CRAFT

Climate resilient value chains for improved livelihoods

Republic of Kenya

HARAMBEE

Ministry of Agriculture, Livestock, Fisheries and Cooperatives

Climate Smart Sorghum Production Resource Guide

Climate Smart Sorghum Production Training and Resource Guide

CRAFT
Climate resilient value chains for improved livelihoods

AFA
Our Crops, Our Wealth

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Kenya Agricultural & Livestock Research Organization

ASAL
Agricultural Productivity Research Project

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FOREWORD

The government of Kenya has outlined the importance of agriculture to the national economy through the Vision 2030, the Medium-Term Plan III Implementation framework, and most recently the President's Big Four priority agenda for 2017-2022, which emphasizes the importance of 100% food and nutrition security for all Kenyans. This is further supported by the development and implementation of the Food and Nutrition Policy (FNSP)2012; and the Agricultural Sector Growth and Transformation Strategy (ASTGS) 2019 – 2029. The policy documents are based on the fact that food and nutrition security requires a vibrant, commercial and modern agricultural sector that supports Kenya's economic development sustainably.

The National Adaptation Plan (2015-2030) and the Kenya Climate Smart Agriculture Strategy 2017-2026 also ensures that the food production systems in Kenya is developed sustainably.

Sorghum is an important cereal crop grown mainly for subsistence in Kenya that contributes to food security of most food insecure household in the Arid and Semi - Arid Lands (ASAL). Sorghum is thus typically grown by smallscale farmers and is mainly used for home consumption. Sorghum is a vigorous, handy and drought tolerant crop that performs well in many agro-ecological zones; there are various varieties well adapted for dry zones with low agricultural potential.

Besides being grown for consumption, sorghum is considered a good crop for silage to feed livestock because of high yields, high sugar content and the juiciness of the stalks thus grown as a fodder crop. Sorghum is also increasingly becoming an important cash crop especially with contract farming for brewing alcoholic beverages, baking, flour blending, starch, dextrose, syrup, wax and bioethanol production industries. This has considerably increased the demand for sorghum thus the need to increase sorghum production.

More investment in sorghum production will contribute towards achieving food and nutrition security, wealth and employment creation for women, men and youth. With rural to urban migration, population growth, changes in consumption patterns, tastes and preferences has changed immensely. A high majority of the population has become more conscious about their diets with preference to high nutrient dense foods such as sorghum and sorghum products.

Climate change is characterized by rising temperature, variability in precipitation patterns, increased frequency of extreme weather events such as droughts and floods, and emergence of new pests and diseases. These climatic changes and their impacts negatively affect the development of the sorghum value chain leading to increased land degradation, poor grain quality, and high post-harvest losses thus reduced yields.

Participatory engagements of different stakeholders including sorghum farmers and organizations increases the commitment and adoption of the climate smart agriculture technologies, innovations and practices. This will help various actors along the sorghum value chain to adapt, cope and become more resilient to climate change shocks. Climate smart agriculture practices such as management of organic matter, farmyard or green manure, crop specific fertilizers, mixed cropping, conservation agriculture, integrated pest management (IPM), mechanization, agroforestry, circular agriculture and grain bulking can be adopted in the sorghum value chain to make sorghum production sustainable. With the adoption of climate smart agriculture in sorghum production maximum yields of 3 to 4 t ha^{-1} at farm level can be achieved making sorghum value chain a more competitive and sustainable value chain.

The Climate Smart Sorghum handbook integrates the climate smart agricultural technologies, innovations and practices with farming sorghum as a business within climate change vulnerability settings, gender and social inclusion lens while creating an enabling policy environment. It is envisaged that the handbook will contribute towards the achievement of the strategic objectives of increasing sustainable sorghum production.

The Climate Smart Sorghum Production Training and Resource Guide will serve as a guide and a reference in the preparation of training modules/guide/aids for facilitators, extension service providers, farmers, agri-entrepreneurs, processors and all other actors along the sorghum value chain.

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ACKNOWLEDGEMENT

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Appreciation and special gratitude also go to the Steering Committee of technical experts who took time to validate the knowledge shared through this manual. The committee comprised : MoALFC (Teresa Kinyungu, Veronica Ndetu, Mathias Wafula, Paul Obusuru, and Naomi Wangeci), KALRO (Dr. Lusike Wasilwa, Charles Bett, and Victor Wasike) , AFA (Beatrice Elizabeth Langat, Milton Munialo), Anthony Kioko (Cereal Growers Association), the CRAFT project partners {SNV (Joseph Muhwanga, Joyce Munini Mbingo, Oscar Nzoka, and Alphonse Muriu), CCAFS (Osumba Joab, John Recha, Teferi Demissie), WENR (Confidence Duku and Annemarie Groot) and Agriterra (Emanuel Kibet)}, the consultants Rachael Kisilu, Dr. Murenga Mwimali and Nicholas Owiro, Kenya Plant Health Inspectorate Services (KEPHIS), Pest Control Products Board (PCPB); The Ministerial Editorial Committee of MoALFC ; Grace Mugo, Douglas Murunga, James Libaako, George Bosire, Nelson Madera, John Juma, and Some Baraka among others for their valuable input. County Agricultural Departments and farmer representatives from the sorghum producing counties namely; Embu, Meru, Kirinyaga, Tharaka Nithi, and Makueni in central region and Trans Nzoia, Siaya, Nandi, Elgeyo Marakwet, HomaBay, Busia and Bungoma in the western region.

We also wish to thank Dr. Eliud Kireger the Director General KALRO and Mr. Anthony Muriithi, Director General AFA and all the other unmentioned individuals who contributed their valuable input and time towards the preparation of this Climate Smart Sorghum Production Training and Resource Guide.

The Climate Smart Sorghum Production Training and Resource Guide will serve as a guide and reference for sustainable production along the sorghum value chain to contribute towards increased food and nutrition security, incomes, wealth and employment creation.

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EXECUTIVE SUMMARY

In Kenya, agriculture plays a significant role towards national economic development. This is indicated in the Kenya Vision 2030, Agricultural Sector Transformation Strategy (ASTGS), the Big Four Agenda, the National Adaptation Plan (2015--2030) and the Kenya Climate Smart Agriculture Strategy 2017-2026 among other policy documents. However, climate change effects such as recurrent droughts, flooding, poor precipitation and distribution; high temperatures are posing a challenge to these efforts. Cultivation of crops that are tolerant to drought and heat stress is one of the adaptation mechanisms being spearheaded as an adaptation strategy. Sorghum, which is a drought tolerant crop and a staple food security crop for many households in Kenya, is also increasingly becoming an important cash crop. More investment in its production will contribute towards achieving food and nutrition security and employment creation for women, men and youth. High investment in the sorghum value chain will help cope against the detrimental effects of climate change.

Sorghum is grown in the semi-arid regions of Kenya under annual rainfall of 450-900 mm, an altitude of 0 to 2500 m above sea level and optimum temperatures of 20-35 ^{0}C. Kenya's current annual average production is approximately at 206, 234 MT and the yields are generally low between 0.5-0.89 t ha^{-1} at farm level due to various constraints including climatic challenges, policy issues and social economic challenges. The use of climate smart production technologies such as certified and adaptable seed varieties, good agronomic practices, soil and water management, creating good enabling policy environment and improved marketing strategies in sorghum farming will help adapt to most of these constraints, improve sorghum production and productivity, leading to improved food and nutrition security. Agricultural extension providers and lead farmers will use the Sorghum Production Manual as a guide in creating awareness on climate smart sorghum production practices and technologies. The Climate Smart Sorghum Production Training and Resource Guide provides facilitators, extension agents, farmers, agri-entrepreneurs, processors, women, men and the youth (all gender), and all other actors along the sorghum value chain, with a reference tool related to climate smart agriculture and its application in sorghum value chain in Kenya.

These stakeholders can use this manual to understand key terminologies used in climate change and climate smart agriculture, and topics about application of the climate smart agriculture practices and technologies in sorghum production. This **Climate Smart Sorghum Production Training and Resource Guide** explains necessary steps to achieve climate-smart approaches to sorghum production in Kenya.

HOW TO USE THIS CLIMATE SMART SORGHUM PRODUCTION TRAINING AND RESOURCE GUIDE

The Climate Smart Sorghum Production Training and Resource Guide is divided into six chapters that address the following themes:

Chapter 1: Overview of Sorghum value chain: This chapter highlights sorghum production in Kenya, challenges facing sorghum production and the strength, weaknesses, opportunities and threats analysis.

Chapter 2: Climate change and climate smart agriculture: This chapter introduces climate change, the link between climate change and agriculture, causes of climate change, its current and projected impact in Kenya. It also outlines concepts of climate smart agriculture, adaptation and mitigation of climate change, and sustainable increase in productivity amid climate change.

Chapter 3: Sorghum production in a changing climate: This chapter explains the different production systems/techniques that address the challenges in sorghum production and climate change adaptation, mitigation and productivity. It includes different soil and water conservation and management techniques to mitigate and adapt to climate change in sorghum production.

Chapter 4: Economics of sorghum production and market access: This chapter elaborates on the economics of sorghum production under climate smart agriculture, various agribusiness records, marketing, contract farming and cost benefit analysis.

Chapter 5: Gender and social inclusion in the sorghum value chain: This chapter highlights the roles of men, women and youth along the sorghum value chain.

Chapter 6: Enabling policy environment for adoption of climate-smart agriculture approaches: The chapter indicates the importance of creating an enabling environment for the uptake and scaling up of climate smart agriculture technologies. This section advice on policies and strategies that need to be considered to boost sorghum production in Kenya in a changing climate. In addition, it includes various suggestions necessary for the uptake and scale up scaling up of climate smart technologies in sorghum value chain and the need to increase sorghum production.

ABBREVIATIONS AND ACRONYMS

Abbreviation	Explanation/meaning
AFA	Agriculture and Food Authority
AGRA	Alliance for a Green Revolution in Africa
AMRI	Agricultural Mechanization Research Institute
ASAL APRP	Arid and Semi-Arid Lands Agricultural Productivity Research Project
ASDS	Agricultural Sector Development Strategy
ASDS	Agricultural Sector Development Strategy
B	Boron
Ca	Calcium
CA	Conservation agriculture
CAN	Calcium Ammonium Nitrate
CCAFS	Climate Change for Agriculture and Food Security
CGA	Cereal Grain Association
Cu	Copper
CDD	Consecutive dry days
CH_4	Methane
Cl	Chloride
cm	Centimeters
CO_2	Carbon Dioxide
CORDEX	Coordinated Regional Climate Downscaling Experiment
CSA	climate smart agriculture
CRAFT	Climate Resilient Agribusiness for Tomorrow
DAP	Di-ammonium phosphate
EABL	East African Breweries Limited
EAGC	East African Grain Council
FAO	Food and Agriculture Organization
FAOKE	Food and Agriculture Organization-Kenya
Fe	Iron
Ft	Feet
GHGs	Greenhouse Gases
HST	Hermetic Storage Technology
ICRISAT	Internationals Centre for Research in Semi-Arid and Tropics
IDM	Integrated Disease Management
IPM	Integrated Pest Management
IWM	Integrated Weed Management

K	Potassium
KARI	Kenya Agricultural Research Institute
KALRO	Kenya Agricultural and Livestock Research Organization
KCSAP	Kenya Climate Smart Agriculture Project
KCSAS	Kenya Climate Smart Agriculture Strategy
KEPHIS	Kenya Plant Health Inspectorate Services
KES	Kenya Shillings
Kg	Kilogram
KMD	Kenya Meteorology Department
LGS	Length of Growing Spell
M	Meters
MAM	March-April-May
Masl	Metres above sea level
Mg	Magnesium
mm	Millimetres
Mn	Manganese
Mo	Molybdenum
MoALF&I	Ministry of Agriculture, Livestock, Fisheries and Irrigation
MT	Metric Tons
N	Nitrogen
NO_3	Nitrates
NPK	Nitrogen, Phosphorous and Potassium
N_2O	Nitrous Oxide
P	Phosphorus
PCPB	Pest Control Product Board
pH	power of hydrogen
PVC	Polyvinyl chloride
OND	October-November-December
OPV	Open Pollinated Variety
Qty	Quantity
RCP	Representative Concentration Pathways
S	Sulphur
SWOT	Strength, Weakness, Opportunity and Threats
$t\ ha^{-1}$	tons per hectare
SNV	Netherlands development organization
VAT	Value Added Tax
WRS	Warehouse receipting system
WPP	Woven Polypropylene
Zn	Zinc

1 OVERVIEW OF SORGHUM VALUE CHAIN

1.1. Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is an important crop, which is grown globally for food and feed purposes. Among the other cereals it is ranked fifth worldwide in production after maize, wheat, rice and barley (http://Faostat.fao.org/;December, 2009).).

According to FAOSTAT (2018) sorghum production data the area under sorghum cultivation in the world was about 42 million hectares with a total production of 59.3 million Metric tons MT. United States of America is the main sorghum producer with an average of 9.3 million MT. The other top producing countries include Nigeria producing 6.9 million MT, Sudan producing 4.9 million MT, Mexico producing 4.7 million MT and India with 4.5 million MT. The sorghum production in Africa covers an area of about 29.7 million hectares, with a production of 29.8 million MT. The crop was grown in an area of 5.3 million hectares in East Africa with a production of 7.6 million MT. Kenya produced about 206, 234 MT of grain sorghum under an area of 229,883 hectares (USDA, 2020; FAOSTAT, 2018).

Sorghum is mainly grown in both semi-arid regions that experience limited rainfall and areas with adequate rainfall. Sorghum varieties are known to be highly resistant to drought conditions, can grow under relatively low soil fertility and can withstand water logging better than other cereal crops such as wheat and Maize. The crop can survive under seasonal rainfall as low as 250mm, an altitude of 0 to 2500m above sea level and optimum temperatures of 20-35 ^{0}C.

Sorghum in Kenya is grown in Eastern (Kitui, Makueni, Tharaka Nithi, Embu, Meru), former Nyanza (Siaya, Kisumu, Homa Bay, Migori), Western (Bungoma, Vihiga, Kakamega, Busia), some parts of rift valley (Baringo, Bomet, Kajiado, Laikipia, Turkana and Narok) and Coast regions (Lamu, Kilifi, Taita Taveta, Mombasa). The county governments of Siaya, Kakamega, Makueni, Meru, Embu, Kitui, Machakos and Tharaka Nithi, some non-governmental organizations also continue to support farmers in capacity building such as hands on training, facilitation with inputs such as seed, mechanization and financing through credit as well as funding of promotion projects to increase the production of sorghum in the counties and the country. The support for farmers helps build their long-term resilience to the impact of increasingly frequent climate change scenarios.

Despite the efforts at farmer level the production of sorghum in Kenya is still low with an average yield of between 0.5-0.89 t ha^{-1}. Therefore, it is critical to consider and support the role of all the actors in the different levels of the sorghum value chain. These include production actors/farmers, trade and distribution actors, processing and retail actors, input and service providers, financing institutions as well as policy makers. Distortions at one level are likely to cause variability at another level of the sorghum value chain because actors and activities are mutually dependent.

1.2. Importance of sorghum

Due to its adaptation to the dry areas, sorghum is a staple food, nutrition and income security crop for many people. It is utilized as food, animal feed and industrial raw material. As food for human beings, the grain is used in making fermented and non-fermented traditional dishes as well as value added food products. In livestock sorghum is used as feed in form of fodder/forage or grain. Sorghum processed grain is very important as animal feed, low tannin highly digestible varieties have been developed and sorghum-grain based poultry feed is used without negative effects on body weight. Industrially, the grain is used to manufacture wax, starch, syrup, dextrose agar, edible oils and in brewing.

The promotion of white sorghum varieties in beer production has spurred renewed interest in its commercial production in Kenya. Through this endeavor, the commercial potential of sorghum as a raw material in food, feed, fodder and malting industries is realized, it will offer an increased income sufficiency, food security, improved nutrition, and the generation of employment. Sorghum commercialization generates revenue of approximately KES 4 billion resulting from brewing industry, sale of seed, and engages over 250,000 farmers across Kenya.

1.3. Challenges facing sorghum value chain in Kenya

Sorghum is basically a climate-resilient crop but its production faces several constraints; droughts and floods, pests and diseases, low socio-economic status of most farmers engaged in sorghum production (hence inability to afford inputs), limited climate-smart approaches to the sorghum production, institutional bottlenecks such as inadequate research capacity and facilities, policy impediments, poor marketing systems and poor physical infrastructure such as roads. At the industrial brewing and confectioneries, processing of sorghum grain is challenging due to presence of tannins which further lowers quality.

1.4. Sorghum value chain strengths, weaknesses, opportunities and threats analysis

Table 1. Summary of the SWOT Analysis for the sorghum value chain

Strengths	Opportunities
• Government of Kenya's commitment to the strengthening of the agriculture sector for increased food and nutrition security • Access to innovations and technology at the farm level, through the Kenya Agricultural and Livestock Research Organization (KALRO)in collaboration with non-governmental organizations, and private sector for improvement of mechanized operations • It can grow well in both high and low potential areas where maize cannot do well. • Good for fodder and silage making because farmers do not need to add molasses as they do when making silage. • Sorghum can do well in areas receiving adequate rainfall • Availability of new and high yielding stress tolerant varieties	• Stable government policies such Agricultural Sector Transformation and Growth Strategy 2019-2029 (ASTGS), flour blending regulations 2020, regarding socio--economic and industrial development improving the agricultural sector, and increasing production, productivity and marketability • Reduction in excise duty for sorghum products causing increased demand for sorghum • Public and private sector partnerships between farmers and processors like the East Africa Maltings Limited in promoting sorghum production for blending of flour, malting and brewing of beer • Regional integration among the East African Community economies is a major opportunity towards establishment of a common market for consumer population • Manufacturing of aflasafe for management of aflatoxin

Weaknesses	Threats
• Seed recycling • High cost of production in Kenya makes sorghum products to be less competitive in the international market • Limited choices of available commercial varieties • Inadequate information for farmers • Limited support and promotion by county governments • Weak farmer organization and corporative along sorghum value chain • Lean market of sorghum grain • Inadequate access to postharvest handling information	• Unpredictable weather patterns due to climate change including; recurrent droughts, flooding, low precipitation and distribution and high temperatures. • Pricing and marketing policies for sorghum and all other cereal crops are liberalized • Non-tariff trade barriers, such as roadblocks, multiple county access and levies hamper competitiveness domestically and regionally • 25% tariff on sorghum imports into Kenya from Southern Africa Development Community countries and other countries • Maize, rice and the introduction of horticultural crops are growing in popularity thereby taking away the land space that would be for sorghum production • Delays in the East African Community integration of economies by some member countries • High level of tannin reducing suitability for processing • Birds' menace especially the white variety • Agronomic practices practiced by farmers are not updated and followed by farmers. • Reduced sorghum production especially in Eastern region.

2 CLIMATE CHANGE AND CLIMATE SMART AGRICULTURE

This chapter describes climate change, its causes, impacts, projections, risks and opportunities. It also contains climate information and the sorghum crop calendar in Kenya for adaptive decision making. In addition, it indicates information on climate smart agriculture.

2.1. What is climate change?

The term "**Climate change**" refers to the natural climate variability observed since the beginning of 1900s. Climate change is largely attributed indirectly or directly to human activities that alter the composition of the global atmosphere observed over comparable periods (UNFCCC, 2006). This unnatural and human induced climate change is a major challenge that is causing shifts in the normal climatic conditions such as rainfall and temperature, whose effects include more pressure on the planet's natural environment and the resultant negative impacts on human beings.

2.2. Causes of climate change

An increase in human activities which include burning fossil fuels through industrialization, agricultural activities such as excessive use of fertilizer containing nitrogen, deforestation and overgrazing, cause an increased production and release of heat-trapping gases in the earth's atmosphere called 'greenhouse gases'. Greenhouse gases occur naturally in the atmosphere. However, as humans increase the amount of these gases in our atmosphere, more and more heat is trapped which in turn cause the temperature to change. The process where greenhouse gases trap the sun's heat is called the greenhouse effect.

Activities by human beings cause the release of various greenhouse gases; however, there are three gases that are main the cause of climate change; carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Carbon dioxide is the major global contributor to climate change and is released through the burning of fossil fuels more so in the developed countries and deforestation in the tropics. Methane emissions arise from agriculture through manure and organic waste. Nitrous oxide is released during application of nitrogen fertilizers, and fluorinated gases are emitted during industrial processes.

2.3. Climate change projection scenarios and impacts for Kenya

Climate change impacts on agriculture and at the same time agriculture contributes to climate change, therefore there is a need for climate smart agriculture to reduce the negative effects and risks of climate change.

The agriculture sector is the most affected by climate change since it is dependent on water supply as well as other elements of weather including temperature, humidity, radiation, atmospheric pressure and wind. Others include soil fertility and nutrition, occurrence of pests and diseases. Impacts include a rise in climate related incidents such as floods, droughts, frosts, hailstones and destructive storms; the extinction of numerous plant and animal species; the reduction of agricultural harvests in vulnerable areas; the changing of growing seasons; the melting of glaciers; the disruption of water supplies; the growth of infectious tropical diseases; the rising of sea levels and much more. Small-scale farmers in rural Kenya will be the most affected unless awareness is created for them to understand the possible impacts of the climate change.

The climate change projections for Kenya shows increasing temperatures and more frequent climate shocks (droughts and floods). As part of the Climate Resilient Agri-business for Tomorrow (CRAFT) project in East Africa, a climate projection was performed for Kenya, Uganda and Tanzania using a high-resolution data from the Coordinated Regional Climate Downscaling Experiment (CORDEX). The climate projection work was based on two validated regional climate model data that are dynamically downscaled from four Global Circulation Models (GCMs), which has a reasonable skill in East Africa. The GCMs projections were forced by the Representative Concentration Pathways (RCPs), which are prescribed greenhouse gas concentration pathways (emission) trajectory and subsequent radiative forcing by 2100. The climate projection work in the CRAFT project is based on two RCP scenarios, RCP4.5 and RCP 8.5 that are representatives of mid-and high-level of emission scenarios, respectively. The following section summarizes the climate projection work done under the CRAFT project for the sorghum growing areas of Kenya:

Recent climate projections generated by the CRAFT project in some of the sorghum growing regions in Kenya (CRAFT, 2019) shows that:

a) There will be a definite increase in temperature both in March-April-May (MAM) and October-November-December (OND) rain seasons.

b) During the March-April-May (MAM) and October-November-December (OND) rain seasons, the model projection for both the 2030’s and 2050’s shows a temperature rise in all parts of Kenya particularly in the western half of the country.

c) While rainfall is expected to increase in most parts of Kenya during the OND rainy season, the MAM rainy season is expected to suffer from a long dry spell and a decrease in seasonal rainfall particularly in the north western parts of the country.

d) A decrease in the seasonal rainfall and wet-spells accompanied by an increase in the number of consecutive dry days (CDD) in the north-western part of Kenya could lead to shortage of water and drought in the region.

Even though many of the sorghum growing areas will experience increase in rainfall, the benefits to sorghum growing will not be much due to expected increase in evapotranspiration owing to the projected increase in temperature. In addition, there will be increased/decreased time of growth depending on the location and emergence of new pests and diseases, hence the need to develop varieties to suit the new climate conditions and adoption of climate smart sorghum production technologies.

2.3.1 Temperature trend in the sorghum growing areas

The temperature trend (from 1961-2005) for both March, April, May (MAM) and October, November, December (OND) rainy seasons show that temperature has been increasing by about 1°C to 1.2°C in the south-eastern parts of Kenya in the past few decades (Figure 1).

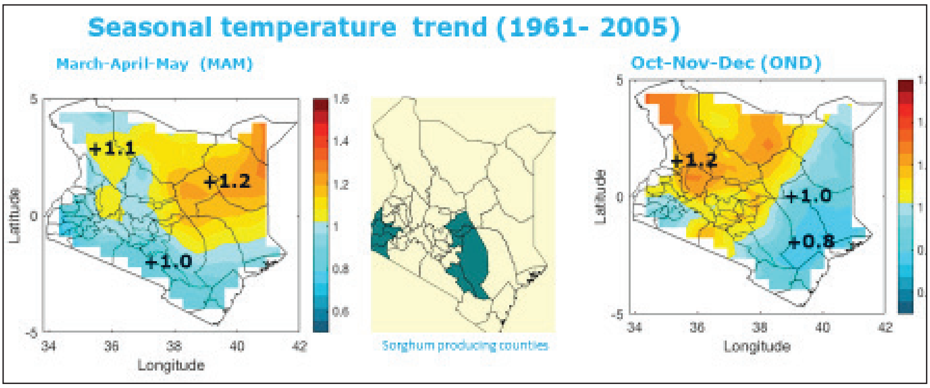


Figure 1. Seasonal temperature trends (1961-2005) for MAM and OND rainfall seasons

Source: CRAFT project, 2020

2.3.1.1 Projection of temperature

During both the MAM and OND rainy seasons, temperature in the 2030's is expected to rise by about 1.4°C to 1.8°C in the south-eastern areas of Kenya (Figure 2 and Figure 3). However, the projection model shows that temperature in the 2050's is expected to rise by about 2.0°C to 2.4°C and 2.4°C to 2.8°C in the south-eastern areas of Kenya during the OND and MAM rainy seasons, respectively.

The rate of warming in Kenya, is demonstrated where temperature over the south-eastern sorghum growing areas rises in the MAM rainy season greater than the OND rainy season by about 0.4°C (Figure 2).

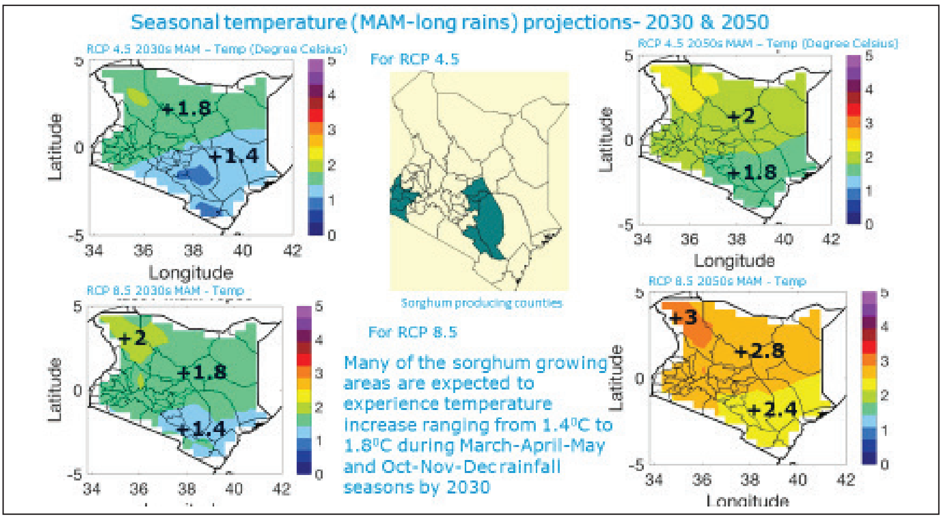


Figure 2. Projected seasonal mean changes in temperature for the MAM rains for 2030s (Left) and 2050s (Right) under the Representative Concentration Pathways (RCP) 4.5 and RCP 8.5, relative to the reference period (1961-2005).

Source: CRAFT project, 2020

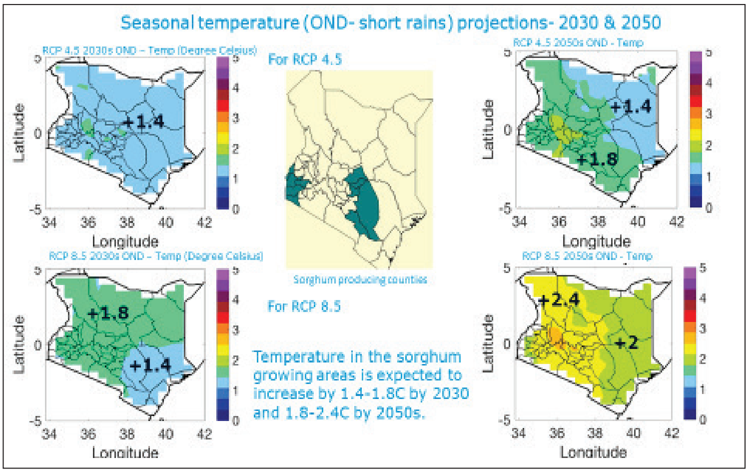


Figure 3. Seasonal temperature projection for the OND rain season for 2030 and 2050 under RCP 4.5 and RCP 8.5.

Source: CRAFT project, 2020

2.3.2 Precipitation/rainfall

The seasonal mean rainfall in the MAM rain season is projected to slightly decrease in the western regions of the sorghum growing areas by about 10% while in the south-eastern sorghum growing regions such as Kitui and Makueni counties it is projected to slightly increase by about 10-20% in both scenarios (RCP4.5 and RCP8.5) for 2030s and 2050s (Figure 4). Projections of the seasonal mean rainfall in the second rainy season (OND) for 2030s and 2050s under RCP4.5 and RCP8.5 show that rainfall is expected to increase by about 20-30% in the south-eastern sorghum growing areas of Kenya, especially during the 2050s while over the western sorghum growing areas it is expected to slightly increase by 5-10 % (Figure 5).

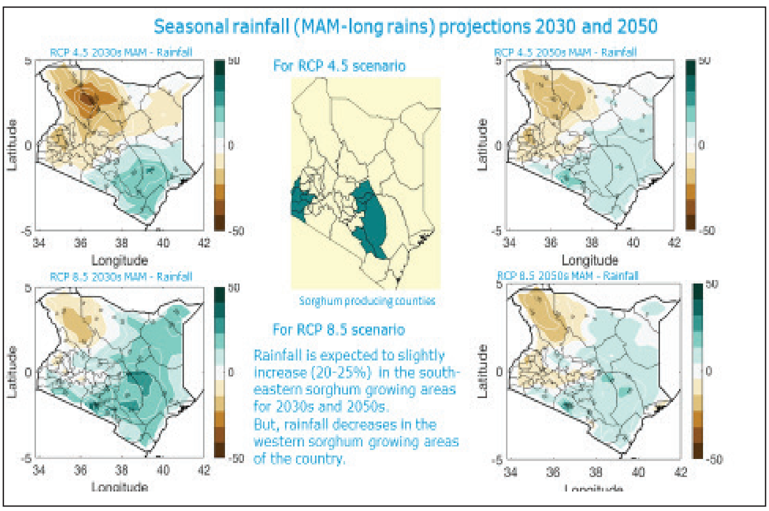


Figure 4. Projected seasonal mean changes in MAM rains for 2030s (Left) and 2050s (Right) under the RCP 4.5 and RCP 8.5

Source: CRAFT project, 2020

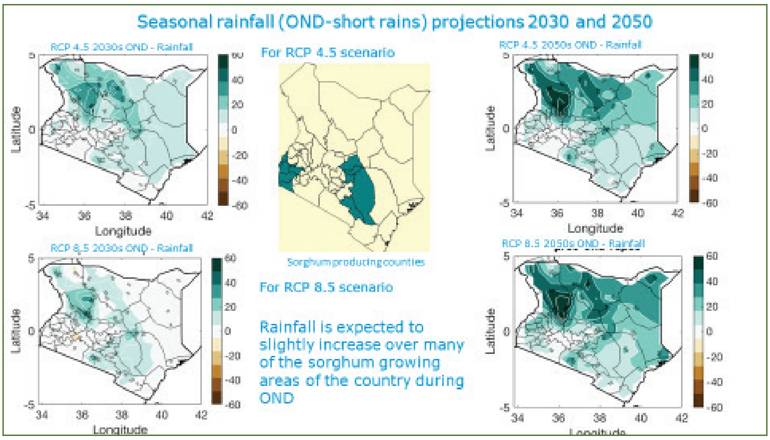


Figure 5. Projected seasonal mean changes in rainfall for OND rains for 2030s (Left) and 2050s (Right) under the RCP 4.5 and RCP 8.5.

Source: CRAFT project, 2020

2.3.2.1 Onset and length of growing spell

The assessment and prediction of the onset and cessation dates, and length of the growing spell of a rainy season is a very crucial element to the agricultural activities of countries in East Africa, whose agriculture is mainly dependent on the distribution and amount of seasonal rainfall. In the CRAFT project, the onset, cessation and length of growing spell for the MAM rainy season is estimated for the historical (1961-2005) and the 2030s and 2050s for both RCP4.5 and RCP8.5 scenarios. Results show that early onset of the seasonal rainfall is expected in most of the south-eastern sorghum growing areas of Kenya by about 10 days (Figure 6). On the other hand, the onset of rainfall is expected to delay by about 10 days over the western sorghum growing areas of the country. Similarly, the length of the growing spell in the south-eastern sorghum growing area of Kenya is expected to increase by about 10 days suggesting a late cessation for the region (Figure 7). The length of the growing spell over some of the western sorghum growing areas of the country is expected to slightly decrease suggesting an early cessation of the season in the region.

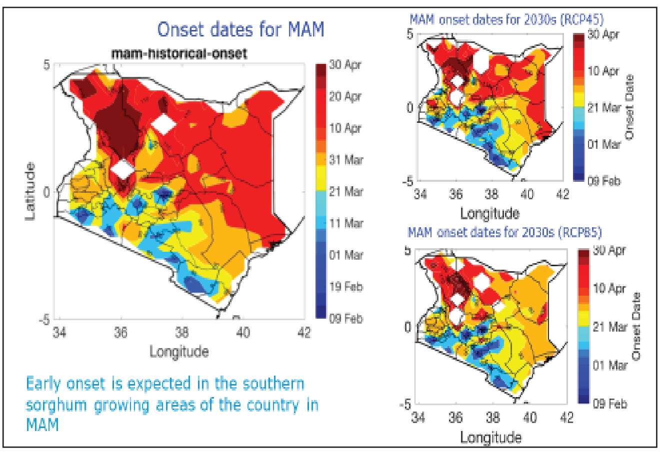


Figure 6. Rainfall onset days for the MAM rainy season for 2030 for RCP 4.5 and RCP 8.5

Source: CRAFT project, 2020

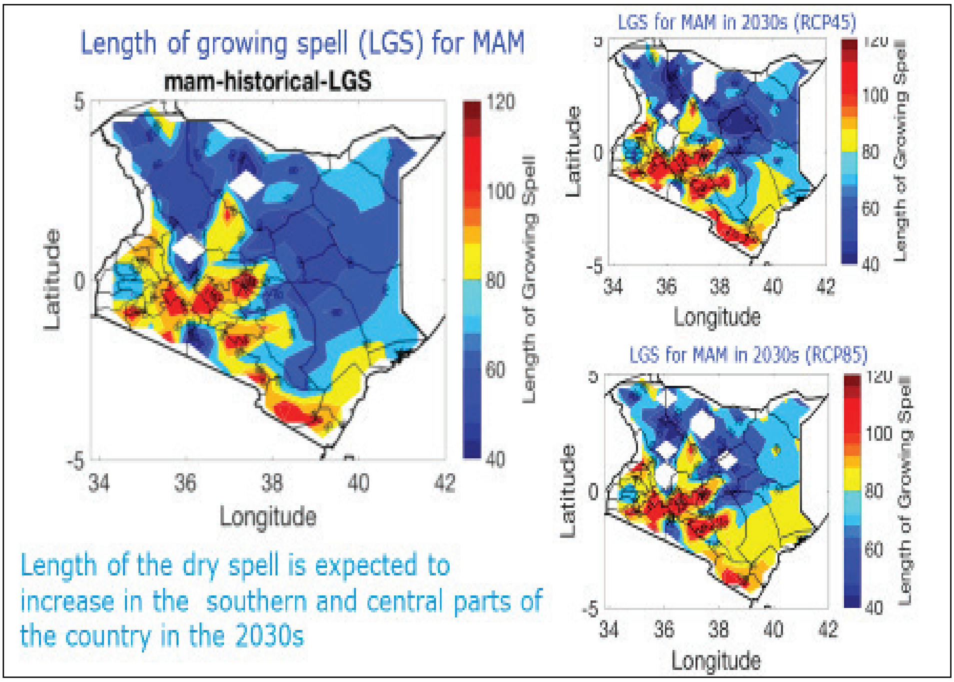


Figure 7. Length of the growing spell (LGS) for the MAM season for 2030 and 2050
Source: CRAFT project, 2020

In summary, during both the MAM and OND rainy seasons, temperature in the sorghum growing areas of western and south-eastern Kenya is expected to rise by about 1.4°C to 1.8°C and 2.4°C to 2.8°C in the 2030s and 2050s respectively.

The seasonal rainfall over the south-eastern sorghum growing areas of the country is expected to increase in both the MAM and OND rainy seasons in the 2030s and 2050s. Early onset and longer length of the growing period is anticipated in this region which favor the sorghum agricultural activity in the region. On the other hand, the seasonal rainfall is expected to decline in the western sorghum growing areas particularly in the MAM rainy season. A delay in the onset and a decrease in the length of the growing period is anticipated in the western sorghum growing areas of the country which will have a great impact on the agricultural activity of the region.

2.3.2.2 Projections of extreme precipitation/rainfall

Precipitation indices such as consecutive dry days (CDD) and consecutive wet days (CWD) are used in the CRAFT project based on the definitions recommended by the Expert Team on Climate Change Detection and Indices (ETCCDI). These indices have been widely used in the detection, attribution, and projection of changes in climate extremes and a detailed description of the indices can be found on the ETCCDI website, http://etccdi.pacificclimate.org/list_27_indices.shtml. The consecutive dry days has been used as an indicator for enhanced dryness and high risk for seasonal drought whereas CWD has been a key indicator of extreme precipitation that could lead to flooding (Figure 8, Figure 9, Figure 10 and Figure 11).

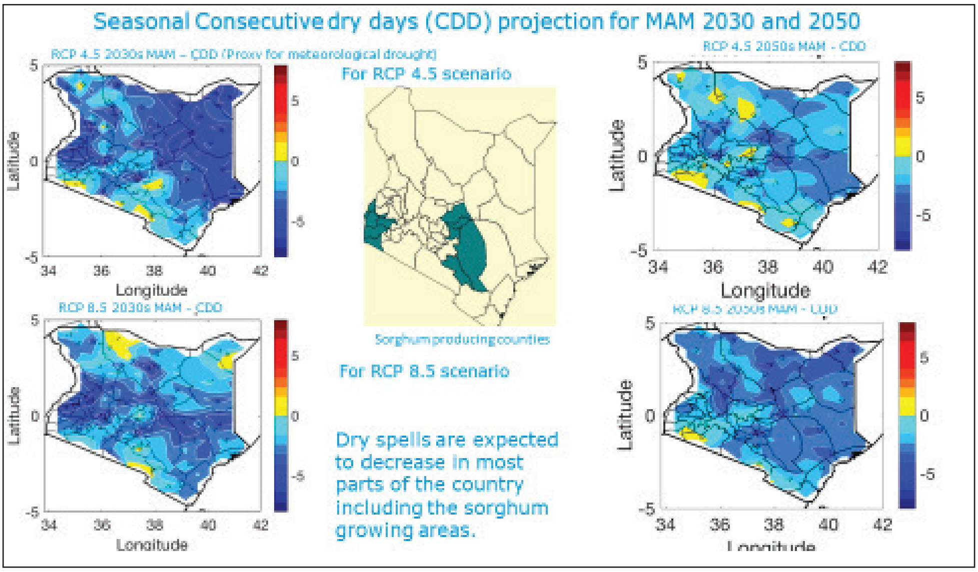


Figure 8. Projected seasonal consecutive dry days for MAM rainy season for year 2030 and 2050.
Source: CRAFT project, 2020

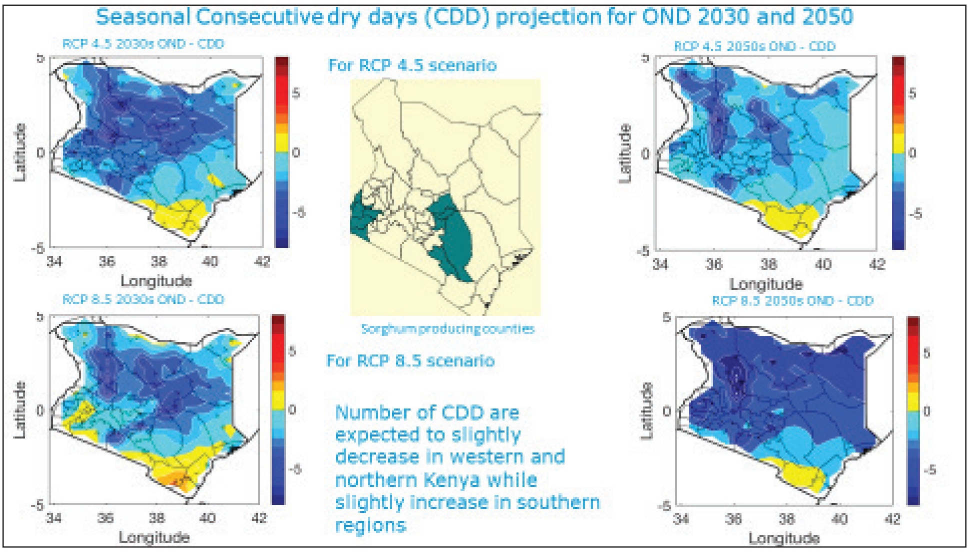


Figure 9. Projected seasonal consecutive dry days for OND rainy season for year 2030 and 2050.
Source: CRAFT project, 2020

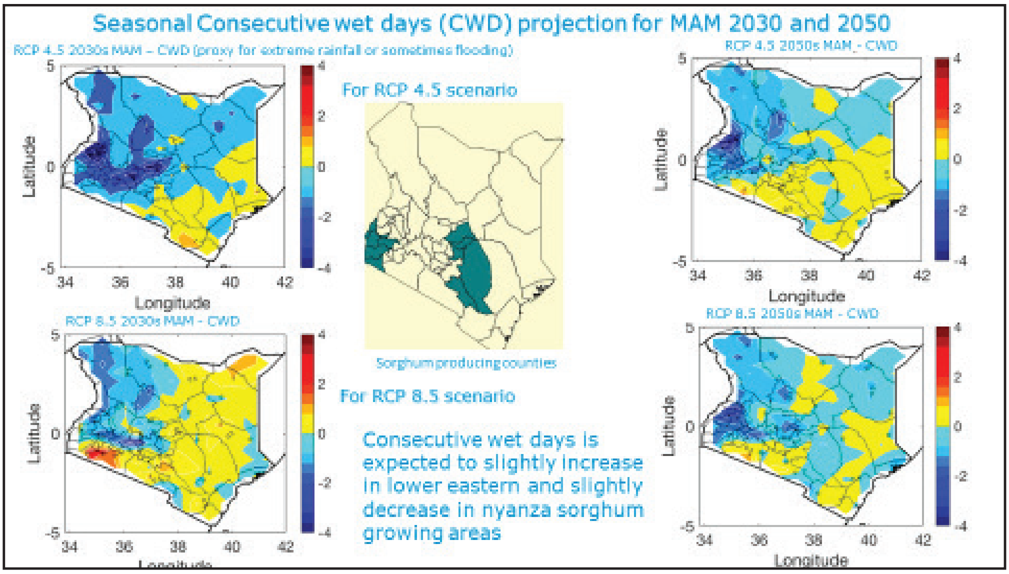


Figure 10. Projected seasonal consecutive wet days for MAM rainy season for year 2030 and 2050.
Source: CRAFT project, 2020

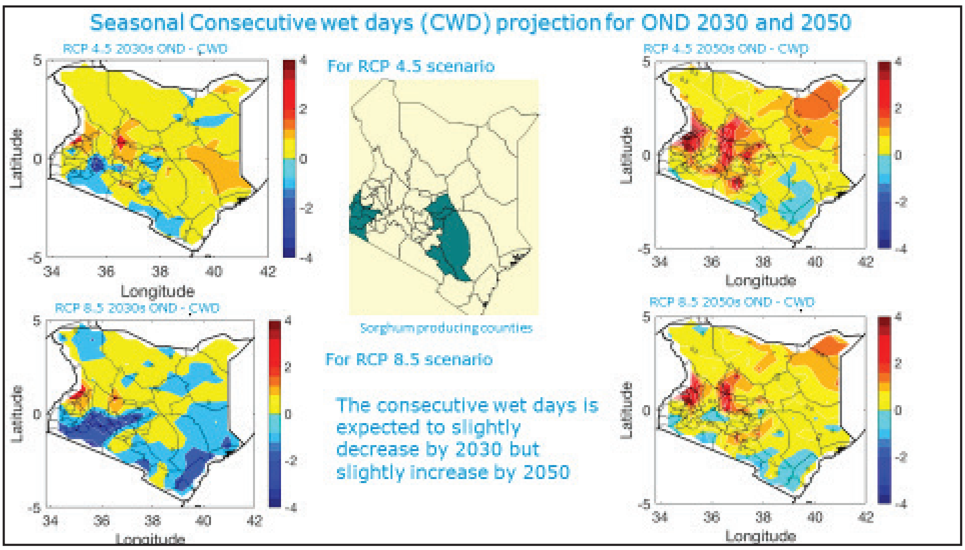


Figure 11. Projected seasonal consecutive wet days for OND rainy season for year 2030 and 2050.
Source: CRAFT project, 2020

2.4. Climate change risks and opportunities in the sorghum value chain

The impacts of climate change on sorghum productivity in the major growing counties were simulated during the climate projections by the CRAFT project, 2020 using the WOrld FOod STudies (WOFOST) crop growth model developed by Wageningen University & Research. WOrld FOod STudies is a simulation model for the quantitative analysis of the growth and production of annual field crops. It is a mechanistic, dynamic model that explains daily crop growth on the basis of the underlying processes, such as photosynthesis and respiration and how these processes are influenced by environmental and climatic conditions (Figure 12 and Figure 13). Specifically, the water-limited yield potential of sorghum was simulated under current and future climate conditions. Water-limited yield potential represents the maximum yield attainable under rain fed conditions and reflect production situations with optimal agronomic management such as soil testing and proper fertilizer application, weed control, pests and diseases control.

Sorghum is a resilient crop and relatively more tolerant to drought/water stress than other crops. Therefore, slight to moderate decreases in rainfall are unlikely to affect sorghum growth and yield. Research has also shown that moderate temperature increases up to 33°C can lead to increases in sorghum yields.

2.5. Impacts of climate projections on sorghum production

The analysis show that in the coming years, sorghum yield is expected to increase during both the MAM and the OND seasons and under all climate change scenarios. However, the degree of yield increases depends on the growing season. During the MAM season, temperature increases are likely to boost sorghum growth and yield despite projected decrease in rainfall. In major gowing areas such as Kitui, Meru and Makueni, sorghum yields are likely to increase by at least 50% in large areas. During the OND rainy season, a combination of temperature and rainfall increase are likely to lead to yield increases as well. The magnitude of yield increases, however, are expected to be relatively lower than in the MAM season. Comparatively, the MAM season is expected to be the most productive season for sorghum production in the major growing areas in the coming decades. Understanding the impacts of climate change on water-limited yield potential of sorghum in combination with information on actual farmers' yields is important for a number of reasons which include estimation of sorghum production potential in Kenya and associated land and water requirements. Identification of areas with substantial opportunities for sorghum yield increases where investments in agricultural research and development can be directed and identification and targeting of suitable adaptation options for different areas such as new sorghum cultivars and increased biotic control.

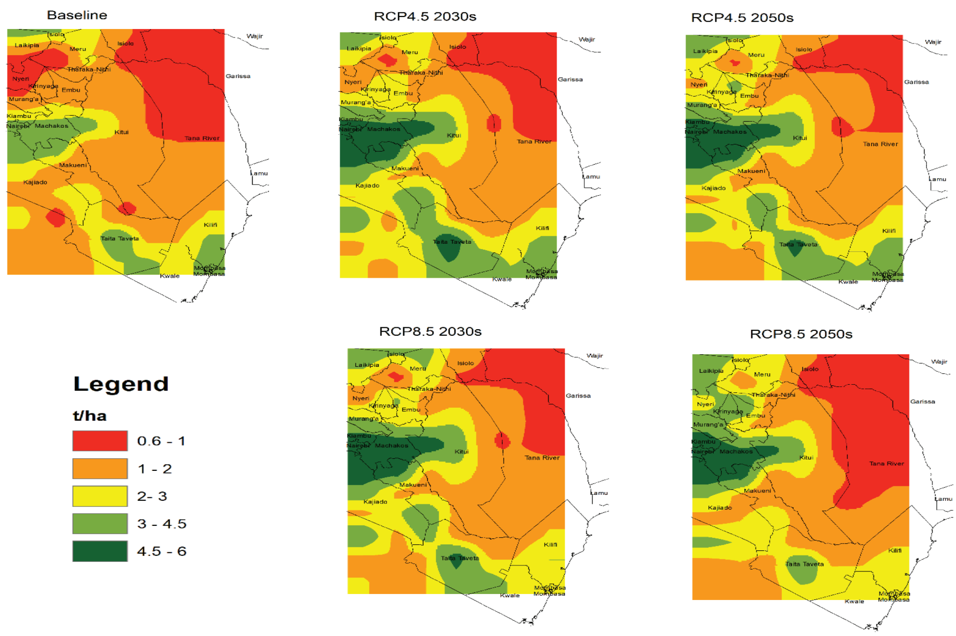


Figure 12. WOFOST crop growth model developed by Wageningen University & Research
Water-limited yield potential during the MAM rainy season.

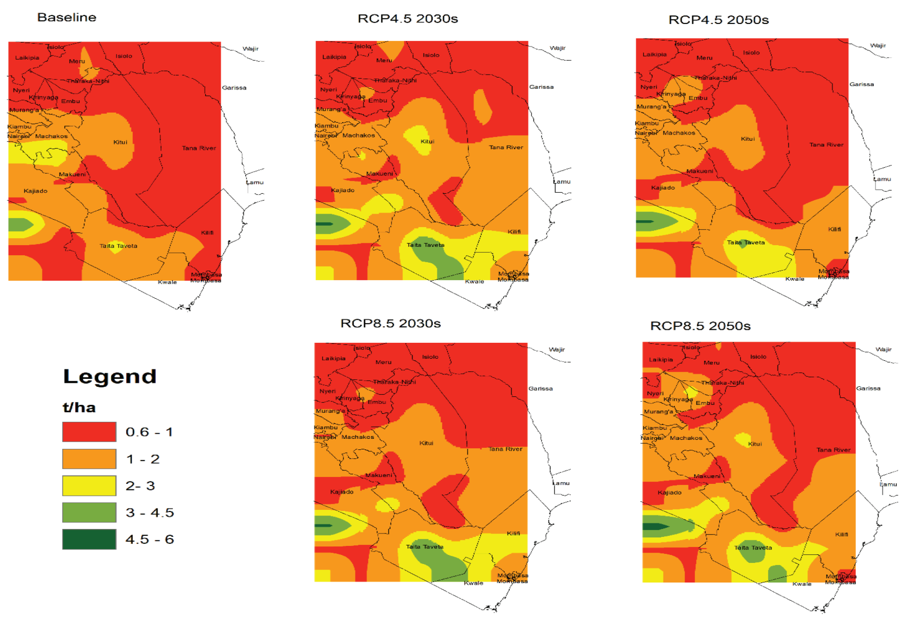


Figure 13. WOFOST crop growth model developed by Wageningen University & Research
Water-limited yield potential during the OND rainy season.

Note that the projected increase in rainfall with the corresponding increase in temperate could also increase evapotranspiration, therefore this water may not be available to the crop and thus the above increase in yields may not be realized. For sorghum value chains actors to be able to adapt and cope better with expected risks and exploit opportunities presented by the projected climate changes there will be a need to: -

a) Promote use of climate smart agronomic technologies and practices such as use of quality seeds of well-adapted varieties, biodiversity management, Integrated Pest Management, Improved water use and management, sustainable soil and land management for increased crop productivity and sustainable mechanization.
b) Promote use of climate smart inputs and services. e.g., soil testing, appropriate and high yielding certified seeds, and crop specific fertilizers etc.
c) Incorporate climate and agro-weather information into agricultural extension services.
d) Mainstreaming climate risk considerations in business planning and decision-making.
e) Enhance climate-based insurance.
f) Crop and enterprise diversification.

2.6. Key climate information for adaptive decision making in sorghum production

The four major types of climate information needed by farmers are:

a. Before the beginning of the season, the interpretation of the agrometeorological crop risk analysis to assess the suitability of sorghum cultivation based on its water requirements and other agrometeorological analysis.

b. Before the beginning of the season, the interpretation of the statistical analysis of rainfall for the determination of the optimum planting date(s);

c. Before the beginning and the end of season, seasonal climate outlooks in order to adapt to the various situations due to the uncertainty inherent in the seasonal climate forecasts.

d. Throughout the season, seven-day weather forecasts for rainfall and temperature (with a focus on forecasts of weather extreme events such as drought, heavy rains and strong winds) and 10-day agrometeorological advises on better adaptation of farmers' practices.

Note that, except for "*c*", other types of information should be tailored to farming communities at the local level and presented in a way that makes it easy to understand. In principle, the four types of climate information are produced by the agro-meteorology Unit of Kenya Meteorology department in close collaboration with agro-meteorology and agricultural research units; after which they are disseminated to farmers with the assistance of the agricultural extension officers at the local level.

2.7. Climate information matrix

Climate information decisions depend on two levels of communication mainly scientific community and the local community. The scientific community processes information including seasonal forecasts from meteorological services that cover wide geographical to support planning, while the local community forecasts give information on what climate may occur in smaller areas and enable communities to adopt specific approaches to their local conditions (Figure 14).

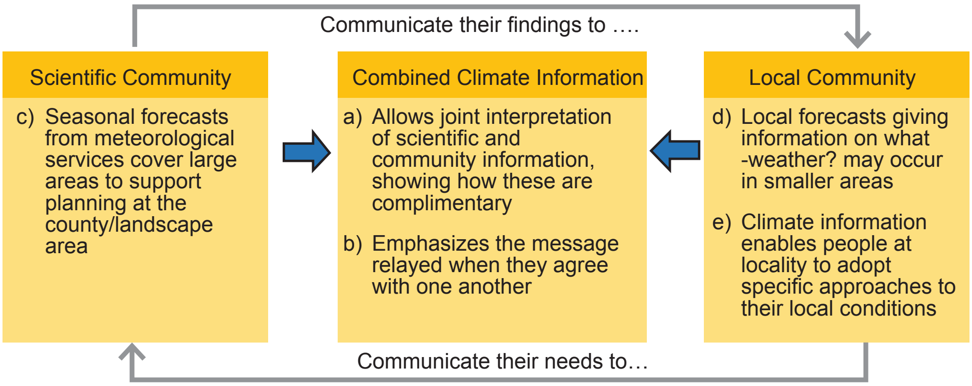


Figure 14. Climate Information matrix and players

Specifically in sorghum production, climate information for decision-making affects part or the whole season in terms of resource use and distribution, the cropland area to be used, land preparation methods, choice of crops, the choice of cultivar variety, crop combinations, input use rates and amounts (seed, fertilizer, and pesticides), time of pesticide application, irrigation plans, management of the weeds, pests and diseases, harvesting, post-harvest processing (threshing and winnowing), packaging, storage, and marketing of the products. Apart from climate information, other factors namely environmental conditions (farm, watershed), economic conditions (local market), social conditions (e.g., availability of labour) and policy environment influence decision making by sorghum farmers.

The Kenya Meteorology Department (KMD) in close collaboration with the Ministry of Agriculture (extension services), Kenya Agricultural Livestock and Research Organization (KALRO), and other non-governmental organizations in the agriculture sector assists in the information dissemination to the farmers at the local levels. Through the Kenya Agricultural Observatory Platform (https://www.kaop.co.ke), the users can implement proper planning using accurate and decision-relevant climate information that could minimize negative impact of climate change variability on their livelihoods and economy.

2.8. The sorghum crop calendar in Kenya

Sorghum calendars allows better planning of all farm activities. It provides timely information to enable planning for land preparation, planting, crop establishment and management, harvesting and storage times, and the main agricultural practices of the crop in specific growing areas and seasons. The calendars support extension agents and farmers in planning and making decisions in the different times of the year in the different agro-ecologies (Figure 15 and 16).

Sorghum Cropping Calendar (Coast, Lower and Upper Eastern, and Northern Kenya)												
	Counties: Lamu, Kilifi, Mombasa, Taita Taveta, Makueni, Kitui, Machakos, Tharaka Nithi, Meru, Embu, Isiolo, Wajir, Mandera and Marsabit											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall seasons												
Activities												
Planting/sowing												
Flowering (45 -70 days after germination)												
Grain filling (Milk stage: 10 days, Dough stage: 10 days, Hard Dough-14 days)												
Harvesting (Early varieties: 90 days, Late varieties: 135 days)												

Figure 15: Sorghum crop calendar for Coast, Lower and Upper Eastern, and Northern Kenya

Source: Modified from FAO Crop calendar, 2018

Sorghum Cropping calender (Mid and High altitude areas of Kenya)												
	Counties: Laikipia, Kajiado, Narok, West Pokot, Siaya, Kisumu, Homabay, Migori, Bungoma, Vihiga, Kakamega, Busia, Baringo)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall seasons												
Activities												
Planting/sowing (Mid Mar to Mid Apr and Mid Oct to Mid Nov)												
Flowering (45 -70 days after germination)												
Grain filling (Milk stage: 10 days, Dough stage: 10 days, Hard Dough-14 days)												
Harvesting (Early varieties: 90 days, Late varieties: 135 days)												

Figure 16: Sorghum crop calendar for mid and high-altitude areas of Kenya

Source: Modified from FAO Crop calendar, 2018

2.9 Climate smart agriculture (CSA)

2.9.1. What is climate smart agriculture (CSA)

Definition

The definition of climate smart agriculture by the Food and Agricultural Organization of the United Nations (FAO), is agriculture that sustainably increases productivity and income, enhances resilience (adaptation), reduces/removes GHGs (mitigation) where possible, and enhances achievement of national food security and development goals. Issues include the timing of growth, flowering and maturing of crops, and the impacts of (and on) pollinators, water resources and the distribution of rainfall. Other factors include changes in market structures, yields for different crops and the impacts of extreme weather events on traditional methods and livelihoods (Stige et al., 2005). Models show that in some areas, specifically where low temperature is a growth-limiting factor, agricultural productivity may increase with climate change. In other areas, where water and heat are limiting factors, productivity may be severely affected.

Climate-smart agriculture (CSA) is an approach that helps to guide actions needed to transform and reorient agricultural systems to effectively support development and ensure food security in a changing climate. Climate-smart agriculture (CSA) aims to tackle three main objectives: sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; and reducing and/or removing greenhouse gas emissions, where possible. Climate-smart agriculture (CSA) is achieved through the implementation of technologies, practices and services that contribute towards the restoration of degraded agricultural ecosystems unlike conventional agriculture (Table 2). It aims at improvement of food security and nutrition, and helping the communities in the adaptation and mitigation process to climate change. This is possible with the adoption of appropriate practices, having enabling policies, having functional institutions, and adequate financial support

Table 2. Differences between conventional agriculture and climate smart agriculture

Features	Conventional Agriculture	Climate-Smart Agriculture
Use of technology	Energy sources mainly from human, animal and fossil fuel	Energy efficient machinery for agricultural power for irrigation or tillage
Inputs in agriculture	High and inefficient use of fertilizer, pesticides	Efficient application of ecologically friendly inputs such as fertilizer, pesticides and herbicides
Area of agricultural land	Deforestation, and conversion of grasslands for agricultural land area	Intensive use of existing agricultural land area
Natural resources	Depletion of natural resources used in agricultural production systems.	Conservation, restoration, and sustainable management of natural resources in agricultural production systems
Production and marketing	Specialization in production and marketing systems	Diversification in production, input and output marketing systems

2.9.2 Pillars of climate smart agriculture

The three pillars of climate smart agriculture are discussed below as;

a) **Productivity:** climate smart agriculture sustainably increases agricultural productivity and incomes from crops, livestock and fish, without having a negative impact on the environment. This will raise food and nutritional security,

b) **Adaptation:** climate smart agriculture reduces the exposure of farmers to short-term risks, while also strengthening their resilience by building their capacity to adapt and prosper in the face of shocks and longer-term stresses, and

c) **Mitigation:** climate smart agriculture helps to reduce and/or remove greenhouse gas (GHG) emissions. We need to stop deforestation from agriculture, and also manage soils and trees such that they become carbon sinks and absorb carbon dioxide (CO_2) from the atmosphere.

2.9.3. Adaptation: strengthening resilience in agriculture

Climate related risks requires effective adaptation strategies and creation of an enabling environment to support adoption. Along the sorghum value chain, there are various actors, perceived risks and adoption and adaptation options that are undertaken (Table 3 and Table 4).

Table 3: Perceived climate related risks for the different sorghum value chain actors

Actors	Most important perceived climate risk	Adaptation options
Input suppliers	- unpredictability of the seasons - low rainfall - high temperatures - floods causing disruption of distribution chain	- soil testing - soil and water conservation structures such as planting basins, terracing, on-farm pan - IPD & WM/C - mechanization e.g. land opening and threshing, use of hermetic bags for storage - contract farming - climate-proof warehousing
Producers	- unreliable rainfall patterns or little rainfall amounts - timing of rainfall -Pests, disease and noxious weed incidences - recurrent droughts - floods causing disruptions - high temperatures	
Aggregators / Traders/Logistics service providers/ Transporters/ Mechanization services	- drought - floods leading to inaccessible roads, - post harvesting losses and mycotoxins contamination	
Processors	- unpredictable rainfall, - drought causing power rationing - excessive rains and floods affecting yields quantity, quality and processing infrastructure - temperature/moisture affecting quality of sorghum for processing (grain size/diseases) - waste in processing	

Source: CRAFT, 2020

Table 4: Adaptation strategies, factors hindering implementation and creation of an enabling environment for adaptation

Adaptation strategies (examples)	Factors hindering implemen-tation of adaptation strategies (examples)	What can be done? An enabling environment to support adoption (examples)
- Drought tolerant seeds - Soil testing and integrated soil fertility management - Soil and water conservation structures such as planting basins, terracing, on-farm pan - Mechanization e.g. land opening and threshing, use of hermetic bags for storage - Contract farming - Climate-proof warehousing	- Weak information flow systems - Counterfeit inputs - Lack of access to financial services - High cost of value addition equipment - Uncoordinated value chain - High costs of transport and for better storage facilities - Inadequate information on available climate smart services and products	- Provision of climate smart inputs e.g. certified seeds, crop specific fertilizers - Provision of customized financial products - Provision of mechanization services- farmers to hire the services - Giving weather information at a fee - Increasing value-addition lines

Source: CRAFT, 2020

2.9.4. Climate change and resilient crop production

Sorghum is mostly grown with limited nutrient and water resources. In Kenya, it is grown both during the long and short rains seasons with about 85% of the crop concentrated in the wider semi-arid areas as well as in western, eastern and coast agro ecologies. Therefore, sorghum is one of the major food crops in drought prone environments, and has great potential for crop improvement for food, feed fodder and biofuel production.

Sorghum is grown as a rain fed crop under most small-scale farmers' conditions. This makes sorghum susceptible to climatic elements in its productivity. Information generated from the CRAFT project's climate change projections and the impacts helps us to be more specific. In some sorghum growing zones, it may lead to increase in yields. Climate change and climate variability is a threat to sorghum productivity. In most parts of Kenya and the tropics where high temperatures and rainfall variability is experienced causing more negative effects.

3 SORGHUM PRODUCTION IN A CHANGING CLIMATE

3.1. Physiological characteristics of sorghum

Sorghum plant grows to a height of 1-3 meters high, with a solid cylindrical rod and elongate maize like leaves and a terminal inflorescence panicle (Figure 17). The panicle has many shapes and sizes, some are tight or open, round or droopy and short or long. The grain may be red, orange, bronze, tan, white or black depending on the variety.

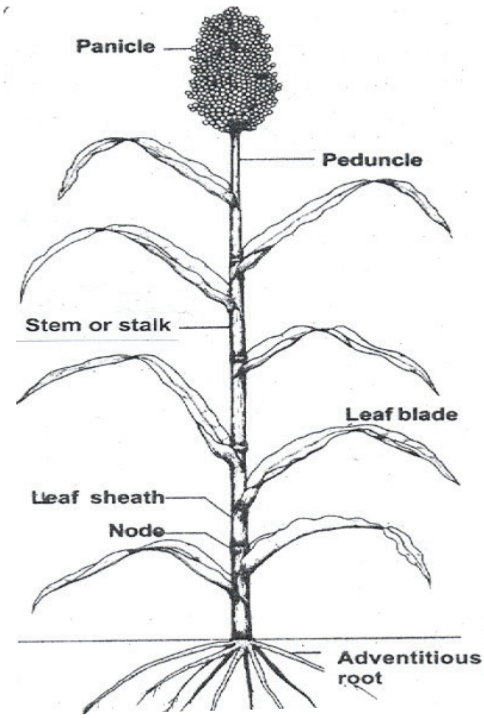


Figure 17. A sorghum plant
Source: Murdy, D.S., Tabo, R & Ajayi, O. 1994. Sorghum Hybrid Seed Production and Management)

The ability of sorghum plant to grow in drier environments better than other cereals especially maize is due to a number of physiological and morphological characteristics.

Extensive root system: Sorghum produces many roots compared to other cereals. Above ground parts of the plant grow only after the root system is well established. The roots can grow to depths of 1 to 2 m by the booting stage and can efficiently extract water to a lateral distance of 1.6 m from the plant.

Reduced leaf area: thus, reducing water loss through transpiration

Waxy bloom: the secretions of a wax coating by the epidermis gives the characteristic "bloom" on the stems and leaves of sorghum plants which enhances the effectiveness of the control of water loss through transpiration by forming a covering for the plant and partly closing up the stomata.

Leaf rolling: This is a dehydration avoidance mechanism, which reduces leaf area thus decreasing transpiration. It is observed that when the temperature is high during the middle of the day, the sorghum leaves fold in along the midrib or roll up covering the top surface and exposing the under surface with its heavy protective coating of wax.

Stay green: genotypes that have the ability to delay leaf senescence or to resist drought-induced premature loss of green leaf coloration are said to stay-green. They delay senescence, hence retaining photosynthesis. It is the most effective post-flowering drought stress tolerance mechanism in sorghum.

A sorghum crop can remain dormant during drought and resume growth when conditions are favourable. It also competes favourably with most weeds.

3.2. Sorghum ecological requirements

3.2.1. Climatic conditions suitable for sorghum growing

Sorghum is adapted to a wide range of environments with the following climatic conditions:

Altitude: 0 - 2500 masl

Agro Ecological Zones (**AEZ):** LM3 (low-midland, Level, 3), LM4 (Lower Midland, Level 4) and LM5 (Lower Midland, level 5)

Temperature: 7 to 10^{0}C **for seed germination**, 20-35^{0}C for optimum growth

Rainfall: 450-900 mm annually. it can however withstand drier conditions and still remain green at relatively low moisture levels.

Soils: deep, fertile, well-drained loamy soils. Sorghum can also be grown on clay, clay loam, or sandy loam soils with a pH of between 5.5 and 8.5.

3.2.2. Areas of cultivation in Kenya

The total sorghum production in Kenya was 206, 234MT under a production area of 229, 883ha (FAOSTAT, 2018; USDA, 2020). Suitable sorghum production areas are indicated (Figure 18).

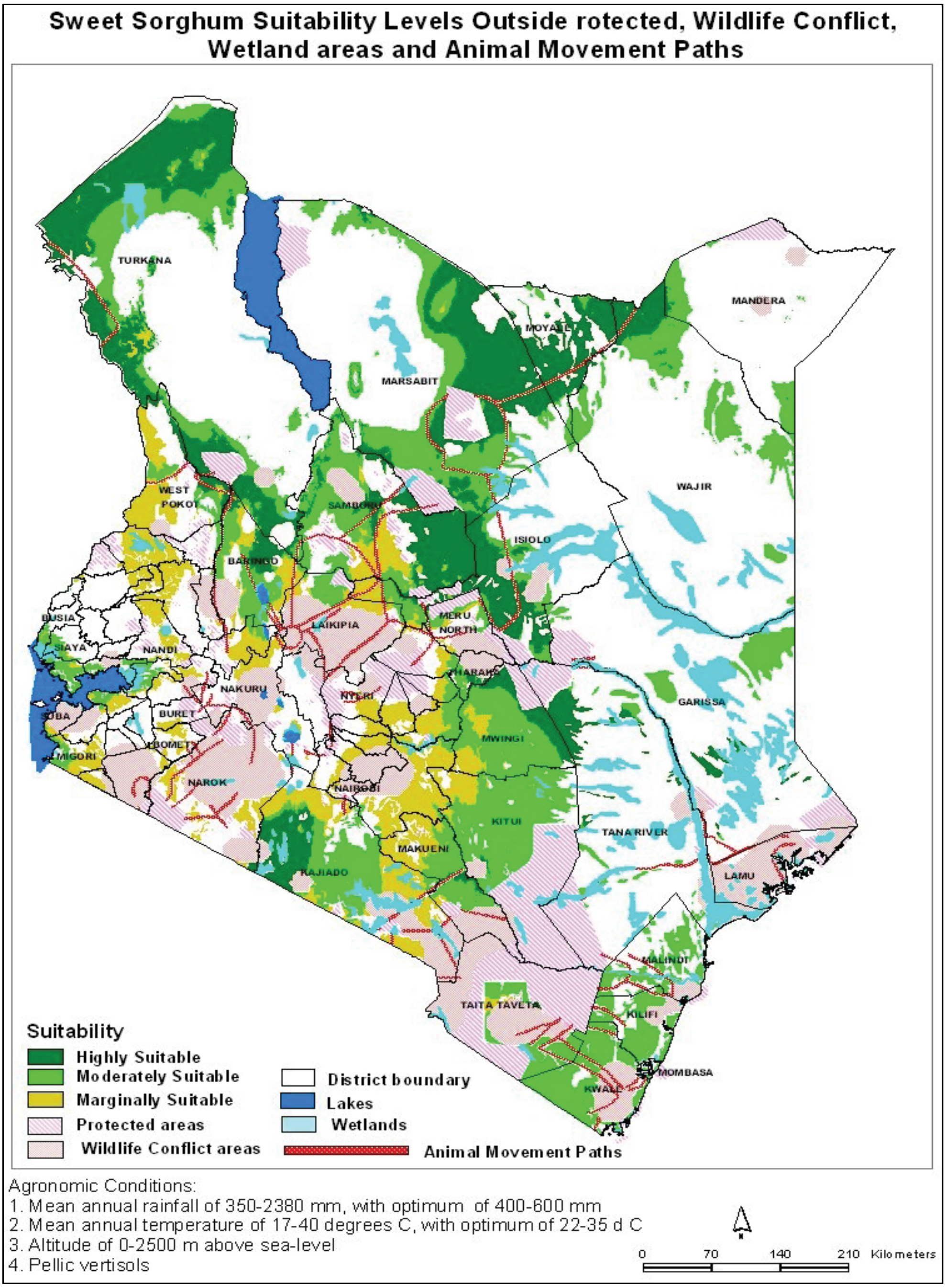


Figure 18. Rain fed sorghum suitability map for Kenya

Source: KALRO Soil Survey, 2020

3.3. Why venture into sorghum farming?

The choice to practice sorghum farming can be due to the following reasons:

3.3.1. Grain for food, nutrition and income

Sorghum is a hardy nutritious crop because it can survive with little rainfall and high temperatures hence it offers farmers food and nutrition security. The nutritional value of sorghum grain is indicated (Table 5).

Table 5. Nutrient Composition of Sorghum Grain.

Sorghum	Edible con-version factor	Energy (kJ)	Energy (kaJ)	Water (g)	Protein (g)	Fat (g)	Carbo-hydrate avail-able (g)	Fibre (g)	Ash (g)
Whole, grain, red, dried, boiled/stewed, drained (without salt	1.00	590	140	63.1	3.9	1.5	24.9	5.8	0.8
Whole, grain, red, flour	1.00	1420	336	11.6	9.3	3.5	59.9	14	1.8
Sorghum, grain, white, dry, raw	1.00	1440	341	11.8	10.8	3.5	60.5	11.9	1.5
Sorghum, whole, grain white, dry, boiled/stewed, drained (without salt)	1.0	599	142	63.2	4.5	1.5	25.2	4.9	0.6
Sorghum, grain, white, flour	1.0	1440	341	11.8	10.8	3.5	60.5	11.9	1.5

Sorghum	Ca (mg)	Fe (mg)	Mg (mg)	P (mg)	K (mg)	Na (mg)	Zn (mg)	Se (mcg)	Vit C (mg)
Whole, grain, red, dried, boiled/stewed, drained (without salt	6	1.4	63	117	129	4	0.78	9	0
Whole, grain, red, flour	10	3	150	296	387	6	1.97	12	0
Whole, grain, white, dry, raw	18	6.4	101	356	233	6	1.69	21	0
Grain, white, dry, boiled/ stewed, drained (without Salt)	9	2.7	43	141	78	4	0.67	9	0
Grain, white, flour	18	6.4	101	356	280	4	1.69	26	0

Sorghum	Vit A RAE (mcg)	Vit A RE (mcg)	Ret-inol (mcg)	Thi-amin (mg)	Ribo-flavin (mg)	Niacin (mg)	Dietary Folate Eq (mcg)	Food Folate (mcg)	Vit B12 (mcg)
Whole, grain, red, dried, boiled/ stewed, drained (without salt	0	0	0	0.05	0.04	1.0	19	19	0
Whole, grain, red, flour	0	0	0	0.24	0.11	3.3	64	64	0
Whole, grain, white, dry, raw	1	3	0	0.24	0.11	3.3	64	64	0
Grain, white, dry, boiled/ stewed, drained (without Salt)	1	1	0	0.05	0.04	1.0	19	19	0
Grain, white, flour	1	1	0	0.24	0.11	3.3			0

Source; Kenya Food Composition tables 2018

Sorghum grain commercialization is another income making choice. This can be done by growing sorghum grain mainly for sale, by becoming a sorghum marketer or even a processor. Value addition in sorghum is a business avenue where there is the freedom to dictate the price against market forces. This is an opportunity mainly for women and youth groups to process sorghum and produce various products for commercialization as sources of income

3.3.2. Sorghum Fodder for livestock feeding

A farmer can choose to produce sorghum as animal fodder either for his or her own livestock or for sell to other livestock farmers. Advantages of sorghum fodder over maize and other pasture grasses include the ability to grow well in both high and low potential areas with poor soils. It can be used in adequate supply when maize and other feed sources fail, produces much more forage than maize, the lower leaves do not dry out as the plant matures but remain green and therefore retain a higher crude protein content. The crop can regenerate (grow again) after cutting the stalks for fodder and harvesting the grain. Therefore, farmers can earn income through feeding their animals with sorghum or selling to other farmers during scarcity.

For all the sorghum ventures (food and nutrition security, farming business, marketing, value addition and livestock feeds/fodder) in the sorghum value chain to be successful, it is very important to make use of the **"latest climate smart production practices"** in order to work towards realizing maximum yields per acreage.

3.4. Soil and water conservation and management in sorghum production under climate smart agriculture

Soil and water are the basis of crop production. Effective soil and water management techniques can improve soil fertility and increase sorghum production in a sustainable manner. The purpose of this section is to highlight some of the best technologies and practices for soil and water management that can help sorghum farmers adapt to climate change.

3.4.1. Components of soil fertility

3.4.1.1. Soil structure

Best soil structures are always crumbly. Soils with good structures allow plant roots to grow both healthy and deep to access the available nutrients and water to support good plant growth. During wet-dry conditions, tillage operations damage soil structure, hence, this hampers the soil structure function to retain nutrients and water, and subsequently the resilience to climate change is reduced. Good soil structures are not compact, and have high organic matter content, soil organisms such as bacteria, fungus and earthworms.

Amend the soil structure through; encouraging biological activity by use of bio pesticides rather than chemical pesticides, add organic matter such as compost in the soil and avoid inappropriate soil management practices such as tilling under wet conditions that cause soil compaction. Also, limit the regular use of disc ploughs that reduces soil aggregates to small particles and produces a compacted layer or plough pan, which prevents air, water or roots penetrating the subsoil.

3.4.1.2. Soil depth

A shallow soil holds much less water and quickly produces run off (erosion). We need to protect and build up our soils, to reduce erosion of topsoil and increase the soil depth. Soils that have been eroded down to bedrock hold no water at all. Soils can be artificially shallow due to a plough pan or compacted zone created by tillage for crop production. Regular use of disk plough is a big agronomic problem. The disc plough turns the soil over and buries the biologically active, organic matter and nutrient-rich topsoil away from the plant roots. It creates a plough pan at 15--20 cm depth. A soil that is 1m deep, has a water holding capacity of 100 mm/m. A soil with a plough pan at 20 cm can only absorb a fifth of this.

3.4.1.3. Soil organic matter

Soil organic matter or humus consists of decomposed animal and plant residues (well-rotten manure and compost). Soil organic matter reduces evaporation, increases soil aggregate stability, release nutrients upon mineralization, reduces surface runoff and improves infiltration. Organic matter acts like a giant sponge and can hold 400 times more water than sand. A one percent increase in organic matter can increase the soil moisture holding capacity by 4%.

Inappropriate farming practices of tillage burn out the organic matter and reduce the soils' ability to hold water and nutrients. A healthy soil should have at least 3-5% organic matter. A healthy soil can absorb about 3-500,000 L ha^{-1} water and sequester several tons of carbon per ha. Soil organic matter functions to increase the prerequisite adaptation potential to climate change through the mitigation of GHG emission and building up resilience to water stress.

To improve soil organic matter, grow perennial pasture, cereal crops and green manure crops in rotation with sorghum as well as applying organic fertilizers such as manure or concentrate organic matter.

3.4.1.4. Soil organisms

Enhance existence of soil organisms by; regularly adding organic matter (livestock and green manures), maintaining residue cover, and diversifying plant types across the landscape (grass waterways, conservation tillage and crop rotation) and limit soil disturbance (soil compaction, excessive use of pesticides, intensive and secondary tillage).

Soil organisms include archaea, springtails, bacteria, fungi, protozoa, algae, mites, earthworms, nematodes, insects and larger organisms like burrowing rodents. They help in decomposing organic matter into humus, cycling nutrients, and therefore ensuring soil fertility, they also play a vital role in control of pests and diseases.

Soil organisms such as rhizobia (bacteria), mycorrhiza fungi and earthworms are the most essential in soil fertility. Rhizobium bacteria grows in roots of leguminous plants fixes nitrogen from the air into the soil for these plants to use. Earthworms are essential since they speed up decomposition resulting into improved soil structure. Mycorrhiza fungi grow in symbiosis in roots of 90% of plants, where fungi bring nutrients and water to the plant and in return, plant roots provide then with sugar. The capacity of plant roots in symbiosis coexistence with mycorrhiza fungi to take up nutrients and water is more than 1000 times efficient than of plant roots without mycorrhiza partners.

3.4.1.5. Available nutrients

Plants require nutrients to realize their full potential of growth and reproduction. Add both macro and micronutrients through either inorganic, organic matter (crop residues and leaves) or liquid manure. **Determine soil nutrient composition through laboratory analysis.** KALRO National Agricultural Research Laboratories (NARL)-Kabete and private service providers like CropNuts, Agrocares, SGS etc. offer soil-testing services at a fee to determine fertilizer/manure rates to apply.

Macronutrients are energy-providing chemical elements consumed by plants in large quantities. They include nitrogen (N), potassium (K) and phosphorus (P). The secondary macronutrients include magnesium (Mg), sulphur (S) and calcium (Ca) and are usually available in adequate quantities in the soil.

The micronutrients are copper (Cu), boron (B), iron (Fe), chloride (Cl), manganese (Mn), molybdenum (Mo) and zinc (Zn).

3.4.1.6. Soil pH

Grow sorghum in soils with pH of between 5.5 and 8.5. **Determine soil pH through laboratory analysis**. KALRO (NARL)-Kabete and private service providers such as Cropnuts, Agrocares, SGS etc. who offer soil-testing services at a fee to determine soil pH. To raise soil pH, add wood ash or lime (pulverized limestone), but to lower soil pH, add peat, sulphur or organic materials (like compost) in accordance to expert recommendations.

Higher temperatures and increased evaporation rates lead to increased salts accumulation in the soils resulting in raised pH levels resulting in intensified salinity, degraded soil structure, hampered nutrients and water availability. Alternatively, substantial increase in downpour accompanied by leaching may lead to soil acidity reducing the activity of microorganisms and release of nutrients to the sorghum plant and the resilience of soil to climate change.

3.4.2. Loss and management of soil fertility

It is important to know how soil fertility is lost and how to manage it:

3.4.2.1. Deforestation

Plant trees to help reduce soil degradation since this protects humus and litter layers on soil surface from soil erosion. Cutting down of trees (removal of the vegetation cover) exposes soil minerals to erosion causing loss of its fertility.

3.4.2.2. Soil erosion

Practice conservation agriculture/farming to mitigate soil erosion. Nutrients and organic matter are located in the top soil. When the top fertile layer is washed away by water or wind, this changes soil composition and structure as well as humus content.

3.4.2.3. Excessive use or misuse of chemical fertilizers/pesticides

Manage pests using the correct rates of pesticides or organic pesticides and particular techniques that have minimal effects on soil organisms. Use correct rates of chemical fertilizers, compost and natural fertilizers to avoid misuse and/or excessive use.

Misuse and/or excessive use of chemical fertilizers and pesticides kill beneficial microorganisms that help to bind the soil together. Additionally, their residues lower soil fertility.

3.4.2.4. Improper cultivation practices

Practice conservation farming/tillage that do not lead to soil compaction, soil erosion, decline in both soil composition and fertility, and soil degeneration.

Convectional land tillage which mainly involves deep ploughing breaks up soil into finer particles and this increases the rate of soil erosion, soil compaction, formation of hardpan and reduced soil cover. Soil compaction prevents plant roots from accessing water and nutrients, and inhibits soil organisms' development.

3.4.2.5. Inadequate organic matter input

Organic matter is important in making sure that water, nutrients and air are available to plants and these are the food source for soil organisms. To mitigate this, add well-decomposed manure or compost to soils.

3.4.2.6. Burning organic waste

Do not burn organic waste since it destroys important soil organisms that are needed for healthy soils and this affects the soil pH. Instead, incorporate organic matter into the soils to decompose and increase fertility.

3.4.3. Soil management adaptations

3.4.3.1. Conservation agriculture

Grow sorghum under conservation agriculture to conserve water, soil and organic matter. This is carried out by ensuring at least 30% soil is under crop, organic matter or mulch cover with minimum cultivation.

The main principles of conservation agriculture include; a) permanent soil organic cover, b) minimum soil disturbance, c) Crop rotation to diversify crop species grown in sequences and or associations and d) prevention of soil erosion

- **Permanent soil organic cover:** Grow cover crops or add dead materials as soil cover to conserve moisture by reduction of water movement and increased infiltration. Use green manure or grow legumes to fix nitrogen from the air through the process of biological nitrogen fixation.
- **Minimum soil disturbance:** Practice minimum mechanical soil disturbance by direct planting to reduce tillage. This helps in protecting soil structure, reduce run off, increase water infiltration and reduce soil compaction.
- **Control of soil erosion:** Although soil erosion occurs naturally, human activities do speed up the process, and this must be avoided at all costs. Hence, it is necessary to describe soil erosion and the need to manage it.

3.4.3.2. Control of soil erosion

Soil erosion is the movement of soil by either wind, water, animal or human activities. It involves three distinct activities – **detachment** of the soil**, movement** and **deposition**. Topsoil, upper 0--20cm, which is high in fertility, soil life and organic matter are relocated elsewhere which leads to poor plant growth due to nutrient deficiencies. Soil erosion leads to decline in cropland productivity and plays a role in pollution of adjacent wetlands, watercourses and lakes. There are four common forms of soil erosion (Figure 19).

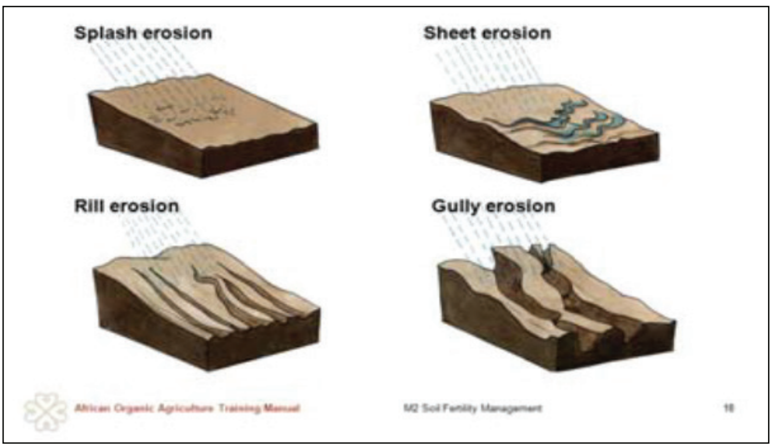


Figure 19. Common forms of soil erosions

Source: FiBL, 2011

3.4.3.3. The causes of soil erosion and their mitigation practices are;

a). **Deforestation** is clearing of trees in large scale. Human beings have cleared forest land to produce food for the ever-increasing population, build houses, build factories and many other reasons. The roots of trees prevent soil erosion by holding soil together. When a large number of trees are cut down in forests, top soil is left exposed to running water and wind. Mitigate this by afforestation and planting of trees on the edges of the field and by the riverbanks.

b). **Over cultivation** refers to continuous cultivation of land, reduces the overall soil structure, in addition to exhausting the content of organic matter in the soil subjecting it to effects of water, rain and wind. Practice crop rotation and add green manures, liquid feeds and compost to solve this.

c). **Overgrazing** leads to reduced plant cover leaving the soil surface exposed to rain and animal stamping that makes soils vulnerable to erosion. Pen livestock as one of the management techniques that ensures vegetation cover.

d). **Slope of the land:** Slope influences soil erosion. Land with steep slope accelerates soil erosion down the slope. Implement contour ridging, terracing and drainage gullies as part of the solution.

Other causes of soil erosion include activities such as mining, construction, and recreational activities.

3.4.3.4. Use of cover crops

Use of cover crops is an important principle of conservation agriculture. Plant cover crops to prevent soil erosion, improve soil properties, biodiversity in the soil and soil fertility. Cover crops can also be used as fodder. A good cover crop a) Does not compete with main crop for nutrients, water and light, b) grows fast and covers the soil, c) is drought tolerant, d) fixes nitrogen in the soil, e) is affordable and easy to reproduce on the farm, f) is pests and diseases resistant, g) is not an alternate host to pests or diseases that attack the main crop, h) produces large quantities of organic matter for mulching, i) has root system that regenerate degraded soils, j) is easy to plant and manage, and k) is a source of food, feeds or fodder. Types of cover crops include legumes, brassicas, pumpkin or watermelons. Legumes are usually preferred since they fix nitrogen from the air. The main cover crops for sorghum include:

i). **Legumes:** Common bean, Soybean, Crotalaria, cowpea, Desmodium, Lablab, Jackbean, Siratro, Velvet bean or Mucuna, Alfalfa, Pigeon peas, green grams, and groundnuts.

ii). **Leguminous shrubs**: Gliricidia, Sunn hemp, *Tephrosia spp* and *Sesbania spp*.

There are several methods of planting cover crops which include;

a) **Crop rotation**: Plant cover crop immediately after harvesting the main crop as part of rotation cycle or during the fallowing season

b) **Intercropping**: Grow sorghum and cover crops in the same field at the same time. Avoid creeping crops in sorghum fields since they can smother sorghum.

c) **Relay cropping:** Plant cover crop when the main crop is in an advanced stage of growth. For example, in a sorghum-bean intercrop, grow bean crop when sorghum is approaching maturity.

d) **Permanent cover:** Plant crops on a piece of land that is not in use and/or is susceptible to erosion. For example, a strip of land on a steep slope, edge of sorghum plantation or river-banks. Cover crops such as Kikuyu grass and Napier grass are essential in holding the soil in place and protecting it from erosion.

3.4.3.5. Mulching

Practice mulching to minimize the effects of the fluctuating weather patterns that increasingly expose soils to increasing temperatures and longer drought periods as a climate change adaptation technique.

Mulch by spreading organic material over the soil surface in order to:

a) Protect it from fertility loss
b) Reduce water and wind erosion
c) Reduce evapotranspiration to enable plants use the available soil water efficiently
d) Improve soil structure which prevents crust formation and keeps pores open to enable water infiltration
e) Suppress weed growth
f) Release nutrients to the soil through decomposition of organic mulching material
g) Provide suitable environment for feeding and growth of soil organisms,
h) Provide shading which retains moisture and keeps the soil cool.

Types of mulching material: Use mulching materials that allow air and water to reach the soil and dense enough to smother weeds. These materials include cover crops, weeds, crop residues, and pruned materials from trees, grass, cuttings from hedges and agricultural processing or forestry wastes. Availability and ease of application, and costs determine the nature of mulching materials that can be used. Strong and fast growing nitrogen fixing shrubs give good and substantial volume of mulching materials.

Green materials decompose faster compared to straws and stalks to provide nutrients in humid climates, limiting soil protection to 1 to 3 months. Slowly decomposing materials are recommended where problem of soil erosions is experienced. Slowly decomposing material should be applied two months prior to sowing main crop. Spreading organic manure (e.g. animal dung) on slowly decomposing mulch will not only accelerate decomposition but also increase soil nitrogen content. When using organic mulch, pay attention not to introduce weed seeds.

Mulching in sorghum fields should be carried out before or at the beginning of the rainy season, or sorghum seeds be planted between mulching materials, or mulching materials be applied in between sorghum rows of an established sorghum crop.

3.4.3.6. Green manures

Grow green manure to add organic matter to the soil. Green manure is defined as a specific crop or plant varieties that are grown for the purpose of incorporation back into the soil to improve its organic content and overall quality. Provide soil cover through green manure as this reduces soil temperature and water evaporation, increases water infiltration, reduce weed infestation, protect soil from erosion, reduce pest and disease infestation, improve soil structure and add biomass to the soil. For these reasons, green manures aid in mitigation of climate change effects through enhancing plants health and making them more robust and stronger, furthermore protecting soils from changing weather conditions.

Qualities of a good green manure crop:

- Simple to plant and manage
- Produce large amount of green and dry mass
- Have low production cost
- Rapid growth and present good soil cover and weed suppression under prevailing climatic and soil conditions
- Have good conservation characteristics
- Avoid pests and diseases proliferation
- Avoid competition for time, land, space and time with subsistence crops or cash
- Production of a great quantity of green and dry mass, above-arts and roots

3.4.3.7. Compost Application

Compost is the controlled decomposition of organic matter (mainly animal manure and plants materials) which can be incorporated easily into the soil. When bunches of organic matter are mixed together in a compost pile they naturally breakdown into nutrient rich compost that helps plants grow healthy and productive. As opposed to uncontrolled decay of organic material, composting is faster with high temperatures that results in high quality products.

Importance of composting

- Amends and improves soil structure, density and porosity, resulting in a better plant root environment and reduced erosion.
- Improves soil water holding capacity, hence reduced leaching and soil water loss. This also results in improved retention of nutrients and finally reduced vulnerability to soil erosion.
- Modifies and stabilizes soil pH.
- Increases the soil's ability to hold essential nutrients.
- Increases beneficial soil microorganisms.
- Binds contaminants and degrades compounds.
- Helps with wetland restoration and erosion control.
- Suppresses weeds and many pathogens.

Preparing a compost

i). **Dig the base for compost pit.** Dig a shallow pit around 2 feet deep. This will not only ensure that the compost heap is steady and not fall over, but also help in keeping the compost moist. The width of the pit should be about 1.5 meters while the length varies in accordance with availability of composting materials. Loosening the soil at the base of the compost pit is vital to increase activity of microorganisms.

ii). **Layering the compost:** After digging the pit, layer the compost heap as follows;

Layer 1: The initial layer should be 30 cm thick comprising of twigs, straw or hay or maize stalk pieces which are not bigger than 5 to 8 cm (2 or 3 inches) in size. This will make sure that compost is well- drained. This first layer should be well watered.

Layer 2: Add a thin layer (3 - 5 cm) of ready compost or pesticide free garden soil to provide microbial.

Layer 3: Add a thin layer of 3 to 5 cm of manure (non-compulsory but highly recommended).

Layer 4: Add a layer of chopped fresh green material to a thickness of 20 - 30 cm.

Layer 5: Sprinkle a thin layer of ash (non-compulsory)

Layer 6: Sprinkle water

Repeat the layering process (Layer 1 to 6) until the compost heap is about 1 to 1.5 meters in height and ensure that the green material is the final layer. Each layer should be well- watered to create humid condition, however, take precaution not to stamp the composed since aerated conditions are necessary for composting process (Figure 20).

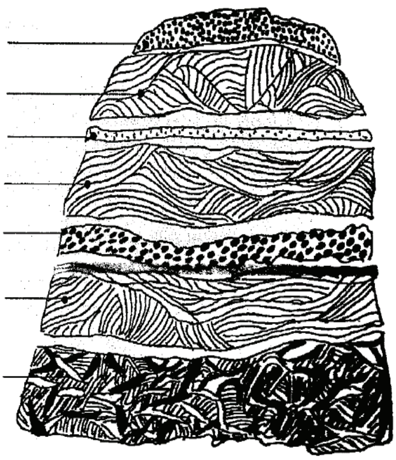


Figure 20. Layering the compost
(Source: Brianwaters, 2014).

- During decomposition process, turn over the heap for it to remain well aerated. Do this after 3 weeks interval.
- Break down the heap and build it up again next to the old one.
- Mix up the layers until the heap is, as it were turned inside out and upside down. Again, make sure that foundation is made up of coarse plant materials.
- Place the drier and outer, less decomposed fraction of the old heap in the central part of the new pile.
- Water the drier materials before building the heap up further.
- Cover the core with the rest of material.
- The compost will be ready in about 60 days.

3.4.3.8. Agroforestry

Grow sorghum together with trees at the same time, in rotation, or in separate plots. Vegetative cover from the trees reduce soil disturbance, provide wild species with a habitat, including crop pollinators whereas animals provide manure (Figure 21).

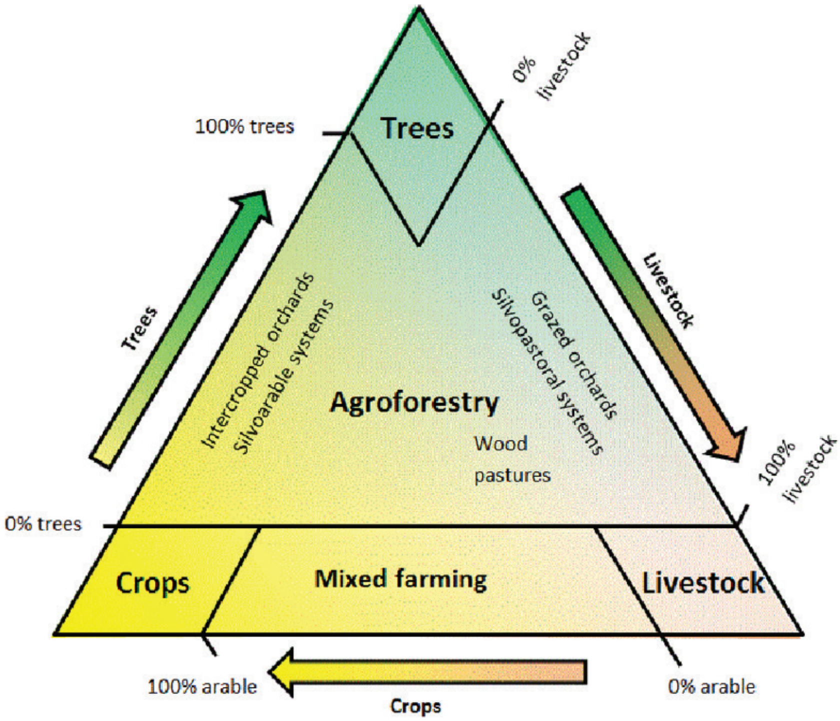


Figure 21. Illustration of agroforestry
Source: den Herder, M., et al., 2015

Importance of Agroforestry in Climate-Smart Agriculture

- **Mitigation:** These are practices that increase tree cover (agroforestry, afforestation and reforestation) while reducing land degradation and deforestation. Agricultural system with trees tend to sequester greater quantities of carbon compared with those without. Trees and shrubs have the capacity to reduce the effects of extreme weather patterns such as drought and heavy rains. Moreover, they remove CO_2 from the atmosphere.

- **a). Adaptation:** Diverse and healthy ecosystems are more robust and can withstand natural risks. Forestry and agroforestry can be used as windbreaks and shelterbelts, and play essential role protection against floods and landslides. Trees on farms hold the soil particles thus improving the structure hence minimizing the threat of erosion, stabilizes riverbanks, leaching and loss of nutrients through improved microclimate. Moreover, vegetation cover help in protecting the soil from rain and wind that can wash away the fertile top soil and reduces soil temperature for underneath crops.

- **b). Productivity:** Forestry and agroforestry support a diverse ecosystem, which can provide food and feed, medicines, construction materials, as well as income, which can be enhanced by the use of climate smart agriculture. Integrating nitrogen fixing woody trees and sorghum improves soil fertility thus leading to more stable sorghum crops with higher yields. Species used include *Tephrosia candida, G. sepium, Sesbania sesban,* pigeon peas, and *Faidherbia albida*. These trees can effectively control weeds, including striga (witch weed). Continued organic matter application improve soil fertility thus striga germination is suppressed. The trees also shade out weeds that are shallow-rooted preventing them from competing with sorghum for growth factors (water, sunlight and nutrients).

3.4.4. Soil water management adaptations

3.4.4.1. Terraces

Terraces can be bench or *fanya juu* terrace (Figure 22). In *Fanya juu* terraces heap soils up the slope to create an embankment, which forms a barrier for running water hence leaving the trench for collecting running water. Dig a canal which is 0.6 m wide and 0.6 m deep, while the distance between the soil embankment and the surface should be about 0.7 m. Direct running water from the external catchment is directed into the dug canal for retention giving the soil enough time to absorb the water. Plant sorghum within or between the terraces while crops such as pawpaw, citrus and banana can be grown in the canals. Plant grass on the embankment to help prevent soil erosion, stabilize the ridges and can be used as mulch or feed livestock. This conservation technique is recommended for areas with more than 5% slope.

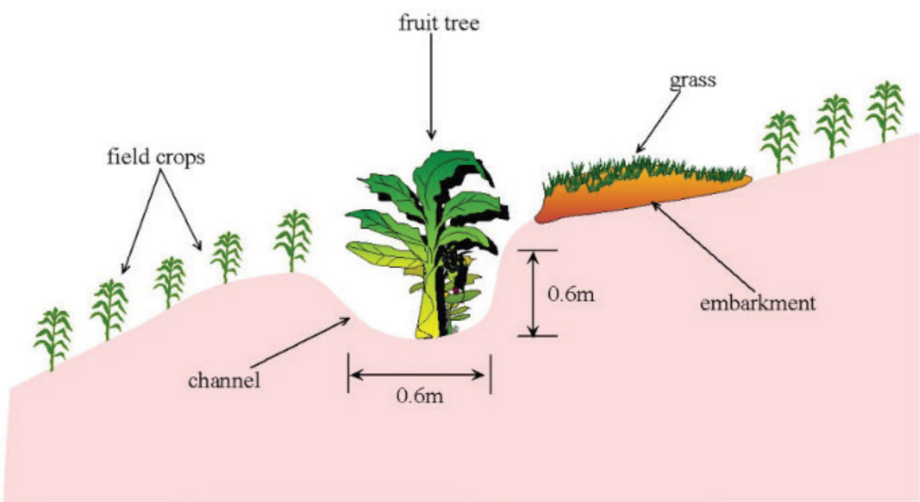


Figure 22. Sketch of *fanya juu* terrace

Source: Mati, 2012 (Soil and Water Manual 5: Soil and Water Conservation Structures for Smallholder Agriculture)

Unlike the *fanya juu* terraces, bench terraces do not have water retention canal on the lower side of the terrace and are closely spaced compared to the *fanya juu* terraces. In bench terraces, convert slope into series of level steps and ledges for water conservation. Grow sorghum on the flat area and close the terrace growing grass at the bottom of the terrace (Figure 23).

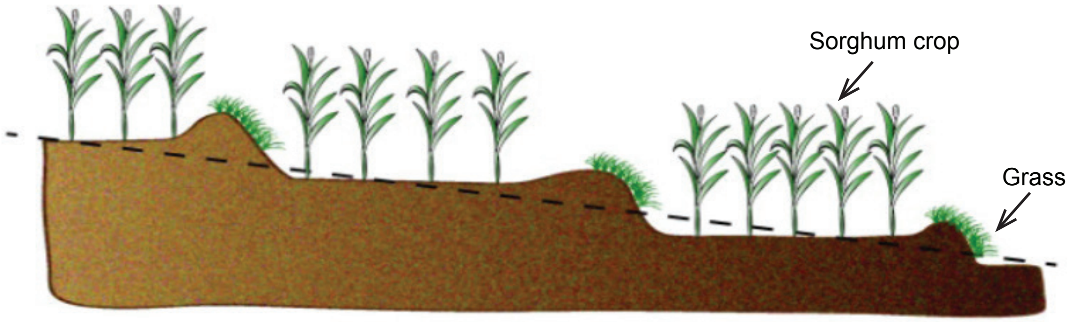


Figure 23. Sketch of a level bench terrace
Source: Mati, 2012 (Soil and Water Manual 5: Soil and Water Conservation Structures for Smallholder Agriculture)

3.4.4.2. Zai Pits

Zai pits are shallow, wide pits that are dug to collect and retain runoff to allow infiltration into the soil. They are used for growing cereals such as sorghum and fodder in drier areas (Figure 24).

Zai pit construction:

- Measure a circular diameter of 60 cm;
- Dig to a depth of 30 cm within the circle, while placing the soil from the hole down the slope to form an embankment;
- Zai pits should be spaced 50 cm along the row and 1 meter between rows and the pits should not be at right angles with each other to avoid erosions in case of heavy rainfall;
- Apply compost or manure into the pit at the rate of 2 t ha^{-1};
- Plant 4-8 sorghum seeds per pit;

Zai pits can be used to rehabilitate crusted, barren soils, and gentle clay slopes (not more than 2% slope), where there is limited infiltration and tillage is challenging (Figure 24).

Figure 24. Zai pits for conservation of rainwater for sorghum production
Source: IIRR and ACT, 2005. Conservation Agriculture: A manual for farmers and extension workers in Africa

3.4.4.3. Tied ridges

Create this by making a series of cross-ridges that block or interrupt the furrows thus preventing flow of water along the furrows, hence allowing trapped water in the rectangular basins to infiltrate into the soil (Figure 25). Conserving soil moisture in drought-prone areas increases sorghum yield, prevent water erosion, and it is simple to use and maintain.

- Clear bushes, weeds and grasses and remove rocks.
- In case it is a slope, mark out contour lines at 3 meters apart.
- Create a shallow furrow (about 30 cm deep and 50 cm wide) along each contour and pile the soil on lower side of the slope create ridge of about 20 to 30 cm high.
- Make crossties (ridges that are about 15 to 20 cm high) at 3 meters interval. Crossties must be lower in height than main ridges so that water never overflows the main ridges.
- Level each basin using a plank or rake, as this is the water catchment area.
- Plant sorghum on the ridges.

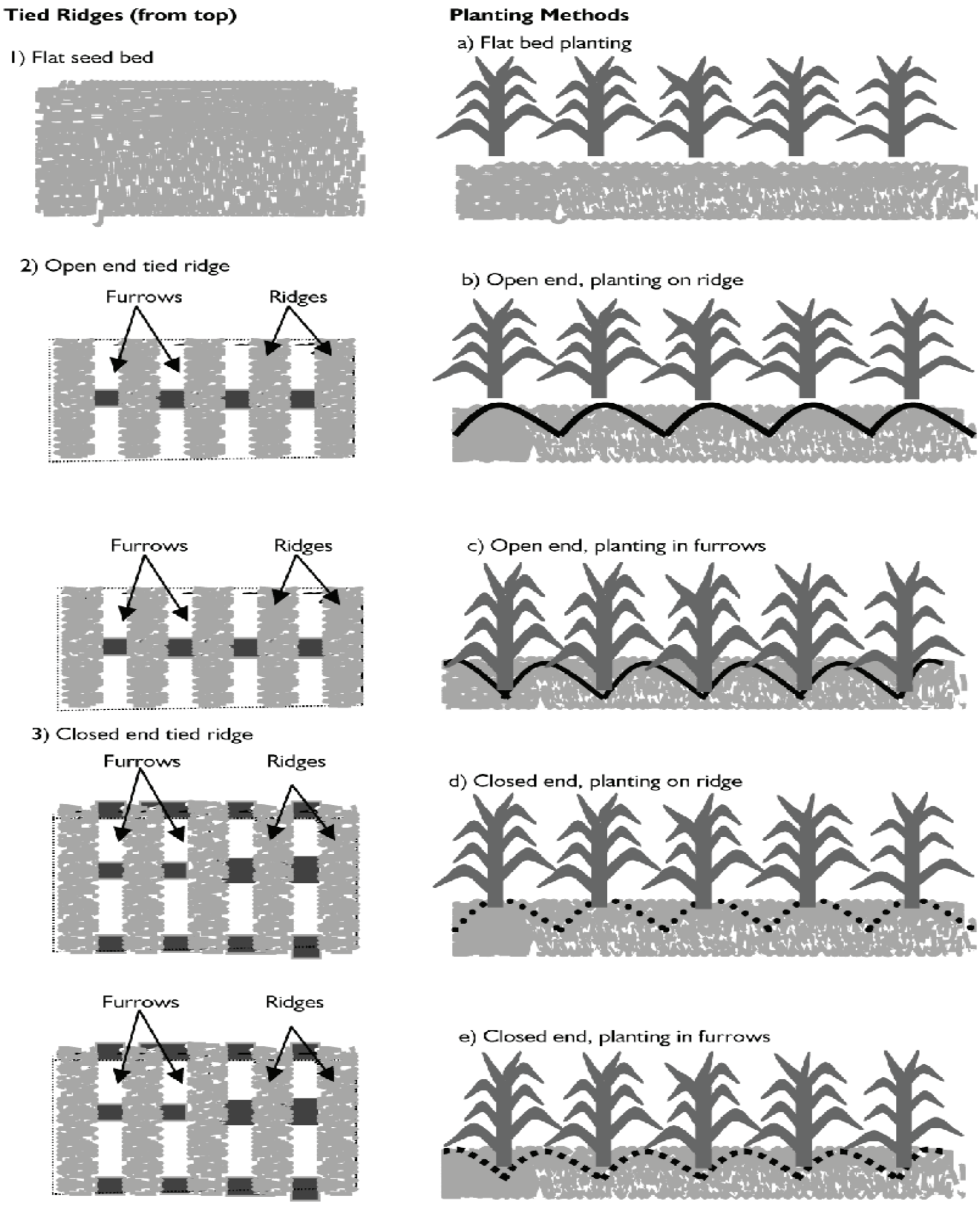


Figure 25. Tied ridges

Source: Gebrekidan, 2003

3.5. Sorghum agronomic practices under climate smart agriculture

3.5.1. Farm selection and land preparation for sorghum cultivation

Do not select sorghum farms in isolated fields and near birds roosting sites. Practice timely land preparation before the onset of rains after the last crop is harvested to eliminate and control undesirable crop volunteers and weeds.

Practice zero tillage land preparation by using herbicides to kill weeds and unwanted crops. This reduces soil erosion, formation of hard pan, conserves soil moisture and maintains good soil structure and health due to less disturbance of microorganisms.

Use minimum tillage implements where the soil is compacted or the land has developed hardpans due to years of conventional ploughing. Hard pans limit crop roots from penetrating deep into the soil and stops water infiltration leading to severe drought for the sorghum crop even when there is enough rain. Minimum tillage implements include sub-soilers and chisel ploughs.

Sub-soiler: It is used to break the hardpans. It can be fixed on an oxen plough beam and can penetrate the soil up to 40 cm to break the hardpan at point of entry. For effective shattering of the hardpan sub soiling should be done when soils are fairly dry (Figure 26).

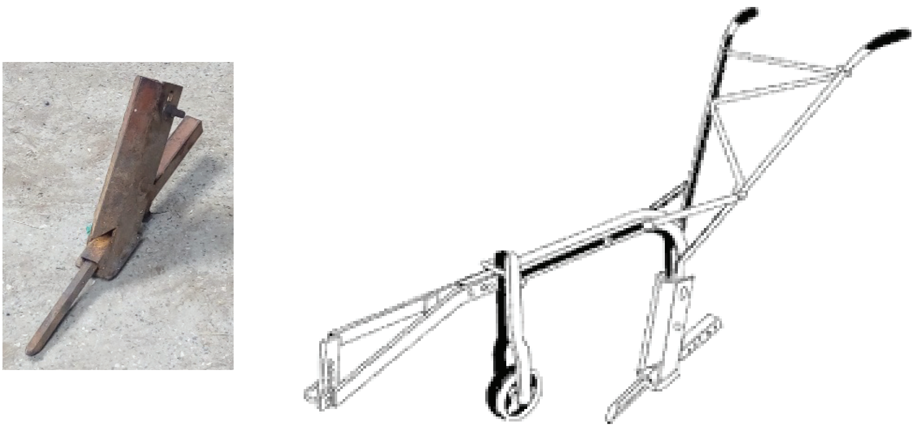


Figure 26. A sub-soiler (left) A sub-soiler fixed on oxen plough (right)
Source: Kisilu R. K 2020 (left) and Gachene and Kimaru. 2018 (right)

Chisel plough: when hardpans are caused by tractor plough, break them with tractor drawn chisel plough because they are too thick and hard to be broken by an ox-pulled sub-soiler. Chisel ploughs are rippers that are designed for use with tractors. They have two or three rows of spring-loaded tines with ripping points attached to a frame and they loosen the hardpans without inversion of the topsoil layer (Figure 27).

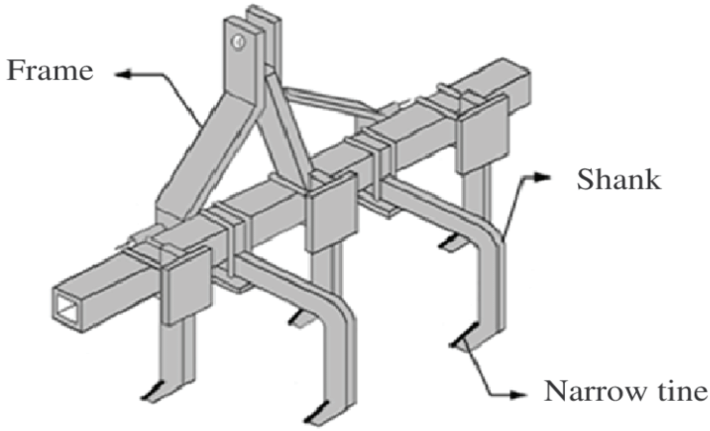


Figure 27. A Chisel plough
Source: Abo Al-kheer, 2010

3.5.2. Sorghum variety selection

Use certified seed of improved varieties, with proper guidance from extension providers, to achieve the yield potential in sorghum. The sources of sorghum seed are KALRO Seed Unit, Kenya Seed Company Ltd., private seed companies and some universities.

Plant improved sorghum varieties which are suited to the area of cultivation and for the intended end use (Table 6).

Table 6. Improved suitable sorghum varieties, sources and ecological suitability

Variety	Source & Description	Suitability	Attributes
 **Gadam**	• Released in 1994 by KARI (KALRO) • Grain yield: 2-2.5 t ha^{-1} • Maturity: 2.5 -3 months (early) • Open pollinated (OPV) • Chalky white grains with a brown testa • Plants are short to medium in height.	• Lower Eastern (Makueni, Kitui and Machakos) • Upper eastern (Embu, Tharaka, Meru) • Western (Siaya, Homabay, Busia, Bungoma, Kakamega). • Taita Taveta	• High drought and heat tolerance • High malting and brewing quality • High demand in brewing industry • Suitable for human and animal consumption.

Variety	Source & Description	Suitability	Attributes
 **KARI Mtama-1**	• Released in 2000 by KARI (KALRO) • Grain yield: 3.4 t ha^{-1} • Maturity: 3.5-4 months • Open pollinated (OPV) • Cream white grains • Plants are medium to tall in height.	• Lower Eastern (Makueni, Kitui and Machakos) • Upper eastern (Embu, Tharaka, Meru)	• High malting and brewing quality (demand in brewing industry due to white grain) • Sweet, palatable and highly digestible low tannins grain (Milling and feed industry)
 **Sila**	• Released in 2006 by AgriSeed Co Ltd • Grain yield: 2-4 t h^{-1}, Fodder yield: 4 t/ha. • Maturity: 3 – 3.5months. • Open pollinated (OPV) • White grains • Plants are medium in height.	• Upper eastern (Embu, Tharaka, Meru) • some parts of lower eastern Kenya where temperatures are not very harsh • western Kenya	• Dual purpose for the production of grain and fodder • High malting quality (high demand for malting) • Good for human consumption and animal fodder.
 **Seredo**	• Released in 1970s by KARI (KALRO). • Maturity: 3 months. • Grain yield: 2.7 t ha^{-1} • Open pollinated (OPV) • Brown grains • Plants are medium in height.	• Dry humid areas • Dry low lands (western and eastern Kenya)	• Relatively bird tolerant due to tannin content in grain • Good milling capacity Mainly used for home consumption • Blending with cassava and maize flour in milling industry. • Grain fed directly to chicken.
 **Serena**	• Released in 1970s by KARI (KALRO). • Maturity: 3 months. • Grain yield: 2.7 t ha^{-1} • Open pollinated (OPV) • Brown grains • Plants are medium in height.	• Most of the sorghum growing counties.	• Relatively bird tolerant due to tannin content in grain • Good milling capacity Mainly used for home consumption • Blending with cassava and maize flour in milling industry. • Grain fed directly to chicken.

Variety	Source & Description	Suitability	Attributes
 **Kamani** (KM 32-1)	• Released in 2019 by KALRO Katumani • Grain yield: 2.7-3.8 t ha^{-1} • Maturity: 3 months • Open pollinated (OPV) • Large White grains • Plants are short and uniform	• Dry low lands • Dry cold zones • Some humid zones. • Lower eastern • Upper eastern • Naivasha, Laikipia, Marigat, Busia and Homabay.	• It has a stay green stress tolerance. • Malting (brewing) quality • Tolerant to covered kernel smut disease • Good for human consumption.
 **E97**	• Released in 2017 by Rongo University. • Grain yield: 4-4.5 t ha^{-1} • Maturity: 3 months • Open pollinated (OPV) • Large White grains	• Western Kenya (Kakamega county), • Low land areas of Lake Victoria basin (Homabay, Migori, Siaya, Kisumu, Busia) • Eastern Kenya, (Machakos, Kitui, Embu).	Tolerant to head smut. Moderately tolerant to striga weed
BJ28 	• Released in 1978 by KARI Lanet • For grain (food) and forage • Grain yield: 2.5-3 t ha^{-1} • Open pollinated (OPV) • Plants are tall	• Dry high lands • 750-2300 masl	• Silage: dry matter digestibility: 52 - 65%, Crude protein: 8-12% Neutral detergent fiber: 60-75%, acid detergent fiber: 34 - 40%. • Ensiled grain: 90%. Digestibility
Ikinyaluka: 	• Released in 1997 by KARI Kakamega • For grain (food) and fodder production • Grain yield: 8 t ha^{-1} • Open pollinated (OPV) • Plants are tall	• Dry high lands 750-2300 masl.	• Silage: dry matter digestibility: 52 - 65%, Crude protein: 8-12% Neutral detergent fiber: 60-75%, acid detergent fiber: 34 - 40%. • Ensiled grain: 90%. Digestibility

Variety	Source & Description	Suitability	Attributes
E 1291 	• Released in 2000 by KARI Lanet, • Dual Purpose for grain and forage • Grain yield: 2.7 t ha^{-1} • forage : 2.7t ha^{-1} • Open pollinated (OPV) • Red grains • Plants are tall	• It is well suited to 750-2300 masl in dry high lands and high potential areas.	• Good for sorghum beverage. • Silage: dry matter digestibility: 52 - 65%, Crude protein: 8-12% Neutral detergent fiber: 60-75%, acid detergent fiber: 34 - 40%. • Ensiled grain: 90%. Digestibility
E6518 	• Released in 2000 by KARI Lanet, • Dual Purpose for grain and forage • Grain yield: 3.4 t ha^{-1} • forage : 7.2 t ha^{-1} • Open pollinated (OPV) • Red grains • Plants are tall	• It is well suited to 750-2300 masl in dry high lands and high potential areas.	• The variety is well adapted to cold dry zones. • Silage: dry matter digestibility: 52 - 65%, Crude protein: 8-12% Neutral detergent fiber: 60-75%, acid detergent fiber: 34 - 40%. • Ensiled grain: 90%. Digestibility

3.5.3. Planting and seed rates

Seek and use climate information to guide the planting date. Plant timely to use the planting window effectively to maximize yield and to reduce losses. Plant in rows as per recommended spacing and seed rates which can be found on the seed packets. Generally, seed rate of 8--10kg ha^{-1} is to achieve a plant population of 130000-150000 plants ha^{-1}. The mainly used spacing is 75 cm inter-rows and 15-20 cm inter-plants in a row.

If possible use a calibrated **sorghum planter** to ensure proper seedling spacing and plant population thus reducing the seed rate (Figure 28).

Figure 28. A tractor drawn sorghum planter. Source: Abo Al-kheer, 2010

If hand planting, use a ripper for minimum tillage.

A ripper is used to create planting narrow, shallow furrows with loose soil on un-ploughed land for manual planting. Ripping requires less draught power than conventional ploughing and is faster than ploughing so farmers can work and plant a larger area. Ripping breaks soil crusts, thus enhancing rainwater infiltration (Figure 29).

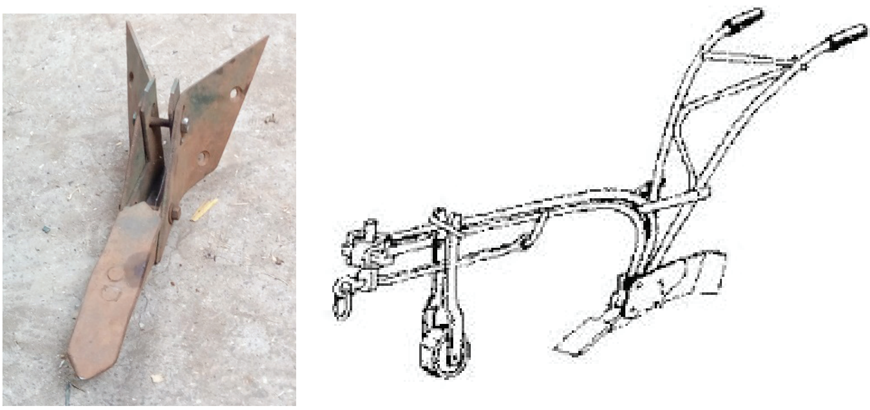


Figure 29. A ripper (Left) and A Ripper fixed on oxen plough
Source: Kisilu RK (left) and Infonet Biovision.org (right)

3.5.4. Integrated Weed Management (IWM)

Perform the first weeding within 2-3 weeks after emergence and the second weeding when the weeds are observed.

Practice integrated weed management (IWM) which involves the use of several measures to control weed in sorghum farms;

a) **Preventive weed Control:** Prevent establishment of weed in the cultivated sorghum crop by using weed free seed and cleaning of farm equipment before moving from one location to another.

b) **Cultural weed control:** Practice crop rotation, plant cover crops, intercrop sorghum with legumes, use well-adapted competitive varieties and maintain good soil fertility.

c) **Chemical:** Apply recommended herbicides to weeds or soil to control the germination or growth of the weed. This prevents soil disturbance. It is cheap in terms of labour, time, and expenses compared to hand weeding.

d) **Mechanical/Physical weed control**

Weed Pulling: Pull the weeds to uproot and remove from the soil to control annuals and tap-rooted weeds. Pulling does not negatively affect neighbouring, non-target plants and has a minimal effect on the growing environment. Use pulling in small weed infestations because when used in large farms it is labour-intensive and time-consuming.

Mowing: control annual weeds by mowing to prevent and reduce seed populations as well as restrict the growth of weeds. Mow weeds before they are able to set seed to reduce the number of flower stalks and prevent the spread of more seed. This method is usually used in combination with other control methods such as herbicides.

Mulching: Use mulch to smother the weeds by excluding light and providing a physical barrier to impede their emergence Mulching is relatively simple and inexpensive. Mulches may be organic or synthetic.

Organic mulches: are plant by products such as wood chips, green waste, compost, leaves and grass.

Synthetic mulches: made from materials like polyethylene, polypropylene, or polyester.

e) **Sorghum Parasitic Weed Control (Striga Weed)**

Striga, (*Striga hermontheca* (Del.) Benth) commonly known as witch weed, is a parasitic weed affecting many cereals including sorghum (Figure 30). Striga attacks sorghum by attaching its roots to sorghum roots, taking up the water, mineral nutrients, and photosynthetic assimilates thereby retarding growth and development of the host.

Striga weed causes stunted growth, yellowing and sometimes failure to bear panicles under severe infestation in sorghum. It causes 20-80% grain yield loss under severe infestation.

Striga plants produce thousands of small seeds in a season that remain viable in soils for up to 15-20 years. A few seeds of striga germinates in a season where host plants exist hence retaining some seed in the soil.

Figure 30. Striga hermonthica infested sorghum field. Source: Musselmanet al, 2001

Control Striga weed by:

- Intercropping sorghum with Desmodium, which inhibits striga seed germination (Khan et al, 2006).
- Planting legume trap crops in an infested field to induce the Striga seeds to germinate without supporting attachment of the parasite. Some of the effective trap crops include cotton, groundnuts, sunflower, linseed and cowpea.
- Planting resistant/tolerant sorghum varieties (Table 6).
- Weeding regularly before the weed flowers.

3.5.5. Thinning

Uproot excess germinated seedlings when the soil is moist to ensure minimal disturbance of the roots of the remaining plants. Thin sorghum seedlings and leave 1 plant per hill 2 to 3 weeks after emergence. This is best done after first weeding in order to accommodate appropriate plant density adjustments in case some plants are damaged during weeding. Sorghum planted with a calibrated sorghum planter has the proper seedling spacing and does not need thinning.

3.5.6. Crop nutrition

Most soils in sorghum production areas are deficient in essential macronutrients such as nitrogen (N) and phosphorus (P), which are important for adequate crop growth. In some areas deficiencies of important micro nutrients exist. Test/analyze farm soils for proper decision before the onset of the season. Soil testing will give micronutrients levels, macronutrients levels, and soil pH range, which is a measure of soil acidity or alkalinity. In some instances, liming may be recommended if soils are acidic. Soils with pH less than 5.5 are subject to liming to remove exchangeable acidity that might limit crop production including sorghum. The desired management of acid soil depends on the soil pH and the ratio of Calcium to Magnesium. The ideal ratio being 2:1 to decide on whether the corrective measure will require calcitic lime or dolomitic lime application. Observe the deficiency symptoms of important nutrients in sorghum plants (Table 7).

Table 7. Nutrient requirements in sorghum and deficiency symptoms

Nutrient and Importance	Deficiency symptoms	Correction measure
Nitrogen(N) Formation of plant proteins and enzymes • A component of chlorophyll, which enables photosynthesis to produce energy for growth and grain yield	• Yellowing (chlorosis) of leaves • Stunted plants • Small heads • Reduced seed	• Top dress Urea 8-10 Kg N / acre or • Calcium Ammonium Nitrate (CAN) 50 Kg/ acre. • Regular use of organic manure
Phosphorus (P) • Root development • Maturity at the right time • Plant resilience against disease	• Plants turn dark green with purple cast. • Small leaves and plants • Poor grain filling	• Di Ammonium Phosphate (DAP) foliar spray of 2%, 2-3 sprays at an interval of 15 days on the seedlings • Organic manure
Potassium (K) • Movement of water, nutrients and carbohydrates in plant tissue, photosynthesis, • opening and closing of the stomata, which regulates the exchange of water vapor, oxygen and carbon dioxide	• Yellow/brown discoloration and scorching along outer margin of older leaves which begins at leaf tip in sorghum • Stunted plant growth • Reduced yield. 	• Foliar spray of Potash (potassium chloride or KCl) fertilizer @ 1%. • Wood Ash: applied directly as a fertilizer or added to your composite pile

Nutrient and Importance	Deficiency symptoms	Correction measure
Magnesium (Mg) • Gives leaves their green colour (chlorophyll) to capture sun energy needed for photosynthesis • Metabolism of carbohydrates • For cell membrane stabilization.	Older leaves have yellow discoloration between veins, finally reddish-purple from edge inward 	• Apply a soluble Mg source such as kieserite or Mg chloride.
Calcium (Ca) • Calcium pectate, holds the cell walls of plants together • Metabolic role in carbohydrate removal • Maintains chemical balance in the soil, reduces soil salinity, and improves water penetration.	• Delayed emergence of primary leaves • Terminal buds deteriorate • Leaf tips may be stuck together to form sword-like projections • Plants stunted • Leaves brittle, brown, sticky near margins and turn brown	• Liming. Adding lime to boost calcium and raise soil pH making it less acidic. • Foliar application of CaSO4 2% twice
Zinc(Zn) • A key component of many proteins and enzymes. • Growth hormone production • Internode elongation	• Broad white to yellow bands appear on young leaves on each side of the midrib. • Plants get stunted and have shortened internodes.	• Apply Zinc sulfate at planting or a few weeks when symptoms start showing
Sulphur (S) • Formation of plant proteins, enzymes, vitamins, and chlorophyll • Metabolism of nitrogen.	• Deficiency appears first on younger leaves, new growth is pale yellow	• Fertilizers or amendments containing sulfur. E.g. ammonium sulfate, calcium sulfate etc. • Use of organic manure

NB: Farmers advised to carry out soil testing and analysis to determine the rate of fertilizer to be used.

Improve crop nutrition and correct these nutrient deficiencies by:

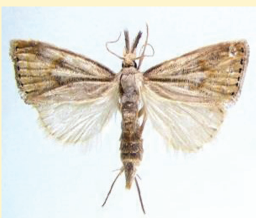
a) Applying organic fertilizers to improve soil organic matter, moisture retention and structure. Broadcast well-decomposed manure in the field close to the onset of the rains and mix with the soil or apply during planting by placing along the planting furrows and mixing with the soil before seeds are sown. The required quantity is two tons per acre. Soil amendments other than organic matter can also be applied if a soil test recommends so; these are materials that build up nutrients in the long term, rather than supplying nutrients primarily for one cropping season. Most soil amendments used to correct soil acidity and salinity are also applied before planting. They include lime, rock phosphate and gypsum.

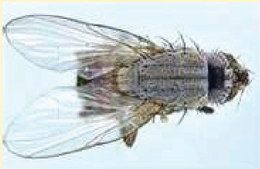
b) Apply inorganic fertilizers especially those that provide the essential macronutrients nitrogen (N) and phosphorus (P). As a rule of thumb: For sorghum, the maximum N should be 60 kg and maximum P_2O_5 should be 30 kg per hectare. At planting apply one bag (50kg) per acre of diammonium phosphate (DAP) or compound fertilizer NPK (20:20:0 or 23:23:0). For top dressing apply one bag (50kg) per acre of calcium ammonium nitrate (CAN) or Urea especially for non-acidic soils three weeks after germination when the crop has been weeded and thinned.

3.5.7. Integrated Pest Management (IPM)

Constantly scout for sorghum pests in order to identify and control them (Table 8).

Table 8 Major insect pests of sorghum in Kenya

Pest	Symptoms	Control
   Stem borer	• Small pin holes in lines in younger leaves caused by larvae. • Drying and eventual death of the growing point of the sorghum called '*deadheart*' due to larvae feed on whorl. • Patches of transparent leaf epidermis (window panes) in older leaves. • Holes in stem caused by larvae tunneling into the stem can result in broken stems	• Practice crop rotation • Timely planting • Plant Napier grass around the sorghum fields as a catch crop. • Spray with insecticide

  Shoofly	• Wilting and drying of the central leaf known as '*deadheart*' as a result of larvae attack • The damaged plants produce side tillers which may also be attacked.	• Plant shoot fly resistant varieties • Planting in time • Use systemic insecticides
 Fall armyworm (FAW)	• Small holes and "window pane" on leaves due to larvae feeding deep in the whorl. • Ragged appearance on the leaves resulting from heavy consumption by larvae. As plants begin to boot larvae may damage the panicles.	• Plant on time as per weather information • Use systemic insecticides
 Locusts	• Large swarms of locusts can completely strip the foliage and stems of plants such as forbs and grasses causing total destruction	• Spray with insecticides • Request for governments intervention in case of big swarms
 Birds	• Bigger birds such as doves consume whole seed • Smaller birds such as the *Quelea quelea* break the seed and eat portions exposing the white endosperm of the seed mainly during milky stage.	• Avoid isolated farms • Plant in clusters of many farmers • Use bird scaring devices • Harvest early at soft dough stage

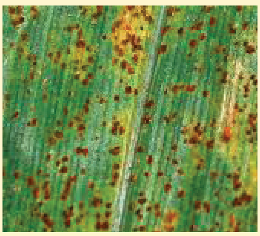
 Sorghum midge	• The larvae eat the young seeds in the heads. • Moderate infestations leave a few round, full grains amongst undeveloped shriveled grains. However, when infestations are severe, full grains are absent.	• Plant on time as per weather information to escape the sorghum midge population build up • Plant sorghum varieties with same maturity period at the same time within the communities • Remove alternative hosts such as Johnson grass and Sudan grass • Practice field sanitation and crop rotation with other none host crops • Use resistant or tolerant sorghum varieties.

3.5.8. Integrated Diseases Management (IDM)

The incidence and severity of the wide range of sorghum diseases depend on the growth stage, genotype, pathogen strain and weather conditions. Use resistant varieties (Table 9) as a primary method of managing crop diseases brought about by increasing temperatures and fluctuations in rainfall distribution and intensity. Use chemical intervention when deemed necessary. Constantly scout for sorghum diseases in order to identify and control them (Table 9).

Table 9. Major diseases of sorghum in Kenya

Disease	Symptoms	Control
 **Covered kernel smut** Cause: Fungus	• The individual grains are replaced by oval or cylindrical structures called sori • The sori have a creamy coloured skin and when broken they release black substance which is the fungal spores • The disease is seed born	• Use disease free certified seed • Uproot the infected plants and burn to prevent further spread of the disease • Destroy disease carrying crop residues by burning • Rotate with non-host crops especially legumes • Use resistant varieties
 **Head smut** Cause: Fungus	• The panicle is completely replaced by a large smut gall covered by a thick whitish membrane, while still enclosed in the boot • The membrane soon ruptures, often before the head emerges, exposing a mass of dark powdery spores • The affected plants are shorter than the healthy plants due to a lack of elongation of the peduncle	• Use of sorghum disease free certified seed • Uproot the infected plants and burn to prevent further spread • Destroy disease carrying crop residues by burning • Rotate with non-host crops especially legumes • Plant resistant varieties

Disease	Symptoms	Control
 **Ergot** Cause: Fungus	• The fungus infects the sorghum flowers converting them into a white fungal mass (sphacelia) • The infected flowers exude an amber-colored, sticky fluid, or "honeydew," which drips onto the leaves and soil further spreading the spores	• Plant clean seed • Burn crop residue • Where possible spray fungicides
 **Anthracnose** Cause: Fungus	• Small circular red spots on leaves with distinct margins • As the disease progresses, the spots increase and coalesce to cover most of the leaf surface • Plants becomes defoliated and may die before reaching maturity	• Practice crop rotation with legumes crops to break the disease lifecycle • Practice field sanitation by destroying sorghum residues • Use resistant or tolerant varieties
 **Leaf blight** Cause: Fungus	• Reddish-purple or tan spots that coalesce to form large, elongated lesions	• Burn crop residues • Practice crop rotation • Use resistant or tolerant varieties
 **Rust** Cause: Fungus	• First pale yellow or orange spots appear on the upper surface of leaves (pycnia) • Then yellow or orange spots appear on lower surface of leaves • Brown spores appear on both surfaces of lower leaves and stems • The spots turn black (telia) • Severely infected leaves turn yellow, dry up and die	• Practice crop rotation to break the disease lifecycle • Destroy sorghum residues before the onset of the rains • Use resistant or tolerant varieties
Grain mold Cause: Fungus	• Grain mold affects short duration varieties under rainy season in warm and humid conditions • Causes discoloration of grains to light whitish, pinkish, grayish or black. • It affects grain weight, viability, quality and market price	• Grow mold resistant cultivars. • Avoid growing early-maturing mold-susceptible cultivars in high rain potential and humid zones. • Harvest physiologically matured crop without delay and quickly dry grains after threshing

Disease	Symptoms	Control
Charcoal rot 	• Charcoal rot affects sorghum plants subjected to moisture stress during the pre-flowering period • Lodging of plants • Premature drying of stalks • Root rot • Reduction in filling up of grains.	• Practice timely planting to escape moisture stress • Do crop rotation • Apply optimum plant population to reduce the incidence • Adopt intercropping other than sole cropping • Grow drought tolerant, lodging resistant, and non-senescing Varieties
Common storage molds and mycotoxins 1. Aflatoxin 2. Fusarium 3. Penicillium	• Aflatoxin is a toxin produced by the fungus Aspergillus flavus. • Mold infestation in storage can be recognized by a gray-green or yellow-green mold growing on grain	• Dry grain to the recommended moisture • Store in well ventilated stores to control the relative humidity and temperature during storage • Use of aflasafe chemicals • Timely harvesting • Proper threshing

3.5.9. Harvesting and Post-Harvest Management of Sorghum Grain

Climate change has a profound impact on production by creating conditions that make harvesting and postharvest losses a greater challenge. The prolonged rainfall seasons affecting harvesting time and the increased mean surface temperature enhancing the storage pests' damage and harmful fungal infestation are some of the impacts. This has increased the current overall post-harvest losses that stand at about 10 to 30% in terms of quantity depending on the crop, with that of cereals estimated at 10%. In terms of loss of quality and nutritional value, this poses serious health hazards if linked to the consumption of aflatoxin while also poor-quality grains lead to reduction in marketing opportunities as damaged grains fetch low prices. Post-harvest losses can be reduced through appropriate technologies, mainly during storage hence boosting food security.

3.5.9.1. Harvesting

Figure 31. Mature sorghum crop ready for harvesting.
Source: Kisilu, R. K., 2020

Harvest on time, by hand-cutting with a knife from the standing stalk, when the grains are physiologically mature. Early sorghum varieties mature within 3 months while late varieties mature within four months. Grains may mature when the plant and some leaves are still green. Test if the grain is ready for harvesting by pinching to ensure it does not have the milky substance. A mature sorghum crop ready for harvesting is indicated (Figure 31).

3.5.9.2. Drying the panicles, threshing and drying grain

i) Drying panicles

Spread the panicles on a clean raised platform on a tarpaulin or mats (Figure 32) to dry under the sun to enable separation of grain from the husks or glumes while threshing.

Dry the panicles for a minimum of 3 days depending on the ambient temperature, relative humidity, depth of grain, and the frequency of turning until the grain attains moisture content of below 15%.

Figure 32. Drying sorghum panicles for threshing
Source: Esilaba, et al. 2019.

ii) Threshing

Use sorghum threshers to thresh the panicles (Figure 33). Thresh the grain on the tarpaulin or mats to avoid contamination with stones and soil. Some threshers will be able to winnow, if not winnow the grain to remove the chaff before storage. The use of sorghum threshers lessens the time and increases efficiency and the quality of the grain.

Figure 33. Motorized sorghum thresher. Source: https://www.cornmachine.com

iii) Drying the Grain before storage

Dry the grain by spreading on mats or tarpaulin under direct sun. Turn the grain regularly to ensure uniformity in dryness. Drying can also be done in a solar drier if available. Use of tarpaulins for drying grains. Test the moisture of the grain to make sure it is within the moisture content wet basis (MCwb) of below 15% before packaging.

3.5.9.3. Methods of testing grain moisture content

i). Moisture meter: Test the grain moisture content using a grain moisture meter (Figure 34). Moisture meters are available with extension providers and can be availed on request.

Figure 34. Grain Moisture meter
Source: Murenga Mwimali, 2020

ii). Salt moisture testing method: For farmers who cannot access the moisture meter, use the salt method. Get 8g of dry salt, a transparent dry glass or clear plastic bottle and about 160g of sorghum grain. Place the grain sample into the dry bottle and add the dry salt (Figure 35).

Close the bottle tightly and shake it vigorously for one minute to mix the salt and grain. Allow the grain to settle for about 15 minutes. If the salt sticks to the side of the bottle then the moisture content of the grain moisture is above 15% MCwb and needs more drying. If the salt does not stick to the bottle, then the grain MCwb is below 15% and so is safe for storage (Figure 35).

Figure 35. Salt moisture testing method

3.5.9.4. Packaging the grain

Package the grain for storage using Hermetic Storage Technology (HST) bags to avoid the need of storage chemical dusting hence reducing health risks. It is a safe and cost-effective for households for the storage of all grain types including sorghum.

Hermetic Storage Technology (HST): The bag has an outer Woven Polypropylene (WPP) bag and the inner liners (Figure 36). The WPP bag protects the inner liners that give the best hermetic properties to block gases and water vapour. Once the hermetic bag is closed, oxygen and other gases are prevented from entering or exiting protecting the dried grains from damage by suffocating any living organisms inside. The stored grain can last up to two years with no appreciable loss of quality and the bag is reusable.

Figure 36. Hermetic Storage bags
Source: https://kaaa.co.ke/hermetic-storage-technology/

3.5.9.5. Storage of packaged sorghum grain

Store the grain in a way that maintains quality and quantity by ensuring that the storage environment is clean, tidy and in a good state of repair. This prevents the damage and deterioration caused by adverse weather conditions. Grain damage during storage includes contamination by extraneous material, grain germination, pest infestation (weevils, beetles moth and rodents), microbial infestations, enzymatic activities and heat problems.

- Store new and old grains separately.
- Select the storage site and storage structure carefully.
- Fumigate empty stores before grain is put inside.

Do regular inspection to ensure proper aeration, correct uniform temperature, cleanliness, dryness and fumigation during the storage period.

3.5.9.6. Construction of storage structures

If the sorghum grain is going to be kept for some time store the bags in a good weather secure storage structure. The size of the structure depends on the amount of grain to be stored.

During the construction of the storage structure;

- Raise the floor from the ground with pillars to a minimum of 90cm from the ground to make the structure rodent-proof and protect the grain from advance weather conditions such as flood waters.
- Fit the pillars with conical rodent guards made of metal sheets.
- Make the flour with good quality concrete to avoid rodents from coming up.
- Construct the walls using stone or local brick and plaster smooth to avoid pest breeding crevices.
- Roof the building with corrugated iron sheet.
- Close the gaps between the wall and the roofing sheets with cement or wire mesh with 12mm openings to keep birds out
- Construct a tightly fitting door to prevent entry of rodents
- Construct ventilation openings to allow aeration and control temperature of the grain.
- Screen the ventilation openings with mesh not exceeding 12mm to keep out insects and birds.

3.6. Sorghum and livestock production

3.6.1. Sorghum as feed grain

Sorghum grain is a significant component of feed for cattle and chicken. Compared to corn, sorghum grain has similar feed characteristics, provides about as much energy, has higher crude protein content, but has less digestibility due to tannin content. Currently, low-tannin high digestible sorghum varieties have been developed. Highly digestible grain can be used as a total replacement for maize in poultry feed without affecting body weight or egg production performance of layer birds.

To efficiently use grain sorghum as animal feed, process by milling, early harvesting, steam-flaking or popping. This enables digestion by the animal and increases rate and extent of starch absorption resulting in large improvements in its feeding value.

3.6.2. Sorghum for fodder

Fodder sorghums are classified into three key classes;

a) Forage sorghums
b) Sudan grasses
c) sorghum-Sudan grass hybrids

Fodder sorghum varieties containing 52 to 65% dry matter digestibility have been released in Kenya.

3.6.2.1. Forage sorghum

Sweet sorghum varieties and hybrids (Figure 37).

Figure 37. Forage sorghum
Source: Sorghum Solutions Africa, 2016

Tall plants (2--4 m) with sweet thick stems.
Source: Sorghum Solutions Africa, 2016

The varieties have poor regrowth ability after harvest therefore good for a single-cut system. Best utilized as a silage crop, as hay or grazed.

3.6.2.2. Sudan grass

- Has small, fine stems and leafy growth (Figure 38).
- Regrows rapidly after cutting or grazing.
- Can be harvested as pasture, green chop or hay.
- The thinner stems give it better drying characteristics for hay making.

Figure 38. Sudan grass
Source: Sorghum Solutions Africa, 2016.

3.6.2.3. Sorghum-Sudan grass hybrids

- They are crosses between Sudan grass and other sorghums.
- Taller, thicker stems and high yielding than Sudan grass.
- Harvested for silage or hay-making (Figure 39).

Figure 39. Sorghum x Sudan grass hybrids
Source: Sorghum Solutions Africa, 2016

3.6.3. Utilization of fodder sorghums

Fodder sorghums may be utilized in a number of ways namely; a) as green chop, b) hay, or c) silage.

a) Green chop and grazing: For grazing, plant Sudan grass or sorghum x Sudan grass hybrids. Graze or cut the crop at a height of 0.6-0.9m and above as it is very palatable and has a high nutritive value, which ensures a good feed intake. Do not allow the plants to flower. Do not graze the crop to below 0.2m for better regrowth.

b) Hay: Plant Sudan grass and sorghum x Sudan grass hybrids for hay making. Plant with high seed rates to get high plant population and induce thinner stems that dry easier. This is because haymaking involves reduction of the moisture content in the green matter from 70--90% to 20--25% or less. Harvest hay before head emergence or at booting stage and dry uniformly and rapidly.

c) Basic Method of Making Hay

- Cut forage sorghum before full maturity and before seeding to maximize its nutritive value and compensate for reduced yields
- Cut more leaves than stems since leaves have high nutritional value.
- Do not leave cut forage to dry in a moist environment, as this will encourage the growth of moulds, mycotoxins and development of rots
- Lay the cut forage out in the sun in thin layers as possible and turn regularly to hasten drying
- You can also chop forage into small pieces to hasten the dying process which may take between 2 to 3 days
- Do not over dry hay to avoid fermentation
- Store dried hay in form of bales when the moisture content is less than 15%.

d) Silage: Plant forage and grain sorghum types for the best silage production. Harvest the fodder sorghum at the mid to late soft dough stage of grain maturity and store as silage. The use of silage ensures year-round feed supply for high production of animals for beef and dairy cattle.

3.6.4. Anti- quality factors in sorghum feed and fodder

i). Cyanide (Prussic) acid poisoning: Most Sorghums contain varying amounts of cyanogenic glucosides, which depend on the variety, growth stage, and environmental conditions. If sorghum is cut for hay and sundried the prussic acid is rapidly volatilized and can be fed to livestock.

ii). Nitrate poisoning: Sorghums can accumulate nitrates (NO_3) during weather condition that interferes with normal plant growth; however, drought is the most common cause. Nevertheless, ensiling the forage can lower the NO_3 by approximately 50%.

4 ECONOMICS OF SORGHUM PRODUCTION AND MARKET ACCESS

4.1 Theoretical Background of Economics

Economics is essentially the planning of scarce resource allocation to enhance productivity. The prevalent climate changes and their proven agricultural challenges call for appropriate resource allocation to ensure farmers get maximum returns out of the limited resources and the prevailing constraints such as unpredictable rains, flooding, recurrent droughts as well as pests and diseases.

Kenya has high potential for sorghum production, however, it has remained underutilized, with low production associated with constraints both in the supply side and the demand side. While some constraints are biotic (pests, diseases and weeds) and abiotic (climate and soil), addressing social and economic constraints are crucial in upgrading the sorghum value chain. On the supply side, productivity at farm level remains low while on the inputs and outputs market, it is disorganized and consumption is low. Some of these issues could be addressed through measuring sorghum productivity using crop potential yield and comparing with what farmers achieve at farm level. Similarly, the demand side challenges could be addressed through analyzing current existing markets and new market models that have been used in other enterprises successfully.

In understanding the economics of sorghum, the farmer should practice record keeping, enterprise management, gross margin analysis, sorghum product diversification and marketing.

4.2 Record Keeping

Farmers should keep record because it provides the information and data needed for planning and minimization of risks. It reduces the level of uncertainty and promotes more informed decision-making by the farmers in a timely and accurate manner. Specifically, record keeping has several advantages such as:

a) Determining accurate profit or loss of the farm operations.

b) Helping in monitoring progress or scheduling of essential activities to mitigate emerging problems, for instance, farm record of disease and pest control helps reduce chances of outbreaks since the farmer will be aware of the last time he/she sprayed thus they will be able to adhere to the recommended routine of pest and disease prevention measures. Recording emergence of a pest or disease symptom and its subsequent behaviour is useful for future management due to changing agro-climatic parameters.

c) Guidance on the appropriate type and level of insurance to take for cushioning against the uncertainties associated with climate change and also as a supporting evidence for loans and strategic collaborations such as contract farming.

d) Appropriate resource allocation; equipment, funds, variety and operations.

Farm records can broadly be categorized into physical and financial records

4.2.2. Financial Farm Records

Cashbook: It records cash in and cash out on daily basis and also serves as source of information for other types of records. It is important that the farmer captures as much details as possible including dates, descriptions of quantities, unit prices and total amounts for all receipts and payments.

Payroll/labour records: It takes care of the various transactions related to labour on the farm including number of labourers, payment for work done as well as pending labour costs among other things as may be relevant to the farm.

Sales/Consumption Records: This records the quantity sold and/or consumed by the farmer and his family, or given out to friends and relatives.

Profit and Loss Accounts: This is one of the most important records in the farming business because it shows whether the farm is making profits or losses and by extension whether or not the farm business is sustainable in the long run. The record captures revenues, usually from sales and expenses related to production and marketing.

4.2.3. Physical Farm Records

Farm Inventory: It records the various assets held by the farm and their conditions. This helps to identify items that need replacement

Farm Management Practices record: Shows the various past and planned activities on the farm such as planting dates, weeding, pest control, planned dates of harvest and so on.

Input Records: This gives details on the type and quantity of different input obtained and/or utilized in the farm over a given period.

Production Records: This record measures the productivity of the land, and success of farming operations generally. It shows how much crop has been harvested or the anticipated level of harvest.

4.3 Sorghum Enterprise Management

Sorghum enterprise management can be defined as a decision-making process which affects its profitability. This decision will include what variety of sorghum to cultivate, to what extent, how to produce it and how to obtain the production resources such as land, labour, capital and management. It is important to note that once the decision of sorghum production has been made, then the production costs and returns are analysed based on these premises. The sorghum enterprise performance will be based on the technical (physical) and economic (monetary) performance indicators.

4.3.1. Sorghum Enterprise Analysis

4.3.1.1. The Nature and the Objectives of Sorghum Enterprise Analysis.

Enterprise analysis is a management tool that enables evaluation of profitability and the reason for it. It is a guide in deciding what should be done in order to increase profitability. An enterprise's profitability is determined by both external and internal factors. External factors are those which the farmer has no influence over, for example, prices or government policies. Internal factors are those that can be determined by proper management and decisions by the farmer; for example, varieties of sorghum grown, the kind and quality of inputs to be used and time of marketing.

Enterprise analysis is concerned with decisions taken on the internal factors in order to increase profitability from limited resources. To achieve this objective, we have to measure constantly the results obtained, calculate both technical and economic performance indicators, and use these indicators in making informed decisions with regard to future production of sorghum.

4.3.1.2. Use of Enterprise Analysis.

Enterprise analysis is used for;

a. Farm management decisions
b. Supplying data to public institutions and government for use by agricultural policy makers
c. Preparation of enterprise budget
d. Preparation of farm

4.3.1.3. Production Costs in Sorghum Enterprise

The cost of production gives a clear idea about expenditures incurred due to production of sorghum. Production process is a transformation of inputs to outputs, thus the cost of production of sorghum reflects the value of inputs that are essential. Production costs may be calculated for the following purposes:

a) Farm/enterprise planning
b) Comparative enterprise analysis
c) Price determination and policy making
d) Production, monitoring, control and evaluation.
e) Accounting and bookkeeping.

4.3.1.4. Sorghum Profitability Analysis

Many farmers do not keep records and rarely evaluate their sorghum business to determine profitability. Profitability analysis is a component of enterprise resource planning (ERP) that allows one to forecast future trends of the farm. The aim for profitability analysis is to identify the most and least profitable products or services, change the product mix to maximize profits in the short and long term as well as isolate and remedy the causes of decreasing profit margins.

The first step towards conducting profitability analysis is to calculate the gross margins. Gross margins are total sales (revenue) minus its total variable costs of production (Equation 1). It can be expressed as a percentage by dividing by total sales revenue. The higher the percentage, the more the farmer retains on each shilling of sales.

(GM)=TR(PxY)-VC……………………………………Equation ….

Where:

GM = Gross Margin per hectare
TR = Total revenue (P x Y)
P = Price (KES per 90kg bag of Sorghum)
Y = Yield (No of 90kg bag /ha)

VC = Cost of the variable inputs; labour, machinery, land and other inputs

4.3.1.5. Sorghum Enterprise Gross Margin.

The gross margin is the real change in farm/ enterprise profit which occurs as a result of an implementation of a particular activity, usually an enterprise, in this case sorghum. It makes it possible for us to conduct a meaningful analysis of past performance and provides the relevant profitability indicators for planning. Gross margin is actually the difference between income (returns) and variable (avoidable) costs. It is usually calculated per production unit (one hectare) or per unit of output (kg of sorghum) (Table 10).

Table 10. Gross margin analysis guideline for sorghum production per hectare

	Conventional agriculture				Climate smart agriculture			
Intermediate input	**Unit**	**Qty**	**Price**	**Total Cost Ksh/Ha**	**Unit**	**Qty,**	**Price**	**Total Cost Ksh/ Ha**
Variable Inputs								
1. Land preparation								
2. Herbicide application								
3. Ploughing								
4. Harrowing								
5. Ridging/furrowing								
6. Soil & water conservation agriculture structures								
7. Labour								
Sub total								
Planting								
1. Certified seeds								
2. Planting								
3. Manure								
4. Fertilizer DAP								
5. Labour								
Sub total								
Crop management								
1. Weed control								
• Integrated weed management								
• Hand weeding								
2.Thinning								
3.Fertilizer CAN								

	Conventional agriculture				Climate smart agriculture			
Intermediate input	**Unit**	**Qty**	**Price**	**Total Cost Ksh/Ha**	**Unit**	**Qty,**	**Price**	**Total Cost Ksh/ Ha**
4.Disease management								
• Integrated disease management								
• Non-integrated disease management								
5.Pest management								
• Integrated pest management								
• Non-integrated pest management								
6.Labour								
Sub total								
Harvesting & post harvesting								
1.Cutting heads								
2.Machine Threshing & 3.winnowing								
4.Hand threshing and 5.winnowing								
6.Packaging								
• Hermetic bags								
• Normal bags								
7.Transportation								
7.Labour								
Sub total								
TOTAL VARIABLE COST (VC)								
Production				**Total**				**Total**
Yields/Acre (Bags) (Y)								
Price/bag (90kgs) (P)								
Total Revenue (TR) = (P*Y)								
Gross margin (TR –VC)								

Example: Gross Margin for Conventional Production per Hectare at KALRO-Alupe Busia County

Variable Costs	Operations/Inputs	Average Cost (Kshs. / Ha)
Cost Areas	Primary land preparation	6,032.64
	Secondary land preparation	3,938.01
	Planting material (Seed)	390.85
	Fertilizer	5,295.48
	Furrowing	3,624.09
	Drilling	1,242.91
	Weeding	10,255.12
	Pest management	313.70
	Harvesting	4,340.22
	Threshing	2,373.30
	Transport to homestead	1,031.21
	Drying (direct sun)	2,540.30
	Transport to market	302.66
	Total Variable cost /Ha	41,680.47
Actual yields	Yield(90kgBags)/Ha	11.14
	Price/90kgbag	3,077.08
	Gross Revenue	34,816.18
	Gross margin	(6,864.29)
	Break even Yield /Ha	15.29
	Return/shilling invested	0.91
Adjusted yields (60%)	Yield(90kgBags)/Ha	17.82
	Price/90kgbag	3,077.08
	Gross Revenue	55,705.89
	Gross margin	14,025.42
	Break even Yield	15.29
	Return/shilling invested	1.46

Source: KALRO unpublished data, 2019

In order to calculate the gross margin, we have to classify the costs according to the criteria of being variable (avoidable) or fixed (unavoidable).The classification of costs will be done according to the case under consideration

4.3.1.6. Fixed Costs in Sorghum Enterprise

There are two main groups of fixed (unavoidable) costs:

a) Costs incurred in the past, before the period related to the relevant activity period e.g. investments in machinery, building, purchased land etc.

b) The costs incurred during the relevant time period but not connected with the activity in question e.g. overhead costs.

The classification is determined by the time span of events in relation to the decision to be made (Annex 1).

4.3.1.7. Opportunity (Alternative) Costs.

In some cases, inputs are limited and cannot be bought in the market. Land, labour and some fertilizers are the most common examples. Market prices here are meaningless and irrelevant since inputs cannot be bought.

If a new enterprise or the expansion of an existing one is being examined, the inputs for the examined alternative must be transferred from the enterprise already in the farm. Thus, the cost of alternative examined would actually be the losses of the alternative enterprise foregone. These costs are called alternative or opportunity cost, and are defined as follows:

“Alternative or opportunity cost represent the cost of an opportunity which is foregone because of limited resources that are used in the chosen alternative and therefore cannot be disposed of or used for other possible income, in producing or expense reducing alternatives”.

The gross margin obtained from one unit when it is used in a particular enterprise, is actually the profit foregone if it is transferred to another alternative. When labour cannot be hired, the gross margin per man-day in an already existing enterprise would be alternative cost of labour on the farm. The enterprise according to which the input alternative cost will be calculated is the one which provides the lowest gross margin for that input; it is the marginal enterprise from this point of view.

Alternative costs are usually for economic analysis and are not included in the balance sheet or income and loss account. They are determined by the relevant alternative which should be defined carefully. There are no strict rules concerning the calculating of an opportunity cost of a certain input. A thorough understanding of each case is needed together with common sense.

4.3.1.8. Opportunity Cost Determination Scenarios.

There are three basic possibilities when calculating opportunity cost as determined by the prevailing conditions (Table 11).

Table 11: Various possibilities for opportunity cost calculations

Case	Conditions	The opportunity cost is:
1	Resources at hand, cannot be sold and they are in surplus	Zero (0)
2	Lack of resources, additional amount cannot be bought	The gross margin per unit obtained by another alternative which must be forgone.
3	Resources can be bought in any amount to the need	The market price

Certain kinds of resources face all these kinds of possibilities according to the prevailing conditions. Let us consider labour. When the farmer cannot find any work off the farm, he/she faces condition1. When he/she has much more work than he/she is able to do, and hired labour is not available condition no 2 obtains. When the possibility exists to hire workers, the farmer should calculate the labour value as in case no. 3

4.3.1.9. Costs Related to Yield and Break-Even Yield.

It is quite often necessary to determine to what extent a particular enterprise is sensitive to a change in one or more elements determining its profitability. When yield is the element considered it is necessary to isolate the costs which are directly related to the yield. Cost related to the yield are costs which change in proportion to the yield i.e., harvesting, packing and transport. The break-even yield is thus defined as that which covers all relevant costs i.e., a higher yield provides profit and small one a loss.

4.3.1.10. Break-Even Yield Determination.

Let us define the following variables:

a) Break even yield(kg/ha) =Y
b) Cost not related to yield (Ksh/ha) =C
c) Unit cost related to yield (Ksh/kg) = CR
d) Price of the product (Ksh/kg) = PR

4.3.1.11. Break-Even Formula.

The break-even yield (Y) is that yield which satisfies the following formula:

1. $Y*PR=Y*CR+C$

2. Or $Y = \frac{C}{PR-CR}$

The denominator of the second equation is the returns per production unit after deducting the cost related to yield (per output unit). Thus, we need enough units of yield (Y) to cover the cost which is not related to yield(C).

4.3.1.12. Performance Indicators

Indicators are values (signals) which can be used for comparing the performance of an enterprise in different cases. They are physical (technical) or financial (monetary) quantities usually related to a single unit of production or resource for example:

4.3.1.13. Economic (Monetary) Indicators.

a) Gross margin per hectare of sorghum.
b) Gross margin per man day.
c) Variable (avoidable) cost per kg of sorghum.
d) Gross margin per kg of sorghum.

Another group of indicators might include proportions and prices. For example,

a) Price of one kg of sorghum.
b) The ratio between the fertilizer cost and variable cost (%).
c) Daily wage rate.

4.3.1.14. Technical Indicators.

c) Sorghum production per hectare (kg/bags).
d) Amount of sorghum consumed at home.
e) Quantity of fertilizer per hectare.
f) Number of work days per hectare.
g) Quantity of manure used.

A set of indicators which will be helpful in making management decisions, must be prepared for each specific enterprise. This must be done together by farm management and technical specialists.

In order to evaluate the performance of a sorghum enterprise we may compare it with one of the following criteria:

a) Performance of the sorghum enterprise in the previous year(s).
b) Planned budget for the sorghum enterprise.
c) Performance of other farmers.
d) Standards or norms.
e) Performance of the other enterprises on the farm.

A comparison can be made only if some kind of central agency is compiling data on regional or country wide basis. Point (e) is used whenever we extend our analysis to the consideration of the entire farm. In this case we have to compare the returns made to the limited resources by all enterprises concerned.

When we analyse an enterprise for the first time or a single year, special care must be taken in drawing conclusions. This particular year might be one of exponential prices or growing conditions, weather or insect/disease attacks. A continued analysis of the same enterprise, over the course of a few years can affect the influence of several factors in the analysis of a single year. Inflation has great influence on the meaning of the results of an enterprise analysis. When we compare indicators from two different periods, the data must be adjusted by inflation adjustment factors. If this is not done, and the inflation rate is high, serious mistakes in farm management can be made.

4.4. Sorghum Marketing

Agricultural marketing covers the services involved in moving an agricultural product from the farmer to the consumer. Numerous interconnected activities are involved in doing this, such as planning production, growing, harvesting, grading, packaging, transport, storage, agro and food processing, distribution, advertising and sale. Such activities cannot take place without the exchange of information and are often heavily dependent on the availability of financial resources. Production in Kenya is low with farmers producing enough for home consumption. It is estimated that only 30% is exported (FAO, 2013). Therefore, to improve production, there is need to understand marketing of sorghum and related products along the value chain.

Some of the important marketing strategies include:

a) market based production (production decisions are market informed)
b) Use of business models such as contract farming
c) Use of warehouse receipting systems.

4.4.1. Market Based Production

This is an approach where the farmer conducts market research to understand the needs and trends in the market before deciding what and how much to produce at what time. This would for example help the farmer to know which varieties are in highest demand and in which market segments.

4.4.2. Contract Farming

This is the arrangement where the farmer enters into an agreement in which the farmer agrees to sell to the buyer a given quantity of a particular grain at a specified price and other conditions and the buyer agrees to buy the given quantity and quality at the said price. It is an important approach that farmers can use to reduce the risks of price fluctuations given the growing market uncertainties associated with unpredictable weather patterns. However, there is some flexibility that may allow negotiation of prices and produce specification. The bargaining powers of both the farmer and buyer are enhanced by contract farming.

Sorghum farmers may cushion themselves against the price uncertainties through contract farming arrangement with the beer brewing industry. In addition to price and supply stabilizations, there may be an arrangement where the buyer supplies the farmer with appropriate inputs in time, therefore allowing farmers to fix conventional as well as climate change related input needs such as pesticides needed to control emerging pests and diseases. Contract farming may also enable the farmers to access credit from lenders due to the presence of a valid contract. What is critical is that farmers should take adequate steps to address risks such as unexpected crop damage or that may constrain their capacity to honour the contractual obligations at a profit.

4.4.3. Warehouse Receipting System (WRS)

The warehouse receipt system is defined by the Warehouse Receipt System Act of 2019 of the Laws of Kenya as "part of the whole process of depositing commodities in a licensed warehouse, the issuance of a warehouse receipt reflecting the quantity and quality of the deposited commodity, the management of the transfer of the receipts as a document of title and includes the regulation of warehouses and actors associated in the processes". The warehouse receipt system will enable the national commodity exchange, and trade in agricultural commodities. These will improve profitability, liquidity and price stability in the trade of agricultural commodities.

The warehouse receipt system works in such a way that farmers deposit their produce to the licensed warehouse also called collateral operator. The operator issues the farmer with a legally recognized receipt showing the type of produce for example, sorghum grain, the quantity and quality of the produce. The farmer (depositor) can then use that receipt as collateral to access credit including farm inputs. The warehouse receipt system will allow farmers to access the credit needed for timely interventions without necessarily having to sell their produce at farm gate prices soon after harvesting when the prices are quite low. The credit obtained will enable the sorghum farmers to access appropriate inputs in time, therefore plan well and effectively overcome the negative effects of climate change.

In addition to credit and access to markets, the warehouse receipt system provides farmers with good storage for their produce. This is particularly important given the unpredictability of weather and prevalence of post-harvest pests, and poor drying and storage conditions that deteriorates the quality and value of the grain.

4.5. Sorghum Farming Business

Farming is generally considered a business because like any other profit-making business, farmers seek to combine the three main factors of production namely land, labour and capital to produce goods that they aim to sell at a profit. To earn a profit sustainably, it is important that sorghum farmers effectively understand the prevailing forces of demand and supply. In particular, farmers should approach production by focusing on the market. Before investment of resources, farmers should assess available markets and decide for which customer(s) to produce for, the quality required as well as the quantity and timing of supply to that market. This may require farmers to change sorghum varieties planted and the agronomic practices to be implemented. Such changes attract different cost, revenue and profit expectations.

In pursuit of higher profits, farmers should seek cost reduction and/or revenue enhancing strategies such as collective action, mechanization and contract farming so that they benefit from economies of scale, enhance efficiency, improve quality and minimize risks. Sorghum has an advantage over many crops in that it has many uses, implying farmers may specialize and target different market segments/uses and reduce the level of competition that they face. The option that promises the highest profits for long periods of time should be given highest priority in resource allocation. Some of the common uses of sorghum for which farmers may produce the crop include:

a) **Food:** Sorghum grains can be processed as flour or used for baking purposes. There are some sorghum varieties that serve as a substitute for rice or maize while the sweet sorghum can be used as food sweeteners (as syrup).

b) **Fodder/Livestock Feed:** Forage sorghum contains rich protein and fat nutrients making it an exceptional feed for farm animals like cattle, goats and other herbivores, while the grains can be processed for poultry feeding.

c) **Brewing:** Sorghum has high maltose, which is primary ingredient for breweries to manufacture malt soft drinks. In addition, fermentation of this ingredient produces beer powder and lager beer. This is a great business opportunity for sorghum farmers.

d) **Ethanol Production:** Some sorghum varieties can be used for the manufacture of ethanol; a bio-fuel that can provide energy to run engines.

4.6. Sorghum Processing and Utilization Products

There are several products from sorghum depending on the methods of processing, intended utilization and variety. The marketed products for sorghum in Kenya are limited to dry grain, and a few processed products compared to other parts of Africa. The main processed or value-added products of sorghum in Kenya for human consumption are de-hulled grain for boiling, flour for making porridge/ *ugali* and starch for the brewing industry.

About 24 % of the sorghum supply in Kenya each year is used in industrial processing. In recent years, the beer industry has started to play a key role in the sorghum value chain. There has been a growing demand for sorghum for use in beer production. This is largely due to the EABL's increasing demand for higher quality sorghum varieties, such as Gadam.

The diversification and commercialization of sorghum products is envisaged to create a market and consumption demand to benefit the key players in the sorghum value chain particularly the smallholder farmer and consuming public. It may be used to replace rice in meals, milled and blended with wheat, maize, millet or cassava flour to make cakes, porridge, *ugali* etc, popped, flaked (and used to make cookies, beverages etc) or made into syrup to be used as sweetener in processed foods. Sweet sorghum has the potential to be an effective feedstock for ethanol production for auto and jet fuel.

Some of the value added products that are compelling, providing indigenous versions of popular products and safe urban versions of rural favourites and the recipes are listed (Table 12).

4.6.1. Recipes of Value-Added Products

Table 12. Local recipes of value added products of indigenous versions of popular products

Product	Recipe	Preparation
Sorghum Flour 	Clean sorghum grain	a) Clean and sort dry sorghum grain b) Mill the grain using a *posho* mill
Sorghum cowpea *pilau* (sorghum with cow pea) 	500 g pre-boiled de-hulled sorghum (2 cups), 500 g cowpeas (2 cups), 2 chopped onions, 50 ml oil 4 table spoons), 15 g *pilau* masala (1 tablespoon), 1 crushed ginger, 1 teaspoon ginger powder, one clove crushed garlic, 1 bunch coriander (*dhania*), one capsicum, salt to taste.	c) Clean the cow peas and soak in water for one hour d) Par Boil the cow peas e) Add pre-boiled sorghum to par boiled cowpeas f) Boil together until tender g) Drain the water h) Fry the onions to golden brown i) Add garlic and ginger and fry until brown j) Add *pilau* masala and cook evenly k) Add sorghum cowpea mixture, simmer for 10 minutes l) Add chopped *dhania* and serve with vegetables)

Product	Recipe	Preparation
Sorghum Chapatti 	500 g/2 Cups sorghum flour, 500 g/2 Cups wheat flour, 10 g salt, 1/2 Cup cooking fat and warm water (Makes 8 chapattis)	a) Mix flour, salt and fat, using the fingertips until all the fat is well mixed b) Pour in half the water, mix with a wooden spoon, adding a little water at a time, until the dough is firm but soft c) Knead the dough and when soft divide into 8 balls d) Roll each ball into a circle e) Rub each circle top with oil and fold into a wheel f) Roll each wheel to a circular in a floured surface g) Shallow fry each circle on a low heat on both sides in a pan until chapatti is golden brown h) Serve the chapatti hot
Sorghum Porridge  *Source: Kenyan Food recipes 2018*	8 tbsp. (83 g) sorghum flour, whole 6 ½ tbsp. (68 g) finger millet flour, whole 8 ¼ tbsp. (82 g) maize flour, whole, white 1 2/3 cups (366 g) cow milk 7 ¼ cups (1833 g) water Sugar/honey to taste	a) Mix the whole maize flour, sorghum flour and finger millet into a bowl. b) Add 2 cups of cold water into the flour mixture, stir until smooth using a wooden cooking stick. c) Bring 5 cups of water to boil in a cooking pot. After the water has boiled, add the mixture as you stir. Keep stirring to avoid forming lumps. d) Add milk after 10 minutes of cooking. Keep stirring until cooked. If the porridge is too thick add a little water (¼ cup) or until desired consistency is achieved. e) Serve hot.

Product	Recipe	Preparation
Sorghum *Ugali* 	2 cups (255 g) whole maize flour, white 1 cup (132 g) red sorghum flour 1 cup finger millet (113 g) flour 5 cups (1139 g) water	a) Put all the water into a cooking pot and bring to a boil. b) Meanwhile, mix the dry ingredients; whole maize flour, finger millet, red sorghum until an even colour is attained. c) Pour the dry mixture all at once into the cooking pot and slowly start mixing everything d) Mix while pressing the mixture against the walls of the pot to avoid forming lumps. e) Continue mixing the paste until smooth. f) Reduce the fire and simmer for 8 minutes. g) Remove from fire, turn over onto a plate and serve hot.
Sorghum Cake  *Source: AgIn, 2018*	3 cups of sorghum white flour, 1 cup of Wheat flour, 4 tablespoons of sugar, 4 tablespoons of margarine, 3 Eggs, 3 cups of milk or water, 1/2 teaspoon of baking powder, 1 pinch of salt	a) Mix the margarine and sugar b) Add beaten eggs in the mix c) Fold in sifted flour and add remaining ingredients d) Add milk (or water) to make soft paste after stirring with the table spoon. e) Place mixture in a well-greased pan, baking tin or tray f) Bake for 20-30 minutes
Sorghum beverage 	Sorghum grains (especially red or brown)	a. Sort sorghum grains b. Roast them on a pan until they turn golden brown. c. Grind them into fine flour d. The flour is then used to make the sorghum tea

Product	Recipe	Preparation
Gluten free sorghum bread  *(Source: Felicia Lim, 2017)*	3 teaspoons of active dry yeast (10.5 g), 2 teaspoons of granulated sugar (4.2 g), 1 1/2 cups of warm water, 3 1/2 cups of sorghum flour (444.5 g), 1 cup of cornstarch (120 g), 1/3 cup of tapioca starch (40.66 g), 1 teaspoon of salt (5 g), 1 teaspoon of xanthan gum (2.5 g)	a) In a medium bowl, mix the yeast, sugar, and warm water together in a bowl. b) Let the mixture sit in a warm place for 5-7 minutes, until it becomes frothy with small bubbles. c) Mix the sorghum flour, cornstarch, tapioca starch, and xanthan gum in another bowl d) Beat the eggs in a bowl e) Pour both the egg and yeast mixtures into the dry flour mixture. f) Stir everything with a wooden spoon until you get a homogeneous wet dough. g) Grease a loaf pan and pour the dough mixture into the pan. h) Smooth the surface with the back of a wet spatula i) Allow the dough to rest for 40 minutes in a warm place without any drafts until the dough has doubled in size j) Preheat the oven to 350°F about 15 minutes before the dough has finished proofing. k) Bake for 50 minutes to 1 hour on the middle rack, until the loaf is golden brown on top and sounds hollow when tapped on the bottom l) Cool completely before slicing it.

Product	Recipe	Preparation
 **Sorghum beer**	1 kg of Sorghum grain with brewing/malting quality 7g of Baking Yeast	a. Soak sorghum in water, allowing it to begin germination. b. Dry the partially germinated grains. c. Crush the sorghum and boil in water for about 15 minutes. d. Drain and put into a large vessel. e. Add 4 liters of hot water and let sit for 1 hour. f. Transfer liquid portion of mash to a large vessel and add 8 liters of hot water. g. Let the mixture cool to room temperature. h. Add the yeast and 1 cup of additional crushed sorghum malt (from germinated grains) and stir vigorously. i. Ferment for 2 days at room temperature then strain the beer into storage vessels. j. Serve to thirsty customers.

Sources: Harris, A. KF11 Rwanda, Kai, C. (2017), KALRO Katumani food utilization program (2017), Kenyan Food recipes (2018), Lim, F. (2017), SmartFoodKenya (2017).

4.7. Sorghum Market Outlets

To increase production and productivity of sorghum, there is need for farmers to be assured of the market and related products. In this regard, there is need to link farmers to the market. Market outlets for sorghum include; the rural consumers, rural market centres, urban centres, the brewing industry, schools, hospitals and export market. The sorghum marketing map/channels in Kenya are shown (Figure 40). Other markets are flour millers who sell sorghum flour or blend it with maize, cassava and wheat flour and baking companies who make gluten free bread. There are specifications for the East African standard for sorghum grains which can be used for quality assessment (Annex 2).

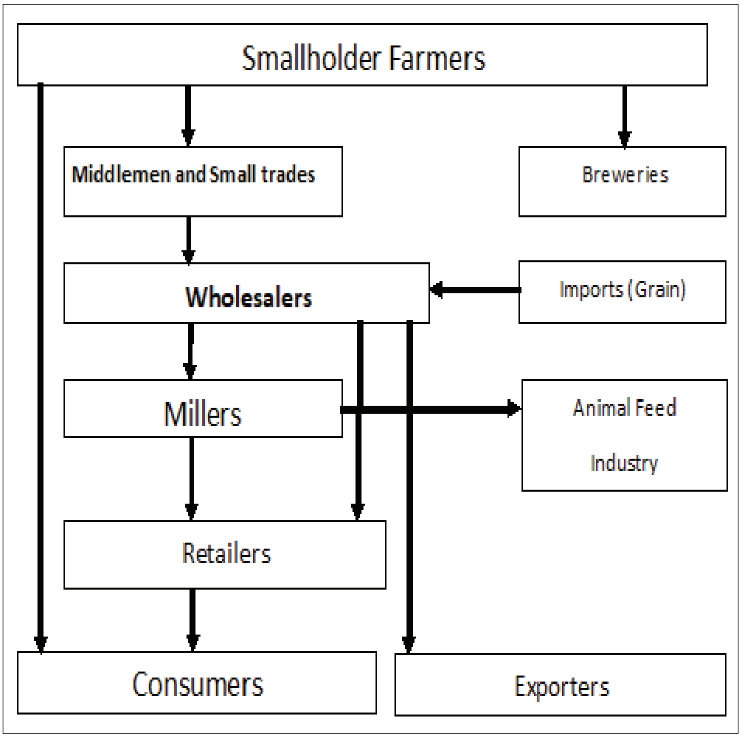


Figure 40. Marketing map for sorghum in Kenya
Source: FAO, 2013

4.8. Marketing Constraints and Opportunities

Although farmers and other stakeholders in the sorghum value chain face many challenges, opportunities exist which may not have been exploited.

4.8.1 Marketing Constraints

- ***Low pricing***: This is one of the major challenges for agricultural products due to their seasonality, perishable nature and collusion by buyers. In Kenya, sorghum prices are volatile and rise or fall depending on the season.

- ***High cost of inputs***: Cost of inputs is another major challenge correlated with pricing. Cost of production is a major determinant for pricing. High cost of production will reduce the farmers' profit margins. The cost of land preparation, bird scaring and fungal diseases control such as smut is quite high.

- ***Government Policies***: In some instances, there may exist some government policies that may constrain agricultural production. Weak regulatory framework, for example, may result in the rejection of farmers' produce. Also, the taxation policies for agricultural produce in transit across counties can result high transaction costs.

- ***Infrastructure***: Movement of agricultural produce is dependent on good infrastructural network. In many rural areas in sorghum growing regions, there is poor distribution network for inputs and outputs and roads.

- Other challenges include; inadequate information on markets, undeveloped markets, and insufficient knowledge on differentiated products and capital. Many sorghum producers may not be aware of emerging markets such as the ever growing brewing industry and health sector.

- Levies and taxes by local governments.

4.8.2. Marketing Opportunities

Despite the existence of the marketing constraints enumerated above, there are opportunities and possible solutions that include:

- ***Promotion****:* To solve the problem of inadequate information on markets and knowledge on differentiated products, promotion activities could be done. For example advertising in various fora such as electronic media, shows, trade fairs, food fairs and village gatherings. The health and nutritional qualities of sorghum present a great opportunity for marketing and promotion which producers and other stakeholders should exploit.

- ***Policies***: If regulatory framework is a problem there may be need to lobby for amendment for reduction of any unnecessary acts, taxes and non-tariff barriers.

- ***Undeveloped Infrastructure***: The solution for undeveloped infrastructure is to improve it through lobbying the policy makers. This can be done through the politicians and other opinion leaders in the community.

- ***Inadequate information on markets***: lack of markets could be solved through applying the market growth matrix of market research and penetration, market development, product development and product diversification.

- ***Market penetration*** - increase sales of products to current market segments, without changing the product offered. This can be obtained by reducing prices and increasing promotion and distribution.

- ***Market development*** – identify and develop new market segments for current products. These segments can be institutional markets and other geographical areas, including export.

- ***Product development*** - offer of new or modified products to current market segments. Products can be, for example, improved or packaged and labelled differently.

- **Diversification** – produce new products for new markets

Other possible solutions include provision of credit services, linking producers to consumers, availing processing plants within production zones and lowering production costs.

5 GENDER AND SOCIAL INCLUSION IN THE SORGHUM VALUE CHAIN

5.1 Introduction

Gender refers to the difference in socially, culturally and politically constructed roles and opportunities associated with being a woman, man or youth and the interactions and social relations between the different categories. Gender determines what is expected, permitted and valued in a woman, man or youth in a determined context. Gender relations, local norms, and power dynamics across social lines may cause women, men and the youth to have different knowledge, skills, and perspectives.

Gender equality refers to the equal access of women and men, not only to social services, but also to livelihood opportunities, production opportunities such as land and markets.

Climate change affects men, women, and youth differently. Women tend to be more vulnerable to climate change than men are, because they are more dependent on natural resources that are increasingly being depleted due to the effects of climate change for livelihoods. The socially constructed roles of women such as food production, fetching water, fuel wood, cooking, care of the children and family makes them more vulnerable to climate change. Climate change affects women and the youth more especially with extreme events such water scarcity, recurrent droughts, flooding, crop failures, etc. Their high dependence on natural resources, added to social and economic difference results in lower levels of access to and control of key productive assets such as land, information (education and knowledge skills) and technology. Women and youth farmers are affected by climate change because they have a lower ability to respond to/astgs or adapting to climate impacts including climate smart agriculture practices.

Effective climate-smart agriculture approaches require understanding the needs, priorities, and challenges of different stakeholders, and the identification of what is appropriate at the local level. Men, women and youths have different opportunities and challenges that may help or disadvantage them in the implementation of climate smart agriculture technologies in sorghum production. Implementation of climate smart agriculture practices without gender considerations leads to a widening gap of inequalities.

The main purpose of this information is to create awareness of the links of gender with agriculture and climate change, promote mainstreaming and integration of gender in climate change policies, and finally to create responsiveness of existing climate-smart agricultural practices that encourage gender equality and social inclusion.

5.2 Opportunities for women and youth in the sorghum value chain

In Kenya, sorghum has traditionally been identified as women's crop in many smallholder- farming communities. However, in the major Agro- ecological zones, the majority of the male-headed households planted sorghum with only 13% of the youth headed household participating in sorghum production (Table 13).

Table 13: Sorghum productivity by household type

Household type	Cultivated sorghum (%)	Productivity (Kgs/acre)	Commercial-ization	Land size owned (Acres)
Male- headed	58	190	0.06	4
Female-headed	31	216	0.07	2.6
Youth	13	220	0.13	2.5

Source: Gender and youth mapping, CRAFT project, 2019

While the majority of male-headed households cultivated sorghum, their yields were lower than that of female and youth-headed households. This is an indication that female and youth-headed households manage their farms better than the male-headed counterparts. Youth-headed households had higher yields per acre (220Kgs acre^{-1}) compared to adult male and female- headed households. This is because sorghum cultivation is extremely labour intensive, especially during harvesting and threshing when most of the post-harvest losses occur. Female and youth- headed households are less likely to own agricultural land compared to male-headed households. From the Gender and youth mapping carried out by CRAFT project it is evident that sorghum production is not inclusive, and this may be the reason why its production has lagged than other cereals in Kenya.

A gender-sensitive value chain approach to agricultural interventions increases the visibility of men's and women's roles in various nodes and eliminates gender-specific barriers to entry and opportunities for growth in the society. Some of the documented gender barriers include low access to markets owing to cultural seclusion of women, reduced income control by women with increased commercialization and women's lower access to technology (Odongo, 2014). These barriers influence the level of entry in the value chains and an actor's capacity to compete with other actors. Mostly, while there is the variation of opportunities and constraints for women, men and the youth between regions and value chains, women tend to play significant roles in production and elementary post-harvest processing that are often key determinants of size and quality of the final product/produce. These roles are however often informal, unacknowledged, and under-resourced. These challenges also face the youth hindering their participation in sorghum value chains.

While most early works on agricultural value chains centered on improving the competitiveness of different supply channels, many recent efforts have instead focused on increasing opportunities for the poor and the marginalized in the society in the spirit of inclusive growth and development. Inclusivity of value chains can be broadly interpreted to mean equal availability and accessibility of various opportunities and benefits thereof along the value chain to all actors. Women and the youth are in most cases the most constrained groups to participate effectively in various nodes of the value chains. Inequality is still high in Kenya although some social indicators have improved (GoK, 2016);

there are significant differences in opportunities and outcomes between men and women living in remote and most under-developed regions.

Women and the youth are an integral part of the agricultural transformation and must be accorded equal opportunities to contribute to the desired sustainable agricultural growth meaningfully. Agricultural Sector Growth and Transformation Strategy (ASTGS) notes for instance that to attract the youth to agriculture; there is need for attitude change among the rural communities to perceive agriculture as a business and make it commercially viable. In 2017, the Ministry of Agriculture, Livestock and Fisheries (MoALF) developed the Kenya Youth Agri-business Strategy 2017 - 2021 aimed at addressing the challenges that hinder youth from efficiently participating in the sector and provide new opportunities for the youth in agriculture and its value chains.

In the sorghum beer industry, women tend to concentrate more on production at the farm level where they mostly provide agricultural labour. Studies have indicated that females were more involved in sorghum production than men (Muui et al., 2013). This finding can be attributed to the subsistence nature of sorghum production, where it is produced for home consumption. Women were likely to be involved in planting, weeding, harvesting and post-harvest processing. Along the value chain, the roles of men become more prominent.

The youth offer labour at the farm level and are mostly involved in support services to the value chain. The youth, for instance, offer loading, offloading, transportation, and advisory services in the sorghum beer industry. Looking at sorghum value chain, however, asserted that men tend to be more concentrated in high status, more physical, and more remunerative activities in the value chain. This could also be the case for sorghum value chains. Youth will participate in an agricultural activity if they deem it more lucrative than participating in on-farm activities (Figure 41).

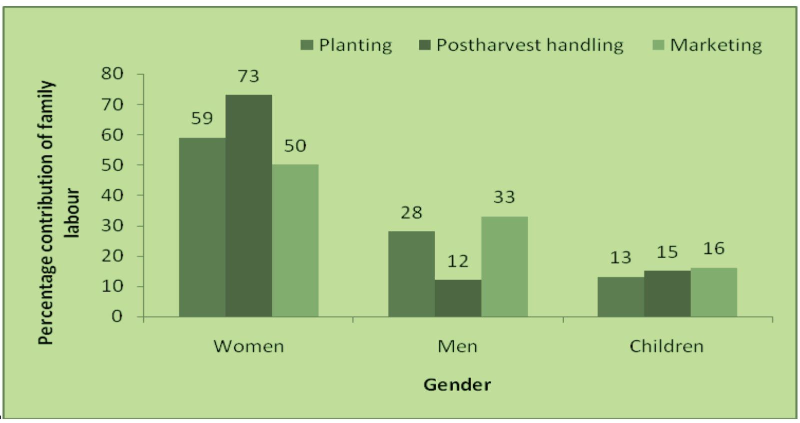


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Figure 41: Family labour contribution

Source: Gender and youth mapping, CRAFT project, 2019

(The above graph results are based on the 3 counties: Meru, Embu and Tharaka Nithi)

The growth of the sorghum beer industry offers a huge opportunity for the value chain actors especially women and the youth. The continuing expansion of EABL's capacity implies that there is demand for more sorghum and presents an excellent opportunity for farmers to continue in commercial sorghum production given ready market and the price assurance. Sorghum, therefore, plays a critical role in economic security for all actors especially women (Oar et al., 2018). The roles of both youth and women in the value chain move in tandem with available and accessible opportunities along the value chain. Sorghum value chain agribusiness could be the key to unlocking the potential of an inclusive sorghum industry in Kenya with opportunities for women and the youth.

5.3. A Gender-responsive approach to Climate-Smart Agriculture

The accepted procedure for addressing the gender gap in agriculture is adopting a gender-responsive approach. In practice, this means that the differentiated needs, priorities, and realities of men and women are recognized and adequately addressed in the design and application of climate-smart agriculture so that both men and women can equally benefit (World Bank, FAO and IFAD, 2015). The ultimate goal of a gender-responsive approach to climate-smart agriculture is to give women and men equal incentives and opportunities to invest in or adopt climate-smart practices.

The fundamental component of a gender-responsive approach is to carry out gender analyses, aimed at developing understanding of specific social and economic contexts and gender-related inequalities. As part of a gender analysis, an assessment is made of women's and men's control of assets such as land, water and other productive resources; income; of the labour involved and the time required until benefits are realized; and of access to information, credit and markets – as well as gender-related vulnerabilities to climate change. The results of such an analysis can reveal the underlying causes of gender inequalities, social and economic barriers and other challenges, including cultural facets that could offer insights that inform solutions. All this information is crucial to understand the factors that influence adoption of climate-smart agriculture.

During the gender analysis phase and the subsequent design of gender-responsive, climate-smart, and adaptive capacity-developing interventions, several approaches can be applied (Table 14). These could include:

- Context analysis to understand broad social and economic patterns and their role in gender relations
- Stakeholder analysis devised to identify the female and male stakeholders and their converging and diverging interests
- Gender-sensitive needs-assessment to understand the specific needs and priorities of men and women
- Livelihood analysis that looks at women's and men's access to resources.

Table 14. Summary of key points on conducting a gender analysis for climate-smart agriculture in the value chain

Gender analysis is the study of the different roles of women and men in order to understand what they do, what resources they have, and what their needs and priorities are. Although no blueprint exists for conducting a gender analysis, and several approaches can be adopted to carry it out, some initial general questions aimed at understanding gender relations in the context of climate change can include:

Climate vulnerabilities and coping strategies

1. Which hazards occur in the area and what is their frequency?
2. Who is most affected by each climate-related hazard? Where? When? Why?
3. Do men and women respond to a climate hazard in different ways? How? Why?
4. Do men and women share the same views on climate change patterns?

Gender roles and relations:

5. Who does what? How? Where? When? Why?
6. Who benefits from decisions over resources? How? Where? When? Why?
7. Who is included in planning at household, community and national scales? How? Where? When? Why?
8. How much time do women spend on a certain agricultural activity? How much time do men spend on each activity? Are climate changes affecting that?

Access to resources:

9. Who owns what? How? Where? When? Why?
10. Who learns and knows what? How? Where? When? Why?
11. Do weather and climate influence access to resources? How? Where? When? Why?
12. Does climate change influence access to resource?
13. How could households diversify their production and livelihood strategies?

In designing capacity development interventions for climate-smart agriculture, it is important to identify which approaches will address immediate needs of men and women and which approaches can promote a shift toward lasting equality between women and men. The more immediate needs are referred to as men and women's practical gender needs, such as employment and food for the family, and these can generally be addressed through extension services. On the other hand, strategic gender needs – equal access to resources, elimination of discrimination and adequate participation in decision-making mechanisms – require long term commitment and changes at different levels in the society. Meeting these strategic needs is fundamental to advancing toward gender equality. Possible actions to address practical and strategic gender needs can blend into each other as they determine the path for developing adaptive capacities.

The design and implementation of the climate smart agriculture practices must be gender--sensitive and socially inclusive sorghum production. In addition, the climate smart sorghum value chain approaches must accommodate the different knowledge levels, perspectives, needs, and challenges of diverse social categories among women, men and the youth.

Therefore, any climate smart agriculture adaptation interventions to climate change has to be gender responsive so that the needs of the women, men and the youth are considered. A deep analysis of the cause and effect of climate change is required in the development of suitable adaptation options to adequately address women's needs. In sorghum production process there is a need for gender mainstreaming in the adaptation interventions to make them more gender responsive. Gender disparities and inequalities exist in terms of economic opportunities, access to and control of land, financial capital, agricultural extension services, and new information. The critical role of each gender in agriculture and sorghum production needs to be clearly understood before designing and initiating any interventions for adaptation and mitigation to climate change.

Women and the youth, when supported with access to productive assets, and education and skills, they can be active agents of change and climate resilience. Women and the youth, when included in the management decisions improves community benefits. Women, youth and men have different responses to climate change. It is important to consider women's knowledge in the adoption of new technologies in the climate smart agriculture practices, sorghum management practices, and organizational procedures. Mitigation measures and policy recommendations are not accessible or useful to local communities and development experts. However, research studies have shown that the removal of barriers to access to finances, education and skills, climate information and technical advisory services and reduced workload leads to a higher adoption of the sorghum CSA practices for women and the youth. Consideration of the women's and the youth benefits will increase the probability of adoption of new CSA practices. Finally, gender-sensitive, socially inclusive efforts toward equal opportunities can help women and the youth to build resilience from their existing strengths, and to help them in making better farm management decisions.

5.4. Gender concerns and stakeholder engagement climate smart sorghum production

In Kenya, women, men and the youth and all other vulnerable groups have different roles which are less appreciated. In the world, about 40% of the labour in agriculture is provided by women, while in Kenya it approximately 80%. However, women, youth and all other vulnerable groups, suffer lots of barriers that create gender gaps and inequalities.

In the same scale, women farmers face challenges in adopting climate smart agriculture practices, including in access to credit, technology, knowledge and agricultural inputs. Climate change is highly likely to increase these inequalities. Climate-smart agriculture practices and policies will need to take these challenges into justification and develop solutions to address them. These will not only improved food security and increase incomes but also benefit women and reduce barriers to gender equality and social inclusion. Stakeholder engagement can help recognize gender gaps and social and economic inequities to be addressed.

There are three levels in addressing the gender concerns and stakeholder engagement in climate smart agriculture namely' a) policy at both national and county levels, b) community, and c) household/ intra-household

a) **Policy level:** In the development of the gender and socially inclusive climate smart agriculture policies, there is a need to address the particular needs of women, men and the youth of various backgrounds, endowments, and ages. All voices must be recognized in the policy and decision-making processes in agriculture. This is explained in the National Policy on Gender and Development (2000) that recognizes that it is the right of men, women, boys and girls to participate in and benefit from development and other initiatives.

b) **Community level:** Participatory engagements of different stakeholders in the community increases the commitment and adoption of the climate smart agriculture technologies. The development of gender-sensitive, socially inclusive community efforts provides better prospect for men, women and the youth to build resilience from their existing strengths and to experience the accrued benefits. However, there should be a recognition that the women, men and the youth are not homogenous in the climate smart agriculture initiatives. These initiatives include farmer field schools, technology demonstrations, peer learning among others to ensure men, women and the youth train and access climate information.

c) **Household levels:** Appropriate gender sensitive participatory tools are useful in identification of the different existing levels of knowledge, needs, and challenges with the households so as to inform the efforts towards the implementation of the climate smart in sorghum value chain.

The success of adoption of the CSA practices in sorghum production will depend on the level of inclusion of women, youth and vulnerable groups in the identification and upscaling of the CSA solutions, the development of gender responsive investment and financial instruments (Table 15 and Table 16). There is a need to support in a participatory and consultative manner, the women, youth and vulnerable groups in agricultural initiatives. In addition, for women, youth and vulnerable groups training, an increase access to productive assets and decision-making is required to take gender mainstreaming in CSA to a higher level. Finally, the development of the CSA practices and technologies should be those that reduce women's workload.

Table 15. Summary of key points on gender-differentiated impacts of climate in Kenya

Climate change affects men and women, boys and girls, in different ways. Therefore, it is important to see how interventions can be better designed to address the needs of different actors along the value chain and to overcome existing gender-based discrimination and associated inequalities. Women agricultural producers tend to be more exposed to climate risk compared with men, for many of the same reasons that farm productivity is, on average, lower for female than male farmers: women have less access to, and control over, productive resources and services – including climate information – with fewer employment opportunities, and they are generally less mobile for cultural and economic reasons (FAO, 2011).

Table 16. Summary of key points on the gender gaps in agriculture in Kenya

Gender productivity gaps exist in agriculture. Due to traditional gender-based discrimination, women have fewer privileges, entitlements and endowments. Women face more challenges than men in accessing, using and controlling productive resources and services, such as land, water, credit, inputs, technologies, information, knowledge, education, extension and other rural advisory services, markets and weather and climate information. This affects their vulnerability and adaptive capacity to climate threats. Gender-specific consequences in the context of climate-smart agriculture vary by the degree to which women can equally access resources such as land or livestock, services, employment, and business opportunities (World Bank, FAO and IFAD, 2015). It has been estimated that closing the gender gap in agriculture would reduce the number of hungry people by 100–150 million (FAO, 2011). However, climate change exacerbates the existing barriers that women face.

6 ENABLING POLICY ENVIRONMENT FOR ADOPTION OF CLIMATE-SMART AGRICULTURE APPROACHES

6.1. The Kenya Climate Smart Agriculture Strategy

Climate smart agriculture practices can address the possible impacts of the climate change. Resourceful and transformative approaches are required immediately to help all stakeholders in covering all value chains in the agriculture sector to mitigate against the current and projected effects of climate change. The government of Kenya through the Kenya Climate Smart Agriculture Strategy-2017-2026, provides enabling strategies that have goals and actions points that promote investment in climate smart agriculture. The Kenya Climate Smart Agriculture Strategy-2017-2026, indicates the political, environment, social, and technology, legal and economic factors that affect the implementation of the climate smart agriculture practices. An analysis of these factors will enable us develop of interventions that may be a limitation to climate smart agriculture approaches.

6.1.1 Objectives of the Kenya Climate Smart Agriculture Strategy

The broad objective of the Kenya Climate-Smart Agriculture Strategy (KCSAS) is to adapt to climate change, build resilience of agricultural systems while minimizing emissions for enhanced food and nutritional security and improved livelihoods. The specific objectives of the KCSAS are to (i) enhance adaptive capacity and resilience of farmers, pastoralists and fisher-folk to the adverse impacts of climate change; (ii) develop mechanisms that minimize greenhouse gas emissions from agricultural production systems; (iii) create an enabling regulatory and institutional framework; and (iv) address cross-cutting issues that adversely impact climate-smart agriculture.

The creation and implementation of appropriate policies and an enabling environment is essential for achieving the widespread adoption of climate-smart agriculture (CSA). The wide scale adoption of climate smart agriculture technologies depends on the creation and implementation of appropriate policies. The climate change policies, strategies, actions and plans are coordinated by the National Climate Change Secretariat under the Ministry of Environment and Natural Resources.

In addition, the government recognizes the threats posed by climate change and has taken action to address them through the Kenya National Adaptation Plan 2015-2030.

6.2 Kenya National Adaptation Plan

It is envisioned that the plan will result in reduced climate-induced loss and damage, mainstreamed disaster risk reduction approaches in various sectors, reduced costs of humanitarian aid, and improved knowledge and learning for adaptation and the future protection of the country. The adaptation plan encompasses agriculture and food security plans, development and poverty reduction strategies.

The national adaptation plan includes the policies and strategies of other actors, such as private sector actors and investors, regional and intergovernmental organizations for example *Climate Change for Agriculture and Food Security* (CCAFS), national and international civil society organizations, farmer organizations, and others.

6.2.1. Objectives of the Kenya National Adaptation Plan (2015-2030)

The objective of the plan is to highlight the importance of adaptation and resilience building actions in development; integrate climate change adaptation into national and county level development planning and budgeting processes; enhance the resilience of public and private sector investment in the national transformation, economic and social and pillars of Vision 2030 to climate shocks; enhance synergies between adaptation and mitigation actions in order to attain a low carbon climate resilient economy; and enhance resilience of vulnerable populations to climate shocks through adaptation and disaster risk reduction strategies.

The plan serves as a policy engagement guide and remove components that act as disincentives for adopting climate smart agriculture practices, such as public subsidies, while reallocating resources to programmes that provide incentives for the adoption. Policy tools and instruments, such as rural credit programmes, input and output pricing policies, subsidies, support for investment with public-good benefits, property rights, research and extension services, and safety net programs, can all be used to increase the incentives for farmers to modify production systems and build capacities for climate smart agriculture. The Kenya National Adaptation Plan 2015-2030 encompasses a deeper understanding of the power structure and policy decision-making process on climate change at the national and county levels. Great knowledge on policy formulation is required by policy makers at both national and county governments, particular information is tailored to help in decision-making processes and to ensure a great link between science and policy levels.

6.3 Challenges in policy development and creation of enabling environment in sorghum value chain

However, there are some challenges in supporting the development of policy and enabling environments. These include;

- **a)** Ensuring ownership by those responsible for formulation and implementing policies and strategies, and those who are likely to be affected by the policy,
- **b)** Creation of an inter and intra-sectoral approaches and policies that can create integration and coordination among actors,
- **c)** Ensuring effective implementation of plans and strategies at both national and county governments,

d) Finally, it is unfortunate that most policy processes are complex and require high level of commitment.

e) Inadequate funding in policy development, implementation and enforcement

Participatory assessments, multi-stakeholder scenarios and use of simulation models, multi-criteria analysis, participatory power mapping, companion modelling and participatory game design, methods to calculate participatory social returns on investment are some of the tools that can be used in guiding the policy formulation. These can enable development of climate smart agriculture policies for the sorghum value chain that are compatible with the local needs.

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ANNEXES & APPENDIX

Annex 1: Definition of Terminologies

Term	Explanation/Meaning
Adaptation	Adaptation refers to responses by individuals, groups and governments to actual or expected changes in climatic conditions or their effects.
Adaptive capacity	Adaptive capacity is the ability or potential of a system to respond successfully to climate variability and change, and includes adjustments in both behavior and in resources and technologies.
Agroforestry	Agroforestry is the practice of integration of trees, plants, and animals in conservative, long-term, productive systems.
Cashbook	It records cash in and cash out on daily basis and it serves as source of information for other types of records.
Climate	Climate is statistical information, a synthesis of weather variation focusing on a specific area for a specified interval. Climate is usually based on the weather in one locality averaged for at least 30 years.
Climate change	Climate change is a large-scale, long-term shift in the planet's weather patterns or average temperatures.
Climate variability	Climate variability refers to variations in the mean state and other climate statistics (standard deviations, the occurrence of extremes, etc.) on all temporal and spatial scales beyond those of individual weather events.
Climate-Smart Agriculture	Agriculture that sustainably increases productivity and resilience (adaptation), reduces/removes GHGs (mitigation), and enhances achievements of national food security and development goals.
Compost	Compost is simply controlled decomposition of organic matter (mainly animal manure and plants materials) which can be incorporated easily into the soil.
Conservation Agriculture	Conservation Agriculture (CA) is an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment.
Deforestation	Is clearing of trees in large scale
Drought	A temporary reduction in moisture availability significantly below the normal for a specified period
Dry Spell	A period of dryness that have no or little effect on soil moisture or water levels.
Farm Inventory	It records the various assets held by the farm and their conditions. This helps to identify items that need replacement
Food Security	Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.

Term	Explanation/Meaning
Gender	Gender refers to the difference in socially, culturally and politically constructed roles and opportunities associated with being a woman, man or a youth, and the interactions and social relations between the different categories.
Labour/Payroll records	It takes care of the various transactions related to labour on the farm including number of labourers, payment for work done as well as pending labour costs among other things as may be relevant to the farm.
Input records	Input records give details of the type and quantity of different input obtained and/or utilized in the farm over a given period.
Marketing	The management of processes through which a product / service, sorghum, is produced and finally delivered to the ultimate buyers.
Mulching	Mulching is the spreading of any organic material to cover the soil surface to conserve soil moisture, and to protect soils from fertility loss and erosion.
Production records	This record measures the productivity of the land, and the success of farming operations generally. It shows how much crop has been harvested or the anticipated level of harvest.
Sales/ Consumption Records	This records the quantity sold and/or consumed by the farmer and his family, or given out to friends and relatives.
Soil erosion	Soil erosion, involves movement of top soil by either wind, water, animal or human activities. It involves 3 distinct activities – detachment of the soil, movement and deposition.
Soil fertility	Soil fertility is the capacity of soil to accumulate, store and transfer nutrients to sustain plant growth. Soil fertility is the component of the general soil productivity, which encompasses its available nutrients and its ability to release nutrients from its reserve and those applied externally for crop production.
Tied ridges	Tied ridges are a series of cross-ridges that block or interrupt the furrows thus preventing flow of water along the furrows, hence allowing trapped water in the rectangular basins to infiltrate into the soil.
Weather	Weather describes the conditions about what is happening outdoors at a specific time over a specific area. It includes the following parameters namely; wind, barometric pressure, precipitation (rain or snow) or temperature.
Zai pits	Zai pits are shallow, wide pits that are dug to collect and retain runoff to allow infiltration into the soil.

Annex 2. East African Standard for Sorghum Grains –Specification

Characteristic		Specification			Method of test
		Grade 1	Grade 2	Grade 3	
Description		Grain sorghum of red, white or yellow varieties only			
Moisture, max (%)		13	13	13	ISO 711/712
Test Weight Min (kg/hl)		71	62	62	ISO 605
Total Admixture Max (% by wt) (Total of foreign material, screenings and trash)		11.0	30.0	50.0	
Foreign Material Max (% by wt)		2.0	3.0	4.0	
Foreign matter, decorticated seed (% by wt)		0.5	0.5	0.5	
Screenings Max (% by wt)(All matter passing through a 2.0 mm slotted screen – 40 shakes in the direction of the slots using an agitator)		11.0	25.0	50.0	
Trash Max (% by wt) (Chaff and other sorghum Trash retained above a 2.0 mm slotted screen following the Screenings process)		5.0	15.0	15.0	
Crude protein, % by dry mass basis, min		7.0	7.0	7.0	EAS 82
EAS 82 Ergot affected grains %m/m		0.05			
Tannin content, % on dry mass basis, max.	Whole grains	0.5	0.5	0.5	ISO 9648 Decorticated grains
	Decor-ticated grains	0.3	0.3	0.3	

Characteristic		Specification			Method of test
Defective grains, max (% by count, 300 grain Sample	Weather stained	5.0	20.0	20.0	ISO 605
	Field fungi	5.0	10.0	10.0	
	Dry green	5.0	10.0	10.0	
	Immature grain (Fully green in colour)	5.0	10.0	10.0	
	Split/Bro-ken	7.0	10.0	10.0	ISO 605
	Total de-fective	5.0	8.0	10.0	
Small Foreign Seeds (% by weight)		1.6	1.6	1.6	
Total Aflatoxin (AFB1+AFB2+AFG1 +AFG2)), ppb max 10		10			ISO 16050
Aflatoxin B1 only, ppb max		5			
Fumonisin ppm max		2			

Appendix 1. Avoidable costs as related to the decisions' time span.

Decision cost item	To be a sorghum farmer or not	To begin growing sorghum	To keep the plot for another year
Land rent	X		
Establishment	X	X	
Weeding	X	X	X
Harvesting	X	X	X
Transport	X	X	X

x = specifies variable (avoidable) cost

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