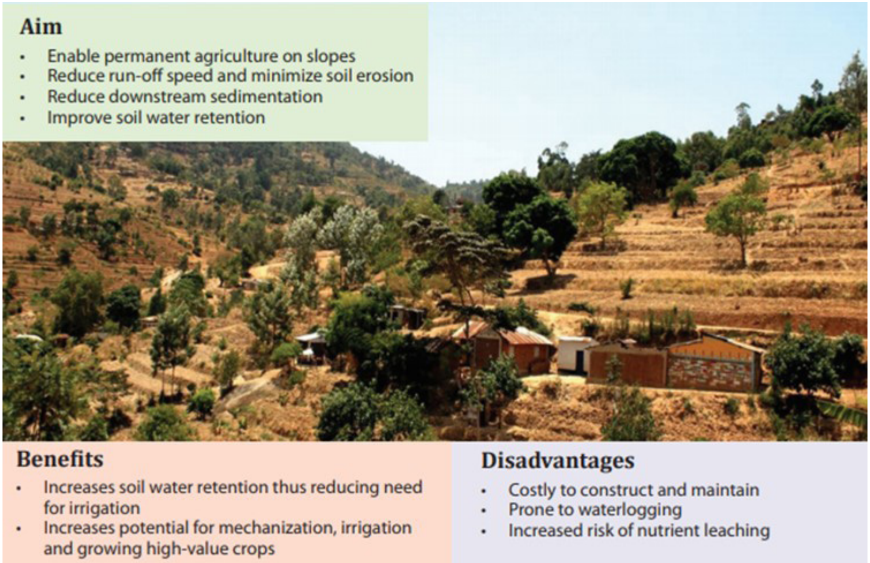


Figure 15: Bench terraces constructed along a slope in Lukenya, Machakos County in Kenya (Lukhovi, 2012)

Design and construction

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

Terraces should drain runoff along the horizontal gradient of the slope, either in outward or reverse direction (Figure 16). The outward gradient can range from 0.5% in arid or semi-arid regions to 3% in humid regions with clay soils. Maximum gradients can be 5% for reverse terraces. In high rainfall areas (more than 1000 mm annually), it is necessary to make additional drainage provisions off the terraces – although this has a risk of causing erosion on very steep slopes. These additional drainage channels should be trapezoidal in shape and planted with grass to prevent erosion. Machine construction is possible on slopes of 12-36% while manual construction can be used on slopes of 12-47%.

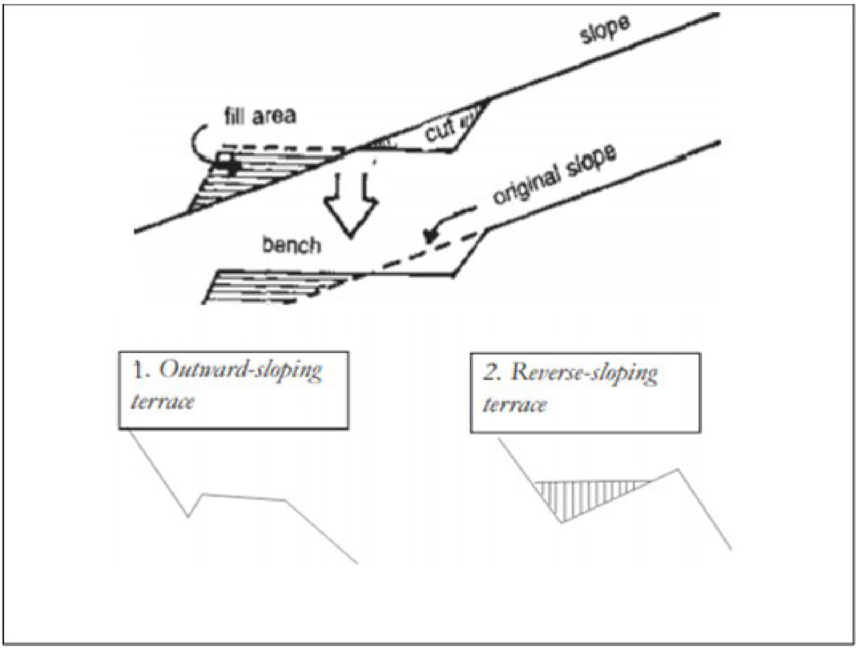


Figure 16: Bench terrace construction

Fanya juu' terraces

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

Where suitable

i. Low annual rainfall areas (less than 700 mm)
ii. Moderate slopes (less than 20%)
iii. Deep soils (more than 60 cm)
iv. Hilly areas that are subject to widespread erosion.

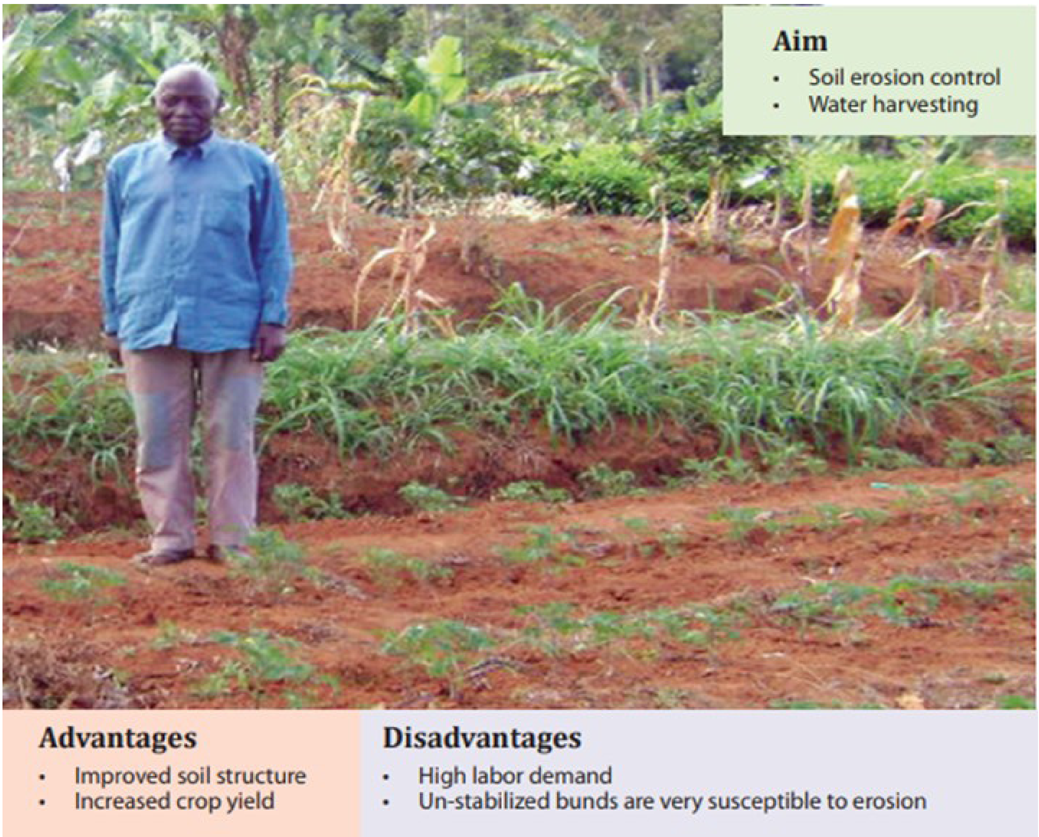


Figure 17: Fanya juu terrace in Kapingazi watershed in Embu, Kenya

(Mokua, 2007)

Design and construction

The 'fanya juu' trench is 60 cm wide by 60 cm deep, and the bund 50 cm high by 150 cm across. In arid regions the trenches can be enlarged to 150 cm deep and 100 cm wide. Distance between bunds can be from 5 m on steep slopes to 20 m on gentle slopes (Figure 18 and 19). Stone terrace walls can be built to reinforce the bunds on very steep slopes to allow surplus water to pass between the stones without damaging the terrace. Excess water can be drained from the trenches using cut-off drains.

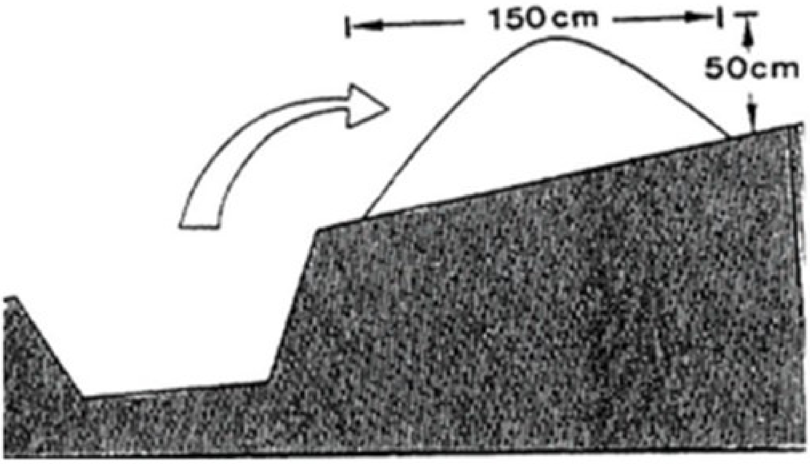


Figure 18: Construction of the fanya juu terrace

Figure 19: Banana trees planted in a fanya juu ditch in Kapingazi in Embu County

Stone Lines

Stone lines are stones placed along contour lines to slow down runoff. With time, the soil builds up on the upslope side of the stone line and a natural terrace is formed (Figure 20).

Where suitable:

i. Gentle to moderate slopes (less than 10%)

ii. Low annual rainfall areas (200 - 750 mm)

iii. Stony areas

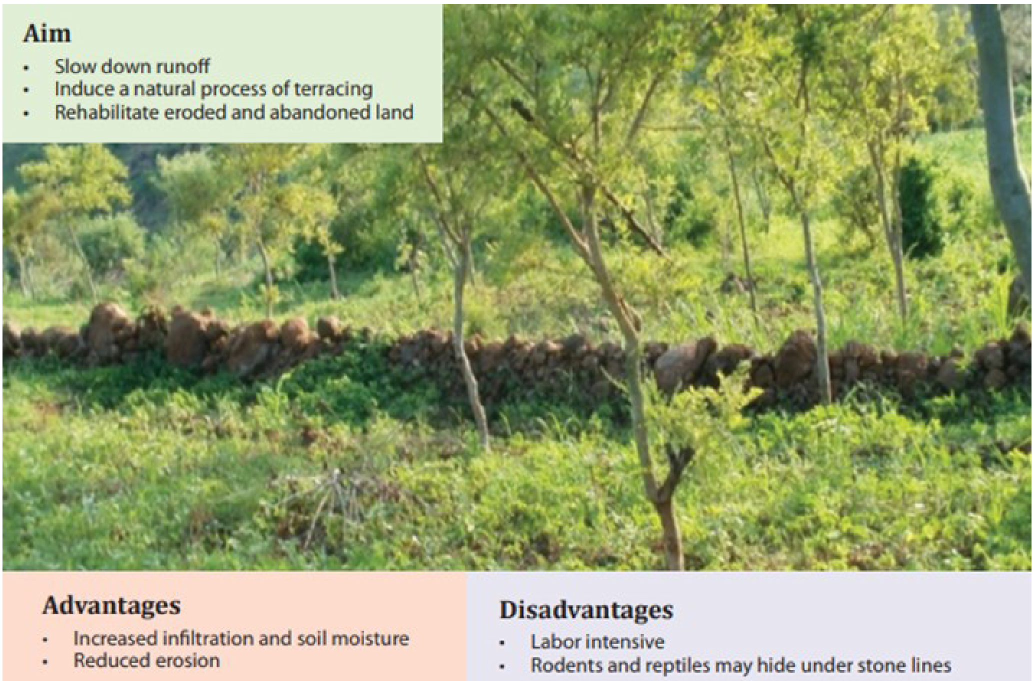


Figure 20: A close view of a stone line in in Turasha Nakuru County

Design and construction

Stone lines are 35-40 cm wide and approximately 25 cm high. Construction includes a shallow foundation trench of 5-15 cm made along the natural contour with larger stones on the downslope side of the trench and smaller stones are used to build the rest of the bund. The stone lines can be reinforced with earth, or crop residues. Stone lines are spaced 15 - 30 m apart; spacing may be reduced for slopes greater than 10% (Figure 21 and 22).

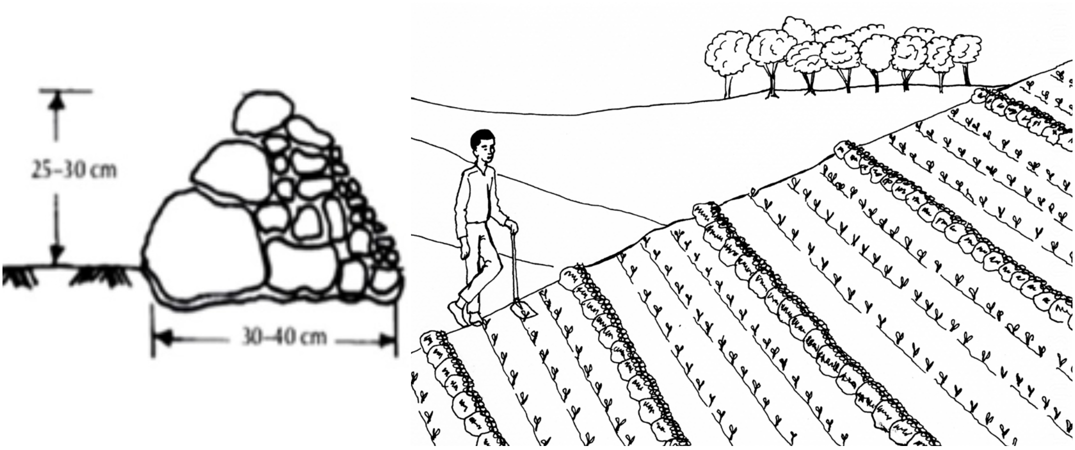


Figure 21: Cross section of a stone and Stone lines along a contour

Figure 22: Stone lines across a slope in Kibungo, Ulugurus, Tanzania

Retention Ditches

Retention ditches are designed to catch and retain incoming runoff and hold it until it infiltrates into the ground (Figure 23). They can be an alternative to waterways in high rainfall areas, but they are most often used in semi-arid areas to harvest water

Where suitable

i. Semi-arid areas

ii. Permeable, deep and stable soils

iii. Flat or gentle sloping land

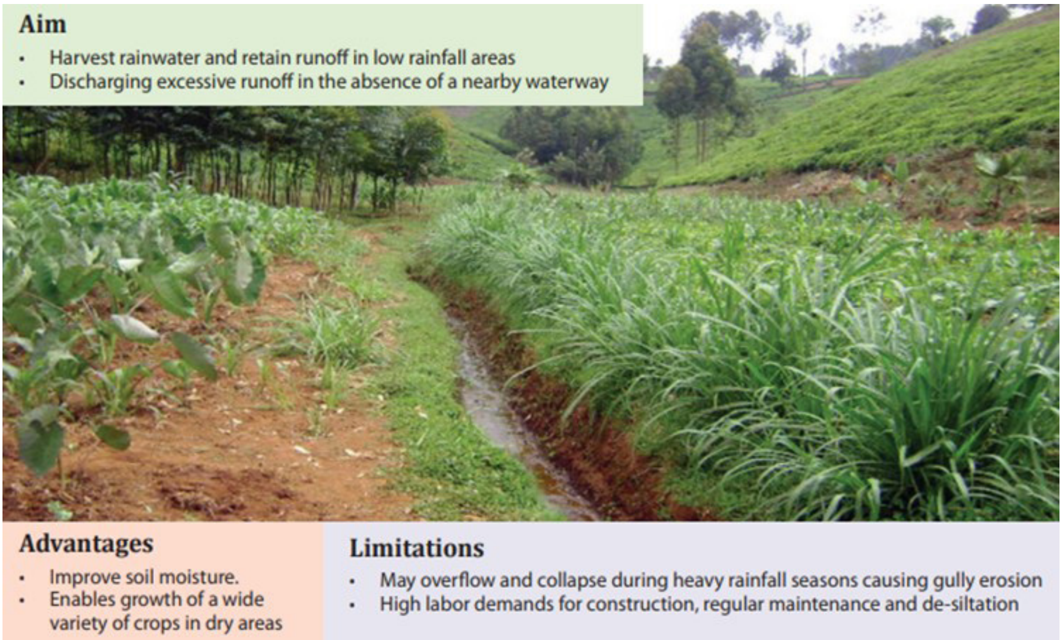


Figure 23: Retention ditch to hold runoff in Malewa in Naivasha, Nakuru County

Design and construction

The ditches are dug to about 30-60 cm depth and 0.5-1 m width across the direction of the slope. In very stable soils it is possible to make the sides nearly vertical, but in most cases the top width of the ditch needs to be wider than the bottom width (Figures 24 and 25) . The soil is thrown to the lower side of the slope to prevent it falling back in and form an embankment. On flat land, ditches are spaced at about 20m and have closed ends so that all rainwater is trapped. On sloping land ditches are spaced at 10 - 15 m intervals and may have open ends to discharge excess water.

Figure 24: Farmers' in Mulala Makueni County

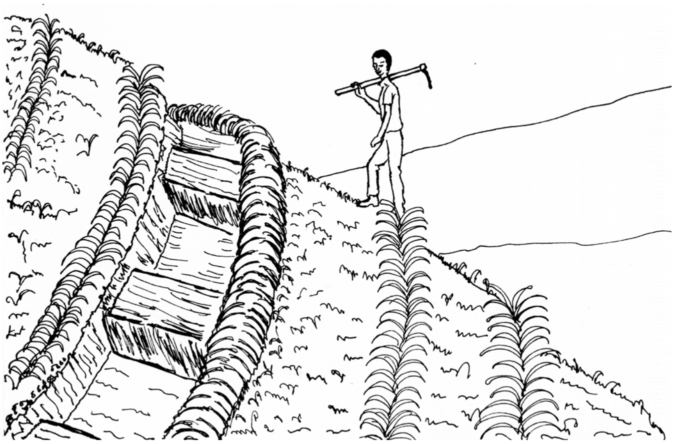


Figure 25: Retention ditch planted with banana trees

Trash lines

Trash lines (Figure 26) are formed by placing crop residues in lines across the field slope to form a semipermeable barrier to soil erosion that allows passage of excess runoff. The lines are temporary, usually seasonal and the trash can be moved into the field to exploit trapped soil fertility gains.

Where suitable

i. Semi-arid areas (400 - 750 mm)

ii. Slopes 2-30%

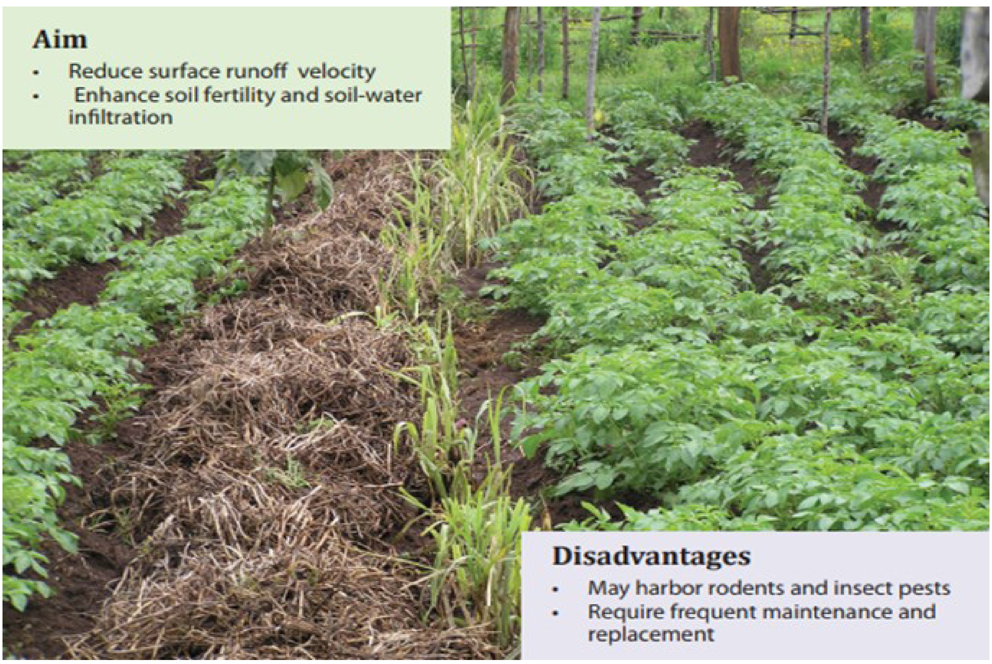


Figure 26: Trash lines on- farm in Turasha watershed in Naivasha, Kenya

Design and construction

Trash lines (typically ± 50 cm wide and ±30 cm high) are constructed mainly from sorghum and millet stovers which, compared to maize decompose slowly and are of low palatability to livestock. Spacing between trash lines is 5-10 m, depending on the slope. Trash lines can be left in place for four seasons before they are ploughed into soil (Figure 27).

Figure 27: Trash lines on a gentle slope

Grass strips

Grass strips (Figure 28, 29 and 30) are dense strips of grass planted up to a meter wide, along a contour. With time, silt builds up above the strip and benches are formed. Grass strips can be planted along ditches to stabilize them, or on the rises of bench terraces to prevent erosion. They are a popular and easy way to terrace land, especially in areas with relatively good rainfall.

Where suitable

i. Fairly gentle slopes (0 - 6%)

ii. Areas where grass is needed for fodder

iii. High rainfall areas

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

(Obwocha, 2009)

Design and construction

Spacing between grass strips depends on the slope of the land. It can be 20-30 m on gentle slopes and 10-15m on steep land. Grass strips can be planted along ditches to stabilize them, or on the rises of bench terraces to prevent erosion. The grass needs to be trimmed regularly, to prevent shading and spreading to cropped areas.

Various grass species are used, e.g., Vetiver, Napier, Guinea and Guatemala depending on what is locally available. Vetiver grass is drought resistant and good for reducing erosion.

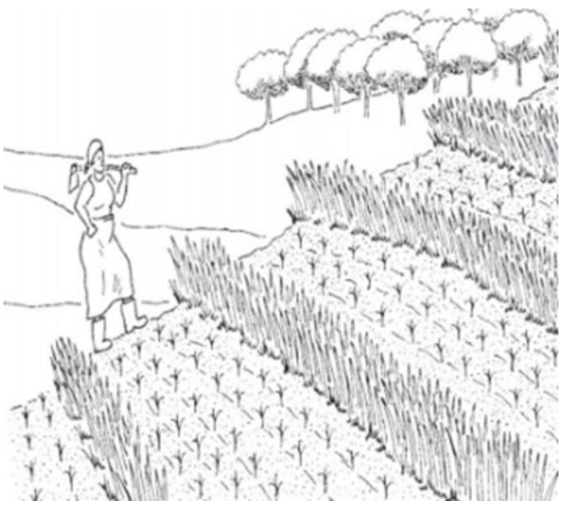


Figure 29: Grass strips along the contour

(Source: PRESA, 2009)

Check dams

A check dam is a small temporary or permanent barrier constructed of rock, gravel bags, sandbags, fiber rolls, or reusable products, placed across a gully, channel or drainage to lower the speed of flows from storm events (Figure 31). Check dams ease the slope of a gully by providing periodic steps of fully strengthened material that collect and hold soil and moisture at the bottom of the slope. Check dams enable growing of tree seedlings, shrub and grass in gullies by protecting them from being washed away by flowing water.

Where Suitable

i. Dry regions with annual rainfall of 700 mm or less

ii. Slopes of less than 2%

iii. Small streams, long gullies or small open channels that drain 4 ha of land or less

iv. Areas with a local supply of stones or the means to transport them

v. Productive land prone to gully and rill erosion.

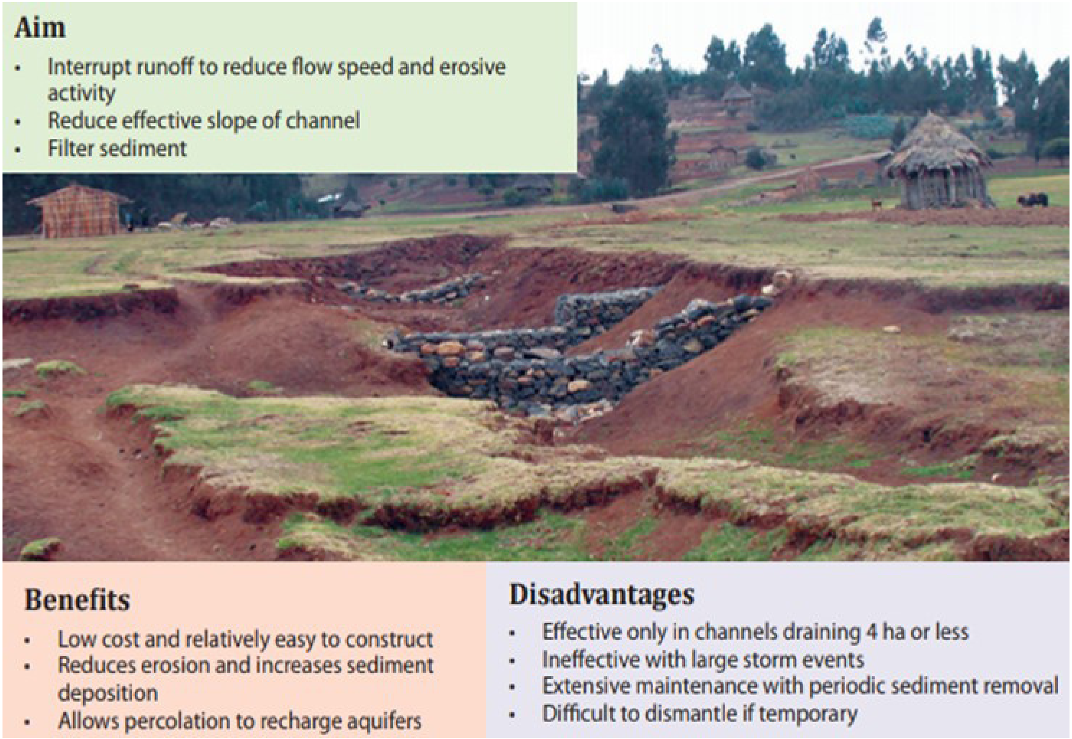


Figure 31: Stone check dams constructed along a gully in Zefie Ethiopia

Design and Construction

Check dams are built using rocks arranged in sequence such that the base of the previous dam is at the same height as the top of the second dam (Figure 32). Stones with a diameter of 10-35 cm are suitable, but large enough not to be dislodged by flowing water. Shale and sandstone should be avoided as they wear away easily. Permanent check dams are built with stones, bricks and cement. Rock check dams should have a notched, “V” or “U” shape with the center portion at least 15 cm lower than the sides to prevent normal runoff from going around the dam, and eroding the sides of the channel. The check dam height is often about ¼ of the base width. The foundation of the dam should extend below the soil surface to bedrock or for at least 30-50 cm to prevent water from undercutting the check dam structure. Lateral trenches should be dug into the sides of the gully to extend the check dam into the sides to stabilize the dam.

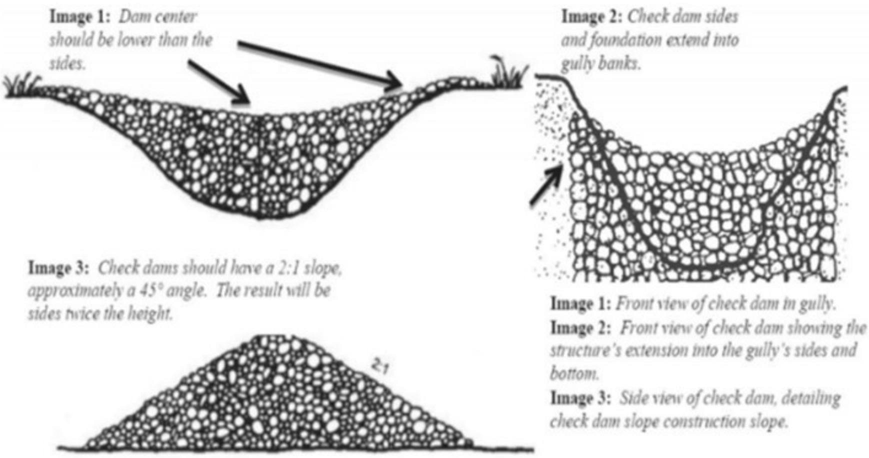


Figure 32: A stone check dam profile

Zai pits

Zai pits (Figure 33) are holes dug to collect and retain runoff to allow infiltration into the soil. The dug pits collect and concentrate water to the plant. This reduces the risk of water stress in areas with low and erratic rainfall. They are usually fertilized with plant debris or compost. Zai pits are primarily used to cultivate crops for example sorghum, maize, millet, cowpeas, sweet potatoes, groundnuts and bananas. At the bottom of the pits farmers place about two handfuls of organic material (animal dung or crop residues). Organic matter placed at the bottom of the pit attracts termites, which play a crucial role as they dig channels in the soil and by doing so improve its "architecture". The termites also digest the organic material, making nutrients more easily available to the crops planted or sown in the pits. Crops are planted in these pits as soon as the rainfall starts.

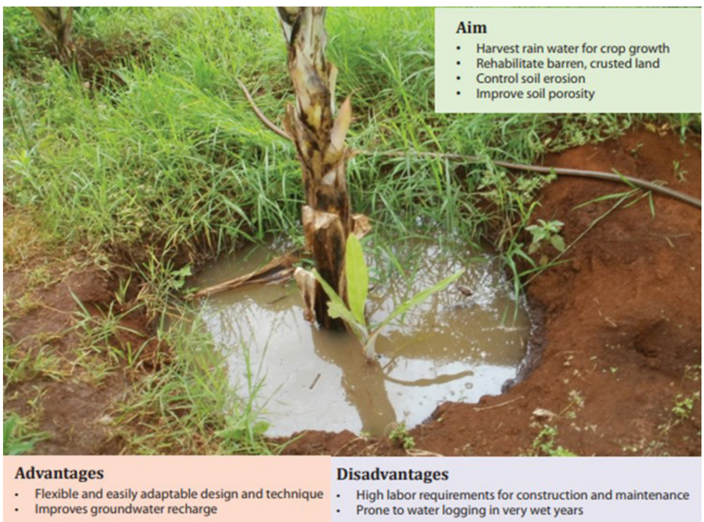


Figure 33: A banana tree planted in a Zai pit in Kapingazi in Embu County

Where suitable

i. Arid to semi-arid areas (annual rainfall of 200-750 mm)

ii. Gentle slopes (less than 5 %)

iii. Soils of limited permeability e.g., silt and clay, where tillage is difficult.

Design and construction

Zai pits are 5-15 cm deep, 15-50 cm wide and 80-100 cm apart (Figure 35). In dry areas the size of planting pits can be enlarged. Compost or manure is placed in the pits before planting to improve soil fertility. It is not necessary to follow the contour when constructing pits.

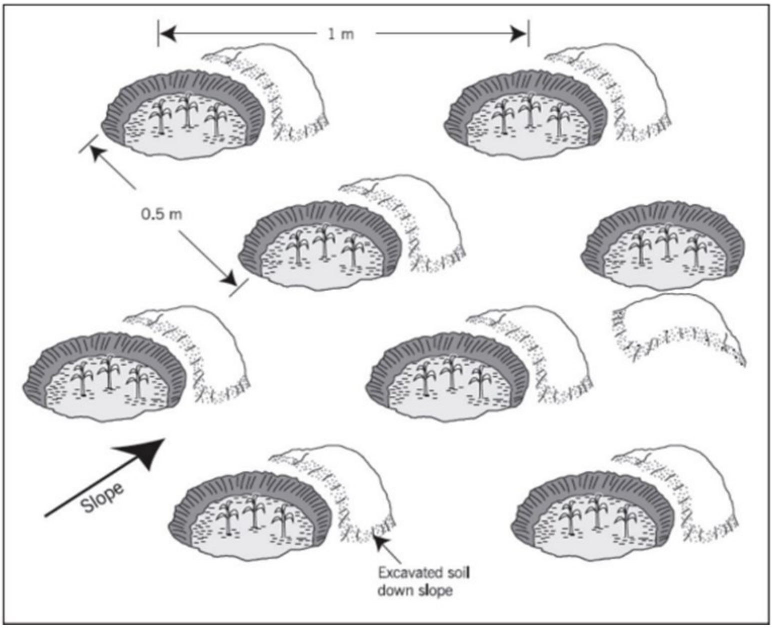


Figure 34: Layout of zai pits constructed on a gentle slope (PRESA, 2009)

Socio-economic and environmental benefits of Zai Pits

Use of the Zai technique produces higher grain yields, particularly on highly degraded sandy soils. Other benefits include:

i. Zai pits offer a good potential to both increase the livelihood of the rural population in the drylands and while combating land degradation.

ii. They are useful for rehabilitating crusted soils and gentle clay slopes with limited infiltration and difficult tillage.

iii. It can work with other techniques such as stone contours, Nardi/Vallerani and hand dug trenches to restore degraded soils, soil erosion, and soil moisture stress.

iv. They serve to collect and concentrate water at the plant. It thus can reduce the risk of water stress in a region of low and erratic rainfall.

v. Offers a good potential to both restore degraded lands and maintain their biological status.

vi. They improve soil fertility and hence agricultural productivity of several crops.

Constraints of the technique

Of the few constraints to the use of Zai Pits System, labour poses the great challenge. Some studies have shown that it takes about 300-450hours/ha to dig the zai pits plus another 250 hours/ha to fertilize them. For this reason, the Zai system is more realistic when undertaken by groups of farmers instead of individuals. This means that wealthier farmers tend to benefit more from the technology. Though labour intensive, the pits can be dug during the off-season when farmers do not engage in other field activities and thus labour time is less of a constraint.

Tied Ridges

Tied ridges are small earthen ridges, 30 cm high, with an upslope furrow which accommodates runoff from a catchment strip between the ridges (Figure 35). They increase the water that is available to plants by collecting rainfall from unplanted sloping basins and catching it in furrows and ridges. Planting takes place on either side of the furrows, where the water infiltrates. Specialized planters and cultivators must be used to maintain the permanent ridges created for planting a row crop. The ridges tops are cleared of the previous crop residue at planting, to allow for the new crop to be planted on the ridges.

Advantages	Disadvantage
• Enables crop cultivation over a wide moisture regime including high water demanding crops e.g. bananas and maize • Stabilizes soils	Labor intensive

Figure 35: Tied ridges in Katumani, Machakos County

After harvest, crop residue is left undisturbed on the soil surface until planting time. Maintenance of the ridges is essential and requires modified or specialized equipment for a successful ridge tillage system. The loss of water through evaporation is minimized by placing mulch in the furrows.

Where suitable

i. Low annual rainfall areas (less than 700 mm)

ii. Gentle slopes (0-6%)

iii. Deep soils (more than 60 cm).

Design and construction

Tied ridges may be constructed by hand or using mechanical ridgers. The ridges are constructed along the contours of the field using “A” frames to measure the contours along which the ridges will run. The ridges are made by digging out shallow furrows along the contour lines of the slope and making ridges on the downside of the furrows. These are “tied” together by slightly lower ridges which are made at regular intervals along the furrows. Ridge spacing depends on the spacing between rows of the crop but the height of the ridges is 30cm high (Figure 36).

Minimal maintenance is required if the ridges are properly constructed initially. Maintenance involves reconstruction of any lines and ridges that might have collapsed.

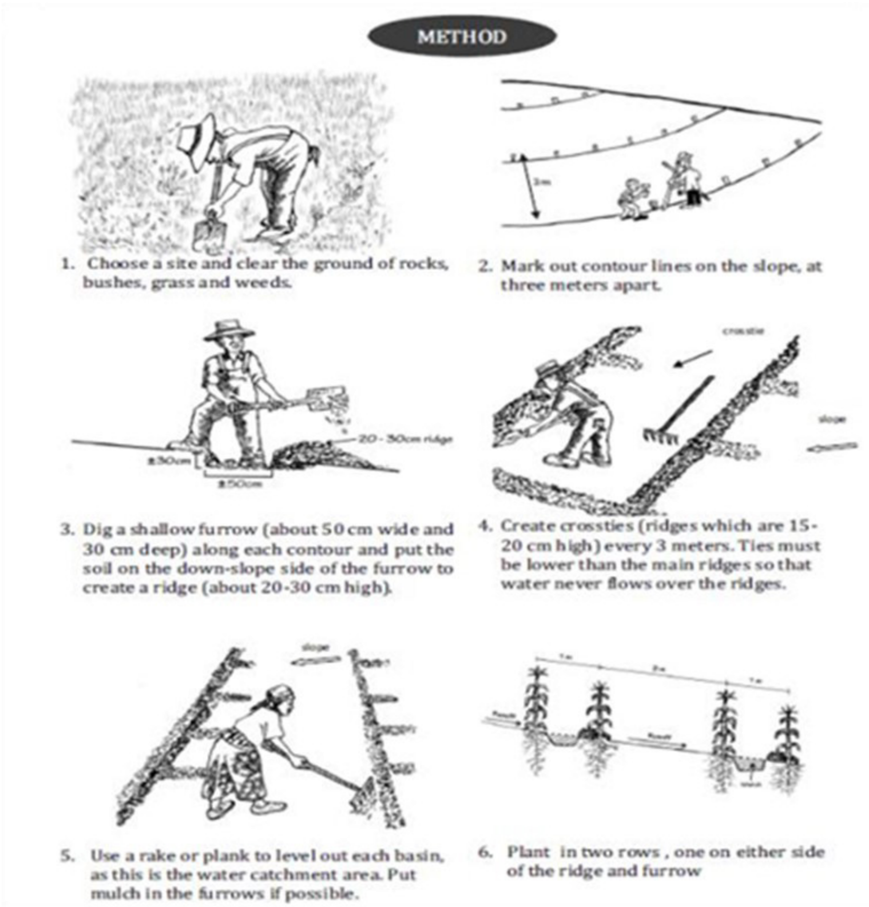


Figure 36: How to make tied ridges

Advantages of Tied ridges

i. Reduction in herbicide use, hence cost. Herbicide costs are reduced because herbicide is banded at planting. While input costs are reduced, yields stay virtually the same, making ridgetill a profitable alternative.

ii. Improved weed control.

iii. Residues for the previous crops between the ridges makes the rides warm. Warm soil temperatures speeds crop emergence, increases competitiveness with weds and increases the likelihood of a good crop to stand.

iv. Better soil moisture. The system is well adapted to poorly drained soils since the ridge dries out sooner.

v. Soil compaction in the root zone is reduced.

vi. Ridge tillage leaves large amounts of crop residue on the soil surface which greatly reduces erosion and runoff, thereby enhancing erosion control.

Disadvantages

The unusual cropping system of planting on ridges and next to furrows, but leaving the catchment unplanted, is thought to be a disincentive for adopting this technology. Further, the labour-intensive approach is not thought to be attractive in the areas where the technology has been tried. The relatively low planting density discourages farmers, especially in a good year, and the technique does not work well on steep slopes.

How does water harvesting contribute to CSA?

Water harvesting practices' contributions to the three pillars of climate change differ significantly.

i. Increasing agricultural productivity and income: Harvesting water for irrigation helps crucially to increase production efficiency and yields per unit. It thereby provides yield stability throughout the year because water is normally the most limiting production aspect.

ii. Enhancing resilience or adaptation of livelihoods and ecosystems towards climate extremes: Water harvesting and adequate irrigation enables crops or fodder to be grown despite inadequate rains, or outside growing seasons. Thereby it contributes significantly to strengthening resilience.

iii. Reducing and removing GHG emissions from the atmosphere: Water harvesting and use of efficient irrigation techniques and renewable energy can reduce methane emissions compared to inadequate ways to irrigate.

6 INTEGRATED SOIL FERTILITY MANAGEMENT (ISFM)

6.1 Introduction

Generally, low soil fertility and nutrient depletion are the main reasons for low agricultural production hence improved use of fertilizers is considered as a necessary measure for improving the crop yields. Despite increased fertilizer use through the government subsidy programme, the crop yields remain low owing to unskilled use of fertilizers especially among the smallholder farmers. Furthermore, lack of knowledge on key practices that should be combined with fertilizer worsens the situation. Therefore, alternative means of replenishing soil fertility are needed to ensure food security.

Integrated Soil Fertility Management (ISFM) has been identified as a sustainable way of increasing soil fertility through use of a combination of both organic and inorganic soil amendment technologies that reduce the cost, easy and cheap to access.

6.2 What is ISFM?

A set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs, and improved germplasm combined with the knowledge on how to adapt these practices to local conditions, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity. All inputs need to be managed following sound agronomic principles (Vanlauwe *et.al.* 2010).

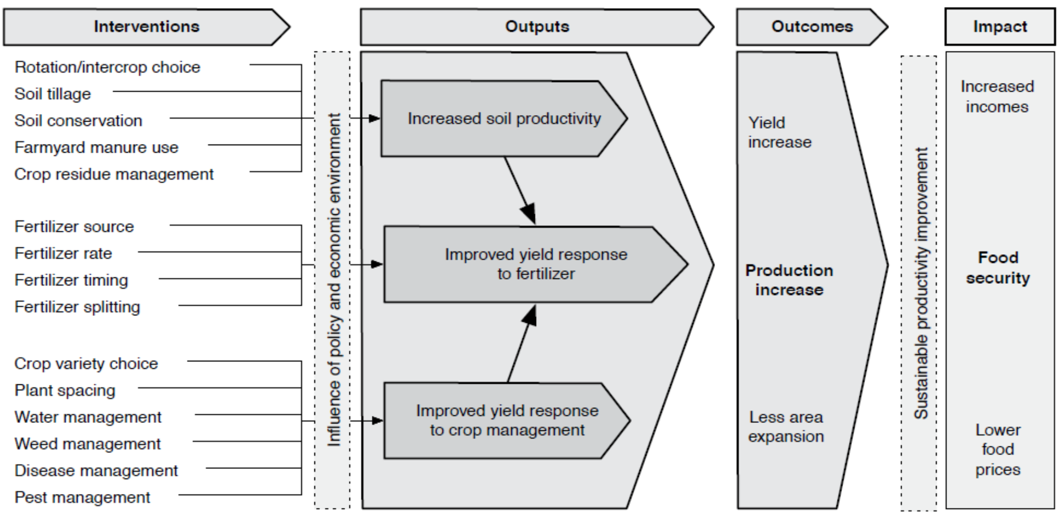


Figure 37: Graphic presentation of ISFM

When a soil is not functioning to its full capacity as a result of various constraints, then sustainable productivity and net farmer profits are at risk. This definition combines all the agronomic practices necessary to make crops grow and yield well, including the use of high yielding and healthy planting materials, plant nutrients, whether supplied as organic materials or mineral fertilizers, and other soil amendments. Figure 37 shows a graphic presentation of ISFM.

6.3 Why ISFM?

Because farmers often have limited cash resources and often buy small amounts of fertilizer, it is important to implement management practices that minimize the loss and cost of nutrients added to the farming system. With good management practices, a significant proportion of nutrients added to the farming system in the form of mineral fertilizers can be recycled many times through crop residues and farm-yard manures from livestock. ISFM is a means to overcome some of the challenges faced by small-scale farmers as it offers them better returns for investment in fertilizer through its combination with available organic and indigenous agro-mineral resources.

6.4 Principles of ISFM

- Effective application of ISFM requires a good understanding of the basic nutritional requirements of a plant.
- Undertaken in isolation, each of the principles of ISFM by themselves might not reverse the trend of declining soil fertility. A holistic approach is therefore, needed. While singular approaches e.g. appropriate use of mineral fertilizers, can succeed in ameliorating soil fertility, it is becoming increasingly evident that resources usually exist in any given setting to permit adoption of more than one approach at the same time. For example, many farmers, both small and large, may cultivate field crops as well as keep livestock. Such farmers have more than one resource at their disposal with which to manage soil fertility, that is, manure from livestock, crop residues after harvest, and mineral fertilizers. In ameliorating soil fertility, ISFM would constitute practices that combine all the available resources within any given farming environment.
- ISFM is not characterised by unique field practices, but rather a fresh approach to combining available technologies in a manner that preserves soil quality while promoting its productivity. Soil fertility management includes timely and judicious utilization of pre-plant and top-dressed mineral fertilizers; the generation, collection, storage, enrichment and application of available organic resources; and the maintenance and enhancement of beneficial soil organisms and biological processes. These practices reduce production costs, maintain soil fertility and conserve soil moisture.
- Farmers who have adopted ISFM technologies have more than doubled their agricultural productivity and increased their farm-level incomes by 20% to 50%.

Some of the the key principles of ISFM include the following:

6.4.1 Use of mineral fertilizers

Mineral fertilizers are required to supplement the nutrients recycled or added in the form of crop residues and animal manures. Fertilizers are concentrated sources of essential nutrients in a form that is readily available for plant uptake. They are often less costly than animal manures in terms of the cost of the nutrients that they contain (i.e. KES/kg nutrient) but often viewed as more extensive by farmers because they require initial cash resources. ISFM places great emphasis on using mineral fertilizers on fields in the farm where they provide the greatest beneficial effect. It is important to use fertilizers, including basal application of a phosphate (P) fertilizer at planting.

6.4.2 Use of organic inputs

Organic inputs (i.e. crop residues and animal manures) are an important source of nutrients, but their Nitrogen (N), Phosphorus (P), Magnesium (Mg) and Calcium (Ca) content is only released following decomposition. By contrast, Potassium (K) is released rapidly from animal manures and crop residues because it is contained in the cell sap. However, the amount of nutrients contained in organic resources is usually insufficient to sustain required levels of crop productivity and realize the full economic potential of a farmer's land and labour resources.

The benefits of organic inputs to crop growth include increase in the crop response to mineral fertilizer; improvement of the soil's capacity to store moisture; regulating soil chemical and physical properties that affect nutrient storage and availability as well as root growth; adding nutrients not contained in mineral fertilizers; creating a better rooting environment; improvement of the availability of phosphorus for plant uptake; ameliorating problems such as soil acidity; and replenishing soil organic matter. ISFM emphasizes the importance of optimizing the use of organic resources after exploring their opportunity cost (e.g. comparing the retention of organic resources in the field with their use for livestock feed, mulch or compost production).

Basal application of manure can be followed by top dressing with nitrogenous or any other top dressing fertilizer later in the season.

6.4.3 Use of improved germplasm

Farmers are advised to use crop planting materials best adapted to the particular environment in terms of how they respond to nutrients (varieties differ in their responsiveness to added nutrients); adaptation to the local environment (i.e. soils, climate); and resistance to pests and diseases (unhealthy plants do not take up nutrients efficiently).

Improved varieties usually have a higher harvest index (HI) (i.e. the ratio of crop product to total biomass production) because more of the total biomass production is converted into the harvested product than in unimproved varieties. Improved legume varieties with a lower HI are sometimes selected. This is because they can be treated as 'dual purpose crops.

Use of improved varieties means seeds, seedlings and other planting materials that have been bred to meet particular requirements of the environment in which they are to be grown. Therefore, it is important to have information on the currently available improved varieties for a particular region, where these can be purchased, and their price.

It is also important to investigate existing community-based seed production systems since improved varieties for certain crops, especially legumes, may not be available from commercial sources.

6.4.4 Combination of organic and inorganic fertilizers

This entails the use of half the rates of manures and inorganic fertilizers in combination for crop production. For example, during planting time; half rate of manure and half rate of phosphate fertilizer can be applied to enhance crop production. Since the inorganic fertilizer is readily available to the plant, it will give it some vigorous growth. As the manure decomposes and releases its nutrients later on, the plant will be able to have a continuous supply of nutrients thereby ensuring a healthy crop.

6.4.5 Importance of local adaptation

ISFM emphasizes the necessity of 'local adaptation' to take into account variability between farms, in terms of farming goals and objectives; farm size; labour availability; ownership of livestock; importance of off-farm income; and in the amount of production resources (i.e. land, capital, labour, crop residues and animal manures) that different farming families are able to invest in their farm.

Emphasis is also placed on the importance of using often scarce resources like fertilizer and organic inputs efficiently while reaching economic goals that are achievable for each farm household. Local adaptation also refers to the need to take into account differences in the responsiveness of soils to fertilizers and fertility levels.

The farmer can and should grow and take advantage of nitrogen-fixing legumes, either singularly, or in rotation or in intercropping systems. Legumes through the process of nitrogen fixation will enrich the soil with N that will also benefit the subsequent crop. This will be best captured in the practice of crop rotation, whereby a legume crop cultivated for one or more seasons is followed by one that does not fix N and can therefore take advantage of the fixed N that will be made available following decomposition of the legume residues.

It is not enough to add nutrients to the soil if those nutrients will not be retained in the soil especially on sloping lands, whereby nutrients may be lost through soil erosion. Therefore, the above measures should be superimposed on land that has been managed to control soil erosion.

6.5 Key considerations in devising ISFM strategies

i. Fertilizer advice must not only provide suggested types and rates but also offer guidelines on how to make adjustments in conjunction with the use of commonly available organic resources.

ii. ISFM approaches many follow two parallel paths. One for strictly commercial production that optimizes returns per unit area and another intended for resource-poor farmers that makes best use of limited affordable fertilizer amendments.

iii. Different resource endowment categories exist within a given farming community and the capacity of each category to invest in fertilizers differs.

iv. Different households have different degrees of labour availability.

v. Different ISFM recommendations can be given for different soil types within the farms with varying fertility levels and topographies. Differences within and across farms results from topography, nutrient and soil gradients with specialized attributes that influence nutrient management practices.

vi. Localized fertilizer recommendations are best developed, adjusted and validated through close collaboration between researchers, extension agents, farmers'/farmer associations and their members. Participatory research enhances users' adaptive and adoptive response. This enables farmers to adjust recommended management practices to their farming conditions and household priorities setting.

The various ISFM practices are summarized in Table 2.

Table 2: ISFM practices and their rationale

Practice	Rationale
Combination of fertilizer and manures	It is important to use fertilizers, including basal application at planting. Basal application of manure can also be similarly adopted followed by top dressing with nitrogenous later in the season. Augments soil fertility and boost crop vigour and early maturation.
Growing of nitrogen fixing legumes	Nitrogen-fixing legumes enrich the soil with nitrogen benefitting the crop. It is more beneficial to do crop rotation with legumes. Intercropping/relaying with legumes such as *Mucuna*, beans, cowpeas, pigeon peas, crotalaria etc. and cover crops e.g. *Desmodium, Dolichos lab lab*, improve nutrient cycling, soil fertility and maintenance of soil structure.
Use of crop residues	Crop residues when incorporated after crop harvest decompose to release nutrients back to the soil for use by the crops.
Adoption of soil conservation measures	It is not enough to add nutrients to the soil if those nutrients will be lost e.g. through soil erosion and leaching, hence the need to control erosion. Through these measures, added nutrients are conserved, and a gradual build-up of fertility can be realized.
Combination of fertilizer and manures	It is important to use fertilizers, including basal application at planting. Basal application of manure can also be similarly adopted followed by top dressing with nitrogenous later in the season. Augments soil fertility and boost crop vigour and early maturation.

Practice	Rationale
Growing of nitrogen fixing legumes	Nitrogen-fixing legumes enrich the soil with nitrogen benefitting the crop. It is more beneficial to do crop rotation with legumes. Intercropping/relaying with legumes such as *Mucuna*, beans, cowpeas, pigeon peas, crotalaria etc. and cover crops e.g. *Desmodium, Dolichos lab lab*, improve nutrient cycling, soil fertility and maintenance of soil structure.
Use of crop residues	Crop residues when incorporated after crop harvest decompose to release nutrients back to the soil for use by the crops.
Adoption of soil conservation measures	It is not enough to add nutrients to the soil if those nutrients will be lost e.g. through soil erosion and leaching, hence the need to control erosion. Through these measures, added nutrients are conserved, and a gradual build-up of fertility can be realized.
Soil acidity correction	Some soils are strongly acidic, either because of inherent soil properties or due to long-term acidity-inducing management practices (e.g. the long term use of ammonium-based fertilizers like DAP). Acidity is a problem with low pH severely restricting the growth of some crops e.g. maize. Liming is used to increase the pH of acidic soils.
Drought Buffering	These are practices that are meant to conserve soil moisture and hence increase soil water content by increasing infiltration and reducing runoff and evaporation. Increased infiltration improves water use efficiency and buffers crops against drought.
Breaking soil hardpans	Continuous management of soils that are prone to compaction can result in a sub-surface soil barrier to crop root growth. Breaking such hard pans by deep ripping allows roots to penetrate the hardpan and access more nutrients and water, resulting in better crop growth.
Water harvesting	Efficient nutrients uptake by plants can only be realized if there is sufficient plant available water. By maintaining organic mulch and water harvesting structures (e,g, Zai pits) in the farms reduces losses of soil water through reduced run off and evaporation. Furthermore, the resulting build-up of soil organic matter increases the soil water holding capacity.
Composting	Involves collecting crop residues to allow them to decompose and then adding them back to the soil to improve soil fertility, texture and water filtration.
Use of improved and stress-resilient varieties	Improved varieties are seeds, seedlings and other planting materials that have been bred to meet particular requirements of the environment in which they are to be grown.

6.5.1 ISFM guidelines for integrated fertilizer use

Farmers require knowledge for better management of fertilizers. There is need for ISFM guidelines that are more specific to particular categories of land environment and household resource availability. These guidelines include the following:

i. *Optimize micro-dosing and top-dressing of nitrogen fertilizers and conduct campaigns to increase the use and effectiveness of these practices*. Applying fertilizers in micro-dose amounts permits more precise and better timed fertiliser placement, particularly in combination with water harvesting.

ii. *Match different water conservation measures to specific dryland and soil conditions*. Combining water harvesting techniques e.g. Zai pits, stone bunds and tied ridging; with micro-dosed fertilizer, agro-minerals and manure application results in substantial increases in crop yield.

iii. *Better management of soil organic matter*. Fertilizer is a key entry point toward organic matter management. This enhances greater root biomass production, symbiotic N fixation and soil conservation for increased crop production.

iv. *Promote legume based practices for weed, pest and diseases management*. The incorporation of legumes into cropping systems provides additional benefits besides N input, particularly in terms of pest and diseases control, increasing soil organic matter content.

v. *Target results per unit input not per unit area.* Many fertilizer recommendations made to small-scale farmers are regarded as excessive because expressing gains per unit area is inappropriate for resource poor farmers. Farmers must also be discouraged from broadcasting fertilizer as they tend to waste most of it with little benefit to the crops.

Specific guidelines on better use of fertilizers for ISFM are summarized in Table 3.

Table 3: Fertilizer use and rationale for ISFM

Fertilizer	Accompanying ISFM practice	Rationale for ISFM
DAP	Pre-plant: apply at least 0.5t/ha of manure or compost	Manure and compost are rich in macro-nutrient and micro-nutrients that improve nutrient retention
DAP	Pre-plant: periodically apply agricultural lime	DAP is an acid-forming fertilizer and may require periodic pH adjustment through liming

Fertilizer	Accompanying ISFM practice	Rationale for ISFM
Urea	Pre-plant: retain some crop residues and incorporate with rock phosphate as a substrate for DAP	Decomposing crop residues solubilize rock P, promote N transformation and provide short-term immobilization that preventing prevents N loss
Urea	Top-dressing: apply in conjunction with later weeding	Incorporating urea and weed biomass prevents ammonia volatilization and improves use efficiency
CAN	Pre-plant: stimulate symbiotic legumes	Apply small amounts of N to stimulate root development, too large applications suppress biological nitrogen fixation (BNF)
CAN	Top-dressing: apply to cereals in micro-dose placement, avoiding symbiotic legumes	More accurate placement of top-dressing fertilizer improves N use supply and efficiency during peak N demand
KCL	Pre-plant: apply manure or dolomite	Maintain proper base nutrient ratios by supplementing K with Ca and Mg

In conclusion, ISFM aims at effective input use by combining a number of nutrient sources and process regulators. ISFM practices involve:

i. Judicious use of mineral fertilizers and agro-minerals in terms of their form, placement and timing of application.

ii. Management of crop residues and other locally available organic resources that improve agronomic efficiency.

iii. Use of locally adapted germplasm that is resistant to local stress conditions, both biotic and abiotic.

iv. Other field practices determined by local agricultural conditions, particularly pest and diseases management, soil erosion control, moisture conservation and enhancement of beneficial biota.

These considerations lead to a basket of options based upon past experience, current information and changing farming conditions that result in better soil fertility management and productivity.

7 AGROFORESTRY

7.1 What is agroforestry?

Agroforestry is the growing of woody perennials (trees, shrubs) as agricultural crops alongside other crops and/or livestock in the same land. Existing trees are protected and managed, or/and new ones planted. Agroforestry has three major attributes: productivity, sustainability and adoptability. Good agroforestry practices maintain or increase production (productivity), meet the needs of the present generation without compromising those of future ones (sustainability) and are culturally acceptable and environmentally friendly (adoptability).

7.2 Types of agroforestry

Agroforestry systems can be divided into five different categories:

i. Agro-silviculture, where annual or perennial crops are integrated with trees

ii. Silvo-pastoral systems that integrate livestock and trees

iii. Agro-silvopastoral systems, where livestock, trees and crops are combined

iv. Entomo-silvicultural systems, combining insects with trees

v. Aqua-silviculture, where fish are combined with trees

The combinations of components in the various agroforestry systems differ according to the AEZs. A summary of the various agro-forestry systems and their characteristics are presented in Table 4.

Table 4: Agroforestry systems and their characteristics

Agroforestry practice	Brief description (of arrangement of components)	Major groups of components	Agro-ecological adaptability
Agri-silvicultural systems (crops including shrubs/vine/tree crops and trees)			

Agroforestry practice	Brief description (of arrangement of components)	Major groups of components	Agro-ecological adaptability
Improved fallow	Woody species planted and left to grow during the 'fallow phase'	Fast-growing woody preferably leguminous Common agricultural crops	In shifting cultivation areas
Taungya	Combined stand of woody and agricultural species during early stages of establishment of plantations	Usually plantation forestry spp. Common agricultural crops	All ecological regions (where taungya is practiced); several improvements possible
Alley cropping (hedgerow intercropping)	Woody species in hedges; agricultural species in alleys in between hedges; microzonal or strip arrangement	Fast-growing, leguminous woody species that coppice vigorously Common agricultural crops	Sub-humid to humid areas with high human population pressure and fragile (productive but easily degradable) soils
Multi-layer tree gardens	Multispecies, multilayer dense plant associations with no organized planting arrangements	Different woody components of varying form and growth habits Usually absent; shade tolerant crop sometimes present	Areas with fertile soils, good availability of labour, and high human population pressure
Multi-purpose tress on crop lands	Trees scattered haphazardly or according to some systematic patterns on bunds, terraces or plot/field boundaries	Multipurpose trees and other fruit trees Common agricultural crops	In all ecological regions esp. in subsistence farming; also commonly integrated with animals

Agroforestry practice	Brief description (of arrangement of components)	Major groups of components	Agro-ecological adaptability
Plantation crop combinations	(i) Integrated multistorey (mixed, dense) mixtures of plantation crops (ii) Mixtures of plantation crops in alternate or other regular arrangement (iii) Shade trees for plantation crops; shade trees scattered (iv) Intercropping with agricultural crops	Plantation crops like coffee, cacao, coconut, etc. and fruit trees, esp. in (i); fuelwood/fodder spp., esp in (iii) h: usually present in (iv), and to some extent in (i); shade-tolerant species	In humid lowlands or tropical humid/ subhumid highlands (depending on the plantation crops concerned); usually in smallholder subsistence system
Home gardens	Intimate, multistorey combination of various trees and crops around homesteads	Fruit trees predominate; also other woody species, vines, etc. Shade tolerant agricultural species	In all ecological regions, esp. in areas of high population density
Trees in soil conservation and reclamation	Trees on bunds, terraces, raisers, etc. with or without grass strips; trees for soil reclamation	Multipurpose and/or fruit trees Common agricultural species	In sloping areas, esp. in highlands, reclamation of degraded, acid, alkali soils, and sand-dune stabilization
Shelter breaks and wind breaks, live hedges	Trees around farmland/ plots	Combination of tall-growing spreading types Agricultural crops of the locality	In wind-prone areas
Fuelwood production	Interplanting firewood species on or around agricultural lands	Firewood species Agricultural crops of the locality	In all ecological regions
Silvo-pastoral systems (trees, pasture and or animals)			
Trees on rangelands or pastures	Trees scattered irregularly or arranged according to some systematic pattern	Multipurpose; of fodder value	Extensive grazing areas

Agroforestry practice	Brief description (of arrangement of components)	Major groups of components	Agro-ecological adaptability
Protein banks	Production of protein-rich tree fodder on farm/rangelands for cut-and-carry fodder production	Leguminous fodder trees, fodder, herbs	Usually in areas with high person: land ratio
Plantation crops with pastures and animals	Example: cattle under coconuts in South-East Asia and the South Pacific	Plantation crops	In areas with less pressure on plantation crop lands
Agro-silvopastoral systems (trees, crops and pasture or animals)			
Home gardens involving animals	Intimate, multistorey combination of various trees and crops, and animals, around homesteads	Fruit trees predominate; also other woody species and annuals	In all ecological regions with high density of human population
Multipurpose woody hedgerows	Woody hedges for browse, mulch, green manure, soil conservation, etc.	Fast-growing and coppicing fodder shrubs and trees	Humid to sub humid areas with hilly and sloping terrain
Apiculture with trees	Trees for honey production	Honey producing trees (other components may be present)	Depending on the feasibility of apiculture
Aquaforestry	Trees lining fish ponds, tree leaves being used as 'forage' for fish	Trees and shrubs preferred by fish (other components may be present)	Lowlands
Multipurpose woodlots	For various purposes (wood, fodder, soil protection, soil reclamation, etc.)	Multipurpose species; special location specific species (other components may be present)	Various

(Source: Nair, 1991)

7.2.1 Benefits of agroforestry

i. Improves farm incomes, nutritional security and livelihood diversification.

ii. Reduces the cost of agricultural production thus enhances the sustainability of the farming systems.

iii. Agroforestry provides all the ecosystem services that include provisioning, regulating, cultural and supporting.

iv. Improve soil fertility and soil moisture through increasing soil organic matter leading to increased agricultural productivity.

v. Provides forage for livestock in pastoral and dairy livestock production systems Fodder trees are being used by farmers and pastoralists on intensive and extensive livestock production systems highly reducing the need for external feeds.

vi. Sustainable energy in the form of fuel wood and biofuels.

vii. Provides timber for domestic and industrial use.

viii. Agroforestry trees serve as a natural carbon sink/store.

Selection of suitable trees, tree/crop associations and the right management practices for different places is important. Common agroforestry practices include improved fallows using fertilizer trees and shrubs (e.g. *Sesbania, Tephrosia, Tithonia, Faidherbia albida, Gliricidia*), Shamba system (growing annual crops as a forest plantation establishes), tree gardens, multipurpose trees and shrubs, plantation/crop combination, boundary trees/ live fences, fodder tree banks, shelter belts, conservation hedges, wind breaks, trees with pastures/fodders and tree apiculture. Table 5 gives examples of agroforestry practices and their role in climate change adaptation.

Table 5: Agroforestry practices and their roles in adaptation

Agroforestry system	**Ecological functions**				**Economic roles**	**Social/cultural roles**
	Enhancing water use, storage and efficiency	Soil productivity and nutrient cycling, and soil erosion control	Control of pests and diseases. Buffering against natural calamities	Providing shade and shelter; improving microclimate (shade)	Improvement in farm productivity and profitability; Diversifying income and food sources; Increasing incomes; Spreading income risks; Stabilizing/ enhancing livelihoods	Providing multiple food and energy sources during extreme events; Providing social security through sale of trees during crises period; improving nutrition through fruit production
Agroforestry in general						
Alley cropping						
Improved fallows						
Taungya						
Legume trees						
Home gardens						
Trees in soil conservation						

8 AGRICULTURAL INSURANCE

Most farmers in Kenya depend on rain fed crop production, which is prone to climatic risks. The production system is reported to experience crop failures in 3 out of every 5 seasons, especially in the ASALs. This results in financial and livelihood losses. Traditionally farming households climatic risk management strategies include: crop breeding, targeted selection of varieties, enhanced crop rotation and intercropping; mixed farming; use of supplemental irrigation; contract farming; reserves and savings, remittance and borrowing; use of seasonal forecast and early warning information.

Though these risk management strategies are being adopted to counter the impacts of climate change and increased variability, risks from extreme weather events still remain high and challenge their effectiveness. Insurance is a potential solution to augment the existing strategies to mitigate of the effects of climate change. On the other hand this should not be seen as a way to avoid taking proper adaptation measures; nor should it be seen as replacing other programmes that address the effects of climate change.

Insurance is risk pooling and has evolved as a response to the need for protection from risks. Some form of simple insurance always existed in our traditional societies. However, the key shortcoming of these traditional methods was that they only catered for a loss after it had occurred. Modern insurance predicts losses and creates a pool of funds upfront to compensate for those losses before they occur.

In Kenya, insurance products for the agriculture sector are relatively new. Insurance products have existed in the past under the "guaranteed minimum return (GMR)" scheme that was set up in the colonial era. Little agricultural insurance has existed after GMR arrangement collapsed. However, things are changing now with agricultural insurance developing to reach both large scale, medium and small scale farmers. The demand for insurance comes hand in hand with the development of the agricultural sector, as it approaches farming as an enterprise like any other, risks are identified that need to be mitigated.

Several insurance companies exist in Kenya today to provide agricultural insurance services. Examples of these companies include Jubilee Insurance Co., UAP Insurance Co., APA Insurance Co., CIC Insurance Co among others.

8.1 Classification of risks

There are many types of risks, some man-made or natural. Some of the risks farmers face and their insurance status are:

i. **Natural risks** - acts of God, diseases, pests, drought, excessive rain. These risks are generally insurable.

ii. **Social risks** - theft, civil disturbances, terrorism, political violence. These risks are generally insurable.

iii. **Economic risks** - price fluctuation, loss of investment made in crop production through change in prices of farm inputs. These risks could be insured (but currently no insurance company insuring them).

iv. **Personal risks** - accident, sickness, old-age of farmer, death/disease of draught animal, injury to third party and property. These risks are generally insurable.

8.2 Coping with Risks

There is no single solution for all agricultural risks. A combination of solutions that avoid, reduce, and transfer the risk at the farm are available. Options available to farmers include:

i. **On-farm risk mitigation techniques**

a. Irrigation
b. Crop diversification
c. Conservation agriculture techniques - zero tillage
d. Crop protection/ pest control.

ii. **Self-insurance tools**

a. Savings
b. Income diversification
c. Asset accumulation - e.g. buying a cow than can be sold
d. Emergency informal credit - Family and Chamas.

iii. **Formal risk transfer tools**

Insurance - Farmers often cannot manage the less frequent but more severe losses affecting their agricultural activities. Farmers can transfer these risks to other parties through financial mechanisms such as insurance.

8.3 Key Terms in agricultural insurance

i. Insured risk – the identified event that a person transfers to an insurance company by payment of a fee. Only loss from the occurrence of this event will lead to the insurance company paying the insured.

ii. Insurable risk - a risk, for which the insurer can estimate its likelihood to occur through historical statistics and therefore will be willing to offer protection at certain cost.

iii. **Coverage** - The time period over which the insured is protected by the insurer from the identified event.

iv. **Insurance** - a promise between two parties to protect against losses. It allows a person to pay a small amount of money in advance in exchange for a promise that when a bigger loss occurs, the insurance company will return the insured person to his initial financial position.

v. **Insurer** - a company selling insurance. These are companies specialize in pooling risks from individuals.

vi. **Insured** - the person buying the insurance protection from the insurer.

vii. **Sum Insured** - the total value of the property to be insured. The maximum amount agreed upon that can be compensated from insurer in the event of the identified risk.

viii. **Contract** - a legally binding agreement made between two or more persons or companies.

ix. **Premium** - a calculated fee that acts as a small contribution that each client of the insurance company contributes to the pool. The accumulated money from the pool is used to compensate the few who actually suffer losses.

x. **Risk pooling** – An insurance company gathers together people who want insurance protection and sets itself up to operate a pool. It takes contributions in the form of premiums from many people exposed to similar risks and pays the few who incur losses. In this way the financial burden is spread among all those who contribute to the pool. Risk pooling is based on the assumption that the losses of the unfortunate few will be compensated by the fortunate many. The total premium contributions are used to compensate the losses.

8.4 Informal Risk Management

A few examples of traditional forms of insurance are:

i. **Extended family system**: For example, if a house burned down, members of the extended family would assist in building another.

ii. **Harambee:** People form a group to contribute money for personal or community expenses such as a high medical bills or school fees.

iii. **Welfare and burial societies:** A group of people with a common interest agree to pay a certain sum of money to a fund which is used to help members of the group, when they require cash to pay for emergencies such as funeral expenses or medical costs.

iv. **Herd shifting:** A system where a percentage of one's animals - mostly cows, sheep, and goats - are kept at a relative's farm. This ensures that in the event of an outbreak of disease in one area, a part of the herd would be saved.

8.5 Types of Agricultural Insurance

There are two major types of insurance products

i. Indemnity-based Insurance Products

ii. Index-based Insurance Products.

8.5.1 Indemnity-based Insurance Products (Damage-Based Products)

Indemnity-based insurance products determine claim payment based on the actual loss incurred by the policy holder. If an insured event occurs, an assessment of the loss and a determination of the indemnity is made at the individual or herder level.

Most insurance is indemnity-based, meaning the company insures against crop loss or damage. This process involves the farmer buying insurance, reporting damage after it occurs, filing a formal claim and receiving a visit from an insurance agent to determine the validity of the claim. After the validity of the claim is established, the farmer receives a payout. The requirement of personal visits to remote, rural areas makes this costly and burdensome for the insurer. Indemnity-based insurance also leaves more room for tampering and fraud on the part of both the farmer and the insurer.

Indemnity-based insurance offers the advantage of covering losses from any type of damage, since the cause is not the only determinant of a payout; any cause from drought, flood or other natural disasters would be indirectly covered if the resulting crops are damaged. However, this advantage is far outweighed by the lack of certainty surrounding the claims process and higher cost to both the farmer and insurer. Many farmers have a negative impression of insurance due to stories of their peers being tricked by insurers—partly because of actual fraud but also because of poor communication. Moreover, due to the high costs of implementation, a typical insurance plan must have higher premiums than small-scale farmers can afford in order to be profitable.

Crop Insurance Products

i. Named Peril/ Damaged Based Insurance Products - Payout: % of Damage

ii. Yield Based Crop Insurance - include MCPI yield shortfall cover - Payout: Yield Loss.

Livestock Insurance Products

Named-peril accident and mortality insurance - Payout: Full Payment

8.5.2 Index-based Insurance Products (Damage-Based Products)

Weather index insurance is a type of insurance that pay out when there are crop losses caused by bad weather. Bad weather can be too little rain, too much rain, very cold days, very hot days, high humidity or other weather that may cause losses to crops. It is not based on the actual damages on a farmer's field, but rather pays out when specific weather events, are recorded by the reference weather station as the monitoring instrument. Measuring risk in this way allows the insurance to be affordable, but still cover crop losses the farmer may experience.

This insurance product is index-based, meaning payouts are determined by comparison to historical, regional rainfall patterns. During the planting season, actual rainfall is measured using a solar-powered weather station in the area. If the rainfall is determined to be too little or too much then there is a payout, the amount of which is based on the deviation from the rainfall index. This is a departure from indemnity-based insurance, which is based on crop damage after the harvest. An example is Kilimo Salama which insures farming inputs, not outputs, and insurance payouts are independent of actual crop damage, meaning a farmer may receive a payout without experiencing crop damage and may not receive a payout when they do have crop damage.

Index based agricultural insurance products are non-indemnity and parametric; that is, pay out based on the value of an "index", which is assumed to be proxy to actual losses. Index based agricultural insurance products pay out based on the value of a "formula", not on losses measured in the field. The index is a variable that is highly correlated with losses and that cannot be influenced by the insured.

8.6 Types of insurance products

8.6.1 Crop Insurance Products

Area Yield Based Index Insurance - Payout: Area Yield Loss. This is a multi-peril micro-insurance product rolled out together with the Government of Kenya and other insurers. It covers smallholder maize and wheat farmers against poor yields due to poor weather and natural catastrophes.

Weather Index Based Insurance - Weather Index Payout Scale. This cover compensates farmers for crop damage as a result of deficit or excesses in weather conditions such as temperature, sunlight, wind speed or rainfall resulting in losses during the length of the crop growth cycle up to physiological maturity.

Index insurance uses weather data from satellites and automated weather stations as a proxy to estimate farmers' harvest situation. At the end of each growing season, the collected weather data are automatically compared to an index of historical weather data. If the season's rainfall was, for example, 15% above or below the average, the insurance payout owed to client farmers is calculated and sent.

8.6.2 Livestock Insurance Products

Normalized Deviation Vegetation Index Insurance - Payout: NDVI Payout Scale. This compensates livestock keepers upon accidental death of their domesticated animal of economic value through accidents, illness, or complications while giving birth. Farmers are also compensated for the theft of their animals.

8.7 Benefits of insurance and weather index for a farmer

i. **Peace of mind**. When individuals have insurance in place to deal with the financial burden of losses from insured risks, they are encouraged to invest more in their farms.

ii. **Risk transfer**. Insurance does not prevent losses from occurring. The primary function of insurance is to transfer the financial consequences of an insured risk to an insurance company.

iii. **Risk pooling**. Insurance gathers together people who want insurance protection and creates a pool from which contributions of the entire pool compensate the unfortunate few who suffer from loss.

iv. **Objective measure of loss**. In Index insurance the weather is easy to observe and provides an objective trigger for the insurance payout. Since weather events mainly affect large areas simultaneously, index insurance is a good tool for helping small holder farmers farming in similar crops in a region.

v. **Fast claims process**. Payouts are calculated automatically for all insured farmers under one reference station – there are no claims to file.

vi. **Preservation of source of income**. Payouts come quickly to provide compensation when you need it hence improving sustainability of crop production.

vii. **Boost access to credit**. Financiers are more willing to offer credit because with weather index insurance their risk has reduced. Insurance may also enable contract farming. An agricultural marketing company contracting farmers would be interested in securing continuity of production for their farmers. They identify the crops key risks and would encourage their farmers to protect their inputs and potential harvests against the identified risks.

Key Points on Index Insurance:

The weather is easy to observe and provides an objective measurement for the insurance payout:

i. Weather insurance only covers losses related to a specific weather index such as excess or deficit rainfall, other non-weather risks like pests and disease are not covered.

ii. Payouts are based on the weather observed at the local weather station, not at the farm. If rainfall is different at the farm than at the weather station, the farmer may not receive a payout even if he experienced a drought or excess rain that damaged his crop. Payouts come quickly to provide compensation when you need it.

iii. There is a cost, premiums. Premium is paid in advance and are non-refundable. Typically, premium covers one season only and is not carried over to the next season if there is no payout.

iv. Weather insurance can improve sustainability of crop production using the payout to purchase inputs after a poor season.

v. Financiers are more willing to offer credit because with insurance reduces their risk.

9 RENEWABLE ENERGY

About three quarters of the energy used globally is generated from fossil fuels that include oils and coal and natural gas. The combustion of fossil fuels emits carbon dioxide, a major greenhouse gas. Greenhouse gases are a major cause of climate change.

Renewable energy is seen as one of the strategies for moderating effects of climate change. Renewable energy, often referred to as clean energy, comes from natural sources or processes that are constantly replenished. Sources of renewable energy include wind, sun, geothermal, water and biofuels.

Kenya has made great strides in the development of renewable energy sources from geothermal, wind, solar and water.

9.1 Bioenergy

Bioenergy is one of the sources of renewable energy. Bioenergy is defined as energy that comes from renewable biological sources. The oldest form of bioenergy is firewood, typically used for heat. Biofuel is just another name for bioenergy. Bioenergy provides 11% of all energy used globally.

9.2 Why Bioenergy

The consumption of biofuels can reduce the reliance on fossil fuels and thus reduce carbon dioxide emissions as they are carbon neutral. It is assumed that there is a positive carbon balance from biofuel consumption as the carbon dioxide produced from the production and consumption processes is absorbed by the vegetation through photosynthesis.

Biofuels emit lesser amounts of greenhouse gases than fossil fuels and they decompose completely unlike the conventional fuel additives. In addition, the materials used in the generation of biofuels are largely agricultural by-products. The great thing about bioenergy is that the biomass is typically a by-product of some other agricultural activity which pose no competition.

9.3 Biofuel Materials

There are two major sources of materials used for biofuel production. These are crops grown specifically for biofuel production such as maize, soybeans, canola, switch grass and sugarcane. The second source of biofuel materials is agricultural waste such maize stover, straw from rice, wheat, sorghum, barley, waste wood and livestock dung for biogas generation.

9.3.1 Benefits of Bioenergy

i. The use of bioenergy reduces greenhouse gas emissions.

ii. Bioenergy is a renewable source of energy.

iii. Biofuels are biodegradable thereby reduces possible contamination from effluents.

iv. Some forms of bioenergy source like biofuels produce both heat and electricity.

v. Less destructive to the environment as there are no major excavations thereby reducing economic costs of land refilling.

vi. Provides an environmentally friendly technology for managing waste disposal that would otherwise be debris.

vii. Bioenergy can be stored with minimal energy loss.

viii. The bioenergy technology is dynamic that's able to deliver reliable energy.

ix. The production of bioenergy can be carried out wherever there are agricultural crops and forestry.

x. Production of bioenergy materials increases soil stability, reduce soil erosion, improves soil fertility can help to stabilise soils, improve soil fertility and reduce erosion.

9.3.2 Disadvantages of Bioenergy

i. A higher quantity of biofuel is required to produce the same amount of energy as the traditional fuels.

ii. The processes for production of biofuels that include clearing of forests for cultivation and processing are reported to emit greenhouse gases.

iii. The production of biofuels requires high initial financial costs.

iv. The use of food crops for biofuel production reduces the amount of food available leading to high prices and food insecurity.

v. The production of biofuel crops requires high amount of water for irrigation thus may strain water availability for other uses.

10 GENDER IN CLIMATE SMART AGRICULTURE

10.1 What is gender?

The term 'Gender' does not refer to biological distinctions (referred to as "sex"), but rather to the social differences between women and men. Gender refers to roles, rights, relationships, and responsibilities ascribed to women and men in a specific society and cultural context. What it means to be a man or a woman is (re)created and learned in everyday life in our families and societies. These gender roles and responsibilities of men and women are not fixed, but are changeable over time.

There are significant differences between the rights and opportunities of women and men, which are entrenched in the social norms and values of specific communities. While gender shapes both men and women's lives, the tendency is that women are more disadvantaged than men. This can have significant effects on the adoption and sustainability of practices under a CSA approach.

10.2 Why consider gender?

i. **Practically:** The differences in women and men's roles, needs, and interests demand different policy approaches and project interventions.

ii. **Smart economics:** Women still face inequality in access to resources, opportunities, participation, and decision-making that constrains them from attaining their full potential. If these inequalities are not addressed, part of the population's potential to contribute to social, economic, and environmental development of the society will not be realized.

iii. **Sustainability:** Long-term development is only possible if everyone in the society is empowered to improve their livelihoods. Women are central to socialization—that is, they teach future generations the importance of protecting their environment and play an important role in their education for a better future.

iv. **Just cause:** Equality for all social groups independent of their gender, age, or wealth is a development goal in itself and is a prerequisite for a flourishing and happy society.

10.3 What is gender equity and equality?

i. **Gender equity** is the process of creating a level playing field for women and men. It means fairness of treatment for women and men, according to their respective needs. This may include equal treatment or treatment that is different but considered equivalent in terms of rights, benefits, obligations, and opportunities. Gender equity includes fairness in women's and men's access to socioeconomic resources. Gender equity leads to gender equality.

ii. **Gender equality** refers to the equal rights, responsibilities, and opportunities of women and men and girls and boys as well as those with special needs. This means that the different behaviour, aspirations, and needs of women and men are considered, valued, and treated equally.

iii. **Equality** does not mean that women and men have to become the same, but that their rights, responsibilities, and opportunities will not depend on whether they are born male or female.

10.4 Why gender matters to CSA

The inter linkages between gender roles and climate change, and respective action, can be summarized as follows:

i. Climate change affects women and men differently

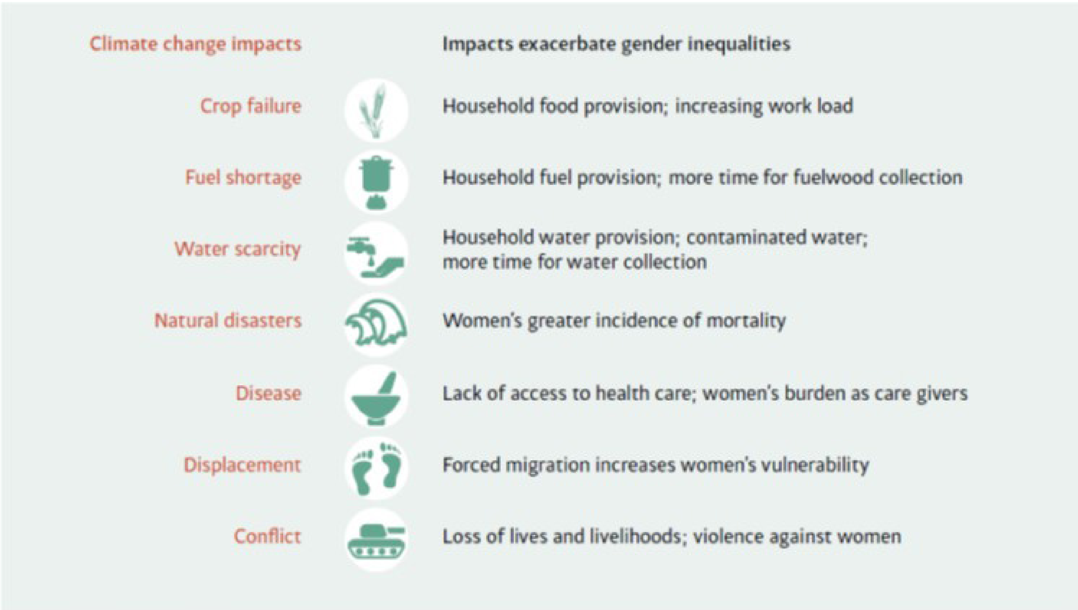
a. Climate change can cause an increase in gender inequality (Figure 38).

b. Gender-specific roles and responsibilities ascribed to different gender within a given society lead to inequalities in the access to resources, to barriers to participation, and to unequal adaptive capacities.

- For example, poor women often have less access to land rights, education and extension services and an income, which makes them more vulnerable to droughts, floods, crop failure, and increasingly limited supplies of natural resources. This makes them have less capacity to adapt to climate change and to recover from disasters.

c. With the same access to resources as men, women can accelerate food production by 20-30 per cent, and this output could reduce the number of hungry people by 12-17% (Figure 39).

- Women and men exhibit different ways of responding to climate change.
- Climate policies and measures affect women and men differently.



Source: Adapted from WEDO 2012.

Figure 38: How climate change exercabates gender inequalities

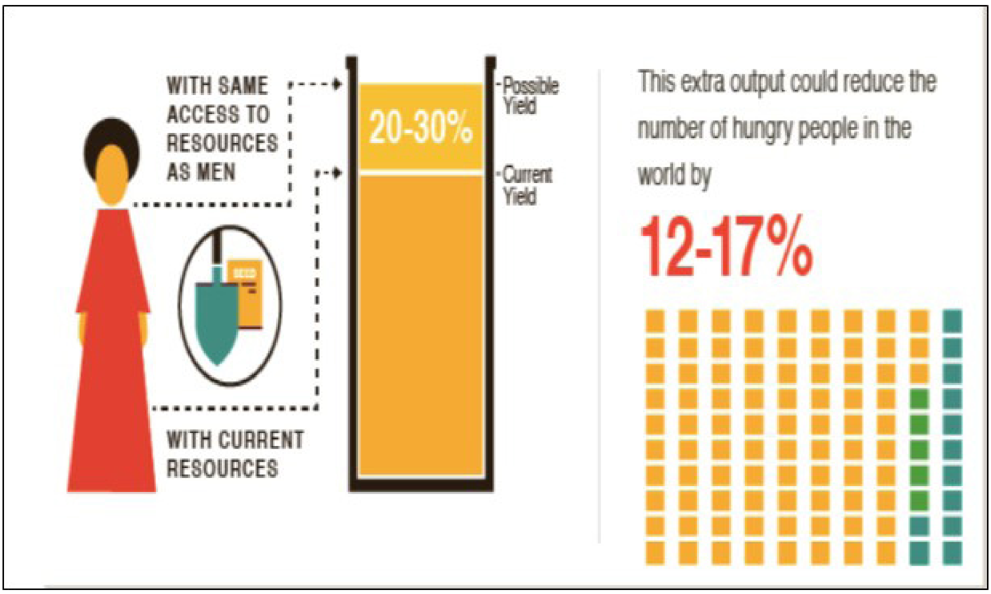


Figure 39: How gender impacts on agricultural productivity

10.5 Gender equality in the three pillars of CSA

A gender-responsive approach will achieve more effective and equitable outcomes, reduce climate risks, and reduce the gender gap in outcomes from CSA activities (Green Climate Fund, 2015) because it better reflects the lives and experiences of agricultural communities.

Pillar 1. Sustainably increase agricultural productivity and incomes

Some of the efforts to address gender in the context of Pillar 1 include:

i. Systematic gender analysis to identify any differences in men's and women's productivity.

ii. Resolving the challenges or constraints women experience in accessing, using, and supervising farm labour.

iii. Improving women's access to productive inputs and resources such as extension services; technologies, innovations and management practices.

iv. Improving women's use of agricultural inputs like seeds and fertilizers.

v. Improving women's tenure of natural resources e.g. land.

vi. Participatory identification and implementation of income-generating opportunities.

Pillar 2. Adapt to and build resilience to climate change

The impacts of climate change and related adaptive strategies are not gender-neutral because vulnerability is often determined by socio-economic factors, livelihoods, people's capacity and access to knowledge, information, services and support –all of which may differ along lines of gender. In addition, men and women may have different coping strategies.

As resilience-enhancing practices and approaches are developed, it is critical that climate information is made available and accessible to men and women, boys and girls, and that any potential increase in workload is minimized.

Pillar 3. Reduce and/or remove greenhouse gas emissions, where possible

When pursuing practices that contribute to climate change mitigation, it is good to note that women and men are often in different starting positions to take them up. For example, agroforestry may be less accessible or offer fewer incentives to those with weaker land tenure rights, and soil and water conservation may be difficult if hiring labour is not possible. On the other hand, some practices, like improved cooking stoves, biomass for energy and biogas, may be more attractive to women for their labour-saving features. Proposed mitigation actions therefore should harness the experiences, expertise, and realities of women and men alike.

10.6 Guiding questions when addressing gender and Climate Smart Agriculture

Possible questions to address are:

i. How does climate change affect the livelihoods of men and women?

ii. Who (men and women) uses available resources and services, and for what purpose?

iii. What types of households are there? How many households are female-headed? Are these increasing?

iv. How do men, women, boys, and girls make their living? Are there differences between various socio-economic groups?

v. How do the livelihood systems of men and women from different socio-economic groups compare?

vi. What are the most important sources of income for men and women? What are their main areas of expenditures?

vii. What are the likely climate change impacts on current livelihoods? Are certain sectors or socio-economic groups more or less vulnerable than others? Why? What are the perceptions of men and women?

viii. How diversified are the livelihoods of men and women? What specific solutions have they applied in response to the changing climate?

ix. What are the most important environmental, economic, institutional, and social patterns?

x. Do men and women have the same or different views on the patterns related to climate change?

11 GENERAL CONSTRAINTS TO UPTAKE OF CSA

The following are the constraints that hinder the uptake of CSA policies and practices in Kenya:

i. Limited mainstreaming of CSA activities in the organizational setup occasioned by the changes in the governance structures as a result of the two levels of government (i.e. national and county government.

ii. The goodwill from many stakeholders has not been translated into action as there is insufficient financial support on the implementation of the policies by government, development partners and the private sector.

iii. Limited awareness on climate change related issues in the national and at the county level.

iv. Slow or delayed uptake of research developed adaptation and mitigation measures and technologies. This could be due to limited financial capital resources and high poverty levels; limited awareness on adaptation and mitigation options; top-down approach in technology development; low awareness of CSA technologies; land use change.

v. High cost of implementation of the laid out policy actions coupled with the lack of proper financial monitoring and tracking system.

vi. Challenges in coordinating initiatives on adaptation and mitigation initiatives at the national and county level.

vii. Insufficient and inaccurate local data on weather variability due to limited weather observational network. Vast areas still remain unmonitored. These leads to lack of important weather data that is necessary for early warning and food security surveillance as well as the weather based insurance products.

12 FURTHER READING

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KCEP-CRAL Extension Manuals are well-written and up-to-date publications with basic information that Extension Officers and service providers need in each value chain. The comprehensive manuals cover all areas of the value chain.

Available extension manuals cover basic cereals (maize, millet and sorghum), pulses (beans, cow peas, pigeon peas and green grams), soil Climate Smart Agriculture and Farming as a Business as listed:

1. Common Dry Bean Extension Manual
2. Cow Pea Extension Manual
3. Green Gram Extension Manual
4. Pigeon Pea Extension Manual
5. Maize Extension Manual
6. Millet Extension Manual
7. Sorghum Extension Manual
8. Climate Smart Agriculture Extension Manual
9. Farming as a Business Extension Manual
10. Soil Fertility Management Extension Manual
11. Farm - Level Agricultural Resilience and Adaptation to Climate Change Extension Manual