Climate Resilient Potato Production Handbook

A guide for farmers and trainers

NATIONAL POTATO COUNCIL OF KENYA

CRAFT
Climate resilient value chains for improved livelihoods

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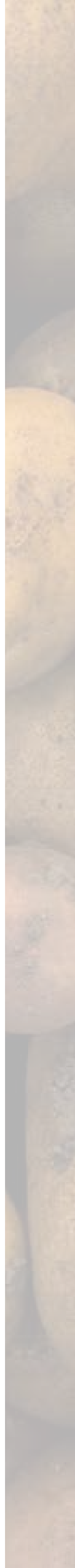

The National Potato Council of Kenya (NPCK) is a Public Private Partnership (PPP) and a multi-stakeholder organization whose responsibility is to help plan, organize and co-ordinate value chain activities of the potato subsector and develop it into a robust, competitive, and self-regulating industry in Kenya. Its membership include farmers, researchers, public institutions, extension providers, seed producers, traders, processors, regulatory agencies, financial services providers, input providers, Ministry of Agriculture for National and County Governments, Development partners, other value chain actors and players

Disclaimer

The first version of this publication was produced by the NPCK in collaboration with its partners and stakeholders who are acknowledged in this report. This handbook is the updated version of the Potato Production Hand book with climate resilient agriculture practices. The updated version was done with the help of the Climate Resilient Agribusiness for Tomorrow (CRAFT) project that is implemented in partnership with SNV, Wageningen University & Research (WUR), the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Agriterra, Rabo and Netherlands Ministry of Foreign Affairs. The contents of this publication are the sole responsibility of the NPCK and the technical review team.

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FOREWORD

Agriculture directly contributes 25% and indirectly 27% to Gross Domestic Product (GDP). The sector also contributes 65% of export earnings in Kenya. The government of Kenya has outlined the importance of agriculture to the national economy, through the Kenya Vision 2030, the Big Four Agenda, the National Adaptation Plan (2015-2030) and the Kenya Climate Smart Agriculture Strategy 2017-2026 among other policy documents. Potato (Solanum tuberosum L) is an important food and cash crop in Kenya. It is produced by over 1 million farmers and cultivated on an acreage of 161,000ha. In addition, potatoes are grown in almost half of the 47 counties in Kenya. Potato as food is highly versatile because it can be cooked at home and be processed. Potato processed products like crisps and chevdas are favorite snacks among the middle income population and the youth who are the majority population. Potato has been identified as one of the key crops that has the potential to enhance food security and drive economic growth in Kenya. Its increased production will contribute towards achieving food and nutrition security and employment creation especially among women and youth. With urban and population growth, consumption patterns, tastes and preferences will change tremendously. For instance, consumption of chips, crisps and other value-added products of potato have evolved in the markets. Despite the evolution in the markets, production does not match demand. Currently, potato productivity levels are very low, averaging below 10 tons per ha against a potential of 40 tons/ha obtained under research. Factors such as low technical farmer capacity, increased climate variability, inadequate use of certified seeds, pests and diseases, inadequate storage facilities and market challenges affect potato value chain. If climate resilient potato production practices are adopted by farmers maximum yields of 40 tons per ha can be achieved and the industry could become a more competitive sector.

Potato production is dependent on two very important elements of weather; rainfall and temperature. Climate change is characterized by changes in these two important elements of weather like rising temperature, varied variability in rainfall patterns, increased frequency of extreme weather events such as droughts and floods as well as outbreak of pests and diseases. These changes in climate and their impacts already are negatively affecting potato value chain development. Such effects include crop damages, crop failure, reduced yields, poor tuber quality, increased land degradation and post-harvest losses. Stakeholders should work with potato farmers and organizations to increase their awareness on climate change, support farmers to implement activities that will help them either adapt, cope, resist, mitigate or become more resilient to climate change shocks.

Sustainable potato value chain can both be affected and contribute to climate change. Potato production involves land preparation, use of inorganic fertilizers and pesticides, generating wastes or crop residues, post-harvest losses, transportation which significantly generate greenhouse gases (GHGs). There exist Climate Resilient Agriculture (CRA) practices that can be locally adopted by farmers and actors in the potato value chain to increase productivity at the same time creating resilience, adaptation and mitigation to climate change. The CRA practices such as intercropping, conservation agriculture, integrated pest and disease management (IPDM), sustainable mechanization and agroforestry can be adopted in the value chain to make potato production sustainable.

The Climate Resilient Potato Production (CRPP) Handbook is an update of the Potato Production Handbook 2019 that was developed by NPCK and stakeholders. The handbook was developed with the background of six other training potato production manuals developed by KEPHIS, KALRO, FAO and CIP. The knowledge existing in these training materials were consolidated and existing gaps were identified. The CRPP handbook incorporates CRA practices and approaches with a gender equality and youth empowerment lens. It is a tool that will help achieve one of the strategic objectives of increasing sustainable potato production in Kenya.. The handbook will be a reference for the trainers in the industry and a guide in preparing training materials for farmers, Trainer of Trainers (ToTs), the youth and women. It is important after training the trainees will gain new knowledge, change their attitudes and behavior towards a more sustainable potato value chain in the wake of climate change.

Wachira Kaguongo
Chief Executive Officer
National Potato Council of Kenya

ABOUT THIS HANDBOOK

The Climate Resilient Potato Handbook aims to provide guidance on CRA technologies and practices for Kenyan farmers, trainers and agri-entrepreneurs who wish to engage in production of potatoes.

This handbook is presented in four chapters: the introduction that covers history of potato production in Kenya and potato production and market trends, climate change and impacts on potato production, climate resilient agriculture and climate resilient potato production. Each of the topics covered can be designed in the form of modules, with topics and sessions covering production to marketing of potato depending on the stage of the crop growth and the needs of the trainees. Every chapter has demonstrated climate change/climate resilient lens in potato production. During training, the trainer introduces a topic and shows how climate change impacts on potato production, select suitable CRA practice, define the practice, describe how is done, its costs (inputs, labour etc) and its benefits (productivity, adaptation and mitigation), how it can be monitored, and with a women and youth lens- how they participate and benefit.

A separate handbook on seed potato production has also been produced targeting agri-entrepreneurs with interest to engage in seed multiplication and distribution.

ACKNOWLEDGEMENT

The NPCK appreciates GIZ - Nutrition Sensitive Potato Partnership Project (NuSePPP) for the financial support in the development and publication of the initial Potato Production Handbook 2019. The committee of experts was drawn from NPCK, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Kenya Agriculture and Livestock Research Organization (KALRO-Tigoni), International Potato Center (CIP), Ministry of Agriculture Livestock Fisheries and Irrigation (MoALF&I), Agriculture Food Authority (AFA), Kenya Plant Health Inspectorate Services (KEPHIS), Pest Control Product Board (PCPB), SNV-Netherlands development organization, International Fertilizer Development Centre (IFDC) and potato producing Counties represented by Kiambu and Nakuru County agricultural departments. Special gratitude goes to the technical team which included: Charity Maina (NPCK), Judith Oyoo (KALRO-Tigoni), Meshach Rono (GIZ), Mary Mendi (Department of Agriculture-Kiambu), Charles Mwangi (KEPHIS), Judith Chabari (IFDC), John Burke (Teagasc), Seamus Crosse (Teagasc), and Antony Njogu (consultant) for their hard work and dedication in developing the Potato Production Handbook 2019 Other contributors were: Jackson Muchoki (GIZ), James Mugo (CIP), Peter Kariuki (NPCK), Gillian Kadenyi (SNV), Florence Wambeti (PCPB), Elizabeth Langat (AFA), Alex Kang'eri (MoALF & I), Hannah Odour (Department of Agriculture-Nakuru) and Duncan Maina (Toyota Tsusho).

With the support of the CRAFT project, the Potato Production handbook has been enriched with information on climate change and its impact on potato production and mitigation measures which are climate resilient potato production practices thus the name 'Climate Resilient Potato Production Handbook'. In addition, the book has included climate resilient potato production practices considering gender categories.

Special gratitude goes to Joseph Muhwanga, Oscar Nzoka, Joyce Mbingo, Joab Osumba, John Recha, Teferi Demissie, Annemarie Groot and Confidence Duku from The SNV CRAFT project team and Wachira Kaguongo and Charity Maina from NPCK for reviewing the handbook with a climate change lens. Many thanks goes to the professional technical consultant Judith Oyoo (KALRO-Tigoni), for her dedication in editing this handbook. We also wish to thank all the other individuals who shared their valuable inputs in preparation of this Handbook.

EXECUTIVE SUMMARY

Climate resilient potato production handbook was co-developed by National Potato Council of Kenya (NPCK) stakeholders and experts to increase knowledge of climate change adaptation and mitigation in potato value chain. The manual aims to be used by stakeholders for Training of Trainers (ToTs), farmers, women and youth participating in potato value chains. This handbook demonstrates how carbon footprint[1]can be reduced in potato value chain. The handbook has four chapters which are Introduction, Climate Change and Impacts on Potato Production, Climate Resilient Agriculture and Climate Resilient Potato Production.

Introduction chapter describes the potato crop, consumption and uses, stakeholders, commercialization and requirements in terms of ecology, nutrients and marketing, pests and disease control, harvesting and post-harvest management practices (processing and value addition). Chapter two describes the possible impacts of climate change. The major effects of climate change that affect potato production significantly include extreme hazards such as storms, floods, droughts, extreme heat, frost and pests and diseases. In Kenya, since 1961 to 2005 the temperature has being increasing by 1^0C to 1.2^0C. Rainfall variability has increased during potato cropping seasons for past six decades such that it is either too high or too low during growing seasons. The temperature and rainfall variability during growing seasons has adverse impacts on potato production with many farmers experiencing crop failure or damages, reduced yields, poor quality and decay of tubers, seed degeneration, increased costs of production and post-harvest losses.

Chapter three describes what climate resilient agriculture (CRA) is, its components, its aims and risk reduction concepts.

Chapter four describes CRA practices in potato production. The climate resilient agriculture (CRA) practices, technologies and approaches are described under crop management practices, soil fertility management, sustainable land preparation, soil and water conservation, tillage and residue management, agroforestry, renewable energy, integrated pest and disease management (IPDM) and post-harvest management.

1 The amount of greenhouse gases—primarily carbon dioxide—released into the atmosphere by a human activity e.g. burning of diesel

ACRONYMS

ASL	Above Sea Level
ASDS	Agriculture Sector Development Strategy
CA	Conservation Agriculture
CAN	Calcium Ammonium Nitrate
CCAFS	Climate Change Agriculture and Food Security
CRAFT	Climate Resilient Agribusiness for Tomorrow
CRA	Climate Resilient Agriculture
CIP	Center International Potato
CM	Centimeter
DLS	Diffused Light Store
DV	Daily Value
FAO	Food Agriculture Organization
FYM	Farmyard Manure
GAP	Good Agricultural Practices
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft Fur Internationale Zusammenarbeit
GMP	Good Manufacturing Practices
GM	Gross Margin
GoK	Government of Kenya
HA	Hectare
ICT	Information Communication Technology
IPCC	Intergovernmental Panel on Climate Change
IPDM	Integrated Pest and Disease Management
KALRO	Kenya Agricultural and Livestock Research Organization
KEFRI	Kenya Forestry Research Institute
KEPHIS	Kenya Plant Health Inspectorate Services
KM	Kilometer
KMS	Kenya Meteorological Services
KGS	Kilograms
LGS	Length of Growing Season
MAM	March-April-May
MAP	Monoammonium Phosphates
MD	Man Days
NPCK	National Potato Council of Kenya
OND	October-November-December
PCN	Potato Cyst Nematode
PTM	Potato Tuber Moth
PVA	Potato Virus A
PVS	Potato Virus S
PVX	Potato Virus X
PVY	Potato Virus Y
RKN	Root Knot Nematodes
SOC	Soil Organic Carbon
SG	Specific Gravity
SMS	Short Message Service
SSP	Single Superphosphate
Ton	Tonnes
ToT	Trainer of Trainees
TSP	Triple Superphosphate

1 INTRODUCTION

1.1 Potato production in Kenya

According to the FAO, (2020), Agriculture directly contributes 26% to GDP and indirectly 27% to Gross Domestic Product (GDP). The sector also contributes 65% of export earnings in Kenya (GoK, 2016). The national economic instruments and policies such as Kenya Vision 2030, Big Four Agenda and the Agricultural Sector Development Strategy (ASDS) 2009-2020 aims reducing hunger, famine and starvation (Gok, 2018a). However, the current climate change projections for Kenya shows not only seasonal shifts but also increasing temperatures and more frequent climate shocks (droughts and floods). This, coupled with the expected exponential increase in human population estimated to increase to 95 million by 2050, poses a serious threat to Kenya's future development and attainment of Kenya Vision 2030 and the government's Big Four agenda especially on food security, increased manufacturing and affordable healthcare. This handbook describes how potatoes can be produced sustainably under the changing climate conditions.

Potatoes (*Solanum tuberosum L)* were first grown in Kenya in the 1880's. The crop is in the fourth place of staple foods after wheat, maize and rice and is cultivated in 75 % of countries of the World. Its versatility in utilization makes it the second most important food crop in Kenya after maize. The crop takes 120 to 150 days to mature making it possible to grow twice in a year with areas of bimodal or two rainfall seasons (long-term and short-term). The importance of potato is attributed to its high nutritive value, high productivity and good processing qualities for starch, flour, bread, soap, alcohol, baby foods and animal feed. Potatoes present an important food source with several industrial and processing uses, which depend on the market needs. There are many varieties with singular or multiple uses, whose information is available in the Potato Variety Catalogue, 2019 (https://npck.org/catalogue/.) in addition to existing networks and platforms.

Figure 1 illustrates the morphology of the potato plant which consist the tubers, stem, buds, leaves and flowers. Table 1 describes the functions of various parts of the potato plant.

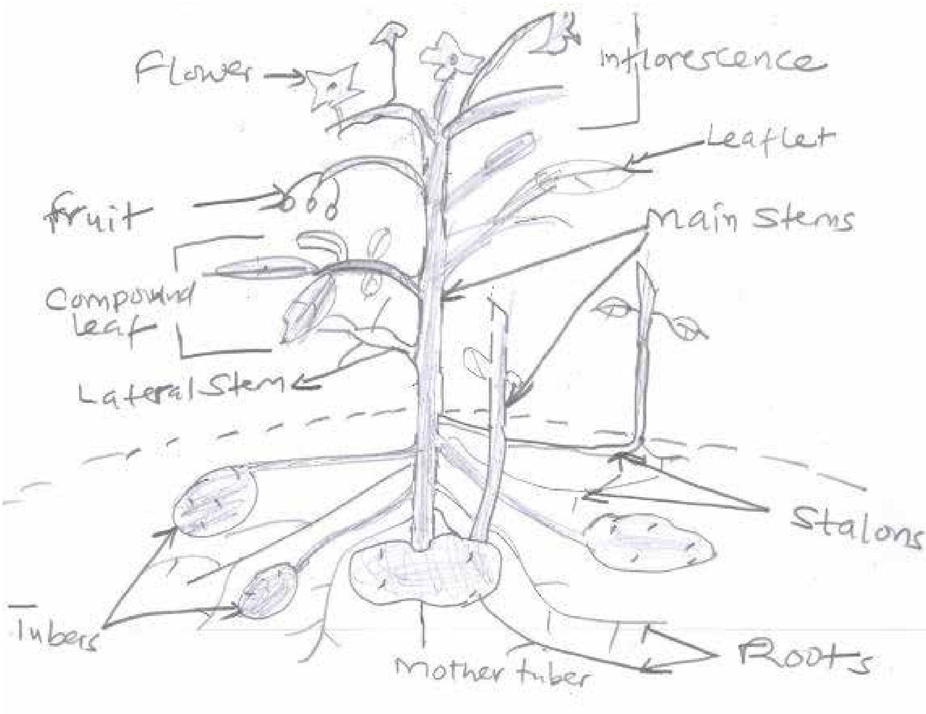


Figure 1. Illustration of the morphology of a potato plant

Table 1: Descriptions of parts the potato plant

No	Part	Description
1	Stem	Consists stem, runners and mother tuber; grows as a single stem for a while then divides into branches; stems will divide into 3 categories based on the height of the plant (short < 45 cm, moderate 45 – 60 cm and tall > 60 cm).
2	Bud	Has two parts; growth of buds is affected by storage conditions; they develop into runners and tubers
3	Leaf	Compound leaves; has midrib and leaflets and leaves help to identify the varieties
4	Flower	Is divided into two; corolla is made up of white and purple petals
5	Tuber	It is expanded runner; has eyes same as a general stem; one or more buds maybe on one eye; it is a planting material and store food

Note: *It is important to know the parts of the plant to determine the performance of the crop or health, pests and disease attacks, nutrient deficiency and stages of development of the crop.*

In Kenya, it is estimated that 1.5 million tons of potatoes are produced annually on about 161,000 hectares of land by more than a million farmers (Kaguongo et al., 2014; KNBS, 2019). This is worth between Ksh 40-50 billion each year and compares well with annual maize production of 40 million bags worth Ksh 120 billion (Potato Strategy 2016 - 2020). The potato industry directly and indirectly employs about 3.3 million actors, as producers, market agents, transporters, processors, vendors, retailers and exporters. Potato has high productivity and yield per unit area. The potential average yield per hectare per season is estimated to be 40 tons under recommended good agronomic practices. In the current decade, the yields of potato have been declining; generally very low with an average yield of 10 tons per hectare. Conventional potato production system faces challenges such as degraded soils, inadequate access to high quality seed, inputs, climate change (extreme weather events like droughts, flooding etc), pests and diseases, inadequate harvesting and storage facilities as well as lack of technical capacities among farmers and stakeholders. In addition, gender inequalities also contribute significantly to low yields since studies have shown that equal access to production resources and inputs can increase productivity by up to 30% (FA0, 2013).

1.1.1 Consumption and uses of potato

Irish potato is one of the most consumed food crops in Kenya due to its availability, wide range product diversification and presentation in fast food outlets. Irish potato capita consumption is estimated at 33 kg per person and this is projected to rise due to its ability to provide nutritious food to the growing urban population (FAOSTAT, 2014). Potato is extremely versatile and can be served boiled, stewed, roasted, baked, and shallow-fried or deep-fried in fresh forms. Change of eating habits especially in the urban centers has led to increased consumption of processed products such as chips (French fries) and roasted potato. It is estimated that there are over 40 local processors of crisps in Kenya. There are many potato varieties, and each has its own qualities and uses (Annex 2). Varieties with high dry matter content and low levels of the reducing sugars, glucose and fructose, are preferred for processing into chips and crisps. Tubers having these attributes produce 'bright' fry colors, which consumers prefer. Table 2 summarizes the food and industrial products of potatoes.

Table 2: Products of potato

Uses	Products
Food products	Mashed, pancakes, cakes, biscuits, dumplings, baked, soups, sauces, stews, salads, crisps, chips, flakes, flour, alcohol, Baby food
Non-food products	**Starch** used as glue, binder, texture agent, and filler in pharmaceutical, textile, wood, and paper **Animal feed**: feed your cow 20 kg per day and pig 6 kg per day of tubers. Add chopped tubers to the silage **Fuel**: Briquettes and ethanol

1.1.2 Nutritional value

The potato tuber is best known for its carbohydrate content (approximately 26 grams in a medium potato). It also contains vitamins and minerals, as well as an assortment of phytochemicals, such as carotenoids and polyphenols. If one takes a medium-size 150 grams potato tuber with its skin, they shall consume 27 milligrams(mg) of vitamin C (45% of the Daily Value (DV)), 620mg of potassium (18% of DV), 0.2 mg vitamin B6 (10% of DV) and trace amounts of thiamin, riboflavin, foliate, niacin, magnesium, phosphorus, iron, and zinc (Figure 2). A detailed nutritional value chart is presented in Annex 1.

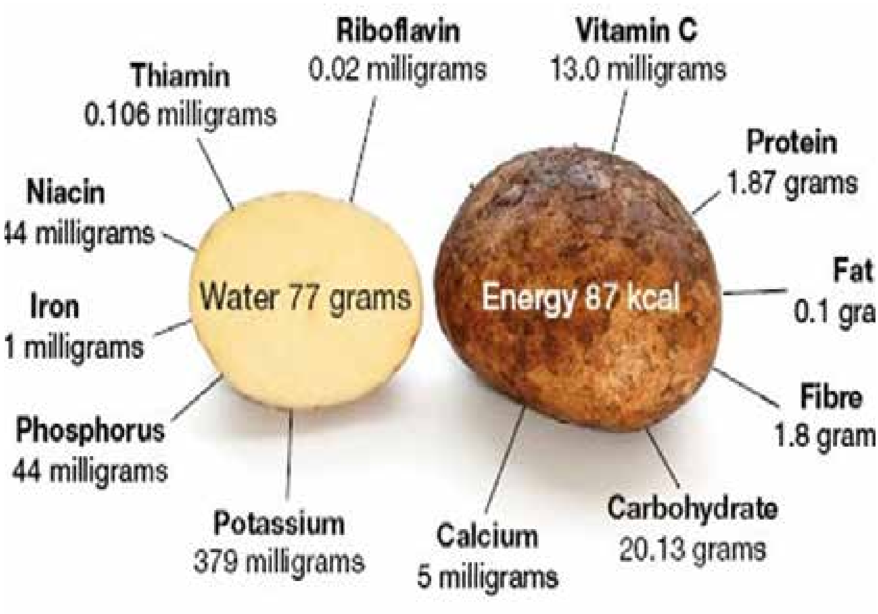


Figure 2: Nutritional value of potato production tuber pith and skin

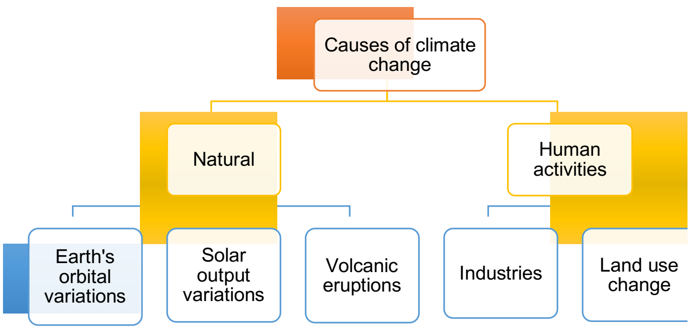
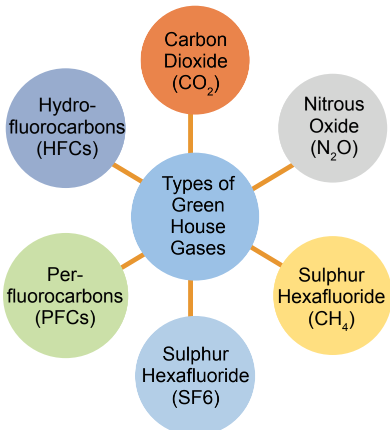
The fiber content of a potato with skin is equivalent to that of whole grain bread, pasta, and cereals. Just under the potato skin is a thin layer of high-grade protein, with a biological value close to that of whey or egg protein. The best ways to take advantage of the nutrition from the skin and the underlying high-grade protein layer is to consume them whole or boil them and very carefully peel the skin and consume everything else. This explains the reason why potatoes taken with skin are more beneficial than potatoes peeled before cooking.

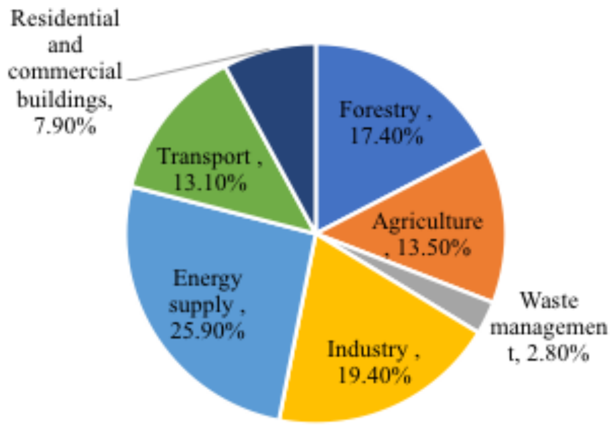
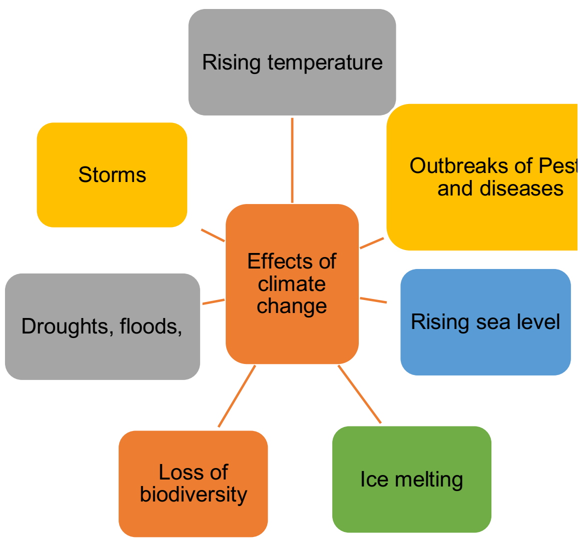
2 CLIMATE CHANGE AND IMPACTS ON POTATO PRODUCTION

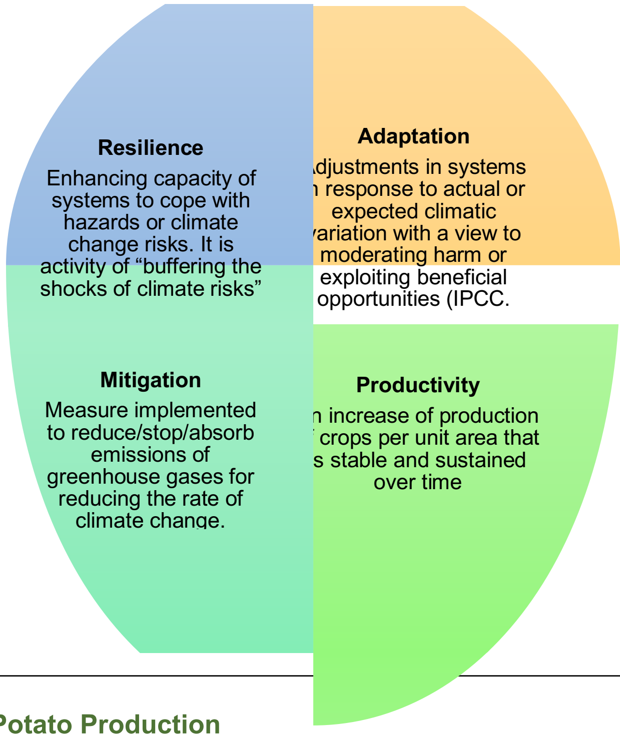
2.1 Overview of climate change concepts

The major concepts of climate change include definitions and explanation of climate change, causes of climate change, greenhouse gases and their sources, greenhouse effect, effects of climate change, productivity, adaptation, resilience and mitigation. Table 3 summarizes these concepts in graphics.

Table 3: Summary of climate change, impacts and mitigation concepts

Topic	**Descriptions**
What is climate change?	Climate change is the long-term or permanent shift either upwards or downwards of average climatic condition i.e. temperature, rainfall, wind, humidity (IPCC, 2007)
Causes of climate change	
Greenhouse Gases (GHGs)	Gases that absorb heat and warm the atmosphere. 

Topic	Descriptions
What is greenhouse gas effect?	
Major sources by sector of greenhouse gases	
Climate change effects	

<table>
<tr><th>Topic</th><th>Descriptions</th></tr>
<tr><td>What are the solutions to climate change?</td><td>


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Climate change effect on Potato Production

Potato production depends on rainfall and temperature. The variability of these key parameters due climate change will affect conditions necessary to cultivate potato. Effects like extreme weather events such as high rainfall, extreme temperatures, high humidity, flooding and droughts will increase risks in potato growing areas. High rainfall intensities might increase land degradation through landslides, mud flows, soil erosion, high incidences of diseases such as tuber rots and fungal diseases as well as destruction of suitable productive lands, hence the risk of decreasing acreage of land under potato production. Drought will accelerate soil moisture loss, enhance land degradation through destruction of soil structure, reduction in soil fertility through high rate of soil organic matter decomposition (low soil organic carbon) and erosion by wind, acidity and alkalinity as well as more pests leading to crop failure and low and /or productivity.

Extreme temperatures and especially high temperatures may trigger emerging pests, mutation of pests and reduced life cycles. Also, crop growth will be shortened such that crops mature earlier than usual, which may look good but quality of tubers may be compromised in terms of biomass partitioning and accumulation. The effect of this might be need for intensive use of pesticides to protect potato crop from destruction and pesticide resistance by pests and so further use of pesticides. Elevated use of pesticides may compromise the quality of potato tubers harvested therefore directly impacting on food safety and also food security. In addition, high temperatures will pose a challenge in potato storage such that postharvest losses may go up due to high rate of tubers deteriorating in quality. On the flip side, dormancy period may be shortened especially in varieties that normally have long dormancy periods such as Unica. Changing weather conditions will affect the potato marketing system directly and indirectly. Low rainfall or failed rainfall season will lead to low yields or 100% crop loss therefore affecting the market prices. Market prices are dependent on supply and demand forces. Usually when there is an oversupply of potatoes in the market or 'glut', the prices are very low and when supply is low, market prices are very high. Extended rainfall periods and high intensity rains disrupt the supply of potatoes to the market due to damage to roads and infrastructure and physical assets. For instance, daily rainfall of at least 45 mm for three days accelerates road damage which leads to market inaccessibility and therefore high postharvest losses and loss of household incomes (GoK, 2018a). High temperatures or heat waves will lead to spoilage and deterioration of quality of produce especially where farmers do not have cold storage facilities. Where cold storage facilities are available, high energy costs may make storage not to be attractive and high energy use may accelerate GHG emissions. Adopting resilient practices is critical to reducing risks and vulnerability in potato production.

Currently, farmers use conventional potato production management practices such as use of inorganic fertilizers and inorganic pesticides to improve soil fertility and control pests and diseases to produce potatoes. In addition, mechanization is being promoted for efficiency in production and so, some farmers use tractors for farm and post-harvest management practices. These operations generate a significant amount of land-use greenhouse gases (GHGs) especially carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4), making agriculture one of the highest emitters of GHGs (GoK, 2018a). Like any other agriculture production system, potato production faces three major intertwined challenges (low productivity, climate vulnerability and GHGs generations) that require a 'triple win' approach (GoK, 2018b). The triple win approach in this handbook includes sustainable productivity, adaptation to climate change and mitigation and/or removal of GHGs emissions as to be delivered through Climate Resilient Agriculture (CRA)

Table 4 illustrates possible impacts of temperature and rainfall variability on crops and how plant respond or adapt naturally. Extreme high and cold temperatures as well as extreme rainfall or soil moisture variability will lead to low yields. Use of natural adaptations, modifications or good practices can be adopted to create resilience for the potatoes to respond positively under extreme weather events.

2.2 Climate change, risks and impacts in potato value chain

Climate change has significantly impacted agriculture and is expected to further impact directly and indirectly food production and livelihood in Kenya. The 2007 IPCC report showed a clear evidence of increase of mean temperature, increased variability in rainfall amount and distribution, changes in water availability, increase in frequency and intensity of extreme events, sea level rise and salinization, perturbations in ecosystems, which all will have profound impacts on agriculture, forestry and fisheries in the region. This, coupled with the expected exponential increase in human population (estimated to be 95 million by 2050), poses a serious threat to Kenya's future development and attainment of Kenya Vision 2030. It will also impact on the Government's Big Four agenda especially on food security, increased manufacturing and affordable healthcare. Hence, robust climate projection using high-resolution regional climate models, is highly required in East Africa (e.g. Kenya), which has a very complex topography and high spatial rainfall variability due to different rainfall regimes.

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

Table 4: Summary of climate hazards, risks, plant responses and impacts

Climate hazard	Risk	Plant Positive response	Impact on potato
Heat stress	High transpiration of plants raising demand for water High evaporation leading to water deficit Reduced tuber initiation, growth and quality (dry matter content) Disease and pest outbreak frequency and population	Efficient protein repair systems and general protein support survival Acclimation/adaptation of potato plant to heat through reduce growth vigour	Reduced tuberization Reduced yields Poor quality of tubers Crop failure Increased incidences of pest infestation High cost of production High pesticide residues due to high frequency of pesticide application
Cold/ chilling stress	Slow rates of growth (low rate of photosynthesis due to slow water and nutrient uptake) Damaged and irreparable cells membranes	Plant stops growth due to changes in metabolism	Crop failure Low yields
Drought or prolonged dry spell	Heat stress and water stress Increased frequency of dry spells and droughts Late onset of rainfall Early cessation of rainfall Increase in incidences of attacks by insects pets and diseases Reduced periods of crop growth	Leaf rolling and other morphological adaptations reducing surface area for photosynthesis Stomatal closure to reduce transpiration Due to stomatal closures, reduced photosynthesis hence low biomass accumulation	Crop failure and death Low yields Poor quality tubers
Increased rainfall or floods	Water logging/flooding Outbreak of pests and diseases Increase in fungal infections favoured by high humidity when it is raining	Plants increase water uptake and evapotranspiration	Crops are washed away loss of crops not tolerant to water logging Nutrient leaching Reduced yields and low quality Tuber decay

climate projection work was based on two validated regional climate model data that are dynamically downscaled from four Global Circulation Models (GCMs), which has 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, which are representatives of mid-and high-level of emission scenarios, respectively. The following section 2.2.1 summarizes the climate projection work done under the CRAFT project for the potato growing areas of Kenya:

2.2.1 Climate change projection scenarios

Temperature trend in the potato growing areas

The temperature trend analysis (from 1961-2005) for both the first (March, April, May – [MAM]) and second (October, November, December – [OND]) rainy season show that temperature have been increasing by about 1°C – 1.2°C degree in most parts of the potato growing areas of Kenya (Figure 3). The rate of warming is slightly higher in the second season (OND) as compared to the first season (MAM) by about 0.2°C.

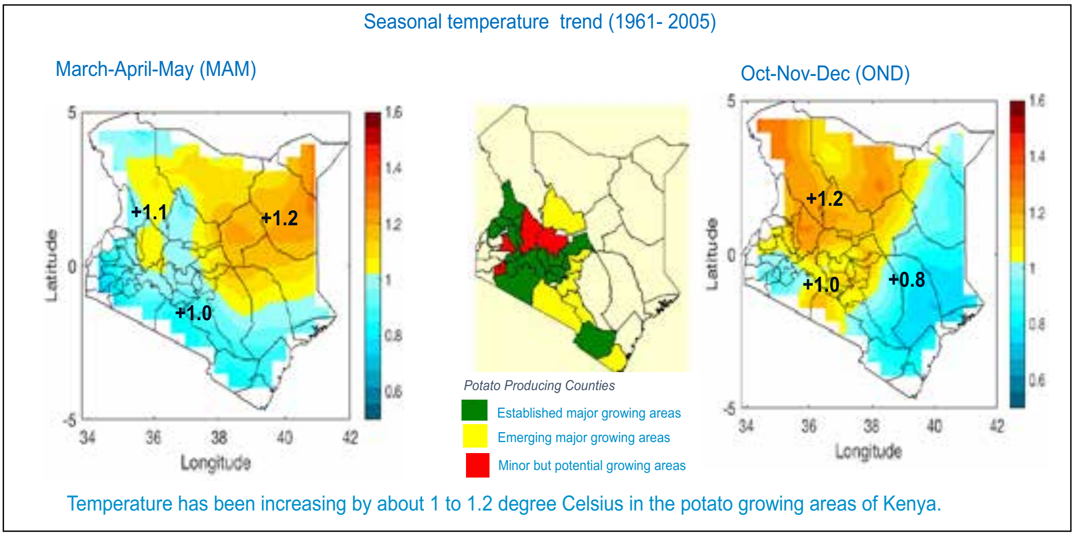


Figure 3: Seasonal temperature changes for the period 1961 -2005 for Kenya
Source: CRAFT 2019

Projection of Temperature:

During both the first (MAM) and second (OND) rainy seasons, temperature in the 2030s is expected to rise by about 1.4°C to 1.8°C in the potato growing areas of Kenya (Figure 4 and Figure 5). However, the projection model particularly in RCP 8.5 scenario (business as usual) shows that temperature in the 2050s is expected to rise by about 2.4°C - 2.8°C and 2.0°C - 2.4°C in the first and second rainy seasons, respectively, over the southern and western potato growing areas of the country. The temperature in the 2050s under RCP 4.5 (most likely scenario) is also projected to increase by about 1.8°C and 1.8°C - 2.0°C in first and second rainy seasons, respectively, in both the southern and western potato growing areas Kenya (Figure 4 and Figure 5). Figure 4 & 5 also demonstrate a rate of warming in the potato growing of Kenya, whereby temperature over the potato growing areas in the first rainy season is greater than the second rainy season by about 0.4°C. The rate of warming is also expected to be higher over the western part as compared to the southern potato growing areas of the country.

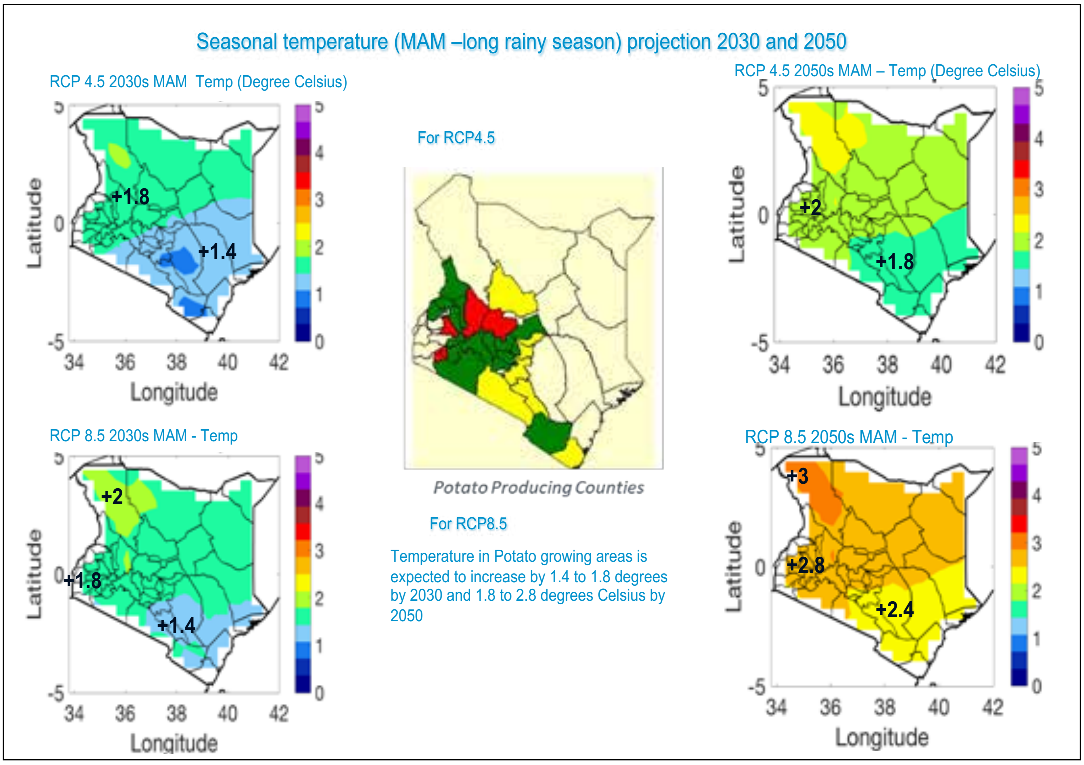


Figure 4: Seasonal temperature projections for long rain season for 2030 –left and 2050 – right *(Source CRAFT 2020)*

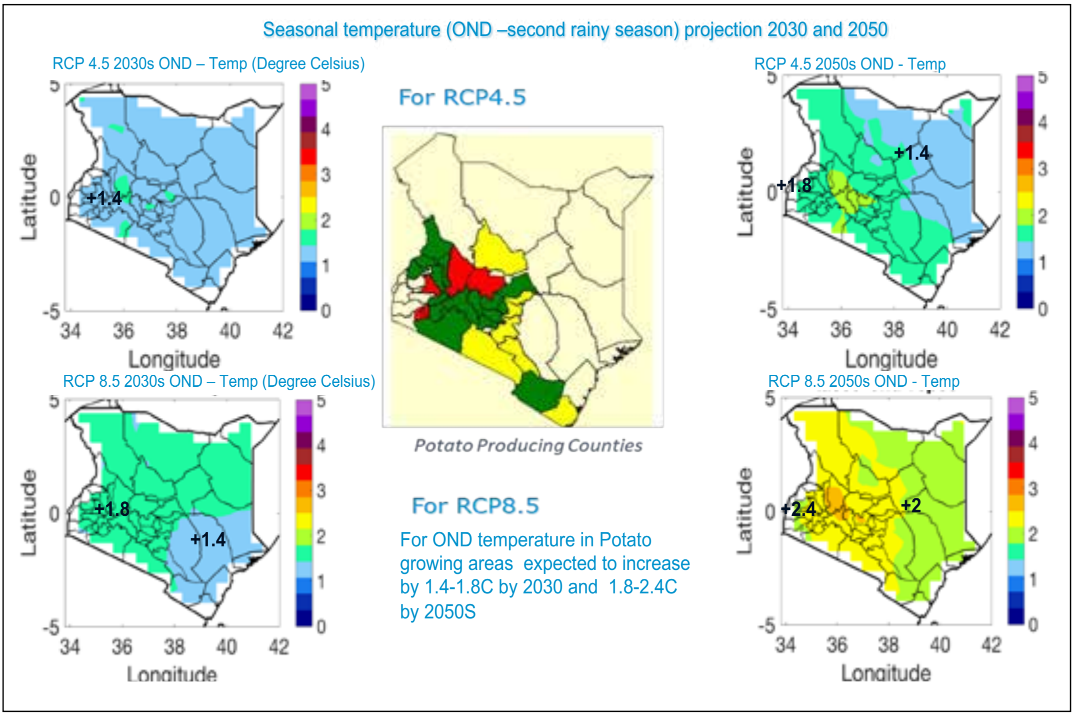


Figure 5: Seasonal temperature projection for short rain season *(Source: CRAFT 2020)*

2.2.2 Rainfall variability

The seasonal mean rainfall in the first rainy season (MAM) is projected to sligtly decrease in the western and central potato growing areas of Kenya by about 10% under both scenarios (RCP 4.5 and RCP 8.5) and for both the 2030s and 2050s (Figure 6). However, the seasonal mean rainfall is expected to slightly increase by about 10-20% over the south and south-western potato growing areas of the country (Figure 6). On the other hand, the seasonal mean rainfall in the second rainy season (OND) for 2030s and 2050s under RCP 4.5 and RCP 8.5 show that rainfall is expected to increase by about 20-30% in the central, south and south-western potato growing areas of Kenya, especially during the 2050s (Figure 7). However, the seasonal mean rainfall in the second rainy season over the western potato growing areas of the country are projected to remain without a significant change in the 2030s but a slight increament (5-10%) is expected in the 2050s (Figure 7).

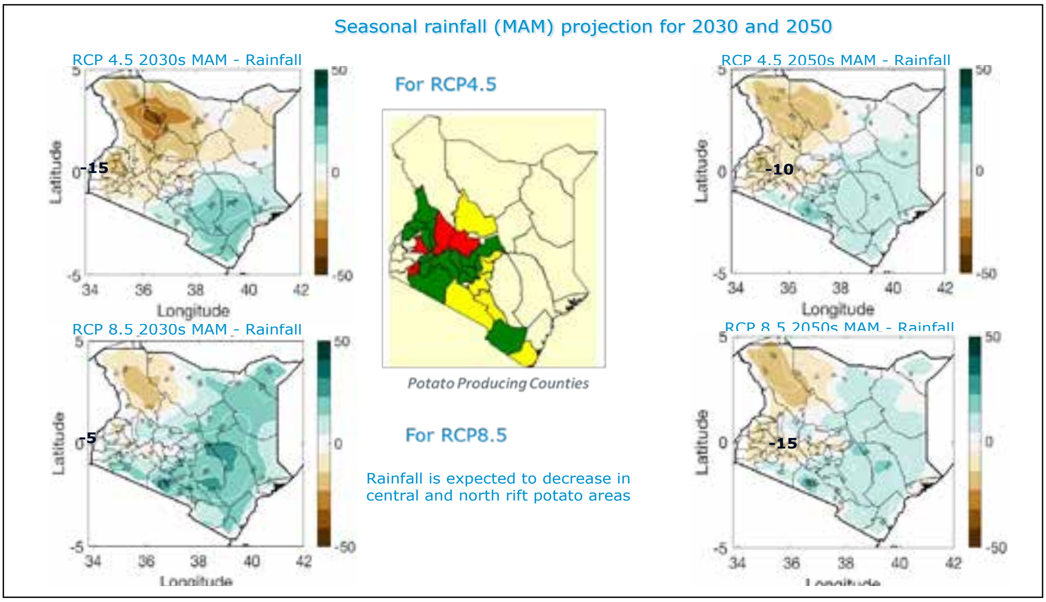


Figure 6: Projected long rainfall seasonal changes by 2030 and 2050 *(Source CRAFT 2020)*

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 first rainy season (MAM) is estimated for the historical period (1961-2005) and for 2030s and 2050s under both RCP 4.5 and RCP 8.5 scenarios. Results from the onset analysis (Figure 8) show that early onset of the seasonal rainfall is expected in most of the south and south-western potato growing areas of the country by about 10 days. On the other hand, the onset of the rainfall is anticipated to slightly delay by few days over the western and central potato growing areas of the country (Figure 8).

Similarly, the length of the growing spell in the south and south-western potato growing areas of Kenya is expected to increase by about 10 days (Figure 9) suggesting a late cessation of the seasonal rainfall in the region. On the other hand, the length of the growing spell over some of the western and central potato growing areas is expected to slightly decrease in relation to the late onset of seasonal rainfall in the regions.

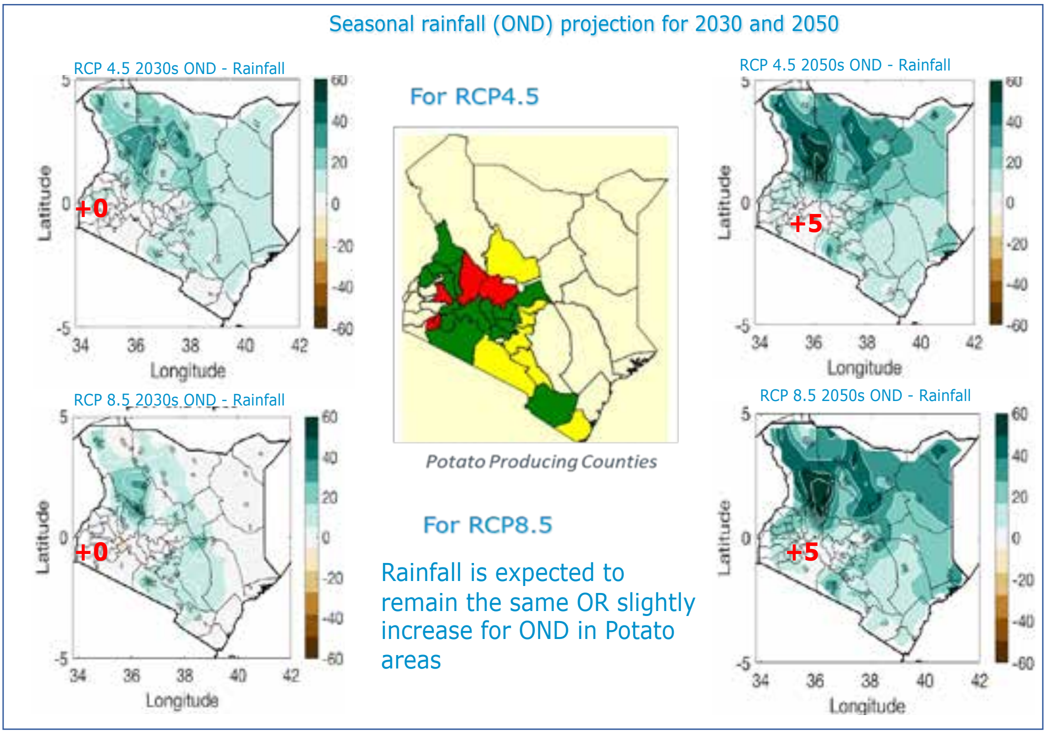


Figure 7: Projected short rainfall seasonal (OND) changes by 2030 and 2050
(Source CRAFT 2020)

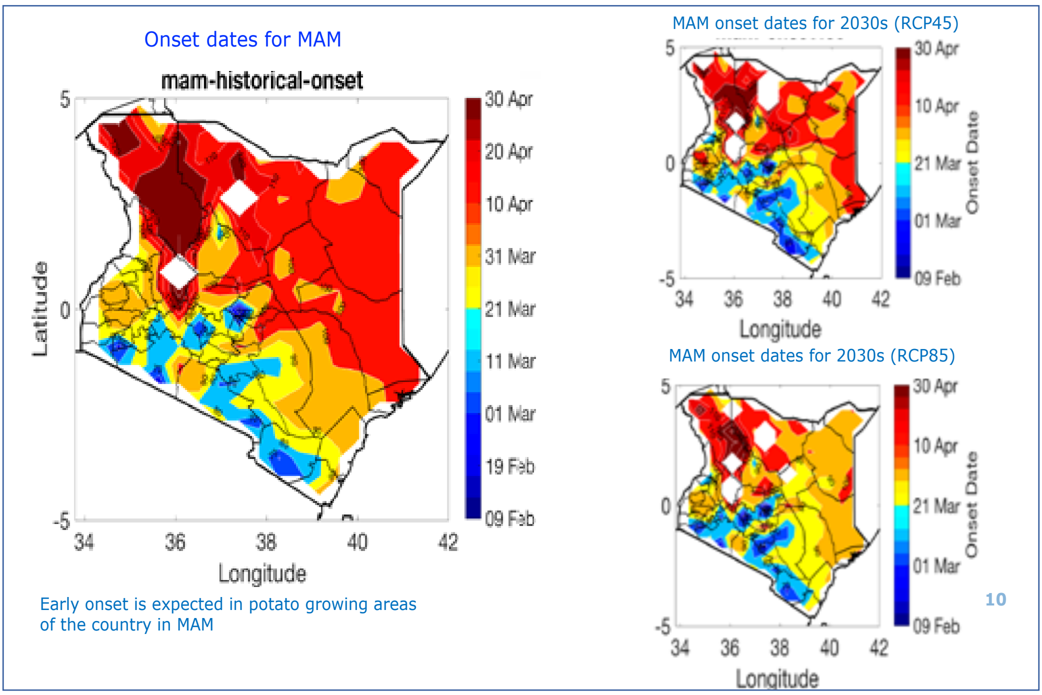


Figure 8. Projected seasonal mean of onset for 2030s *(Source: CRAFT 2020)*

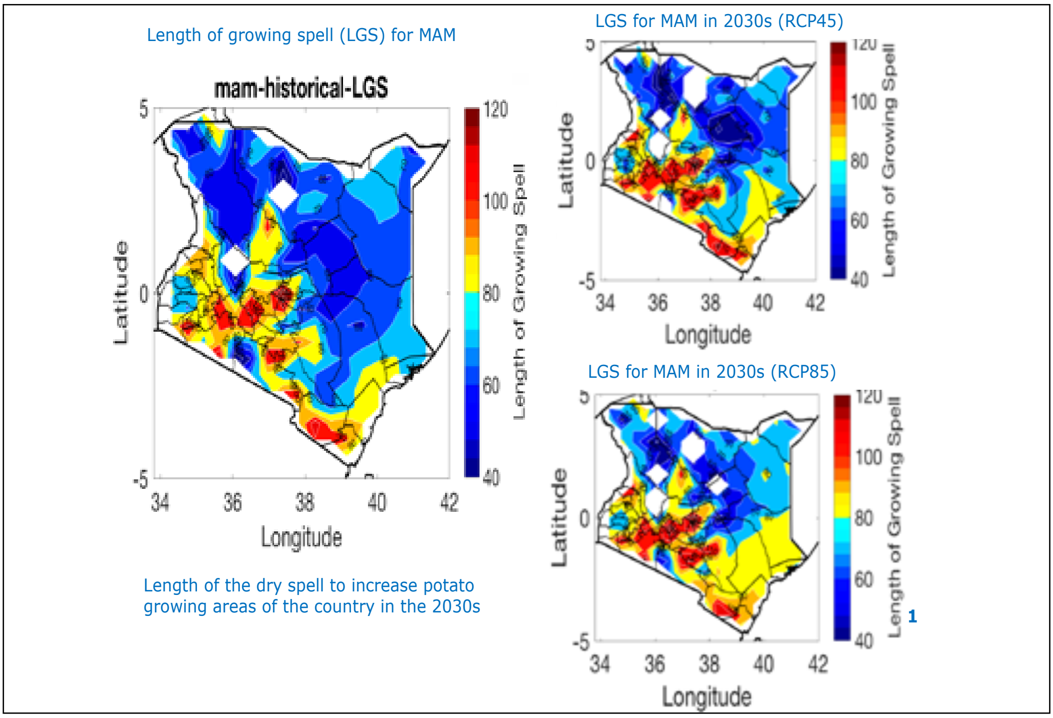


Figure 9: Projected length of growing spell for long rain season for 2030 *(Source CRAFT 2020)*

In summary, it is clear from the temperature trend analysis that temperature have been increasing by about one degree in most parts of the potato growing areas of Kenya. The climate projection analysis shows that a definite increase in temperature is projected for potato growing areas in Kenya in both the first (MAM) and second (OND) rainy season. The temperature projection particularly in RCP 8.5 scenario (business as usual) shows that temperature in the 2050s is expected to rise by about 2.4°C - 2.8°C and 2.0°C - 2.4°C in the first and second rainy seasons, respectively, over the southern and western potato growing areas of the country. In the 2030s, temperature is projected to rise by about 1.4°C to 1.8°C in the potato growing area of Kenya in both the first and second rainy seasons.

While rainfall is expected to increase in the south and south-western potato growing areas of Kenya in both the first and second rainy season, the western potato growing areas of the country is expected to suffer from a long dry spell and a decrease in seasonal rainfall. In addition, a late onset and a short length of growing spell is expected in the western potato growing areas of the country. A decrease in the seasonal rainfall and rise in dry spells accompanied by short length of growing spells in the western potato growing areas Kenya could lead to shortage of water and drought in the region. On the other hand, an increase in seasonal rainfall accompanied by long growing spell over the south and south-western potato growing of Kenya could benefit the potato production in the region.

2.2.3. Impacts of climate change on potato production

As part of the CRAFT project, the impacts of climate change on potato productivity in the major growing counties were simulated using the WOFOST crop growth model developed by Wageningen University & Research. WOFOST 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, respiration and how these processes are influenced by environmental and climatic conditions. Specifically, the water-limited yield potential of potato was simulated under current and future climate conditions. Water-limited yield potential represents the maximum yield attainable under rainfed conditions and reflect production situations with optimal agronomic management such as soil testing and proper fertilizer application, weed control, pests and diseases control.

The analysis shows that in the major growing areas such as Narok, Nakuru, Kiambu, Murang'a, Nyandarua, West Pokot, Meru, Uasin Gishu etc., the water-limited yield potential under current climatic conditions ranges between 13 t/ha to 19 t/ha during the first rainy season (i.e. when sowing starts in March-April) and 5 t/ha to 10 t/ha during the second rainy season (i.e. when sowing starts in October-November).

The analysis also shows that in the future, the impacts of climate change on potato productivity will be varied depending on the growing season and the region. During the first rainy season, yields in the north-western growing counties are likely to decrease by between 1 t/ha to 4 t/ha under all scenarios (Figure 10). The worst affected area will be West-Pokot county. On the other hand, yields are likely to increase by as much as 2.5 t/ha in the southern and central potato growing counties such as Narok, Nakuru, Kiambu, Murang'a, Nyandarua and Taita Taveta. Despite the relatively low yields during the second rainy season under current climatic conditions, yields in the future are likely to increase as a result of climate change (Figure 11). Yield increases of 1 t/ha to 4 t/ha are likely to be experienced irrespective of the climate change scenario. Narok, Nakuru and Nyeri counties are likely to experience the greatest yield increases.

Understanding the impacts of climate change on water-limited yield potential of potato in combination with information on actual farmers' yields is important for a number of reasons. It is important to estimate potato production potential in Kenya and associated land and water requirements. It is also important to identify areas with substantial opportunities for potato yield increases where investments in agricultural research and development can be directed. Finally, it is important for identifying and targeting suitable adaptation options for different areas such as irrigation expansion, new potato cultivars or increased biotic control etc.

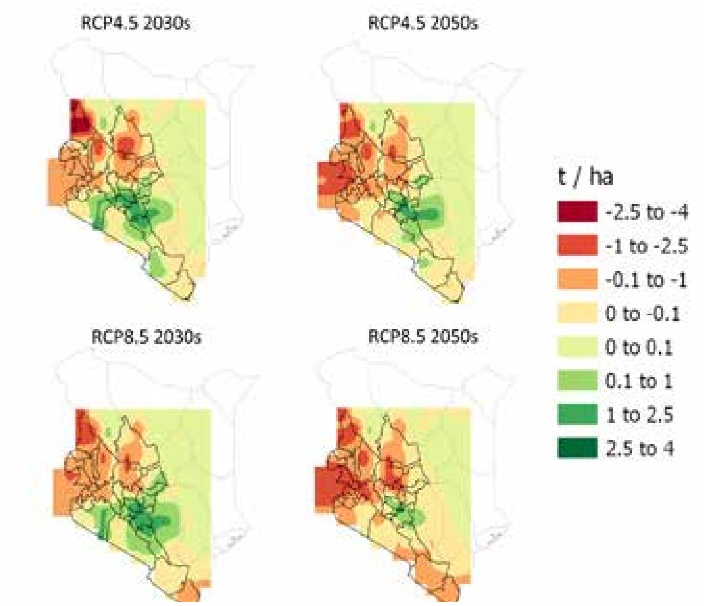


Figure 10: Changes in water-limited yield potential during the first rainy season (i.e. when sowing starts in March-April). Positive values indicate yield increases and negative values indicate yield reductions. The black boundaries indicate the CRAFT targeted potato growing counties.

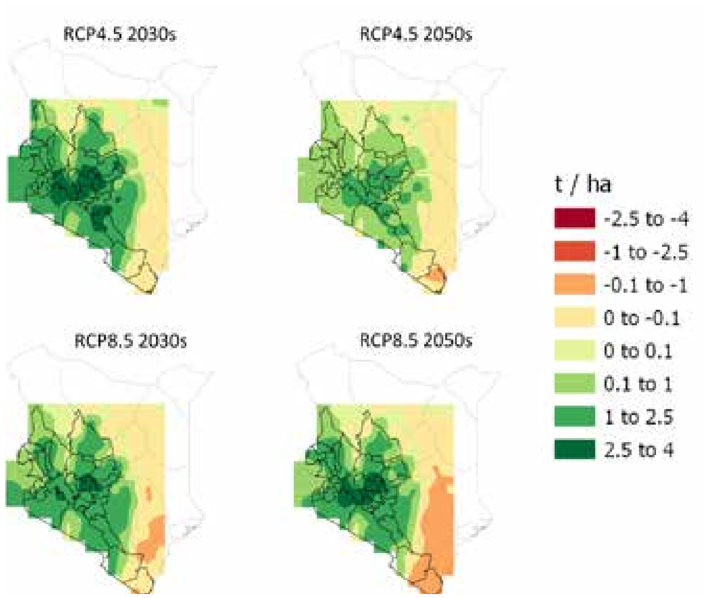


Figure 11: Changes in water-limited yield potential during the second rainy season (i.e. when sowing starts in October-November). Positive values indicate yield increases and negative values indicate yield reductions. The black boundaries indicate the CRAFT targeted potato growing counties.

3 CLIMATE RESILIENT AGRICULTURE

3.1 What is Climate Resilient Agriculture (CRA)

Climate resilient agriculture (CRA) includes a broad set of practices that increase productivity and resilience sustainably, reduce and/or removes greenhouse gas emissions (GHGs) while enhancing the achievement of food security and other development goals (Jost, 2014). Climate Resilient Agriculture (CRA) is an integrated approach with three sustainable development dimensions (economic, social and environmental) by jointly addressing food security and climate challenges (Chesterman and Neely, 2015). Adopting a package of CRA practices in the potato value chain is expected to increase productivity sustainably. CRA is not a single specific agricultural technology or practice universally applied but rather a site specific assessed and suitably selected practice or technology for potato production that can be adopted alone or integrated with others (Nelson and Huyer, 2016).

3.2 Components of Climate Resilient Agriculture (CRA)

Adopting the appropriate CRA practices aim to improve food security, help farmers adapt to climate change and contribute to climate change mitigation. These integrated practices are those that simultaneously:

- Increase productivity, quantities and qualities of farm yields as well as profitability without destroying the environment
- Cushion farmers from the effects of climate extremes such as floods and droughts
- Reduce generation of greenhouse gases (GHG) such as CO_2, N_2O and CH_4 that warm the atmosphere

The aims of adopting CRAs practices in potato production is to increase potato productivity and farm families' household incomes; strengthen the resilience of ecosystems and livelihoods to climate change; and reduce greenhouse gas emissions (Figure 12). It takes into consideration context-specific and locally-adapted actions and interventions, along the entire potato value chain. The practices adopted by farmers to qualify as CRA must manage climate risks, increase yields and reduce GHGs. For example, adopting conservation agriculture and application of manure to the soil can improve soil fertility for increased potato productivity providing more food, boost nutrition and incomes as well as sequester carbon. Such practices also reduce vulnerability of potato to drought, flooding, pests, diseases and other shocks and long-term stresses of climate change such as shortened seasons and erratic weather patterns. Such practices reduce GHG emissions generated along the potato value chain and /or contribute to soil carbon sequestrations. The CRA approach has multiple functions in the agro-ecosystem (Figure 12).

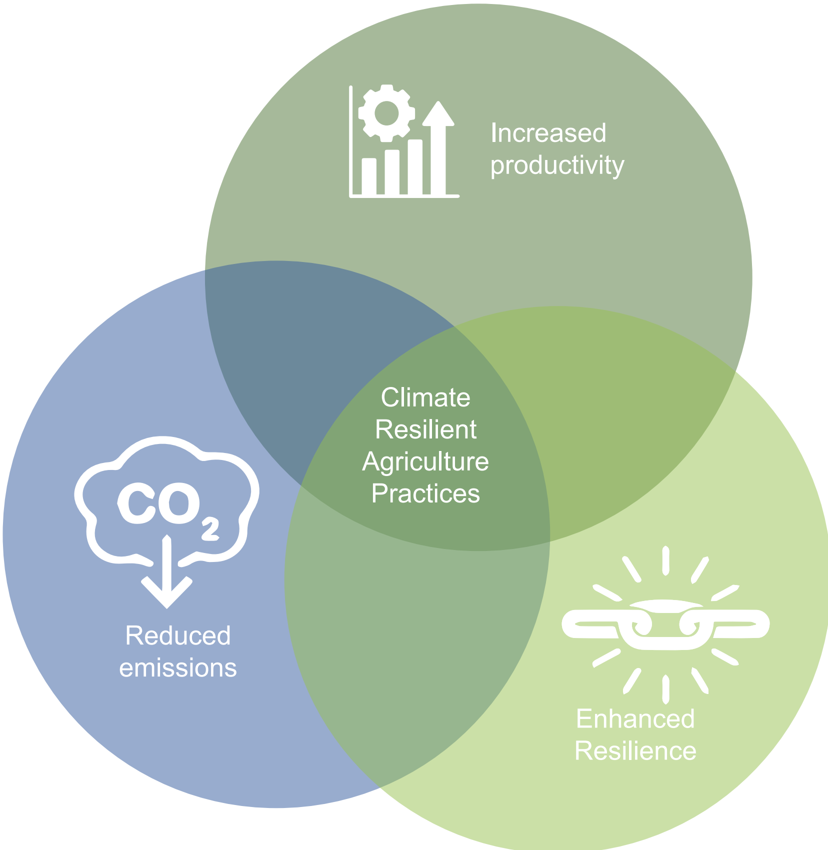


Figure 12: Venn diagram showing interconnected aims and relationships of Climate Resilient Agriculture

3.3 Why Climate Resilience in Potato Production?

Potato is a key food and nutritional security crop, second to maize in Kenya. Potato value chain is a big employer with over 3 million people employed along the value chain as traders, processors, agro-input agents and the like. Potato matures earlier than the popular staple food in Kenya so it plays a big role in ensuring food security in communities before maize matures and is harvested. Potato crop requires cool temperature and high rainfall averaging 500mm in a season to give high yields. With the changing climate, there is possibility of acreage of potato declining due to landslides or mud flows or land degradation with the possibility of 100% crop loss. Climate change impacts such as outbreak of pests and diseases might affect the nutrition values, health and safety of potato consumers. Any threat to potato, is a threat to food security, household incomes and the economy of Kenya. Majority of farm families are dependent on potatoes and so they are exposed to the risks of climate change. Also climate change threat will make Kenya not to achieve its development goals like the Big Four Agenda, Kenya Vision 2030, SDGS 1, 2, 3, 5, 12 &13. Climate resilience will enable sustainable potato production aiming at reducing or removing GHGs emissions, provide shocks and adaptation to farm families that rely on potato through sale of potato hence affording them incomes to fulfil other basic obligations.

3.4 Understanding risks in potato production due to climatic hazards

Climate **hazards** are natural threats that have potential to cause loss of life, injury, property damages, socio-economic disruptions and environmental degradation. For the case of potato, when hazards such as heavy rainfall, lad slides, flash floods, outbreak of diseases and pests leads to low produce than expected or total crop loss. Examples of climatic hazards experienced because of climate change or extreme weather events include tropical cyclones, hurricanes, thunderstorms, tornadoes, landslides, mud flows, drought, floods, flash floods, rain, hail, snow, lightening, fog, wind and extreme temperature or heat events.

Climatic **risks** are uncertain events or conditions that change in climate poses with the possibility to experience loss or injury to life, environment or property when exposed. Hazards create risks. The magnitude of the hazard and level of vulnerability (exposure, sensitivity and adaptive capacity) will determine the intensity of the risk. Figure 13 shows relationship of climatic hazard and the risk.

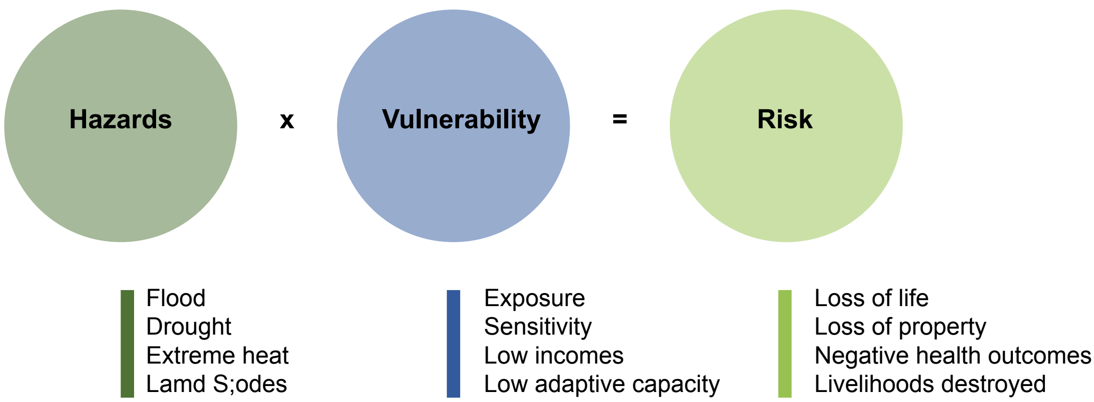


Figure 13: Understanding risk to climatic hazards or disasters

From the above figure, potato production is rain-fed, hence it is very sensitive to inadequate rainfall or droughts hence the risk of a potato farmer to suffer 100% crop failure in drought. Therefore, CRA practices such as soil and water conservation would build adaptive capacity or resilience of potato farmers to droughts or different kinds of hazards. The CRA practices reduces risks in potato production meaning they build potato cropping systems to be adaptive to changes in climate that results in such eventualities like floods, droughts and extreme temperature, hence preventing or minimizing crop loss. Table 5 summarizes some of the climate change hazards and risks which could adversely affect potato value chain and possible adaptation and mitigation measures that can be adopted to increase productivity and sustainable value chain.

Table 5: Summary of climate change risks and types of CRA practices that can be adopted in potato value chain

Climate hazards	Climate risks	Possible impact on potato	Possible Adaptation/ mitigation
Rising temperature > 20 °C	Increased heat stress, leading to risks of crop failure	• Slow tuber initiation and growth • Less partitioning of starch to tubers • Damages of tubers (brown spots) • Shortened tuber dormancy/early sprouts • Reduced yields and quality	• Use of improved varieties (heat stress tolerance)
	Increased frost occurrence, leading to risks of crop failure	• Frost scorching/ damages, reduced growth	• Mulching
	Increased incidences of Pests and diseases, leading to risks of crop failure	• Increased Potato tuber moth (PTM), colorado potato beetle, aphids and late blight damaging crops, increasing pesticides use and cost of production	• Use of improved varieties (disease resistance)
Increased rainfall	Flash floods/ Flooding and/or wet spells, leading to risks of crop failure	• Crop may be washed downstream • Reduced growth, soil erosion and fertility • High nutrient leaching • High incidences of fungal diseases	• Soil and water conservation
Reduced rainfall	Drought and/or dry spells, leading to risks of crop failure	• Reduced soil moisture and water, reduced growth, withering, crop failure • Increased demand of irrigation • High surge of pests like aphids and white flies • High incidences of potato virus diseases	• Use of improved varieties (Fast growth/early maturation) • Water harvesting and irrigation • Soil and water conservation • Use of IPDM strategies

The CRA approach requires using a cost-effective package or integrated crop management practices, technologies and approaches that increase potato productivity per unit area, enhance resilience and/or adaptation and mitigation to climate change simultaneously. Examples of CRA approaches, practices and technologies for increased productivity, adaptation and mitigation in the entire potato value chain include use of improved potato varieties; integrated pest and disease management (IPDM); conservation agriculture (no till, reduced no of tillage, mulching and cover crops); manure application; intercropping (diversification, crop rotation, relay); agroforestry; water management (harvesting, irrigation); terracing; seed potato bulking; value addition; improved storage facilities; information access (weather, market, extension); crop insurance; credit access; gender equality; briquettes/feeds; agro-biodiversity conservation. Comparison between climate resilience and conventional approaches are highlighted in Table 6.

Table 6: Comparisons of Climate Resilient Agriculture Approach and Conventional Agricultural Approach in Potato Value Chain

Climate Resilient Agriculture Approach	Conventional Agricultural Approach
Reduces Greenhouse gases GHGs sequester and stores carbon in the soil and biomass	Increased generation of Greenhouse gases GHGs
Reduced use of chemicals (inorganic fertilizers and pesticides)and fossil fuels	Increased use of chemicals (inorganic fertilizers and pesticides) and fossil fuels
Increased intercropping, crop rotation and plant species diversity	Increased mono cropping of monoculture of potato and crop rotation
Manages pests and diseases keeping their population below economic thresholds, while conserving environment	Eradicates pests and disease and can lead to pollution, damaging environment
Build resilience and adaptation to climate change	Build profit resilience or input efficiency only
Use renewable energy efficient technologies for agriculture power (irrigation, storage or tillage) and lighter machinery	Dependence on non-renewable energy sources like fossil fuels and heavy machinery
Focus on sustainable intensification of existing potato croplands	Promote expansion or conversion of land leading to deforestation and disappearance of grasslands
Value the resilience of traditional varieties	Emphasize use of improved and hybrid crop varieties
Has greater diversification in production, input and output marketing system	Promotes specialization of potato production and marketing
Focus on healthy diet	Chances of pesticides residues found in the potato diet are high

4 CLIMATE RESILIENT POTATO PRODUCTION

4.1 Climate resilient agricultural technologies, innovations and management practices for potato production

Definitions of technology, management practice and innovations

Technology: consists of tools, equipment, genetic materials, breeds, farming and herding practices, gathering practices, laboratory techniques, models etc. Examples of technologies include pest and /or disease tolerant varieties, early – maturing varieties, improved varieties that require less moisture and can tolerate heat stress, mechanized harvesting, soil testing before use of fertilizers, diffused light store, cold storage exploring renewable energy sources

Management practice: Are recommendation(s) or practice(s) that is/are considered necessary for a technology to achieve its optimum output. These include, for instance, different agronomic and practices (seeding rates, fertilizer application rates, spatial arrangements, planting period, land preparation, watering regimes, etc.), crop protection methods, management systems, disease control methods. This is therefore important information which is generated through research to accompany the parent technology before it is finally released to users and the technology would be incomplete without this information.

Innovation: This is defined as a modification of an existing technology for an entirely different use from the original intended use. E.g. fireless cooker modified to be used as a chicken hatchery. Examples hydroponics, aeroponics, rooted apical cuttings, true potato seed (TPS), integrated management, potato product diversification.

Gender integration in CRA: Gender gap in potato production is a pattern in which women have less access to productive resources, financial capital and to advisory services compared to men. This means that men and women are not on level ground when it comes to adoption of technologies (FAO, 2017). This has a great impact on sustainability and adoption of the new technologies or crop management practices. A gender-responsive approach to CRA addresses the gender gap by recognizing the specific needs and capabilities of women and men i.e. particular needs, priorities, and realities of men and women are recognized and adequately addressed in the design and application of CRA so that both men and women can equally benefit. Site-specific CRA practices that are also gender-responsive can lead to improvements in the lives of smallholder farmers, fishers and foresters, as well as more sustainable results. Table 7 highlights some of the CRA practices that can be adopted in potato production.

Table 7: Selected Climate Resilient Agricultural (CRA) practices for potato production

No	Category	Practices
1.	Potato business and marketing plan	Match demand and supply
2.	Site selection	Altitude
		Temperature
		Soils
		Choice of site
3.	Crop management practices	Sustainable cropland preparation
		Timely planting
		Use of improved crop varieties
		Correct fertilizer rates
		Weed management
		Earthing up
		Crop rotation
		Intercropping
4.	Soil fertility management	Soil testing
		Use of manure (Farmyard Manure (FYM) Compost, Vermiculture, green manure, poultry manure, pig manure etc)
		Mulching
		Use of cover crops
		Use of lime
		Appropriate use of inorganic fertilizer
		Agro-weather advisory
4.	Soil and water conservation practices	Terracing
		Vegetation strips
		Stone lines
		Ditches
		Cut-off drains
		Water harvesting and storage
		Irrigation – drip irrigation is most recommended
5.	Tillage and residue management	Conservation agriculture
6.	Agroforestry	Boundary planting
		Woodlots
		Dispersed inter planting
		Fodder trees
		Firewood lots
		Fruit orchards

No	Category	Practices
7.	Renewable energy	Sustainable improved charcoal like briquettes
		Improved cook stoves
		Fireless cookers
		Solar
		Biogas
8	Integrated Pest Management (IPM)	Preventive measures such as use of pest and disease resistant varieties
		Cultural control methods such as field sanitation practices, field scouting
		Biological control – use of friendly predatory insects or microorganisms
		Mechanical/physical methods
		Chemical methods – use of synthetic and organic pesticides. Emphasize use of synthetic pesticides as the last option
9.	Post-harvest management	Improved packaging and transportation
		Improved sorting and grading
		Improved drying and curing
		Improved storage

4.2. Climate resilient Potato production

4.2.1. Site selection

Site selection is a very important aspect under climate resilient potato production. The site suitable for potato production should be free from soil borne pests and diseases such as nematodes particularly potato cyst nematodes (PCN), fusarium wilt and bacterial wilt which are serious soil borne potato pests and diseases. The disease and pest infestation may have been from previous potato or related crops. They could also have been washed down to the farm from other infected farmer fields. When good quality seed potatoes are planted on infected soil it will lead to high yield losses. With climate change, especially rising temperature may affect outbreak of pests and diseases during field production or in storage. This can result in excessive use of pesticides and fungicides, which is harmful to both humans and beneficial organisms as well as generation of greenhouse gases. The adoption of site selection as a CRA practice can reduce the risks and impacts of pests and diseases on potatoes grown in such areas or sites (Table 8).

Criteria for potato site selection: A farmer should seek the following information when choosing a site;

- Has the site been used for production of potato or crops in the Solanaceous family such as tomato, tree tomato, brinjals, capsicum, pepino melons and black night shade for the last 4 seasons?
- Is the site prone to run off from fields where potato or crops from Solanaceous family have been cultivated before?

- Is the surface topography gently sloping or soils light enough to allow for proper drainage?

If the answer to the first two questions is positive, then the site is not suitable, and an alternative site should be identified and subjected to the same selection criteria. Once the above procedure is completed, soil samples from the appropriate sites should be taken for testing for fusarium wilt, bacterial wilt, potato cyst nematode (PCN) and nutrient analysis by a recognized laboratory. The site should also be free from pests and diseases such as bacterial wilt and nematodes.

Table 8: Potato growing counties in Kenya

Region	County
Central	Nyandarua, Nyeri, Kiambu, Kirinyaga and Muranga
Eastern	Upper parts of Meru, Machakos, Makueni, Embu and Tharaka Nithi
Rift valley	Nakuru, Narok, Bomet, Elgeyo Marakwet, Kericho, Uasin Gishu, Nandi, Laikipia, West Pokot, Baringo, Trans-Nzoia and Kajiado
Western	Bungoma and Kakamega
Coast	Taita-Taveta and Kwale
Nyanza	Nyamira and Kisii

Note: *If temperatures rise in the current counties, it will be difficult to produce potatoes or new areas will have to be be identified and might increase land conversion or deforestation. This might lead to increase in generation of GHGs. Research on more heat-tolerant varieties may be needed*.

4.2.2 Ecological requirement

The best potato growing agro-ecological zones include highlands and midlands with altitudes ranging from 1,500 to 3000 meters ASL due to cool weather and adequate rainfall (Laititi, 2014). With climate change, traditional potato growing areas may become unsuitable thus decreasing productive areas for potato production.

4.2.2.1 Soils

Potato can be grown in a wide range of soil types but well-drained loamy to sandy loam soils are the most recommended (Otieno *et al*., 2015). It also grows well with adequate fertilization even in sandy soils. Black soils that have undesirable physical and chemical qualities should be avoided. The pH should range between 5.8 and 6.5 but the ideal pH is 5.8. The soil should be deep, light, loose and well drained but able to retain moisture. Poultry can be used to remove the partially decomposed tubers from the field after the crop has been harvested. With the advent of climate change, soils become damaged more. Bare ground enhance erosion that leads to loss of fertile top soil. High temperatures lead to high faster rate of biomass degradation therefore reduces the soil organic matter and fertility. Low soil organic matter leads to poor soil structure which cannot sustain crop production. In season of intense rainfall, flooding, mudslides and landslides, soil destruction accelerates leaving small portions of land suitable for crop production. To improve soil organic matter, burning of trash should be avoided so that instead of burning, the trash is left to decompose and add humus to the soil. Soils high in organic carbon or organic matter sequester large quantities of carbon, hence most suitable to mitigate GHG emissions.

4.2.2.2 Topography and drainage

The low-lying areas which are likely to be affected with surface runoffs from higher potato growing zones should be avoided. This is because other than carrying away soil nutrients, run off may contain soil borne disease causing pathogens such as bacterial wilt, fusarium wilt, blights and soil borne pests like nematodes. Intense rainfall will worsen the situation while drought will lead to more wind erosion and destruction of soil structure. Climate smart practices discussed in section 4.2.5 on soil and water conservation would be appropriate.

4.2.2.3 Altitude

Potatoes are grown mainly in the high-altitude areas between 1,500 and 3,000 meters ASL. However, some new varieties can still do well in altitude below 1500 meters ASL. (Potato Variety Catalogue, 2019 (https://npck.org/catalogue/). Climate change may alter some elevated areas from being suitable for potato production. Production of potato may extend to altitudes below 1500m a.s.l. though these areas may require intensive pesticide application due to high disease and pest pressure.

4.2.2.4 Temperature

Temperature is the main limiting factor for growing potatoes. Potatoes require an average daily temperature of between 15 to 18 ^{o}C. Temperatures above 21^{0} c have adverse effects on growth of potato as it leads to sharp decline in tuberization (Otieno *et al*., 2015). Above 29^{o} C there is little or no tuber formation. The cooler the soil temperature, the more rapid the initiation of tubers and the greater the number of tubers formed. Optimum soil temperature for tuber formation is 15-24^{o}C.

4.2.2.5 Rainfall

Water is important to plants for photosynthesis and transportation of nutrients. Potatoes require a good supply of soil moisture to maximize the yields and quality. They require between 400 and 800 mm of rains during the growth period or an average of 25mm per week (Otieno *et al*., 2015). In cases of rainfall failure, climate resilient practices that can be adopted include construction of water conservation structures, proper crop management practices such as ridging done, timely planting, use of high quality seed potato, correct spacing and/or adoption of drip irrigation where possible

4.2.3 Crop Management Practices

The crop management practices include a group of sustainable agricultural practices that are used by farmers to improve growth, development and yield of potato crop. Four types of crop management practices when adopted in the potato cropping system that have CRA benefits include sustainable cropland preparation, timely planting, crop rotation, use of improved crop varieties, and intercropping among others.

4.2.3.1 Sustainable cropland preparation

During the dry season the farmer prepares land, prepares seeds and other inputs on time. Land preparation is done before the onset of rain to loosen soil, avoid soil compaction, increase aeration, for drainage or avoiding water-logging, enhance destruction of weeds and decomposition residues. Land preparation practices have been found to contribute to GHGs emissions such as use of machinery that is driven by fuel energy, continuous use of machinery that causes soil compaction, burning of plant residues during land preparation and conversion of forested and grasslands into cultivated lands. Sustainable land practices should promote conservation agriculture or land preparation done by hand tools (slashers, *pangas*, *jembes*, and rakes) use of machinery that has low fuel consumption or utilizes renewable energy (tractor equipment that uses biodiesel or use of ox-drawn ploughs). Farmers need to prepare land using simple and cost-effective machinery (small tractors and simple home tools) to keep land preparation costs low but also consider use of farm implements that have low GHGs or do not emit at all. Table 9 shows four major steps and methods used to prepare potato land for its cultivation.

Table 9: Steps and methods for Climate resilient land preparation

Steps	Methods	Description
1	Vegetation clearing	Slash bushes and weeds. Leave plant residues to decompose on the land. This builds soil organic matter which helps to sequester carbon into the soil. Avoid burning after slashing To give plant residues time to decompose, timely land preparation should be done Herbicides may also be used to eradicate weeds which are difficult to control such as nut grass or couch grass remove and destroy by burning volunteer potato plants and decomposing disease residues
2	Conservation agriculture	Conservation tillage: In an already cultivated land, furrow or ridge making can be done after a crop harvest without ploughing again.
	Ploughing	At least 3 weeks before planting, plough 15 – 25 cm deep. Avoid converting uncultivated lands to cultivated lands as this accelerates GHGs emissions by 37%. Farmer can use ox-drawn ploughs, the chisel ploughs, rippers, rotavators, and ridgers. For soils without hard pan a chisel plough will rip the soil 18 – 30 cm.
3	Harrowing	It is done 1 week to planting, the second harrow pass should lead to prepare furrows and ridges ready to plant. Avoid intense harrowing if it is cultivated land. Very fine soil tilth promotes soil erosion, hence contributing to GHGs emissions.
4	Levelling	Done to allow even surface water distribution. Good water distribution promotes soil microbial activity that leads to high soil organic matter which is good in carbon sequestration

4.2.3.2 Timely Planting

Timely planting means planting potatoes immediately at the onset of the rainfall season. Farmers should access seasonal weather forecast information from Kenya Meteorological Services (KMS) https://www.meteo.go.ke. Due to changes being experienced in seasonal rainfall in terms of its intensity and timing (late onset and early cessation) potato farmers under rain fed potato production systems need to embrace timely planting. Timely planting enables the crop to make use of available soil moisture as to mature earlier and escape disease infestation from neighboring potato crops which is the case with late planting. Planting should coincide with the start of the rains to maximize water utilization and plant escaping pests and diseases. There exists different recommendations on planting potatoes which include planting on ridges or furrows, spacing, manure and fertilizer application, seed rate (amount of seed needed) and depth of covering.

Establishing seed rate

To maximize production, there is a need to have the right plant density in the farm. When the spacing is 75 cm between furrow/ridges and 30 cm between tubers, 18,000 tubers will be required for an acre or 44,444 tubers per hectare. Seed tubers which are physiologically young may have only a single sprout, to achieve more 'eyes' it is recommended knocking off the apical sprout and store for 10 to 14 days for more lateral sprouts to form in a process described as 'chitting'. Each seed should have at least 3 sprouts for good plant density and for high yields.

Using Table 10 a farmer can calculate the amount of seed required. A 50 kg bag of large potato tubers (size II and III) contain less seeds than a 50kg bag of smaller size tuber (size I). Thus, larger seed sizes are more expensive but have the potential to yield more. It is recommended to use medium size seed (size II).

Table 10: Seed rates for different seed sizes

Class of seed	Average tuber diameter size (mm)	Average tuber weight (grams)	Number of 50kg bags of seeds needed per acre
1 (Small)	25-35	39-45	14-16
2 (Medium)	35-45	50-57	18-20
3 (Large)	45-55	60-73	24-26

Placing and covering the seeds

Place seed tubers on the furrow or ridges with the sprouts facing upwards. Space between the tubers should be 30cm or one foot. This is approximately the space between the ankle and the toe of an adult. Once the tuber has been placed correctly, cover it with soil to a height of 15cm for furrows and 10 cm for ridges. When potatoes are planted using machinery, the row spacing will be dictated by the wheel spacing of the tractor.

Ridges which are raised planting beds are used for planting where there is possibility of water logging and also where tractor planting is done. Prepare ridges after harrowing. At ridging up, a narrow top on the drill is desirable in wet conditions as it facilitates water to run down the outside allowing the potato crop to grow on elevated beds. In dry conditions, ridges allow formation of furrows for irrigation between ridges which helps to minimize irrigation erosion and reduction of irrigation water usage. On the other hand, the ridges also help in conservation of moisture in times of less rainfall, promotes tuber expansion and protect the tubers from PTM infestation besides enhancing the quality of tubers by preventing greening of tubers.

Figure 14: Bed forming *Photo courtesy of Agrico EA*

4.2.3.3 Use of improved crop varieties

Improved potato crop varieties include potato varieties that have been researched in, bred and tested to have special qualities compared to the existing varieties e.g. growing in a wide range of altitude, multiple use (starch making, wine and tea production, potato flour), fast/early maturing, stress tolerant (drought, heat, salt, pest, diseases etc), high yielding, high tuber quality (high dry matter content, longer dormancy trait required by processors) and good tuber characteristics (skin colour, shallow eye depth, flesh colour) in combination with CSAs. These varieties withstand the effects of climate change, they grow fast and have high amounts of biomass suitable for processing and storage.

Farmers from different agro-ecological potato growing regions should always consult the Potato variety catalogue 2019 to ascertain suitable varieties.

Acquisition of appropriate seed potato

Annex 6 provides a list of certified and registered seed merchants by KEPHIS where farmers should source seed potato from. The seed potato bag should be contain with KEPHIS certification label (Figure 15) showing species, variety, seed class, seed size, grade in mm, grower number, lot number, year of production, date of certification, country of production, packaging unit (kg) and certificate number. Farmers are advised to keep the certification labels for future use and traceability. Farmers can get seed information through Viazi soko platform by sending SMS to NPCK to get information on the variety available, quantity and price and contact details of the seed merchant (Annex 3).

Figure 15: Front and back of the certification label for certified seed potato (*Photo: Judith Oyoo, KALRO Tigoni***)**

Sprouting seed prior to planting allows the seed tuber to commence growth in the store before planting in the field, producing reduction in time from planting until emergence. In case of insufficient rainfall and imminent drought, planting well sprouted tubers ensures faster emergence, which helps the crop to grow faster and mature early, escaping the drought spell. Sprouting in a diffused light store (DLS) where tubers are spread thinly on a raised flat surface, either on shelves of the DLS or in crates, permits controlled sprout growth in contrast to the uncontrolled growth which occurs when seed tubers are stored in bags or in a pile. Remove the seed from the bags and spread thinly 2-3 layers in trays/crates in the diffused light store. The seed tubers should not be stacked more than three layers deep. This will ensure good sprouting and the sprouts formed will be strong with good colour, so that during transportation to the field for planting, sprouts do not break off easily. Inspect the boxes at regular intervals to check for aphid infestation of the new sprouts and to discard any tubers showing symptoms of rotting. In case of aphid infestation, spray with recommended insecticides to control aphids and white flies. Aphids and /or white flies will infect the seed tubers with potato viruses that will reduce yields of the potato crop. It is essential that the tubers are planted directly from the sprouting box. Tipping them into bags or other containers will knock off the sprout, negating the growth already achieved. This will result in uneven and /or delayed emergence, as the sprouted tubers will emerge earlier than tubers whose sprouts have broken off.

4.2.3.4 Fertilizer rates

The fertilizer rate has been covered under section 4.2.4. The application of fertilizer at planting and top dressing stages requires soil analysis and recommendations of levels of nitrogen, phosphorus and potassium required, or potato formulated fertilizers done following soil test results. Increase efficiency of fertilizer through site-specific nutrient management practices where optimization of existing soil nutrients is done and supplementing only the deficit.

4.2.3.5 Weed Management

Weeding is the removal of unwanted plants from the field. Volunteer crops and weeds compete for nutrients, water, light and space with potatoes in the field as well as harbor pests and diseases. They need to be removed as soon as they germinate in order to give the crop a competitive advantage and to curb yield losses associated with their presence. All volunteer plants and off type crops should be weeded out within the first 2-4 weeks of the emergence before complete crop cover is achieved. To give the crop a competitive advantage, weeding should be performed after full crop emergence (about 2 weeks after planting) and after the plants have reached a height of about 20 cm (1 or 2 weeks later) Use of herbicides should be avoided. CSA practices of weed management are intercropping potato with short term annual cover crops like legumes which will suffocate weeds, promote nitrogen fixation and boost soil organic matter through plant residues, mulching

Off type plants: These are plants that grow among the crops planted on the farm but may not have been the targeted crop. They sprout from the previous season's crop seeds used and may be of different varieties or deformed plants. To ensure uniformity, these plants should be uprooted and destroyed as soon as they are spotted in the field.

Volunteer plants: These are potato plants, which grow from tubers that remained in the field from the previous crop after harvesting. These plants will grow among your crop and may host pests and diseases. They therefore need to be removed preferably before the target crop emerges to reduce chances of pests and disease infestations and spread.

Advantages of weeding

- It reduces competition for nutrients, light, moisture and space.
- Alternate hosts for pest and diseases are eliminated.
- Conditions for disease build up will not be favorable hence you will use pesticides and fungicides less frequently.

Steps and methods of weed management

- Prepare for first weeding two weeks after crop emergence or on appearance of weeds so that you reduce damages to the potato crop.
- To weed, rogue or uproot weeds as they grow by use of hand tools or small equipment fabricated for weeding.
- Strictly no use of herbicides in weeding (herbicides contribute to generation of GHGs, pollution and loss of agro biodiversity)
- Weed again after two weeks, in case new weeds will have emerged. When using a hoe to remove weeds, take care not to damage roots as this will affect uptake of nutrients and water by the plant.
- Do not weed again once the crop canopy has covered the ground because few weeds will grow when the inter row is covered. Avoid walking in an established potato crop. Walking through a mature crop will damage the leaves and stems and risk spreading virus X from infected to healthy plants.

4.2.3.6 Earthing up/Hilling

Earthing up is the raising of loose soil from the inter row space and placing at the base of the potato plant to cover the roots well and promote stolon formation (Figure 16). Tuber development is triggered by cool and dark conditions. As they enlarge, they require complete dark conditions. Loose soil cover is necessary to allow tuber expansion without hindrance. It is recommended that earthing up or hilling should be done at least twice during the potato growing season. It is common for potato tubers to be exposed to the surface mostly if planting was done on ridges and/or during high intensity wind or rainfall. Such tubers are usually deformed and tend to turn green, some with scalded skins because they are exposed to sunlight. In addition, exposed tubers are prone to attacks by the PTM which lowers their quality significantly.

Figure 16: Earthed up/hilled potato field *(Photo: Judith Oyoo, KALRO Tigoni)*

Advantages of earthing-up

- Keep the tubers cool and hence reduce chances of brown spots associated with high temperature.
- Provide fluffy medium for more stolons and tubers to grow.
- Prevent greening of exposed tubers by sunlight.
- Prevent water logging in case of heavy rains as a climate smart practice during high intense rainfall
- Conserves moisture and therefore prevents physiological disorders and low yields that come because of soil moisture stress, also as a climate smart practise
- Reducing chances of PTM infestation, which can lead to heavy losses at the field or in the storage after harvest.
- Reduce chances of stolon developing into secondary and non-productive stems thereby increasing productivity of your land.

Guidelines on how and when to earth up/Hilling

- It should be done during weeding or when the crop is 20cm high. It should be repeated regularly when tubers are exposed by high intensity of rainfall or wind erosion. Use handheld tools like jembe to scoop and to heap the soil along the inter rows space on the potato stems.

- Heap the rows such that the final ridge should be about 25 cm high from the ground
- Repeat the practice 2-3 weeks later if the crop canopy has not covered the inter row space.
- If conditions allow, do the last hilling 2 weeks after the second hilling.

Note - Earthing up should be avoided when the soil is too wet to minimize soil compaction and spread of fungal diseases like late blight. Also carry out spot checks k for any exposed tubers.

4.2.3.7 Crop rotation

Crop rotation is the practice of growing a series of several types of crops in the same crop field in a repetitive sequence defined in order of a year or years of cropping. The main reason for crop rotation is avoiding build-up of pests, weeds, diseases and chemicals. Other benefits of crop rotation include control of soil erosion in cases of excessive rainfall amounts, recycling nutrients and enhancing the rooting system in different depths hence reducing soil compaction and hard pan and thus boosting crop yield. Crop rotation is therefore a climate smart practice that enhances GHG emission through carbon sequestration, cushions farm families against climatic risks and hazards through diverse enterprises that boost household incomes and food diets. Potatoes should be grown on land where potatoes and other Solanaceous crops have not been grown in the previous seasons. Land where volunteer plants from these crops are present should be avoided since these crops usually act as alternate hosts for most potato pests and diseases in case it is a seed crop enterprise.

Designing a potato crop rotation program

Step 1: Inquire about the farm and market/use of alternative crops

- Ask about the history of the farm-what was grown there before. What pests and diseases have been observed in the past on the farm?
- Observe the topography and drainage of the farm (is it sloping or flat?)
- Observe the soil type (is it sandy, black cotton or loam soil?)
- Seek information on the climatic conditions such as rainfall, temperatures, wind etc
- Determine your household food requirements or what other crops are in demand in the local market. What other crops if grown in rotation with potato will be of benefit for the household or have ready markets?

Other questions you may need answers for are;

- What are the rooting depths for various crops to be used in a rotational program?
- What are the feeding habits of the rotational crop (heavy feeders, light feeders, moderate feeders, and givers)?
- What plant residues result from harvest of these crops?
- Is there a need to diversify enterprises for risk management and increased income?

Step 2: Design of rotational plan

After collecting the necessary information, seek the assistance of an agricultural officer or an agronomist to develop the rotation plan. Developing the plan involves dividing the farm into 4 plots for instance and allocating a crop per season for each plot. The crops are rotated on the plots making sure the same family of crop is not planted repeatedly on the same plot. A four-season rotation plan for four plots is suitable for small scale farms. An example is presented in Table 12

Table 11: Four year rotational plan using four plots

Year	Plot 1	Plot 2	Plot 3	Plot 4
1	Potato	Legumes (Beans)	Brassicas & other	Onions & Roots
2	Legumes (Bean)	Brassicas & other	Onions & Roots	Potato
3	Brassicas & other	Onions & Roots	Potato	Legumes (Beans)
4	Onions & Roots	Potato	Legumes (Beans)	Brassicas & other

4.2.3.8 Intercropping

Intercropping is the planting of two or more crops in the same field with potato crop such as maize and potato. Intercropping, also known as inter planting, provides additional income, food, provide shade, fixes nitrogen, and controls weeds and soil erosion. It also provides a lot of biomass to form residues to be returned as organic inputs to the soil in form of mulch and compost. Care should be taken when intercropping potato with other crops because some plants host pests and can transmit diseases to the potato crop. Although a climate smart practice, a cost benefit analysis showed higher profit margins in mono cropping than in intercropping. There are several types of intercropping that can be adopted by potato growers: row intercropping and relay intercropping. These are discussed below:

- **Row intercropping:** It involves growing two or more crops simultaneously, in rows. It is also called alley cropping. A variation of row cropping is strip cropping, where multiple rows or a strip of one crop is alternated with multiple rows of another crop.
- **Relay intercropping:** Two or more crops are grown in the same piece of land during part of the cropping season. A second crop (usually a cover crop) is planted in the same field as the first crop after the first has achieved reproductive maturity but before it has reached physiological maturity. This helps avoid competition between the main crop and the intercrop. It also uses the field for a longer time, since the cover crop usually continues to grow after the main crop is harvested. This allows farmers to grow two crops in one season in places where the growing season is not long enough to accommodate two crops

4.2.3.9 Agro-weather advisory

This is a process providing agricultural advisory information to farmers based on observations and forecasted seasonal weather information. The impact of weather and climate on potato is analyzed based on its sensitivity on the crop, soil and environment. The advice can include land preparation, sowing and harvesting dates, cultivar selection, farm input management and cultural practices or farm operations. The weather information from Kenya Meteorological Station are analyzed, interpreted and organized in an Agromet advisory bulletin and communicated to farmers through several communication channels such as television, radio, newspaper, Ministry of Agriculture extension unit, personal contact and SMS on mobile phones (Figure 17).

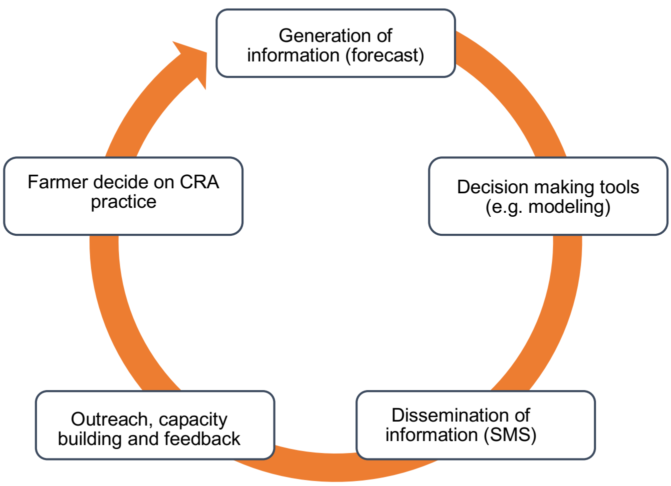


Figure 17: Agro-weather farmer decision making system

4.2.4 Soil fertility management practices

The soil fertility management practices increase availability of crop nutrients such as nitrogen, phosphorus and potassium as well as micronutrients such as iron, zinc and manganese. The first step in determining the soil fertility status of your land is to conduct soil testing.

4.2.4.1 Soil testing

Testing soil helps the potato farmer to know:

1. The type, quality and amount of food (nutrients) available for the potato
2. Soil environment (pH, organic carbon, CEC) suitable for the potato
3. The type and rates of fertilizers to apply to get the best yields

How to collect a good soil sample

1. Items are assembled (, soil auger/Panga or hoe, a bucket, a bag to put the soil sample, notebook)
2. The sample and locations are determined by walking in a zigzag pattern over the area. The area to be sampled should be as uniform as possible in terms of soil type, cropping and fertilizing history. Unusual areas such as very close to ditches, roads and former manure heaps are avoided.
3. Soil samples are taken 25cm deep (a soil auger or panga are used to core/dig up soil and collect soil in the bucket)
4. The soil samples are thoroughly mixed with the collected samples (Remember that samples from different fields (e.g. tree farm or vegetable garden) should NOT be put together). A minimum of 25 cores should be sufficient to make a representative soil sample
5. Fill the plastic bag with the soil sample (In total you should collect between 1/2 to 1kg of soil per sample)

Annex 10 provides detailed information about soil testing and nutrient amendment for potato production.

4.2.4.2 Use of Farmyard Manure (FYM)

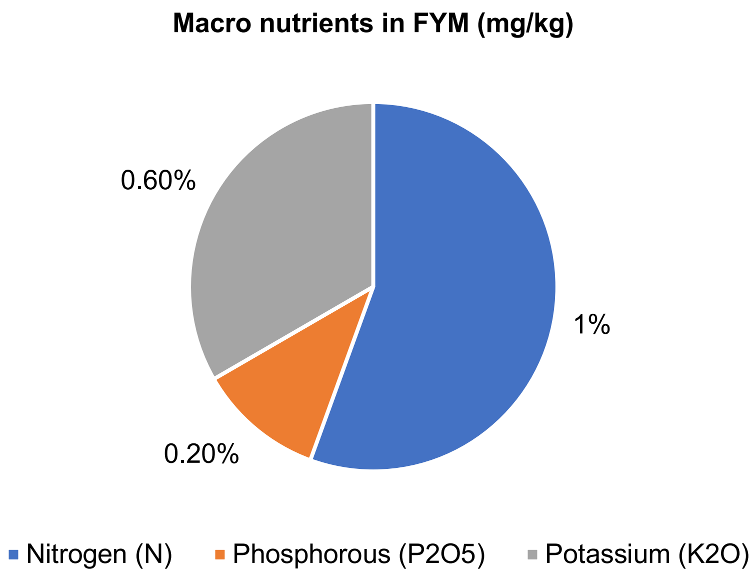
Farmyard manure (FYM) refers to the bulky organic manure resulting from the naturally decomposed mixture of dung and urine of farm animals along with the litter (bedding material). Animal manure is obtained from different animals (poultry, cow, goat, horse) on the farm, but it can also be bought from other farmers or at the market. When managed properly, FYM provides plant nutrients, builds soil organic matter, and improves soil physical properties all of which are vitally important for soil quality and crop production. The efficient use of manure is enhancing the capacity of the soil to conserve and accumulate soil organic carbon; maintain or improve crop yield by supplying nutrients when required by plants and reduce effects of climate change through sequestration of carbon. On the contrary, FYM is one of the greatest emitters of GHG when poorly handled through manures left in the open or on pastures lying uncovered in the fields, contributing 90% of Kenya's GHG emissions; emission of methane (CH_4) gas formed through enteric fermentation (Osumba and Rioux, 2015). Slurry has been found to be the highest emitter of GHG. It is recommended that anaerobic bio-digesters and biogas system in addition to composting are the avenues for reducing GHG production and emission in FYM.

Steps involved in making manure

- Prepare manure pit which should be about 0.9 meters deep, 1.8 to 2.4 meters wide and of any suitable length depending on the number of animals. The pit should be provided with a roof to protect the FYM from the hot sun and heavy rain.
- The mixture of cattle dung and urine-soaked litter should be directly taken to the manure pit and evenly spread uniformly at its bottom.
- If necessary, water should be uniformly added to it. The daily collection of the mixture of cattle dung and urine-soaked litter is spread evenly over the previous layer. This is continuing till the manure heap rises about 30cms above the ground. It is then watered thoroughly, and mud plastered.
- The farmyard manure is ready in about six months.
- Ensure the manure is well prepared and ready for use by ‘feeling’ with your hands. It should feel like ‘cotton’, crumbles easily and when dry it’s ‘floury’.

What Nutrients are derived from FYM?

FYM is used as an organic fertilizer, which if well prepared acts as an organic source of nutrients containing nitrogen (N), phosphorus (P) and potassium (K) as well as iron (Fe), manganese (Mn), boron (Bo), molybdenum (Mo), chlorine (Cl), cobalt (Co) and zinc (Zn). Application rate of manure is 5-10 tons/ha or 2-4 tons/acre (Figure 18)



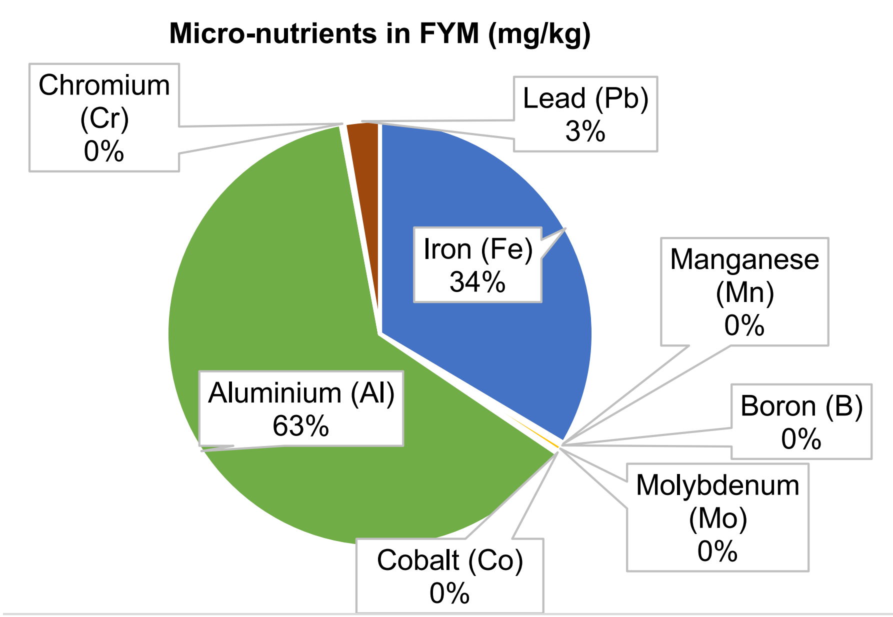


Figure 18: Macro-and-micronutrients levels available in the farmyard manure

The best manure has the following characteristics;

- Not made from livestock fed with potato family crop residue. This is to reduce chances of spread of bacterial wilt and potato cyst nematodes (PCN).
- Not made from compost with crop residue from potato family.
- Well-decomposed manure to prevent occurrence of black leg and black scurf diseases.
- Free from potato pests and other diseases. Take sample for analysis

Application of manure in potato field

Manure can be applied by spreading on land just after ploughing before harrowing. If the amount required is available, spread 2-4 tons/acre. Then incorporate into the soil during harrowing and furrow preparation. You can also spread it in the field using a *fork jembe*, hoe or rake for smaller plots. Thereafter incorporate it when making furrows and or ridging and mixed with soil before placing fertilizer and seed potato tubers.

Steps in applying manure uniformly on a potato farm are as outlined below;

- Divide the land into 4 equal quarters.
- Divide available manure into 4 equal portions.
- Allocate each quarter portion of manure to each quarter portion of land (Figure 19).
- Apply each portion of manure to the allocated portion of land.
- If manure has been placed in ridges or furrows, mix it or cover it lightly with soil before placing fertilizers.

Figure 19: A well decomposed farmyard manure *(Source: Judith Oyoo, KALRO, Tigoni)*

- The level of soil nutrients in FYM can be increased through proper compositing. The compositing process needs to be well managed to reduce loss of nutrients to the atmosphere. During decomposition process cover the manure well to avoid loss of nutrients through vaporization, and also minimise emission of greenhouse gases (GHGs - methane and nitrous oxide) which have negative impact on the environment.
- Avoid storing manure for long periods, this can encourage anaerobic decomposition and lead to increased CH4 emissions.
- Manure should be applied to the field as soon as possible after removal from storage.

Adoption of composting of FYM can be low where farmers don't have zero grazing units thus making manure collection a labour intensive activity. Unavailability of fodder due to dry spell associated with unpredictable rainfall patterns mean less production of manure. Use of manure can only be possible if a potato farmer integrates livestock in his farm. It is challenging to use FYM incases of unavailability, which can hinder those who don't own livestock and have limited financial access to purchase the FYM. Barriers associated with use of biogas include lack of funds to construct biogas due to limited credit services, limited land, limited knowledge on biogas installation, limited quantities of manure and lack of labor for manure collection.

4.2.4.3 Composting and vermiculture

Composting means piling up crop and other farm wastes in layers to make them decompose quickly. It is a bio-chemical process in which micro-organisms decompose organic waste matter (crop residue, kitchen wastes, cow dung, urine) into a soil-improving product. The final product is compost – a uniform, black mass of rotten, nutrient-rich manure. It improves soil fertility, moisture retention and soil aeration. Mature compost acts as soil amendments and has the potential to effectively promote carbon sequestration and reduce GHG emissions.

The below points explain main advantages associated with composting:

- It helps to make use of large amounts household and farm waste into use such as crop remains, garden weeds, kitchen and household wastes, hedge cuttings, garbage, etc.,
- When properly made, compost becomes immediately available as plant food without the need to be first broken down by soil microorganisms.
- Compost does not cause excessive weed growth, as is the case with ordinary farm manure.
- Good crops can be obtained without the need for extra chemical inputs.
- All farmers, regardless of their financial abilities, can make and use compost.

Guide on how to build a compost pit

1. Place the compost pit in a shaded place or under a tree.
2. Dig the pit. It should be 1.5 m wide and 0.5m - 1m deep.
3. Loosen the soil at the bottom of the pit (30 cm deep loose soil). Pour water over the soil.

4. Start piling ingredients into the pit:

First layer: Put 30 cm of rough material at the bottom layer e.g. maize stalks,

Second layer: Put 15 cm of dry grass.

Third layer: Put 15 cm of green leaves from, e.g. high protein legumes, trees, shrubs.

Fourth layer: Put 10 cm of animal/bird waste.

Fifth layer: Sprinkle topsoil and if possible, wood ashes.

· Water the compost before repeating the same process three times.

- Place a stick in the compost in an angle of 45 degrees to check if the pile is too dry or too wet.
- Cover the compost with topsoil and grass to avoid evapotranspiration.
- Keep the compost for 21 days before applying it into the field (Figure 20).

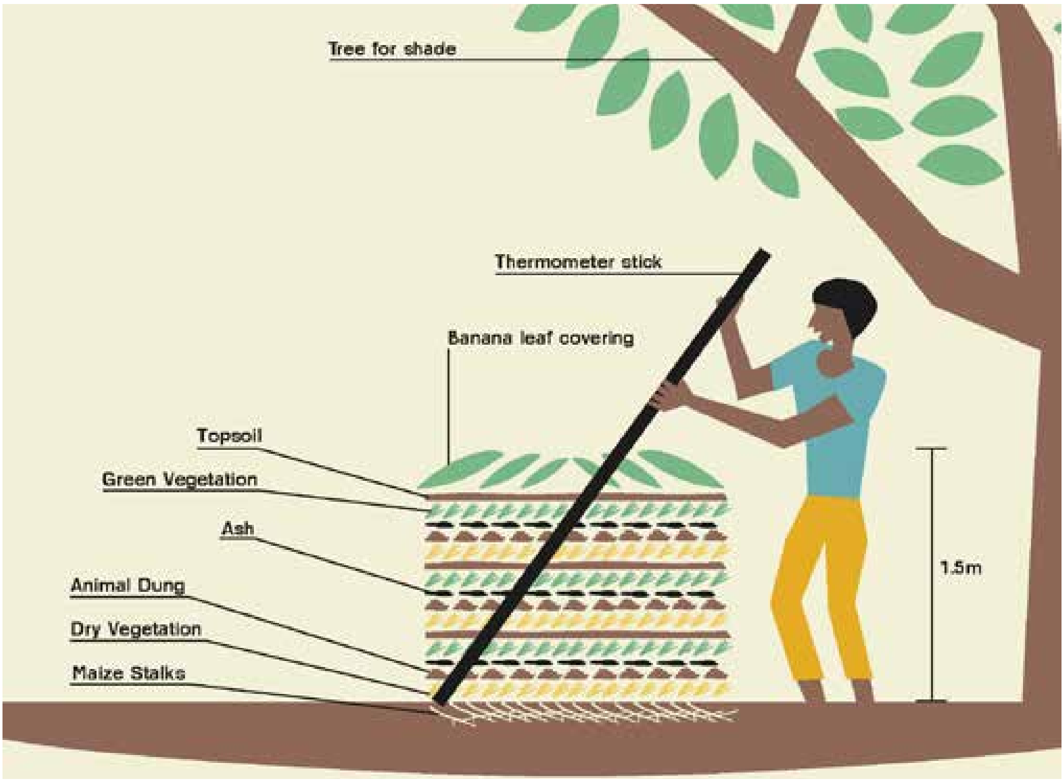


Figure 20: Process of making compost (*Source:* Wekesa *et al.,* 2014)

Composting has some shortcomings:

- Compost preparation requires a lot of labour and time to prepare and to spread it over the farm. This could limit its adoption by women farmers who may consider using inorganic fertilizer which are less laborious. In this case women require an alternative organic sources like poultry manure, commercial organic sources like vermicompost or farmyard manure.

- The nutrient composition of the compost varies a great deal. It depends on the materials used and the preparation methods.
- In drier areas making compost could be a challenge due to low availability of vegetation to make compost.

Vermiculture

Vermiculture is composting organic matter to make organic fertilizer (compost). It starts with the cultivation of earthworms (Table 12). Earthworms are found everywhere in upper layers of slightly dump soils except in sandy soils and soils deficient of humus. Averagely, one acre of land can have about 50,000 earthworms. Earthworms feed on organic matter for nutrition and secrete plant nutrients in simple forms called castings. Castings contain 5 to 11 times of available N, P and K. Earthworms are hermaphrodites (have both male and female sex organs). They produce fertilized eggs which develop inside a cocoon. The young one hatches out of the cocoon in 2-3 weeks.

Table 12: Types of earthworms for Vermiculture

Type of the earthworms	Description and composting
Red worms (*Lumbricus rubellus*)	• Medium in size • Cannot be reared in the farm or garden soils • Thrives well in manure piles and compost heaps • They compost very fast • Turning the heap is not required.
Field worms (*Allolobophora caliginosa*)	• Medium size • Attack compost heaps and manure piles from the bottom • Mix and turn the earth with organic matter and then retreat into the soil • Cannot thrive in active compost and are killed more easily than red and branding worms • Reproduction rate is very high and fast
Night crawlers (*Lumbricus terrestris*)	• Large sized • Attack compost heaps and manure piles from the bottom and then retreat into the soil • Prefer cool soil therefore do not enter compost and manure piles • If they are forced to live in active compost they will die and melt
Branding worms (*Eisenia foetida & E. andrei*)	• Medium – large sized • High growth and reproductive rate • Used as fish bait • Can produce about 400 kg N rich compost per hectare per year
Pheretima	• Common large sized earthworms • Live in soil • There requirements are similar to night crawlers and field worms

Materials for culturing earthworms: Garbage, leaves, banana leaves, banana residues, shredded bark, sawdust, wood shavings, citrus wastes, bagasse and fish scrap (Table 13).

Materials which shouldn't be used for culturing earthworms: Wastes from birds, dogs and cats; human waste; acidic and toxic materials, diseased plants and roadside plant debris

Table 13: Methods of Vermiculture

Method	Description
Bins	Containers made of bricks, cages, sleighs or logs, wood or concrete Should be located in the shade near the garden or kitchen
Indoor heaps methods	Height of the heap should be 12 – 18 inches made up of finely shredded organic materials, arranged in layers (bottom, middle and top), the worms should be introduced after 2 – 3 weeks after cooling below 66 °C

Benefits of Vermiculture

1. Improves soil organic carbon
2. Increase productivity of crops
3. Recycle plant nutrients
4. Recycle and treatment of industrial wastes
5. Reduce the use of chemical fertilizers
6. Drought protection
7. Reduce soil erosion
8. Neutralize toxins
9. Reclaim or restore degraded land
10. Earthworms are food for fish, animals and humans
11. Earthworms can be used as fish bait
12. For sewage sludge management

4.2.4 4 Mulching

Mulching is the process of covering soil with a porous material to improve the condition of the soil underneath. Mulching is an important CRA practice since it conserves soil moisture, improves infiltration, reduces surface runoff flows so controls water and wind erosion, reduces evaporative losses, suppresses weed growth, enhance soil structure and regulates soil temperature. Common mulches include cut grass, crop residues, straw and other plant material. If organic materials are used as mulch, they decay over time thus they enrich the soil, encourage earthworms, modify soil pH, loosen it or bind it.

4.2.4.5 Use of Cover crops

Cover crops, sometimes referred to as nitrogen-fixing crops, are either leguminous or non-leguminous crops with green manure properties that can absorb atmospheric nitrogen and fix it organically into the soil to increase nutrients, conserve soil by reducing runoff as well as help in weed management. Cover crops reduce disturbance of soil through tillage leading to increased soil carbon storage. Examples of cover crops for soil fertility management that can be integrated in potato cropping system include *Mucuna pruriens, Alfalfa, lablab, desmodium, butternut, pumpkins, Lucerne and sweet potatoes*. Cover crops seeds are expensive so farmers can bulk seeds and share amongst themselves. Cover crops should be harvested or ploughed into the soil before they flower and produce seeds. This prevents them using nitrogen already fixed into the soil and they should fit in the farm system but not the farm system fitting in the cover crop system for them to function optimally.

4.2.4.6 Use of agricultural lime

Overuse of inorganic fertilizers, mono cropping and depletion of soil organic matter stocks in croplands makes the soil to become acidic. One of the most common ways of neutralizing soil acidity to achieve the required pH for potato productivity is by lime application, which is a climate smart practice. Different crops have different pH requirements. Lime, also known as calcium carbonate ($CaCO_3$), comes from limestone.

How to apply lime:

- The soil acidity that triggers the use of lime in your farm should be of a pH of 6 or below.
- Lime is applied after the soil is ploughed or tilled well.
- Apply 1 week before planting, or during planting
- Apply 2 or 3 t of lime to one acre of land.
- Repeat every 2 to 5 years depending on the acidity levels in the soil

4.2.4.7 Appropriate use of inorganic fertilizers

Fertilizers are fast acting inorganic materials supplying one or more key nutrients to plant. When chemical fertilizers are used inefficiently or overused, soils get depleted, toxic, and acidic and generate ammonia and nitrous oxide (N_2O) emissions which contributes to climate change. Thus, to achieve optimum benefits from inorganic fertilizers, farmers should ensure their proper use to avoid wastage and pollution. Soil analysis results should guide fertilizer application putting into consideration the principle of '4R' of using the right fertilizer **sources** at the right **rate**, right **time** and right **place** to achieve economic, social and environmental goals. Section 4.1.2.1 and Annex 10 describe soil analysis procedures, nutrient amendments and fertilizer use determination. The following should be considered for proper use of fertilizer:

- Inorganic fertilizers should be applied at rates which ensure high fertilizer use efficiency and reduced amount of unutilized fertilizer to acceptable levels.
- Proper use of fertilizer can lead to better environment management because of greater vegetative growth and higher crop yields hence large quantities of plant residues in the soil thus reducing soil erosion, increasing soil carbon and absorption of more carbon dioxide (CO_2), a major source of greenhouse effect.
- Fertilizer should be applied by spreading along the furrows and incorporating into the soil before planting. Customized and blended fertilizer according to crop specific and soil test result is advisable.
- Farmers are also advised to consider their target yield when considering nutrient application rate. For instance, to produce 56 tons/Ha potatoes require about **235 kg N/Ha**, **31 kg P/Ha** and **336 kg K/Ha** according to Westermann (2005). Although, the recommended rate in Kenya is **90kg N/Ha** and **230 kg P/Ha** based on the commonly used fertilizer (DAP), experts do not recommend the blanket application rate because of the following reasons: potato is a heavy feeder of K which DAP does not have

because it contains only nitrogen and phosphorus; DAP has too much P which could cause long term acidity if used for a long time; and lastly it is advisable to split N applications during the lifetime of a crop because loses of N occur much faster at planting before crop establishment and cannot survive until crop maturity.

NB: *Micronutrients are usually supplied through foliar sprays in cases of deficiency, but it is advisable to apply through field grade fertilizer.*

Fertilizers used in potato production

The fertilizers currently used by growers in potatoes are nitrogen-phosphorus-potassium (NPK) and Diammonium phosphate (DAP). However, potato, being a crop that requires high nutrient levels demands key elements such as phosphorus, potassium, nitrogen, calcium, magnesium and sulfur as macro nutrients and micronutrients like iron, boron, manganese, chlorine, selenium, cobalt. Other fertilizers used include triple superphosphate (TSP), monoammonium phosphate (MAP), calcium ammonium nitrate (CAN) and Urea. Different fertilizer companies have formulated different fertilizers for potato crop which include; Diammonium Phosphate (DAP); (18;46;0); NPK (17:17:17; 20:20:20; 23:23:0); Blended NPK (14:28:14+Te, NPK 18:0:21+Te); Single Superphosphates (SSP) and Triple superphosphates (TSP).

Steps in applying fertilizer

The following are steps that need to be followed when applying fertilizer:

1. Divide the land or furrow into 4 equal quarters;
2. Divide available fertilizer into 4 equal portions;
3. Allocate each quarter portion of fertilizer to each quarter portion of land;
4. Apply each portion of fertilizer to the allocated portion of land and cover with soil awaiting seed placement.

4.2.5. Potato nutrient requirements

A deficiency of any nutrient will limit crop growth and restrict yield. Table 14 describes the essential macronutrients required for potato production. More details on macro, secondary macro and micronutrients is provided in Annex 4. Weather conditions influence the availability of the nutrients to soil and to the crop. For instance, factors such as type and content of each nutrient, soil moisture/rainfall, soil characteristics (type and structure) and soil pH. These factors influence aspects such as leaching, nutrient uptakes and pH of the soil.

Table 14: A summary of important plant nutrients for potato production

Macro Nutrients	Function	Application requirements	Deficiency symptoms
Nitrogen (N)	**Growth**: N promotes formation of chlorophyll, amino acids, vitamins and carbohydrates for growth of leaves, stems, branches and initiation of tubers.	N is needed in early stages for growth. Too much will enhance overgrowth of canopy leading to chances of blight infection, delayed maturity and tuberization Too much N also affects the tuber quality causing starch imbalance	Yellowing of older leaves and younger leaves
Phosphorus (P)	**Growth**: photosynthesis, energy production, transfer of sugars and their storage as starch, respiration, and cell division Promotes root formation, initiation development and maturity of tubers. Support the plant to be tolerant to cold, frost and low moisture	Required during early stages of the plant	Purple coloration on the edges of the potato leaves.
Potassium (K)	regulates the opening and closing of stomata carbon dioxide uptake and water in plants (osmo-regulation). ATP energy production, protein and starch synthesis.	Application should be dependent on soil test results 10 kg/ha per day required at early (during 6 weeks of planting)	Foliage-Inter-venial chlorosis from older to younger leaves, dark-green or silver colorations on leaf margins and stunted growth. Tubers -hollow hearts.
Calcium (Ca)	Proper cell division, elongation and wall development Reduce acidity. enhances immunity to plants through mechanical	Application should be dependent on soil test results Application should be done at planting	Chlorosis of young leaves, tips of leaves, curling of leaves, stunted growth

Macro Nutrients	Function	Application requirements	Deficiency symptoms
Magnesium (Mg)	Chlorophyll formation: It is an enzyme activator and a constituent of many enzymes; it helps in sugar synthesis; it helps starch translocation; enhances plant oil and fat formation and controls nutrient uptake.	Required in the early sprout development and vegetative growth stages to produce green tissue.	Leaf yellowing with brilliant colors and the excess causes calcium deficiency.
Sulphur (S)	Protein and amino acid synthesis for plants to utilize nutrients e.g. nitrogen. Produces chlorophyll. Makes the plants' resilience to disease e.g. *Streptomyces scabiei*	Required in small quantities (sources include soil organic matter, ammonium sulfate or potassium sulfate) to avoid its oxidation leading to acidity	Pale bright yellow young leaves.

Physical signs of nutrients deficiencies

During potato growth the farmer should be keen to observe any signs that could indicate nutrient deficiencies on potato plants. Some of the signs on potato plants that may indicate nutrients deficiencies and the corrective measures needed to remedy them. The physical signs of deficiency may not be conclusive hence a farmer may be required to sample soil from the site for testing and laboratory analysis.

Nitrogen deficiency (*Source: vikaspedia.in;ephytia.inra.fr*)


Phosphorus deficiency (*Source: alamy.com);* Zinc deficiency (*Source: naturepl.com)*


Potassium deficiency (*Source: Judith Oyoo/KALRO, Tigoni; alamy.com*)


Potassium deficiency (*Source: alamy.com; ephytia.inra*)


Calcium deficiency (*Source: alamy.com*); Magnesium deficiency (*Source: ephytia.inra*)


Sulfur deficiency (*Source: alamy.com*); Iron deficiency (*Source: Judith Oyoo/KALRO, Tigoni)*

Visual nutrient deficiency symptoms diagnosis

Nutrient deficiencies can also be identified by looking at usual symptoms of deficiency, either the upper or lower leaves as outlined in the chart in Figure 21. The chart can also be useful in identifying toxic or excessive nutrients levels. After picking the leaves from the lower part, go to the chart on your left side, if using upper leaves refer to the right side of the chart to identify the issues.

4.2.5 Soil and water conservation practices

To avert increased soil erosion and erodibility of soil due to changes in intensity of seasonal rainfall farmers should adopt practices that decrease the erodibility of the soil. Farmers should establish methods such as terraces, stone lines, vegetation covers (strips) on bare steep slopes vegetation strips, ditches, contour ridges, cutoff drains, gabion blocks, etc. These practices help reduce wind and rain erosion as well as gully and fluvial erosion. These are discussed below:

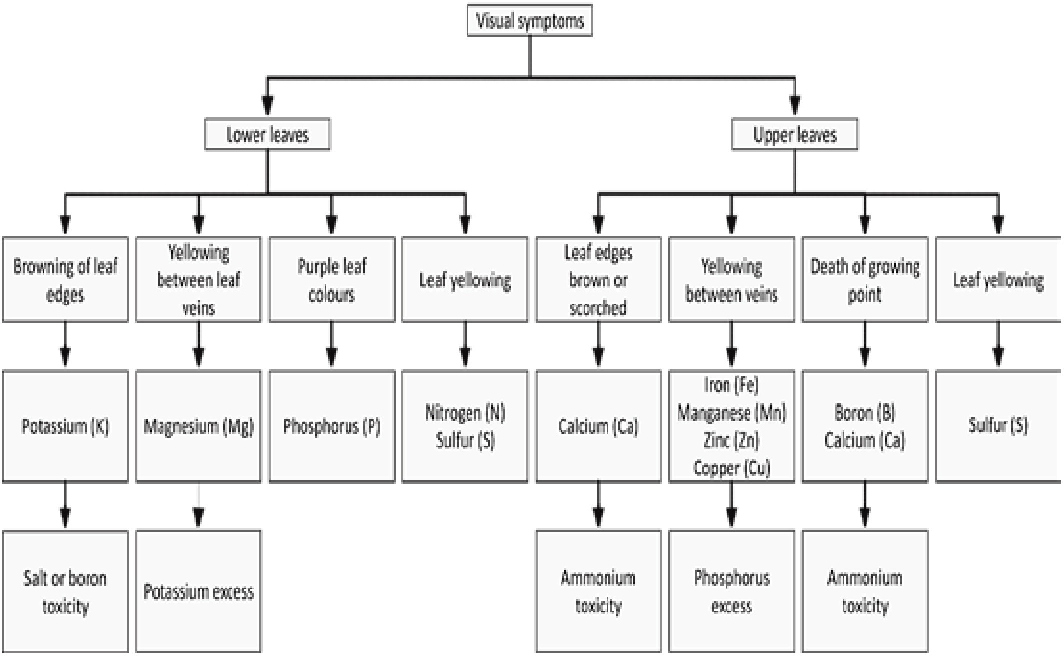


Figure 21: Simple visual nutrient deficiency symptoms diagnosis chart

4.2.5.1 Terraces

Use of '*Fanya juu* or '*bench'* terraces is both a water and soil conservation technique. The main purpose is to prevent surface runoff or water and soil loss and to make conditions more suitable for plants to grow. In addition, terracing contributes to 30% more soil organic matter compared to conventional methods

Benefits of terraces

- Improve the natural conditions for agricultural production;
- Decrease the rate of erosion thus reducing soil losses;
- Conserves and increases soil moisture; and
- Generate positive environmental benefits.

Disadvantages of terraces

Building terraces takes a lot of work and can be expensive and therefore may not be easily adopted by the female gender. Terraces can also be hard to maintain. So it may be better to choose a simpler, cheaper option such as grass strips and stone lines.

'Fanya juu' **terraces**

"Fanya juu" means throw soil uphill or upwards. In drier areas, *fanya juu* terraces may be built along the contour, and trees planted in the ditches. Grass planted on the ridges helps stabilize the ridges, prevents erosion, and can be used to feed livestock or as mulch. In high-rainfall areas, it may be better to build them with a slight gradient, so the water drains slowly away. Trees can be planted on the banks.

How to make *fanya juu* terraces

1. Dig a trench/drainage channel and throw the soil upwards to form a ridge of 40 cm -50 cm in height.
2. The trenches could be 10 m - 20 m apart depending on the steepness of the field.
3. Grasses or trees are often grown on the ridges to stabilize the bank, e.g. nappier grass (in higher rainfall conditions). Bananas can be planted in the trenches. (Figure 22)

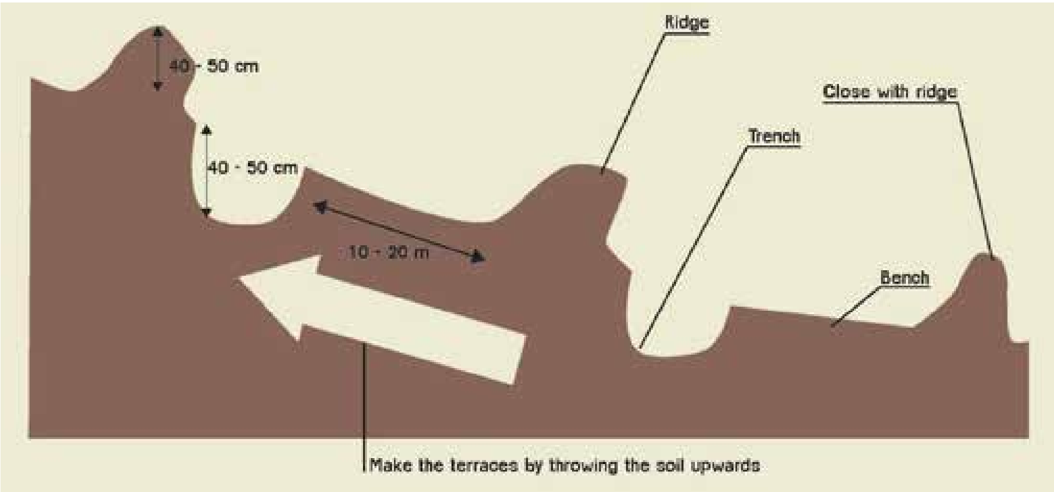


Figure 22: '*Fanya juu*' terrace *(Source Wekesa et al., 2014)*

Bench terraces

Bench terraces are a conservation structure which are platform like construction (looking like staircase on slope) constructed along the contour of the sloping land. The flat area between the terraces (the horizontal step) is used for growing crops such as grass and legumes (which capture water and nutrient runoff), and for animal feed. Close the terrace by growing grass on the last flat area at the bottom of the terrace (Figure 23)

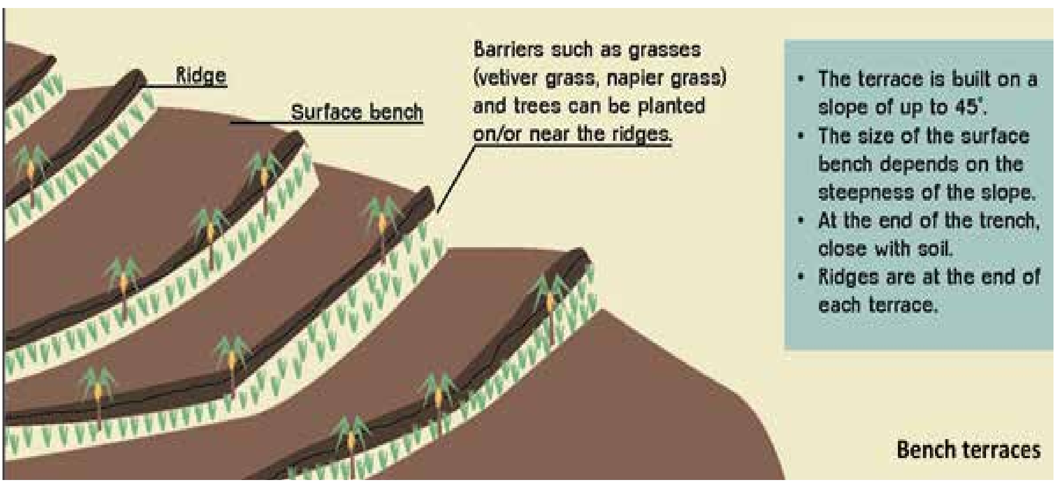


Figure 23: Bench terrace *(Source: Wekesa et al., 2014)*

4.2.5.2 Vegetation Strips

A vegetative strip is a strip planted with grass, shrubs or trees that runs across the slope. It slows water flowing down the slope and catches sediment that has been eroded uphill. Over time, soil may build up behind the strip, forming a terrace. Vegetative strips are cheap and easy to establish. Once they are growing, they are easy to maintain, and they can provide valuable fodder for animals. Conservation agriculture can be practiced on the land between the strips. You can cut mulch from the strips and use it to cover the land in between (Figure 24).

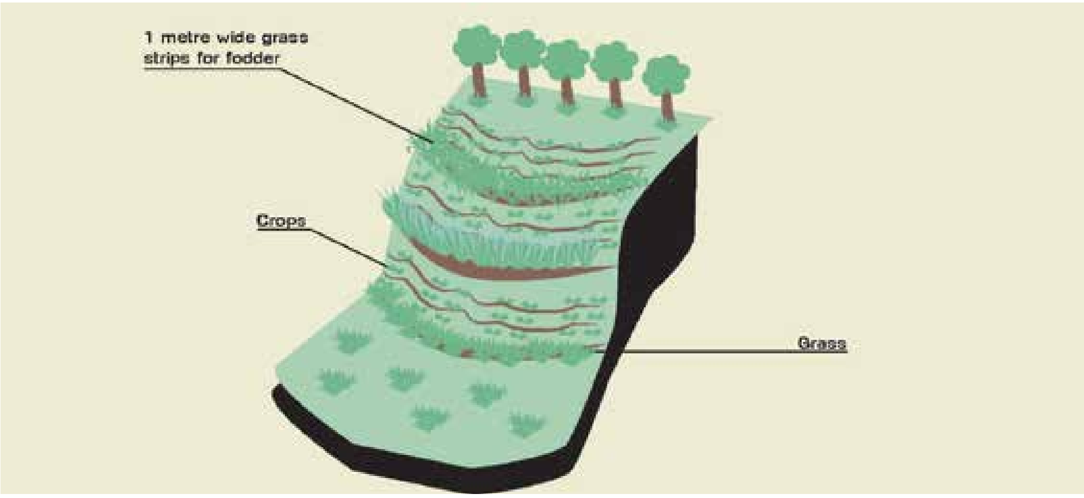


Figure 24: Grass strip *(Source Wekesa et al., 2014)*

4.2.5.3 Stone lines

Stone lines are used in both dry and humid areas wherever there are loose stones in the field. They slow down runoff, and soil gradually builds up behind them. The distance between the lines depends on the slope and how many stones are available. On 2–5% slopes they are often 25–50 m apart. You can make stone lines from stones in your field or bring them in by donkey cart or lorry. Line them up along the contour, and plant grass or trees on either side (Figure 25).

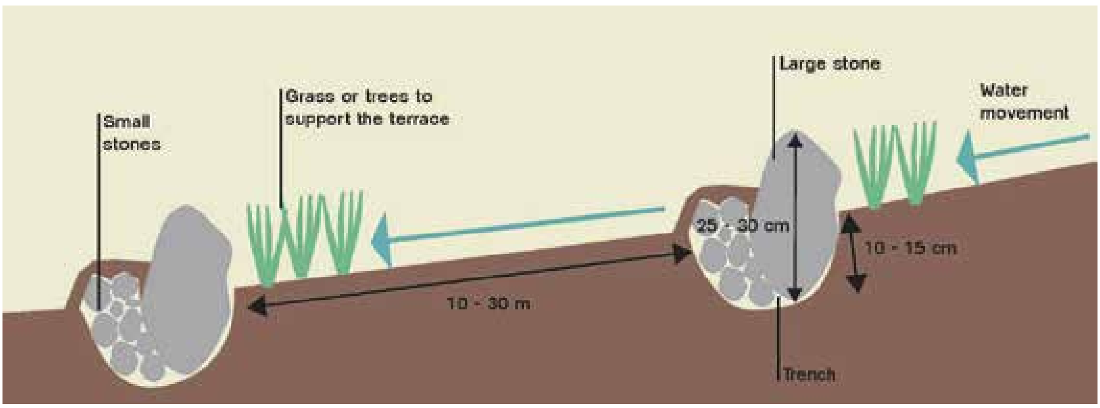


Figure 25: Stone terrace *(Source: Wekesa et al., 201*

4.2.5.4 Ditches

There are two types of ditches; contour ditch ‘retention’ and cut-off ditch ‘infiltration’ ditches.

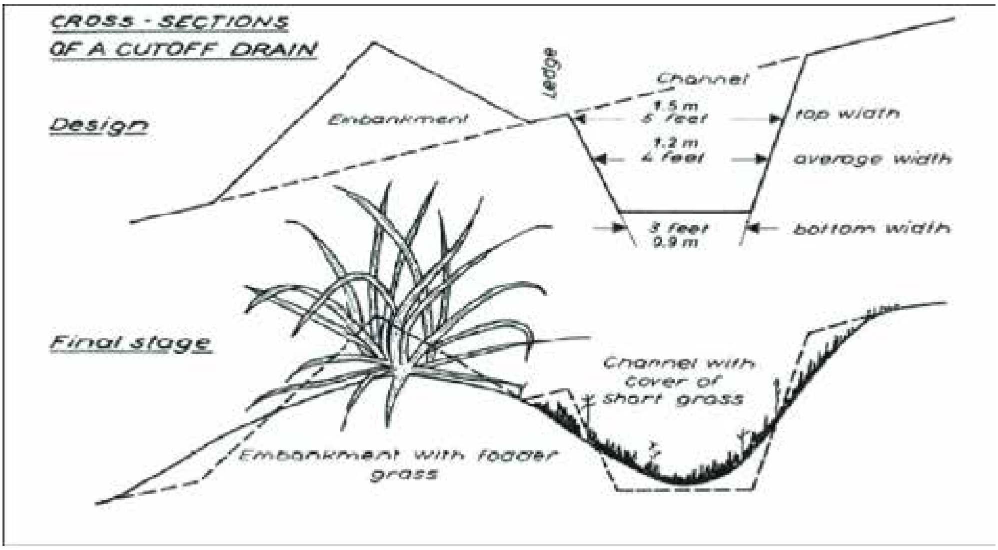
Retention ditches

Retention ditches are dug along the contour. They catch and retain incoming runoff and hold it until it seeps into the ground. They are often used to harvest water in semi-arid areas. Infiltration ditches are one way of harvesting water from roads or other sources of runoff. They consist of a ditch, 0.7-1.5 m deep, dug along the contour, upslope from a crop field. Water is diverted from the roadside into the ditch, which is blocked at the other end. Water trapped in the ditch seeps into the soil. On soils with an impervious layer (such as a hardpan) below the surface, the water does not sink straight down into the soil. Instead, it moves down slope just below the surface, towards the crops in the field below in Figure 26

Figure 26: Retention ditches and contour drainage ditches *(Source: Infonet Biovision)*

4.2.5.5 Cut-off drains

Cutoff drains are dug across a slope to intercept surface runoff and carry it safely to an outlet such as a canal or stream (Figure 31). They are used to protect cultivated land, compounds and roads from uncontrolled runoff, and to divert water from gully heads.



(Source: Researchgate.com)

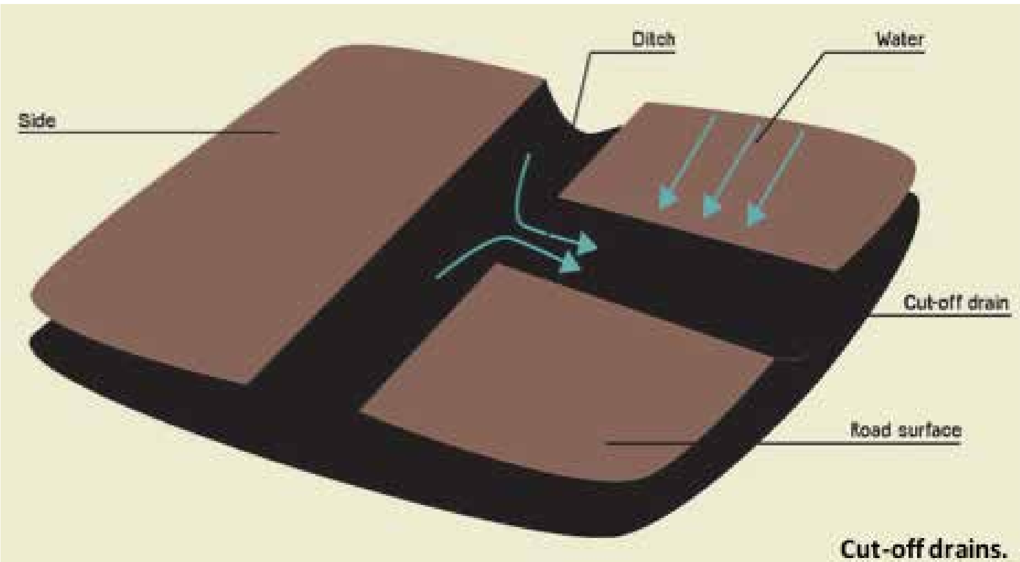


Figure 27: Cut-off drains (*Source*: Wekesa *et al*., 2014)

4.2.5.6 Water harvesting and storage

Rainwater harvesting describes methods of collecting and storing rainwater and various forms of runoff. It involves transfer of runoff water from a land area that is not cropped to supplement the rainfall received directly on the area where crops are grown. With increased rainfall shortage and unpredictability, dependence on rain fed agriculture may not prove sustainable hence farmers need to adopt water harvesting in potato growing systems.

Rainwater harvesting and storage might be the best CRA practice to make water available for irrigation. There are basically three methods of rainwater harvesting:

- **In situ rainwater harvesting**: collecting the rainfall on the surface where it falls and storing it in the soil; such methods include methods that prolong periods of soil moisture availability such as contour planting, mulching; methods that promote infiltration of water and increase surface storage into the soil such as retention of crop residues, ridging/ furrowing, terraces and stone lines
- **External water harvesting:** collecting run-off from rainfall over a surface (e.g. rock surface) and storing it elsewhere. External catchment involves transfer of surface run-off water using simple techniques such as water pans, semi-circular bunds, trapezoidal bands, on-farm ponds, contour furrows, grass strips and zai pits (planting pits).
- **Domestic rainwater harvesting**: this entails harvesting rainwater from roofs and storing it in plastic water tanks or underground concrete water tanks (Figure 28).

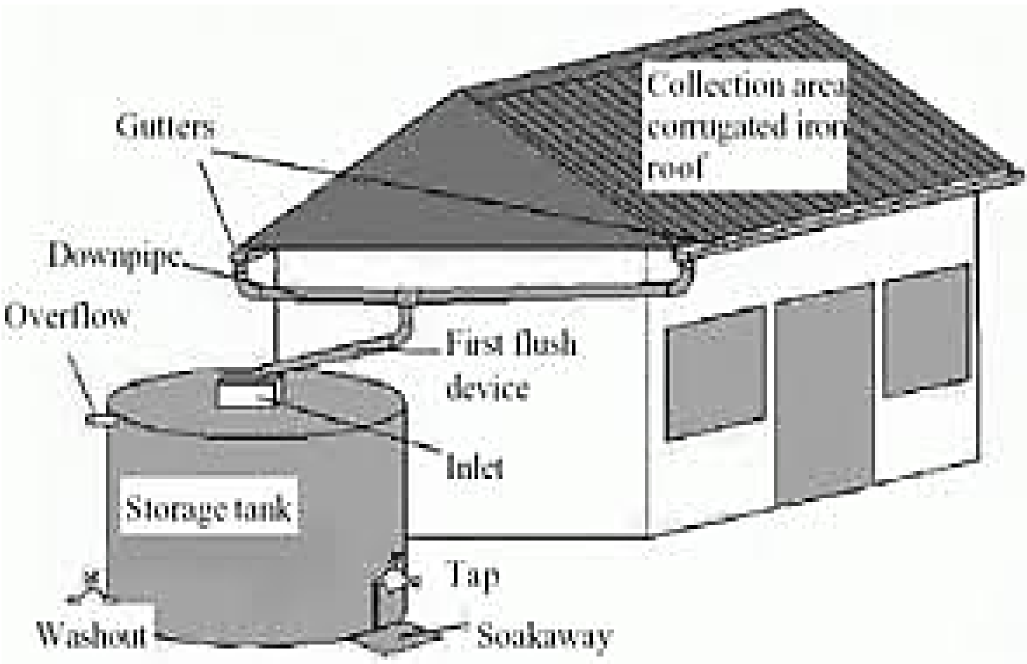


Figure 28: Domestic water harvesting *(Source: Wordpress.com)*

4.2.5.6 Irrigation

Irrigation is the use of collected or harvested water for agricultural purposes (Figure 29). The practice improves soil moisture and mitigates against drought, allowing crops to use the available water efficiently. For potato production, water is required for critical stages such as germination, flowering, emergence, tuber setting and tuber bulking. In this critical stage, farmers can use irrigation.

Figure 29: Harvested water for agricultural uses *(Source: cropmasters.co.ke)*

This section describes irrigation systems suitable for potato production. The choice of type of irrigation depends on the type of the crop, size of the farm, availability of water source and financial capital of the farmer. For CRA irrigation practice, the drip irrigation is recommended due to its efficiency in water use.

1. Drip irrigation

Drip or trickle irrigation, water is led to a farm through a pipe system. A tube is installed in the farm, next to the plants. Holes are then made in the tube at regular intervals, and an emitter attached to the tube is used to supply water slowly, drop by drop close to the plants so that only part of the soil in which the roots grow is wetted. This system is suited to small farms. Other types of drip irrigation include bottle irrigation, bamboo tube irrigation and bucket irrigation (Figure 30). Drip irrigation it is water efficient because it feeds directly into the roots; evaporation and runoff are minimized. Other benefits of drip irrigation include reduced growth of weeds, spread of diseases. Disadvantages of drip irrigation include installation is technical and costly; maintenance is intensive; difficult to maintain large open spaces; and requires a filtration system to prevent blockages.

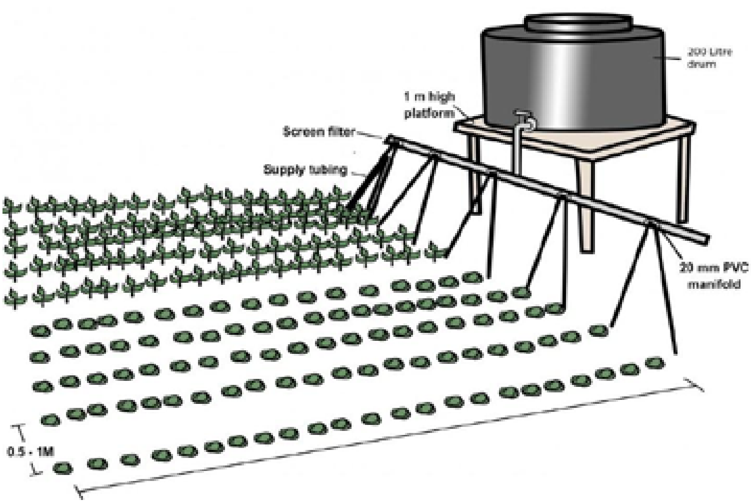


Figure 30: Bucket drip rivirrigation *(Source theorganicfarmer.org; ulis.com)*

2. Sprinkler irrigation

Sprinkler irrigation has sprinkler devices which spay water up in the air so that water breaks up into small drops which falls on the ground where crops are growing like rain droplets (Figure 31). This can cover larger areas, is used anywhere and maintenance costs are low. Initial costs for installation are high, uses a lot of water, blown off by wind, can spread diseases e.g. late blight and stores water in the canopy.

Figure 31: Sprinkler irrigation *(Source: oxfarm.co.ke)*

3. Furrow irrigation

Furrow irrigations made of small parallel channels along the potato field length in the direction of predominant slope. Water is applied to the top end of each furrow and flows down the field under the influence of gravity (Figure 32). It provides water to mass area; it is cost-efficient; it saves time and labour and; it has optimum water distribution rate. Disadvantages of furrow irrigation include costly in labour for making furrows; uses a lot of water; may lead to waterlogging; may induce anaerobic conditions; may spread soil borne diseases; hard to maintain water flow and may lead to land degradation (mineral surfacing phenomenon). If this irrigation is not done properly it might spread pests and diseases rapidly.

Figure 32: Furrow irrigation in a potato crop *(Source: Judith Oyoo, KALRO Tigoni)*

4.2.6 Tillage and residue management

4.2.6.1 Conservation agriculture (minimum, mulching and crop rotation)

Conservation agriculture is an approach that can sustainably manage agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. It seeks to achieve 'resource-efficient' crop production by using three core principles: the first principle is use of minimum soil tillage or zero tillage during land preparation which involves altering ploughing methods in order to minimize soil disturbance; the second principle is ensuring continuous soil cover with organic matter in the form of crop residues, cover crops and trees which helps to reduce soil erosion and the third principle is diversified crop rotations while considering use legumes which are able to fix nitrogen such as beans as well as trees which have the potential to add soil fertility as well as improve soil structure. Minimum tillage, when coupled with permanent soil cover with crop residues or growing plants and crop rotation, has the potential to increase potato productivity and thereby reduce the risk of crop failure. CA helps to promote infiltration of rainwater where it falls and its retention in the soil, as well as a more efficient use of soil water and nutrients leading to higher, more sustainable productivity. It also contributes positively to environmental conservation. CA contributes significantly to carbon sequestration through buildup of soil organic matter and reduced soil disturbance.

Challenges of conservation agriculture

- It requires mindset transformation of farmers which might take long
- Inadequate technical know-how on CA
- Crop residues for the mulch are also used for fodder and fuel
- Financial constraints
- Competition between use of cover crops for food diversity against on food cover crops

4.2.6.2 Crop residue management

Crop residues represent the bulk of the crop biomass left after removal of the main produce (such as potato stems and leaves, roots in the soils, weed plant residues etc.) from the field. Potato residues should be handled with care when they as used as mulch or decomposed and returned in the potato cropland. Such residues should not be used at all. This will minimize pathogen and pests to spread or building up diseases in the soil. Crop residues help in soil and water conservation, as well as for soil organic inputs,, reduce soil erosion, control weeds, pests and diseases, and are critical in building and maintaining soil nutrient stocks. Farmers should practice proper use of crop residues which are in form of straw, stalk, stubble, trash and which have varying uses including sources of plant nutrients either directly or after composting.

Trash lines Trash lines are created across the slope along the contour using previous seasons' crop residues (millet, maize and sorghum stalks), grasses, litter and other dead vegetative organic materials. Trash lines control surface runoff, soil erosion and enhance infiltration. Trash lines can be 1 m wide.

4.2.7 Agroforestry

4.2.7.1 What is agroforestry?

Agroforestry is a land use system of growing of woody perennials (trees, shrubs, vines and bamboos) deliberately alongside agricultural crops alongside other crops and/or livestock in the same land in the spatial and temporary arrangements. The main purpose of agroforestry is to increase food and nutritional security. Agroforestry trees to be grown with crops or pasture are socially accepted, economically viable and ecologically sound. Trees have both direct and indirect influence on soil fertility. Leguminous trees such as *Sesbania sesban, Leucaena leucocephala* and *Glicidia sepium* fixes nitrogen in the soil fertilizing the soil. This will lead to reduced use of nitrogenous fertilizers. Trees also sequester carbon dioxide purifying the air in the atmosphere. Hence agroforestry is a critical CRA practice that increase productivity, incomes, resilience and carbon sequestration. Potato growing areas are also good areas for avocado, macadamia, apple, bears, loquats, syzygium and passion fruit growing areas. Agroforestry approach can increase farmers' incomes and diversification of enterprises. Youth can engage in bee keeping, hive construction, cooking stove constructions and nursery production.

4.2.7.2 Agroforestry tree species

There are many agroforestry tree species farmers can grow in potato growing areas. Most selected agroforestry tree species to be grown by potato farmers are multipurpose or are grown for more than one benefits. Trees provide firewood and charcoal as energy source for most rural and urban communities. Some trees provide fodder, food, fruits, gums and resins, latex and medicinal products for animals and humans (Table 15).

Table 15: Trees commonly grown in potato croplands for Agro-silvopastoral system

No.	Major Function	Examples of Species
1	Firewood and charcoal	*Sesbania sesban, Jacaranda mimosifolia, Acacia xanthophloea*
2	Soil conservation	*Sesbania sesban Leucaena leucocephala* and *Glicidia sepium*
3	Timber and poles	*Grevillea robusta, Croton megalocarpus*
4	Fodder	*Calliandra calothyrsus*
5	Bee forage	*Markhamia lutea and Croton macrostachyus*
6	Shade	*Cordia africana*
7	Medicinal	*Warburgia ugandensis* and *Prunus africana*
8	Fruits	*Persea americana* (Avocado) and *Carica papaya*
9	Nuts	*Macadamia*

4.2.7.3 How a tree improves soil

- Improve the soil structure, texture and water infiltration (mulching and rooting systems)
- Weed suppression through mulching and upper canopy cover
- Contribute to nitrogen fixing and nutrient cycling in the soil
- Contribute to carbon sequestration and storage through tree growth and biomass

- Contribute to agro-biodiversity conservation
- Enhance vegetation soil cover by mulch and canopy
- Shelter belt against wind thereby controlling erosion

4.2.7.4 Agroforestry systems

Agroforestry system is how tree, crops and livestock as components are arranged in the cropping system. There are five major agroforestry system shown on the table 16 below.

Table 16: Major Agroforestry systems

No	Agroforestry system	Components
1	Agro-silvopastoral	Trees + Crop + Grass + Livestock
2	Agro-silviculture	Trees + Crop
3	Apiculture	Bees + Trees + Crop
4	Aqua-silviculture	Fish + Trees + Crop
5	Silvo-pastoral	Trees + Pasture + Livestock

4.2.7.5 Agroforestry practices

Agroforestry practice is the distinct arrangement of agroforestry components in space or time sequence. There are common agroforestry practices that farmers are adopting. Table 17 shows different agroforestry practices farmers commonly adopt.

Table 17: Common agroforestry practices

	Agroforestry practice	Description of the technologies/practices
1	Home gardens	Shade, fruit, fodder, ornamental and medicinal trees in the compound
2	Fruit orchards	Mango, orange, lemons, avocado, macadamia, *annona*, *syzigium*, pawpaw, jackfruits, mulberry, passion and white sapota orchards
3	Medicinal trees	Neem, *Albirzia coriara and Moringa oleifera*
4	Improved fallows	Soil conservation trees*. Gliricidia sepium, Tephrosisa vogelii, Tephrosia candida, Calliandra calothyrus, Leucaena trichandria and Sesbanaia sesban*
5	Shade trees	Provide shade for crops: Silky ork, *Macadamia, avocado, Cordia africana, Maesopsis eminii, Ficus natalensis, Trema orientalis, Polyscias fulva, Albizia chinnensis*
6	Fodder lots	Feeding livestock*. Gliricidia sepium, Calliandra calothyrus, Leucaena trichandria* and *Sesbanaia sesban*
7	Boundary planting	Marking boundary*: Hekea saligna, Markhamia lutea, Melia azadirach, Acacia sps, Jatropha curcas, Croton megalocarpus and Pithlobium dulce*

	Agroforestry practice	Description of the technologies/practices
8	Hedgerow/alley cropping	Planting of leguminous shrubs and trees for fertilizer and fodder. *Calliandra calothyrus, Gliricidia sepium and Leucaena spp*
9	Soil improvement with trees	Trees grown for: weed suppression, water infiltration, nitrogen fixing, nutrient cycling, carbon sequestration, biodiversity, soil cover, windbreakers and erosion control.
10	Woodlots	Timber, charcoal, firewood and conservation trees planted in one place as a farm forest.
11	Multi-storey cropping	Mixed short, medium and tall trees
12	Windbreaks	Mixed trees planted with crops to prevent wind destroying crops

4.2.7.6 Propagation of trees

Trees are propagated using seeds and buds. Different technologies used include direct seed planting, use seedlings, use of wildings, grafting, use of cuttings and regrowth or pollarding. Planting a seedling is called transplanting. Tree seeds and seedlings must come from a certified source such as Kenya Forestry Research Institute (KEFRI) and certified traders and nursery owners.

4.2.7.7 How to make a tree nursery

Sowing seeds certified tree seeds are sown in seed beds for germination. Sunken beds are used in dry areas as they conserve moisture. Raised beds are used in high rainfall areas as they drain excessive water.

Pricking out young seedlings: Seedlings are transferred from germination beds into containers or pots. The seedbed is watered and using a dibbler while holding the shoots, seedlings are removed and put into the water filled ¾ level container (Figure 33).

Figure 33: Pricking out of seedlings ***(****Photo: Amos Wekesa 2014****)***

Potting: This is the process of putting prepared soils (mixture of topsoil, sand and compost at ratio of 2:1:1) into the containers or bags for the purpose of raising seedlings (Figure 34).

Figure 34: Women potting seedlings *(Photo: Amos Wekesa, 2014)*

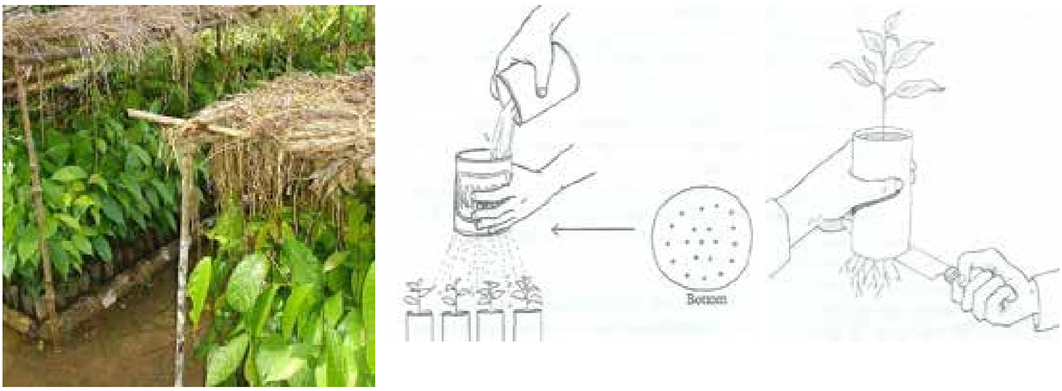


Figure 35: Pictures of showing seedling shading, watering and root pruning *(Photo: Amos Wekesa, 2016)*

Hardening off: Hardening off seedlings involves gradual preparation of seedlings for field conditions 2 - 3 weeks before planting. Include reduced watering frequency and removing shading to increase exposure of seedlings to sunshine.

Transplanting of seedlings: This is the removal of seedlings during rainy season from the nursery and transporting them to the field where they will grow to maturity as trees.

4.2.7.8 How to plant a tree

Should be done when soil has enough moisture and weather is cool especially in the evening. Seedlings should be watered until they establish. The holes should be dug at least 30cm x 30cm or 45cm x 45cm. The planting holes can be bigger in dry areas. Use the well decomposed animal and compost manure, mixed with fresh ash to improve its quality. Fresh ash keeps away termites. If seedlings were raised in polythene bags, transport them in their bags to the planting site (Figure 36).

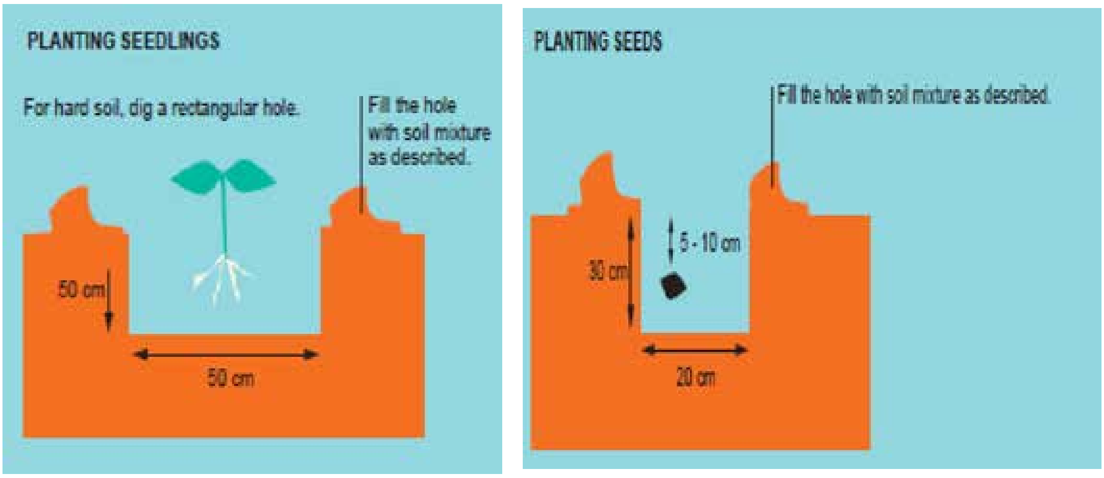


Figure 36: How to plant a tree *(Source: Wekesa et al., 2014)*

4.2.7.9 How to manage a tree

When trees are grown together with potato crops, they should be managed properly to allow mutual interaction between crops and trees so that good products are attained. Table 18 shows five major tree management practices undertaken under any agroforestry system or practice.

Table 18: Tree management practices

Management	Description
Thinning	Removing excess trees to create space for other trees to grow.
Pruning	Removing or cutting branches on lower part of the tree crown to reduce shading and increase growth of tree products and their quality.
Lopping	Trimming various sections of the tree e.g. removing extra branches to speed up growth of the round wood trunk for good timber.
Pollarding	Cutting the entire crown of the tree to harvest, to reduce shade for the crops nearby, increase regrowth or regenerate crown to promote growth of the trunk for fodder, timber and poles.
Coppicing	Cutting the entire tree to allow regrowth and create more branches for more tree products firewood and leaves for fodder. Many tree species have growth ability to re-sprout after the whole tree is cut.

4.2.7.10 Challenges of agroforestry

The following are some of the challenges affecting farmers adopting agroforestry practices:

- Inadequate technical know-how in agroforestry technologies
- Lack of certified germplasm (seeds, seedlings, scions, cuttings, buds and rootstocks)
- Scarcity of resources especially land and water as well as financial resources for inputs, labour and marketing

- Gender inequality in terms of land and tree tenure security among women
- Inadequate or lack of markets for tree or agroforestry products

In most cases, men are the custodians of land title deeds with limited user-rights extended to women and youth, thereby making it difficult for them to plant trees viewed in the community as 'marking own farm boundary'. In most communities, land is ancestral and communal in nature hence this limits majority of households to secure land tenure, thus limiting their ability for long-term investments such as agroforestry and planting fodder trees.

4.2.8 Renewable energy

Potato farmers can produce and utilize renewable energy to reduce stress on natural resources. Renewable energy sources are less polluting, cheaper and more efficient.

4.2.8.1 What is renewable energy?

These are energy resources and technologies they are non-depletable and naturally replenish. Producing and utilizing renewable energy enhance land productivity, conserve environment, improve health and enhance mitigation of GHGs. Also, renewable energy technologies save time, easy to make and use. If potato value chain players used renewable energy it can enhance productivity, build resilience and mitigate climate change impacts.

4.2.8.2 Renewable energy sources

In potato value chain tree planting, farm residues and solar energy sources can provide sustainable energy with reduced carbon footprints. Use of green energy sources will enhance irrigation and cooking. In potato materials such as haulms, peels and waste potatoes can be used to produce briquettes, biochar and biogas as well as other biomass produced as biofuels. Such energy can be used by hotels, traders and processors of potato. A list of forms of renewable energy found in the world to be extracted with different technologies are found in the table below. Table 19 shows sources and technologies of renewable energy potato farmers and traders can access for sustainable energy.

Table 19: Sources and technologies of renewable energy

Source	Technology	Types
Sun	Solar energy	Solar lights, pumps, cookers, solar irrigation kit
Plants (trees, crops and organic waste)	Biomass fuels	Firewood, charcoal, biogas, starch, energy crops, biodiesel, farm residues, ethanol, biochar and briquettes
Water	Ocean currents, waves, hydroelectric power	Grid Electricity
Air	Wind energy	Windmills, pumps
Geological/earth	Geothermal energy	Electricity

4.2.8.3 Sustainable energy technologies

Potato farmers can use diversified technologies to exploit renewable energy resources. Sustainable energy technologies include use of improved cookstoves, solar systems, fireless cookers and biogas. Locally there exist local improved wood-saving stoves that uses firewood, charcoal and briquettes such as rocket, lorena, chebukube, maendeleo, kuni mbili and upesi jiko. Wood saving stove is a suitable alternative to the traditional three-stone stove. The wood saving stove educes smoke and reducing health problems and conserving energy resources. Also, the use of fireless cookers exist that reduce use of fuel and solar equipment such as solar cook kit, solar oven, solar water purifiers and solar milling system. Fireless cookers, solar cook kits and solar ovens use energy from the sun or biogas, reducing the stress on trees caused by deforestation, and land degradation.

4.2.8.4 Challenges of renewable energy production

Some sustainable energy technologies are expensive during installation, purchasing and maintenance or repair phases. For example, solar cooking kit is expensive to purchase; biogas is expensive to install, and water requirements are high. Sustainable charcoal kilns are expensive to construct or purchase. Some cooking stoves are expensive for farmers and traders to purchase.

4.2.9 Potato harvesting

4.2.9.1 Dehaulming

This is the removal or destruction of the haulm (the plant part above the ground level) to allow the skin to harden and reduce damage to the tubers during harvesting. It improves the storability of potato tubers and prevents late spreading of the disease from the stem to tubers. For plants infected with bacterial wilt, it is too risky to assume that the infection has not spread to the tubers simply by removing the haulm. The infected plants should be removed totally (roots, stems and tubers) and destroyed.

When and how to dehaulm: It is done when the crop attains 100 – 120 days from emergence. De-haulm two weeks before harvesting when the crop has attained physiological maturity when at least 50% of the haulms have started to turn yellow. This can be done using hand tools or uprooting the entire stems from the ground resulting in less tuber damage as described below..

a) Cutting of the base of the stem: Use hand tools like slashers to cut off the stems at ground level. Even though this method saves on labor, it has limitations. Some varieties may start growing /sprouting after slashing. There is an increased risk of virus spread from infected to healthy plants, where the cuts above ground can act as entry points for plant pathogens, which may later spread to the tubers. Also, the tools used may spread disease pathogens from unhealthy to healthy plants during dehaulming.

b) Pulling off stem and roots: This involves stepping on the base of the plant with both legs such that the plant is in between your legs and pulling out the stem and roots carefully without exposing the tubers. This procedure is highly recommended but may be tedious and if not done properly, the tubers may be exposed to the sun and/or PTM attack. There should be minimal disturbance of the soil although ensure exposed tubers are covered to prevent greening and sun scalds which reduce the quality of tubers. The plant residues if not affected by pests and/or diseases may be used as mulch at that time to cover the tubers

c) Use of herbicides: Dehaulming may also be done by use of hebicides which usually kill the foliage and other vegetation around the potato crop. This facilitates harvesting, protects the machinery from damage and ensures no tubers are left in the field through tangling in the trash.

4.2.9.2 Harvesting process

Harvesting should ONLY be done when it is dry or during dry weather. It can be achieved manually by use of forked sticks, fork *jembes* or hoes or mechanically using tractor attached harvesters which dig into the ground and lift up tubers from the soils. Untimely, poor lifting and handling of potato tubers leads to high postharvest losses through bruising resulting to rotting of tubers. Potatoes tubers are highly perishable (easily deteriorate in quality) due to their high moisture content (about 80% water), and if not handled properly after harvesting one may experience 20-45% losses at harvest.

When and how to harvest: Determine if the plant has matured and is ready for harvesting, by first sampling and examining some tubers at random, rubbing to see if the skin peels off easily or it has hardened. This technique for determining tuber maturity and skin set is known as the 'Thumb Test"; thumb pressure and lateral force are applied to the skin. When the skin does not slip readily, the tubers are deemed to have achieved skin set and may be safely harvested. The following should also be considered:

1. Harvest when the soil is dry and make sure tubers are not rained on or made wet with wet soil.
2. Harvest when it is relatively cool with cloud overcasts.
3. Do not expose harvested tubers to sunlight by transporting harvested tubers to a shade to prevent them from greening or sunscalds, which would reduce their keeping quality and consumer acceptance.
4. Avoid harvesting when the soils are wet as it increases mechanical injuries and bruises.
5. When packaging into bags ensure you fill the bags halfway for ease of lifting and transporting from the farm.

Steps in harvesting by hand

1. Uproot/ lift the tubers by using handheld hoes or 2-pronged sticks after the haulms are completely dry.
2. Using sticks or fork jembes dig out any tubers that could be stuck in the ground along the ridges or furrows.
3. After harvest ensure the soil on the tuber is removed before transporting the tubers to the store because soil could spread diseases or pests in the store later. Also, soil restricts the movement of oxygen through the pile, inducing anaerobic conditions and consequent tuber rotting.

Mechanized harvesting

Used only when necessary. A mechanized harvester can also be used to harvest the tubers, and this saves on time and labour costs (Figure 37). Adequate skin set is crucial to prevent mechanical damage to the tubers. The machine should be used with care to avoid severe tuber bruising, which results as entry points for pathogens causing secondary infection besides lowering the quality of the tubers.

Figure 37: Mechanized potato harvesting

4.2.10 Post-harvest management practices

The post-harvest activities include harvesting, handling, packaging, transportation, sorting, grading, drying, curing, storage and marketing. Post-harvest losses may include rotting or waste of potato tubers that may render losses or waste of food, farm input, labour, investments and natural resources such as land and water. Climate change effects such as high temperature, excessive rainfall, and extreme weather events such as storms, droughts and floods are impacting on the capacity and abilities to minimize post-harvest losses in potato value chain. Also wasted potato through rotting contribute to generation methane (CH_4). Through proper post-harvest CRA handling management practices, post-harvest losses and generation of greenhouse gases will reduce. This section describes improved packaging and transportation, sorting and grading, drying and curing and storage as key major four sets of CRA practices that minimize post-harvest losses of potato.

4.2.11.1 Improved packaging and transporting

If the potato farm is far from the store or homestead, there will be need for packaging and transporting from the field using carts, wheelbarrows, pickups etc. Package the potatoes in bags weighing not more than 50 kilograms for ease of handling and to avoid damaging the tubers while transporting. During transport of ware potatoes, bruising should be avoided. This is done when the drop height is reduced meaning gently offload and place the bags carefully but do not drop from high heights of above 1m, containers are lined with rubber or a soft material to cushion the tubers from mechanical bruises and extreme temperature is avoided by enhancing natural ventilation. Ware tubers should be protected against unexpected rainfall.

4.2.11.2 Sorting and grading

Select and remove the damaged/bruised, diseased, deformed tubers and any other foreign material such as soil clods or mother tubers. All damaged and cut tubers should be removed after harvesting to discourage infestation by PTM and rotting in the case of cut tubers. Grading should be carried out to separate the ware size (>45mm), seed size (25 to 45mm) and chatts (<25mm). It is advisable that each bag is well labeled according to variety description and weight for ease of identification.

4.2.11.3 Improved drying and curing

Up to 80 % of potato tuber content is water and this needs to be maintained to avoid loss of weight and quality. A warm temperature of 18 to 20°C in the shed or holding area for 10 to 14 days before storage is desirable as it promotes wound healing and further skin set. Higher temperatures may favour curing but when the rainfall intensity is high and temperatures drop, curing process may prolong. In addition, excess soil that was stuck on tubers is given time to dry and fall off before the tubers can be taken into storage. The shed area should be well ventilated to allow good exchange of air and to achieve good temperature control. High humidity of 85 to 90% is essential for optimum wound healing and curing of the tubers. The shed must properly control rain and water runoff from wetting the tubers and should also be rodent proof.

4.2.11.4 Improved storage

The potato tuber is a living entity and it continues to respire in storage, this means that the starch is broken down to simple sugars and in turn they are broken down to carbon dioxide and water as they release energy for the tuber to carry on other metabolic functions. An effective storage management protocol will slow this process down but it cannot be stopped completely. When the process can proceed rapidly through rising temperature and low humidity, tubers lose water through the pores on the skin developing a shrivelled appearance and weight loss, leading to higher postharvest losses. If long storage period (longer than 5 months) is anticipated, the tubers must be stored at temperatures of between 4° to 7°C with 95% relative humidity in completely dark stores to prolong keeping quality. Good storage conditions should be disease free, clean, cool, dry, dark and well ventilated to: keep tubers alive, reduce deterioration through natural process of starch breakdown, reduce storage pest infestation and damage, and reduce storage loses through rotting, greening and increase tuber dormancy period. The store should be sprayed with appropriate pesticides to kill potato tuber moth or sprinkle actellic Super on tubers to protect them from pest infestation. Spread the tubers on crates and turn once in a day to prevent spoilage. Also, you can place *Mexican marigold* or Eucalyptus leaves and branches on the tubers to repel PTM infestation.

For seed potato storage, diffused light stores (DLS) made of wooden or bamboo off cuts and translucent iron sheets are used. The DLS can be made with shelves on the wall or with crates for placing the seed potato which are exposed indirectly to natural light and well ventilated used to control excessive sprout growth and associated storage losses of seed potato. Regular checking to remove rotting tubers should be done.

Other good post-harvest and storage practices to reduce losses and waste are listed below. Ensure:

- Tubers are largely kept in the shade to reduce field temperature of fresh produce;
- Tubers are field packaged, which reduces costs by improving the speed of post-harvest handling and reduces losses and waste
- The tubers are not brought into contact with oil, gasoline or chemicals that should not be applied;

- Containers are not too full if they need to be stacked on top of each other;
- Containers are not dropped or thrown beyond a height of 1m
- Containers in the field and storage are clean;
- Use storage areas with good air circulation and adjustable lighting.

4.2.11 Potato processing and value addition

Potato processing has been carried out in Kenya for a long time and is a climate smart potato process since it promotes longevity of potato while reducing postharvest losses. The potato processing industry is expanding fast with many large manufacturing companies entering potato processing. There is also a rapid growth of small processing companies that have gone into crisps and peeled, ready-to-cook potatoes that are supplied to hotels and restaurants. Despite the interest by both small and large companies there are many constraints that cut across all. The most conspicuous and pressing of this is a shortage of processing varieties and insufficient quantities of raw tubers for processing. Companies making crisps say they do not have a potato processing variety that suits their requirements. The only variety available is Dutch Robyn, which was introduced in Kenya several years ago. It is average yielding and susceptible to diseases, requires high spraying frequency, and as such is not very popular with farmers. KEPHIS collaborating with potato companies in Kenya have released several varieties suitable for processing such as Lenana, Konjo, Wanjiku, Unica, Makies, Manitou among others.

Many potato processors are concentrated in the urban centers due to proximity to physical infrastructure such as roads, running water and source of energy. As a result of the distance between the processing plant and source of raw materials, many processors cite high cost of production as most of them pay premium prices for supply of quality potatoes for processing. With supply sometimes being inadequate and unreliable, some processors are forced to either cut down on production by practicing alternate production days or shut down until supply stabilizes.

There are over 200 companies that process potatoes in Kenya. The processors can be categorized into large and cottage undertakings based on processing capacity. It is estimated that about 9% of the total potato produced in Kenya goes into processing; with 5% of the potato processed into chips, 3% into crisps, while 1% processed into various forms of snacks (Kaguongo *et al*., 2014). Industrial level processing of potatoes involves production of starch and snack foods such as chevda (a mixture of potato crisps, corn, legumes & pepper), potato sticks, frozen potato chips, dried potato cubes and potato flour. Other processing practices include dehydration which may not be variety specific.

4.2.12.1 Tuber quality for processing

The best attributes for high quality tubers include nutritional value, dry matter content and specific gravity (Table 20).

Table 20: Attributes of high-quality potato tubers for processing

No.	Factor considered	Quality attributes considered
1	Nutritional value	Well produced under good conditions (from heath soil, management practices, climatic conditions, good variety and post-handling and storage)
2	Customer acceptability	Nutritional value, shape, light colour, sweet taste, minimum oiliness
3	Status	Fresh throughout and respiring constantly
4	Pest and diseases	Disease free
5	Processing	High dry matter, lower water content, higher specific gravity, quick to process

Dry matter is an estimate of the potato solids when completely dried or water content removed. They include carbohydrates, fats, proteins, vitamins, minerals and antioxidants. Dry matter content determination is difficult to establish.

Specific gravity (SG) is the weight of the tuber compared to the weight of same volume of water. It is calculated by determining weight of tubers in air and subtracting weight of tubers in water. It is easy to measure.

Specific gravity (SG) = (weight in air) divided by [(weight in air) - (weight in water)]

The specific gravity of a tuber depends on the percentage of dry matter, the density of the dry matter and the percentage of air in the tissue. There is a close relationship between dry matter content and specific gravity and over the range normally observed in potato tubers (14% to 28%) the relationship can be considered as linear. Specific gravity is the key determinant of acceptability of a variety for processing. Varieties with high specific gravity are preferred for processing into crisps while varieties for chips expected to have lower specific gravity.

The processing technology should be done in a way that energy and water use is efficient, renewable energy technology is applied, wastes are reduced, reused and recycled and costs are reduced. Sources of energy should be renewable (briquettes or sustainable charcoal, firewood). The processing should enable women and youth to participate and be empowered. The stoves (fuel wood and electric) should be improved and efficient to conserve energy. Youth and women can be trained on how to construct efficient cook stoves and how to establish cottage industries for crisps and other potato products.

4.2.12 Potato marketing

4.2.12.1 What is marketing?

Marketing is about putting the right product at the right price, at the right place and at the right time. Trading in potato starts at the farm gate. Farmers are mostly price takers and play very little role in farm level marketing especially women farmers. The actual marketing activities of potato include pricing and promotion. Search for customers is carried out by brokers who are most of the times youth and men. Figure 38 is a chart showing the potato value chain in Kenya.

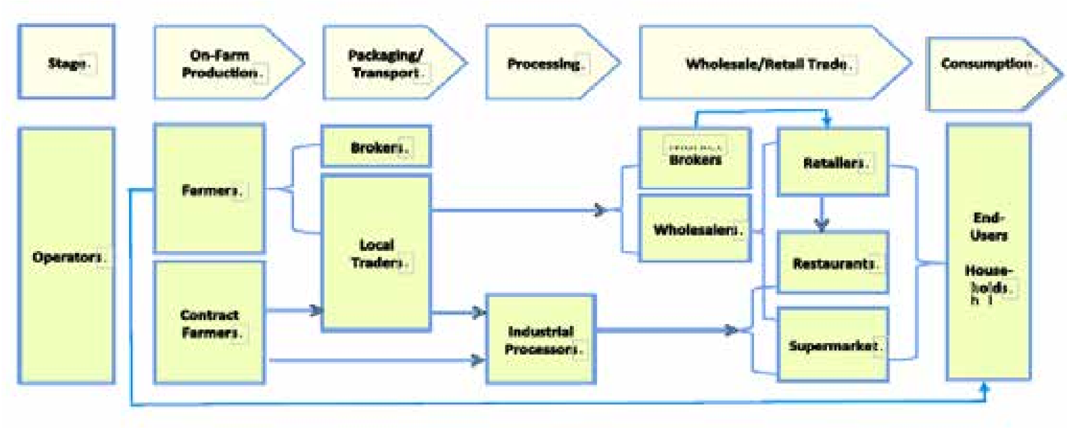


Figure 38: Potato value chain *(Source: Potato Market Assessment for Africa 2015)*

Poor roads also cause delays in transporting harvested potatoes which lead to spoilage and deterioration in quality forcing the farmers to sell at throw away farm gate prices. The potato marketing sector in Kenya is characterized by many layers. The potato regulations 2019 (https://npck.org/Books/THECROPS(IRISHPOTATO)REGULATIONS2019.pdf) have been passed to guide potato marketing. This regulation will also help to curb malpractices associated with the use of extended bags, quality assurance, marketing, licensing of actors in the potato value chain. According to the regulations, the unit weight for a bag of potato will be 50kg and not the extended bag of 110 kg.

4.2.12.2 Market requirements

Several varieties have multiple uses, which presents a greater marketing opportunity. For a variety to get good market, one must conduct a market assessment to determine which varieties and quantities to produce. In terms of climate resilience, variety should be one that does not require too much use of water, pesticides, and chemical fertilizers, have a long shelf/storage period and take too long to mature.

Understanding the characteristics of each variety such as suitability to agro-ecological zones, growth period, yields, tolerance to drought or diseases is equally important. This information can be obtained from the Potato Variety Catalogue, 2019 (https://npck.org/catalogue/). Once farmers have produced potatoes, they can market their potatoes through NPCK ICT platform- Viazi soko (Annex 3). Climate change impacts such as outbreak of pests and diseases might affect the nutrition values, health and safety of potato to consumers. Climate Resilient Agriculture practice such as IPDM that advocates for cultural, organic and biological and spraying with certified bio-pesticides as the last option and where necessary, would guarantee nutritive values, health and safety of potatoes to consumers. Table 21 provides a guidance to the trainer to start a discussion with trainees to identify practical constraints affecting their potato business.

Table 21: Factors constraining potato production

No	Constraint Factors	Description
1	Technical factors	**Biological characteristics**: multiplication rate of seed tubers is low, difficulty and costly, seed tubers are bulky and susceptible to pests and diseases, phytosanitary restrictions limit movements of germplasm, seed tubers and fresh wares, high fertilizer requirement and low utilization efficiency, post-harvest loss due to perishability especially in hot areas (lowlands tropics and sub-tropics). **Pest and diseases**: insect pests (aphids, tuber moths, leaf miners, Colorado potato beetle and Andean potato weevil), diseases (late blight, bacterial wilt, and potato cyst nematodes (PCN). Warming climate increases pests and diseases. **Lack of efficient seed systems**: There is inadequate multiplication and distribution of certified seed tubers, improved varieties, limited technical, managerial and expertise capacity and resources, farmer-based seed systems supply low seed quality.
2	Socio-economic factors	**High production costs:** capital-intensive for purchase of bulky seeds, fertilizers and pesticides. **Lack of credit:** Limited access to loans to invest. **Price instability**: there is frequency in abrupt changes of prices of inputs and potatoes, prices are seasonal. **Inefficient markets**: prices are determined by supply and demand, no measures to control overproduction **Limited access to processing and export markets**: foreign suppliers and trade barriers exist to limited local processing and potato products to penetrate export markets.
3	Policy and institutional factors	**Neglect of the potato value chain or subsector**: low implementation of potato strategy, little public investments for crop improvement, low budgetary allocation, value addition and marketing, breeding rights not respected, lack of incentives, certification of seeds and seed laws, poor infrastructure to store and access markets. **Inadequate capacity building**: there is low support for diffusion of technology, new varieties, methods and skills to growers. **Lack of support to farmer organizations and entrepreneurs**: support to farmer groups, associations, cooperatives and local entrepreneurship is lacking

4.2.12.3 Marketing Strategy

As a potato farmer there is need to analyze the potato market and prepare a marketing strategy and include it in the business plan before embarking on potato production. The strategy should be able to produce with the market in mind. To develop a marketing strategy, a market analysis/assessment must be done. The market analysis report should inform the farmer on the marketing information and marketing opportunities.

An understanding of the marketing mix is important. The marketing mix includes product, price, place and promotion.

The Product: Which is the right product for the target market. The market preferences for the buyers and consumers should guide production.

The Price: This is in consideration with the cost of production at farm level and the forces of supply and demand in the market. Annual price trends at farm gate level, aggregation (broker) level and at wholesale market level are not similar. Farmers should be able to determine their cost benefit ratios of marketing own product verses selling through brokers for them to make an informed choice.

The promotion: This involves market positioning of the product. Knowing the market players (aggregators, transporters, wholesalers, retailers, consumers and market managers) and their roles. Both men and women are usually engaged in packaging, processing, value addition and marketing. Identify competitors (other farmers) including an assessment of their strengths and weaknesses compared to your own.

The place: This involves evaluating the ideal locations were to sell the produce. Knowing the customer behavior and preferences in terms of variety preference, quantities demanded, quality required, payment modes and ways to converting potential clients into actual clients

Other key information required after analyzing market findings;

1. Lists of names and number of market players, their contacts and locations.
2. Generate average prices, volumes and trends.
3. Calculate value added by each player as potatoes moves to the consumer, challenges and opportunities.
4. Identify other value addition activities that can be done at farm level by small and micro enterprises
5. Identify what the local county government, policy makers or development organizations are doing to facilitate trade in potato and new interventions like cooperatives or collective marketing of produce, Funding or insurance at farm level for men and women farmers.

4.2.12.4 Market Assessment

Farmers "*produce and sell*" and not "*produce to sell"*. They plant potatoes because the rain season has come or because it has been grown by their neighbors and relatives and this tends to become as a "habit". The methods and tools (Annex 8) required to conduct the market assessment should be explored and used to develop a potato production and marketing plan. The aim is to increase income and provide business opportunities for an agri-preneur. The information gathered will help in marketing and assist in understanding;

- Where and how many potato buyers are there?

- What varieties do the buyers require from your potato farm and when?
- What prices are they offering and how are payments made?
- What volumes, quality, grade and quantity are required?
- What are the climate risks that may affect the market functions?

Steps in preparing market assessment

As the old age saying goes "*To fail to plan is to plan to fail*". Therefore, one needs to prepare as a form of planning to achieve the goal in market assessment.

- Identify and define the **problem** to be addressed by the market assessment exercise for example where can I sell my ware potatoes to get the best returns? -***how can you do this***? *-discussions with other farmers /farmer group/market players on their experiences in potato markets/Potato processors/Ministry of agriculture and county officials on new markets.*
- Identify and define **information required** to address the problem- market price trends, volumes and trends, supply and demand trends. ***How?*** *–collect and review reports from market management officers, Ministry of Agriculture extension officers or potato processors. NPCK ebsites*
- Choose the **method** to use to get market information. In focus group discussion, identify a group of consumers and prepare a checklist of questions for discussion and record the answers. If you choose to interview individual aggregators, wholesalers, processors or retailers or students prepare a questionnaire which has questions you need answers. ***How?*** *–consult /discuss with consumers or review assessment reports or use own experiences/target to get information from all groups. Men/women and youth*
- Decide on the target **market players** to reach in the assessment and how to sample them in order to get accurate information required –preferably aggregators, wholesalers, processors or retailers. ***How?*** *– review previous assessment reports or do rapid market walk assessment using observations, note books or check lists among others.*
- Decide on **approaches** to reach the respondents (telephone calls short message service, visits or electronic mail). H***ow?*** *-recall previous experiences or refer to other assessment reports.*
- Decide how you will **analyze** the information required (percentages, frequencies/ occurrences, averages or values like numbers, volumes, weights or prices). Prepare analysis programs e.g. simple tables, excel data sheet, SPSS template. ***How?*** *-recall previous experiences or refer to experts in the area.*
- Develop **questions** to ask or observations to make to collect the information required. ***How?*** *-refer to the market assessment objectives or refer to assessment reports.*
- Finalize and produce the **questionnaires or checklists** ready for field data collection
- Prepare **market assessment** charts for market information, price trends as presented in Annex 8.

Steps in market data collection

- Inform the market players early enough and set days for interactions. How –telephone calls, SMS, make pre interview visits.
- Prepare a data collection plan. How –list market players both women and youth and dates and time of the day to visit them and inform them
- Collect data. How – (record observations on camera or notebook), read out questionnaires and fill in data sheets or leave data sheets with market players to fill and collect them later. Its however important to allocate adequate time and collect as much information as you can by yourself. Most of the respondents are usually busy in the market so choice of time to collect data is also important and method that does not involve them a lot.

Steps in analyzing, concluding and action planning

Analysis is simply trying to make sense of the data collected. The results of the analysis makes one to arrive at a conclusion, a way forward and/or recommendation. The guiding steps depending on data collected are as follows

- Enter the data into simple analysis programs and generate information required e.g. average price trends, volume demanded, potato preferences among others
- Draw conclusions like "the best time to market potatoes because prices are usually highest is month Y and particularly to market player A. This is because player A has the best offer on prices, volumes and varieties". They also pay cash through MPESA which is safe for me
- Make simple recommendations like "I will produce for Player A because their prices are reasonable, and my farm can supply the volumes and varieties required. However, a storage structure is required to store for 6 months after harvest which is the best time to sell"
- Develop an enterprise business plan (what and how to produce and handle after harvesting)
- Enter into a supply contract or agreement with your market (supermarket, hotel, aggregator, retailer or processor.

4.2.12.5 Planning and budgeting for potato production

Farmers who produce potatoes at subsistence level produce for home use and only sell the surplus. While farmers operating at commercial level produce for the market and only consume what cannot be sold. Subsistence level farmers rely on low cost input strategies such as own saved inputs (seeds, remnant inputs from previous crops) or own family labor which are rarely documented. However commercial farming is different and requires planning and record keeping for success.

Most subsistence and semi commercial farmers do not know the relationship between land size, crops spacing, and optimal amount of inputs needed and yield. They underestimate on inputs and hence get lower yields and lower incomes. This is because they have inadequate skills in inputs measurement, operational records and application using local containers. They are the most vulnerable to climate shocks and risks since they have very low adaptive capacity

4.2.12.6 Potato Farming Business plan

To develop a potato production and marketing plan you need to seek answers to the following questions

- Do I understand the potato industry fully?
- What kind of inputs are required-types, volume, costs, suppliers
- Operational activities on how to run the business-land preparation up to harvesting and storage?
- The risks involved including pests and disease outbreaks, market change and many others
- Marketing activities-transport, processing, storage, insurance, financing?
- Profitability of the business and costs involved -how much to produce and when to sell?

Steps in costing production and marketing

Step 1: Understanding the common units of measurement on a farm

- **Units of measuring farm size**

Knowledge of units of measurement is important because a farmer will need to know how much input is required per recommendations from experts and per the farm size. It is also important for farmers to familiarize themselves with units of conversion of land area from acres, to hectares to meters square and vice versa (Figure 39).

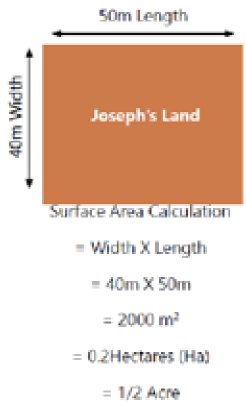


Figure 39: Units of measuring land sizes *Source: GIZ TOT potato production manual (2017a)*

- **Units of measure of volumes and weights**

Figure 40 presents simple standard units of measure of weight, volumes, time and agricultural work. Knowledge of these units will assist one in calculating how to measure or calibrate common containers and how to use them on the farm. The table is therefore useful for the farmer to accurately interpret recommendations for example on amount of water to use when spraying potatoes with fungicides.

Distance	Kilometre (km):1 km is 1,000 meters(m)
Length or width of a field	Meter (m) :1 meter is 100 centimetres(cm)
Surface area	Measured in meter squared (m2)
	Hectare (ha) :1 ha is equal to 10,000 m2
	1 acre : is equal to 4,000 m^2
	1 hectares: is equal to 2.1/2 acres
Yield per unit area	Yield per hectare: yield per 2.1/2 acres
	e.g. 4,000 kg/ha potatoes: 1,600kg/acre
Volume	Measured in Litres(L)
Weight	Grams(g)
	Kilograms(kg):1 kg is 1,000 grams
	Ton (T): 1 ton is 1,000 kg
Time	Minutes (min)
	Hour (h) = 1 hour has 60 minutes
	Man (M) = MD 1 day has 8 working hours
Agricultural work	Man day(MD): The work unit of an adult man in one day
	Example: Work on one hectare requires 10 man days(10 MD/ha)
	The work can be done by 1 man in 10 days or 10 men in 1 day

Figure 40: Units of measurements *GIZ TOT potato production manual (2017b)*

- **Common containers used on farms and their calibration**

In most cases recommendations like use of fertilizer application will be given in bags per acre or kilograms per hectare. There most likely won't be any weighing equipment to weigh the fertilizer in kilograms. Therefore, the containers likely to be used include tins or buckets or wheelbarrows and to some extend use of hands.

Figure 41 presents some of the basic containers and an approximation of their capacities in weights or volumes.

Input	Image	Local units of measurement	How much in metric units
Manure		Debe	10 kgs manure
		Wheel barrow	30 kgs manure
Fertilizers		Bottle top	2 Grams of fertilizer
		Fistful	50-60 Grams of fertilizer
		Hand full	70 Grams of fertilizer
		Kasuku	1-2 kilograms
20 litres of spray volume		Bucket	Make spray mixture for ¼ acre of potatoes field
20 litres of spray volume		Spray pump	Make spray mixture for ¼ acre of potato field
15 litre spray volume		Spray pump	0.18 of an acre or 720 meter square
Time		1 man hour (Man with jembe)	8 hours

Figure 41: Containers used in measurement in a typical farm *Courtesy A. Njogu field experiences)*

Step 2: Identify and list the inputs involved in commercial potato production

Seeds, fertilizers, agrochemicals, land, capital, machinery, transport among other inputs.

Step 3: Identify and list the operational activities involved in commercial potato production

These are operations that require labor, which for a commercial farmer may not be available as free family labor. You must identify the operations and how much labor they need and the cost of labor for example;

- Land preparation
- Sowing /planting
- Agronomic practices-spraying, weeding, ridging, fertilizing
- Harvesting, handling and storage.

Steps 4: Identify and list the marketing activities in potato farming

1. Transport of the products to the market
2. Packaging, labeling and other handling activities include carting
3. Storage
4. Insurance

4.2.12.7 Gross margin analysis

After identifying the inputs and operations for potatoes to grow, it's important to know whether the enterprise will result in income or loss. This will involve carrying out calculations on costs of inputs and operations and benefits accrued from sales of produce. This is also called Gross margin analysis (GMA) or cost benefit ratios in other circles. GM is the difference between total sales of an item (potatoes) and the total costs of producing that item.

That is GM = Total Sales **–**Total Costs of Production.

The key benefits of carrying out GMA are that it facilitates one to:

- Compare returns from two enterprises'
- Make decisions on inputs and costs in relation to expected returns or **net incomes**
- Decide on management of inputs and operations for optimal production and return

Step 1: calculating the total production costs –inputs and operational costs

Using the list of inputs and operations costs in step 3, generate the quantities of inputs required and cost of each unit. Then calculate the total cost of each input or operation and sum them up. These are the costs of production and an example is presented in Table 22 and 23.

Table 22: Inputs costs calculation

Input name	Units required	Average unit cost	Total unit costs
Seeds	200 kg	25.00	5,000.00
Fertilizer (DAP)	50 kg bag	2,400.00	2,400.00
Others			C
Total costs			7,400.00+C

Table 23: Operational costs

Operation name	Units required	Average unit cost	Total unit costs
Land preparation	4-man days	300.00	1,200.00
Applying fertilizer	1/8-man day	300.00	37.50
Others –weeding			D
Total costs			1237.50+D

Step 2: calculating marketing costs

If the farmer will also be engaged in marketing the produce rather than selling on the farm gate, marketing costs such as packaging bags will be incurred (Table 24).

Table 24: Marketing costs

Marketing costs	Units required	Average unit cost	Total unit costs
Gunny bags	4	30.00	120.00
Loading/offloading from truck	4	20.00	80.00
Fuel, cess, etc.			E
Total costs			200.00+E

Step 3: calculating the sales values

The sales value is the product of number of units of produce (potatoes) produced multiplied by the price on offer

Step 4: calculating the GM and net income

To calculate GM, deduct the inputs and operations costs from the GM (GM = Sales Value – Production Costs)

Net income is equal to the GM less that marketing cost. To calculate the net income, deduct the marketing costs from the GM

Net income = Gross margin – (marketing cost)

4.2.12.8 Record keeping

Records assist farmers to evaluate their farms past performance and plan for the next season's activities. The key records required for a potato enterprise include:

- Previous records of potato land used
- Soil tests results
- Rotational plans
- Activity calendars
- Financial records –inputs, operations, sales and GM tabulation
- Climate information records-rainfall and temperature
- Records of inputs used
- Records outbreak of pests and diseases or their trend

Table 25: Example of Cost - Benefit calculation

Potato Production Costs per Acre	Assume Harvest of 160 bags of 50-kg (8,000 kg) per Acre		
	Number of units	Cost per unit	Total cost
A. Land Preparation			
Land leasing (see explanation below)	0.5	8,000	4,000
Soil testing and analysis	1	2,000	2,000
Bush clearing	1	3,500	3,500
Ploughing	1	4,000	4,000
Harrowing	1	2,000	2,000
Ridging (furrowing)	1	2,000	2,000
Sub-total for land preparation			**17,500**
B. Inputs			
Seed potatoes	16	3,000	48,000
Transport of seed	1	1,000	1,000
Fertilizer (DAP/NPK)	4	3,000	12,000
Agrochemicals (fungicides/ insecticides)	1	8,000	8,000
Packaging materials			-
Sub-total for inputs			**69,000**
C. Labour			
Planting (& fertilizer application)	10	200	2,000
Spraying (crop protection),# of knapsack sprays	60	50	3000
1st weeding/hilling	8	200	1,600
2nd weeding/hilling	8	200	1,600
Dehaulming	4	250	1,000
Harvesting (Ksh 50 per bag)	160	50	8,000
Sub-total for labour			**17,200**
Unexpected costs (10%)			**7,070**
Total cost of production			**103,700**
Total Revenue			
Number of bags harvested/acre (50-kg bag) x average selling price	120	1,000	**120,000**
Total profit			
Revenue - cost:	**120,000 – 103,700=16,300**		

Land lease is usually on annual basis (i.e. 2 seasons) hence the figure of 0.5. Farmers buy the certified seed at a cost of Ksh. 48,000 (Unit price of Ksh. 3000/bag plus transport Ksh. 1000, (3000 X 16)+1000 seasons = Ksh. 49,000/season). On average a farmer does spraying of up to 10 times depending on the season with an average of 6 Knapsacks/acre depending on crop growth stage, (10 x 6). Average selling price per season has been calculated in Table 26. Assumption is done that after harvesting the bags are carried to storage area by the labour for harvesting.

Table 26: Break Even calculation for one-acre potato

Marketable Produce (ware potato)	Quantity harvested	Average Selling Price per bag	Cost per bag = total production cost/number of bags harvested	Profit per bag = Selling price-cost per bag	Total Profit = profit/bag x number of bags harvested	Break even yield =Total cost of production/ selling price
Calculation	120 bags	1,000	103,770/120	1,000-864.20	153.80*120	103,770/1,000
			864.20	153.80	18,456	**103 bags**

4.2.13 Integrated Pest and Disease Management (IPDM)

It is an eco-system approach to crop protection that involves use of appropriate measures to discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified as well minimize risks posed to human health and the environment. IPDM involves a combination of techniques such as preventive measures, biological, cultural, mechanical/physical controls and chemical controls. IPDM not only focuses on the existing pest but also on reducing pest invasion and emergence and keeping pest populations low. IPDM principles and practices are combined to create IPDM programs which are unique for every crop, pest and disease. CRA practice such as IPDM that advocates for cultural, biological and organic pest and disease control with certified bio-pesticides as the last option and where necessary, would guarantee nutritive values, health and safety of potatoes to consumers.

4.2.13.1 What are the goals of Integrated and Pest and Disease management programs?

The overall goal is to increase productivity, enhance resilience and mitigation of climate change in cost-effective manner. The following are goals of adopting IPDM in potato production.

- To eliminate or reduce initial pests.
- Reduce effectiveness of initial pests.
- Increase resistance of host plants (genetic or induced resistance).
- Delay onset of a pest situation/attack.
- Slow down pest spread and secondary pest cycles.
- Protect agrobiodiversity and environment
- Reduce/or eliminate use of pesticides
- Reduce greenhouse gas emissions
- Health and safe diets

IPDM is one of the CRA practices that is recommended for pest management in potato production. Table 27 shows the comparison between the conventional pest control measures and the integrated management approach through climate resilient practices in potato pest management.

Table 27: Comparisons of the conventional pest control and integrated pest management

Conventional pest control	Integrated pest management approach with climate resilient practices
Chemical intensive	Knowledge intensive. Use of integrated methods to reduce carbon emissions through manufacturing of pesticide and reduce to the environment, people and non-target organisms
Largely reactive to pest out breaks	Systematic program for long term control.
Less emphasis on prevention	Major emphasis on prevention of pest problems and reduction not complete wipe out.
Emphasizes killing pests directly	Emphasis modification of conditions that favor pest multiplication to discourage their multiplication.
Major purpose of scouting is to apply pesticides	Major purpose of scouting is to inspect, monitor and define sustainable control or preventive measures
General and widespread use of pesticides	Pesticide use is limited to only when it is necessary and based on scouting information

4.2.13.2 Preventive measures

These are practices which get rid of conditions that encourage establishment of pests. They include: early detection, quarantine, continuous research on climate change and pest relationships, breeding of good varieties adapted to the effects of climate change (heat and drought tolerant), policy and regulation, disease and pest surveillance, climate information services, early warning systems, agroforestry, climate change response policies, soil and water conservation. They also include education, training and outreach, mainstreaming climate change and CRA into agricultural policy formulation, crop insurance, monitoring and evaluation, proper storage facilities. They can be done at policy and implementation levels. Prevention measures are assumed to be cost-effective. This approach will reduce use of synthetic pesticides hence reducing GHG emissions and loss of agro-biodiversity. Stakeholders' capacity building, trainings and capital will determine the scaling up.

4.2.13.3 Field sanitation management practices

Sanitation or farm hygiene includes all activities that aim at eliminating or removing disease pathogens/inoculum present in the field, a plant, equipment, soil, water, worker and potato stores. Sanitation also prevents the spread of disease pathogens from unhealthy to healthy plants. Discipline, ethics and consistency are important aspects in sanitation for the benefits to be realized both in the field and in potato stores. The following sanitation management practices aim to reduce spread and transmission of diseases and pests.

- Implement crop rotation plans prepared.
- Plant barrier crops at recommended distances between different crops that share diseases or pests.
- Remove/uproot and destroy volunteer plants.
- Rogue and burn or destroy diseased plants preferably in a properly designated disposal pit.
- Disinfect tools, equipment and machinery before and after working in a potato field.
- Manage insect pests/ vectors well.
- Sort and discard potato tubers suspected of being infected.
- Avoid feeding livestock with potato tubers, peelings and potato plant remnants, if the livestock manure will be used on the potato farm.
- Maintain ventilation, diffused light and cleanliness in the stores or storing facilities
- Avoid the use of infected potato crop residues for mulching or composting into farmyard manure or feeding livestock and recycling the same as manure

4.2.13.4 Cultural control methods

Cultural control methods involve modification of the practices used to grow potato to prevent establishment, survival reproduction, dispersal of the pest. They include changing irrigation practices, proper and timely fertilization or crop feeding, good and early land preparation, use of improved varieties or indigenous varieties which are adapted to that environment, use of mesh screens, rogueing or pruning of infected plants and volunteers before flowering, intercropping with aromatic plants, crop rotation, timely planting, Timely earthing up, timely harvesting, field sanitation, disease free certified seeds and planting material, use of cover crops, minimum tillage and proper residue management. The methods use local materials, are cost-effective, reduce pest build up, and require local capacity for adoption. Too much pests and lack of time among farmers might discourage farmers using cultural methods. Zero carbon footprint would be achieved if other climate smart practices are adopted such as use of renewable energy in machinery during land preparation, proper manure handling to minimize evolution of methane, a GHG and proper soil and water conservation measures among others.

4.2.13.5 Mechanical control methods

Also referred to as physical control methods. They include killing the pests manually, blocking pests, use of barriers or screens for birds, use of traps, use of mulch for weed control, steam sterilization of soil grounds against pests and diseases and sweeping floors and benches to inhibit breeding ground for diseases and pests. It requires proper entry in growing areas by setting up signs showing moving from clean/new fields to old /infected fields, timely and weed control using climate smart practices such as mulching, hand picking and trapping. Local materials are used. It is less costly. Farmers training and understanding is easy. This method guarantees less pesticides use, low GHG emissions, healthy diets, agro-biodiversity, environmental conservation and resilience to climate change.

4.2.13.6 Biological control methods

These methods include the use of the pests' own natural enemies or naturally occurring organisms to suppress the pest population. Organisms can be predators, parasites, pathogens and competitors. Hence biological methods can be used in form of using natural predators and parasites or sprays with bio pesticides to inhibit the growth of pathogens or cause death to the pest. You can make biological sprays from pepper, neem (leaves, bark, seeds), *Tephrosia candida*, and many plants. The methods prevent use of pesticides hence reduced emissions, costs and agrobiodiversity loss.

4.2.13.7 Responsible Chemical control method

It involves intelligent use of chemical pesticides only when needed and after monitoring. There should a supportive role to farmers, ensuring safety to the people, to non-target organisms and the environment. Use the bait stations, spot sprays of certain weeds and judicious use of selective pesticides only when necessary. Use of rodenticides to kill rats, insecticides to kill insects, herbicides to control weeds and fungicides to kill fungi. These methods should be integrated with cultural, mechanical and biological. The farmers should aim at reducing pesticides with time (e.g. after 5 years farmer should stop use of pesticides completely). Careful use of pesticides will enhance safety, environmental protection, reduce GHG emissions, increase productivity and resilience to climate change. Reduced pesticides use will reduce costs of potato production and assure consumers of food safety. It requires training for farmers to have safe and proper handling of pesticides.

4.2.13.8 Pest scouting

A key tool in IPDM is scouting, also called crop monitoring. Its objective is to detect problems before any intervention is executed or before the problems get out of control. Only after a thorough scouting of the field is done, should we able to say which problem exists and to what extent. Proper scouting gives us information about the status of the crop and enables us to make informed decisions about the need to control any occurring pests, diseases and weeds. Crop scouting must be regular; at least once a week. This helps to detect a problem in the crop early and to act before serious damage occurs. Regular scouting also helps in the assessment of previous interventions related to control measures and overall management of the crop (i.e. whether they were effective or not, and if not, to understand what went wrong). Crop scouting methods include plant sampling, the use of insect traps (e.g. light traps, sticky yellow traps, or pheromone traps) and indicator plants (plants that are very susceptible and attractive to pests). To scout a crop, you need to survey the crop area to get an overview of the major problems and the general condition of the crop. This is achieved by methodical inspection of the crop, picking plants at random at sampling sites and recording the observations. Examine the sample plants from soil and roots to the top of the newest shoot, both the upper and lower sides of all leaves, flowers and fruits. Different sampling sites should be chosen each time the crop is inspected. The number of sampling sites on each stretch will depend on the crop and the size of the field. However, there is no fixed approach or protocol that is suitable for all crops and field sizes or shapes. As a guideline, try one of the patterns below and select the best one for the crop and field. Remember, scouting should be done on a regular basis, and more often after an infestation is detected. Examples of sampling monitoring techniques include the zigzag, multi-bisectoral and 'W' Patterns.

Problem recognition

For proper management, it is important for a farmer to know what a healthy crop looks like, and to be familiar with normal crop development in order to recognize the typical damage from pests and diseases during the various stages of crop development. It is also important to be able to differentiate a pest or disease damage symptom from a nutritional problem, a chemical burn, weather damage or physiological disorders. Proper identification of pests and diseases is the first and most major step in their management. A wrong diagnosis will lead to mismanagement and to increased losses and costs. If in doubt after consulting this manual, check with a qualified crop protection professional.

4.2.13.9 Record keeping

Proper record keeping is important. A logbook or record sheet should be kept of the problem type, locality and abundance or any other disorder observed. A record of all remedial measures taken should also be kept. If a pesticide is applied, all its details must be recorded (name, dosage, sprayer type, crop sprayed, target pest or disease, application date, weather conditions and name of the person applying the product). Such records are important in determining the effectiveness of interventions and will also be of long-term benefit in understanding the trends or patterns of arthropod pest and disease development in relation to weather conditions. In the short term, the records serve as the basis for decision-making on strategies for managing production problems.

Decision-making to optimize production

Once the field has been inspected, the farmer must decide what to do to optimize production. To make a valid, informed decision, the farmer must consider the following:

- Prevailing weather conditions
- Crop growth stage
- Yield potential
- Pest or disease stage
- Pest or disease damage
- Previous field records
- Results of interventions already implemented
- Presence and activity of beneficial arthropods such as bees, ladybird beetles, predatory mites, etc.

4.2.13.10 Safe handling of pesticides

Pesticides use should ensure their safe use to human and environment. This helps to avoid problems such as poisoning of humans or animals and pollution to the environment. Proper use of pesticides enhances food safety, health diets and disease control. Proper safe handling of pesticides includes safe transportation, storage, application, disposal and first aid measures (Table 28).

Table 28: Safe handling measures of pesticides

No	Measures	Description
1	Transporting	Should be separated from food, cased, extra bags, containers remain upright
2	Storage	Kept away from children and animals, locked cupboard or boxes, recorded, spillage removed, not stored in soda or juice bottles,
3	Application	Identify pest and appropriate pesticide correctly, seek extensions services, use only pesticide registered by Pest Control Products Board (PCPB), Correct rates used, label read, verified, Personal Protective Equipment (PPE) (helmet, hand gloves, apron, nasal mask, eye googles, gumboots, ear muffs etc), don't mix with hands, use the right knapsack sprayer and hire spraying service provider (SSP), observe the pre - harvest intervals and pre- entry intervals (waiting periods after applying pesticides)
4	Disposal	Read the label, purchase quantities needed, rinse empty containers before disposal, do not burn containers, no burying, no dumb in pit latrines, never use containers for other purposes, collect the containers and give recyclers
5	First aid	Inhaling – move to ventilated area with fresh air Skin contact – thorough wash with soap and clean water Eye contact – thorough Wash with clean plenty of dripping water for at least 15 mins Swallowed – rinse the moth with plenty of clean water, drink water or milk in plenty

4.2.13.11 Potato diseases identification and management

There are 11 important diseases affecting potatoes in Kenya. These potato diseases are caused by fungi, bacteria and viruses. Table 29 gives the summary of types, the causal agents, symptoms, mode of transmission and recommended IMP management measures. The major fungal diseases affecting potato include potato late blight, potato early blight, black scurf/stem canker and fusarium dry rot. The major bacterial diseases include bacterial wilt and blackleg or soft rot. The major viral diseases for potato include Potato virus Y (PVY), Potato leaf roll virus (PLRV), Potato Virus X (PVX), Potato virus S (PVS) and Potato virus A (PVA). Details of pests and diseases will be found on the annex 7 and a training aid will be developed to guide the trainer on potato pests and disease management.

Table 29: Summary of potato diseases and management practices

Type	Name	Agent of cause/ Spread	Symptoms	Management practice
Fungal diseases	Potato late blight	*Phytophthora infestans* (water mold)	Necrosis – death of tissues (leaves)	Certified seed potato and IPM practices such as cultural control-field hygiene practices chemical control- use of Mancozeb and Metalaxyl fungicides
	Potato early blight	*Alternaria solani*	Brown scorching spots	tolerant varieties and IPM practices such as use of certified seed potato
	Black scurf/stem canker	*Rhizoctonia solani*	Hard brown masses on tubers	IPM practices Certified seed potato, don't plant in soils with temperature < 7 °C or wet soils
	Fusarium dry rot	*Fusarium spp (dry rot)*	Necrotic spots outside and browning inside tubers	Certified seed potato, crop rotation of 4 seasons and store freshly harvested tubers in clean-ventilated store (15-21 °C and RH 90% for 3 weeks)
Bacterial diseases	Bacterial Wilt	*Ralstonia solanacearum*	Wilting, stunting and yellowing of the foliage	Crop rotation of up to 7 years and certified seed potato
	Blackleg or soft rot	*Pectobacterium atrosepticum*	Black lesions on infected stem and tuber	Certified seed potato, IPM practices such as crop rotation, ventilated cool storage

Type	Name	Agent of cause/ Spread	Symptoms	Management practice
Viral diseases	Potato leaf roll virus (PLRV)	Vector is Aphid *(Myzus persicae)*	Leaves curl upwards and roll inwards, tighten and turn pale green	Certified seed potato, rogueing, monitoring traps and control aphids with recommended insecticides
	Potato virus Y (PVY)	Vectors Aphid *(Myzus persicae)*	Yellowing of leaves and necrosis of tubers	
	Potato Virus X (PVX)	Vectors	Potato interveinal mosaic	
	Potato virus S (PVS)	Aphids (*Myzus persicae*) and *Aphis nurstatii*,	rugosity of leaf surfaces, vein deepening and leaf bronzing occur in susceptible cultivars	
	Potato virus A (PVA)	Aphids (*Myzus persicae*) and *Aphis nurstatii*,	yellowish or light green patches alternating with patches of very dark green is present on most potato cultivars	

4.2.13.11.1 Fungal diseases

There are four major fungal diseases affecting potato production in Kenya. The four types include late blight, early blight, and black scurf/stem canker. Their agents or fungi of causing fungal diseases include *Phytophthora infestans* (water mold), *Alternaria solani*, *Rhizoctonia solani* and *Fusarium spp* (dry rot) respectively. Potato blight diseases i.e. late blight and early blight are the most serious diseases affecting potato production in Kenya. Necrosis of tissues, yellowing and browning of leaves are the major symptoms and signs of fungal diseases. The sources of infected seeds, volunteer crops, neighboring fields, weeds, wind, irrigation splashes and rainwater. A two consecutive days' temperature of above 10 $^{\circ}$C and the relative humidity of above 90 % are conditions favoring blights to attack potatoes. Temperature and relative humidity increasing above 15 $^{\circ}$C and 85 % respectively can increase the spread of the blights. Blights can kill the plant and result into poor quality tubers. The management of blights include use of improved potato varieties such as Ke*nya Karibu, Kenya Mpya, Unica, Kenya Mavuno, Kenya Sifa, Tigoni* and *Asante* (Table 30).

Table 30: Potato varieties tolerating the late blight disease

Potato variety	Level of tolerance to late blight
Kenya Faulu	Good
Kenya Karibu	Good
Chaguo	Good
Kenya Mavuno	Good
Kenya Sifa	Good
Tigoni	Good
Asante	Fair

The seeds must be certified and obtained from registered seed merchants, clean and healthy up to planting time. Good cultural methods such as crop rotation, intercropping and field hygiene practices when used properly can control blight. Fungicides such as *Mancozeb* and *Metalaxyl* can be applied through IPM process when attack is detected earlier. Use of chemicals should be the last resort. Figure 35 shows transmission routes of fungi in the potato farms.

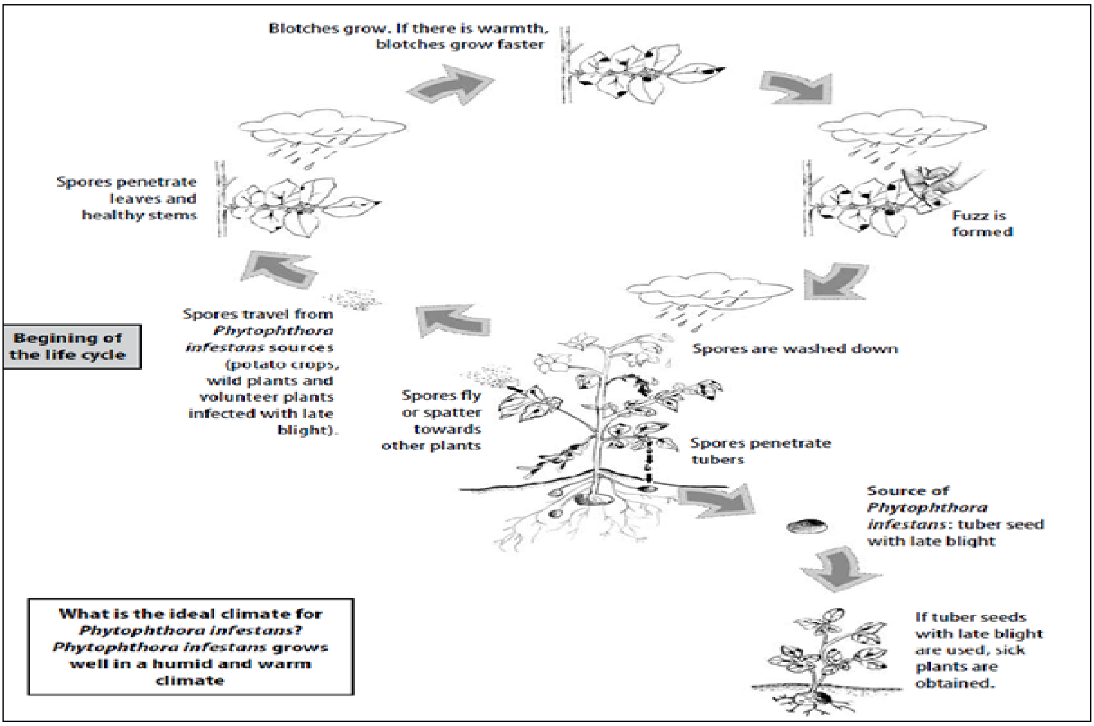


Figure 42: Transmission routes for fungus causing blight (Source *TOT manual GIZ 2017)*

Detailed management practices of blights are shown below on Table 31.

Table 31: Summary presentation of signs, identity and management of fungal diseases

Physical Symptoms of Disease	Name Fungal Disease	Management
		**IPM**
	Symptoms on underside of leaves	Use healthy seeds
	Local: Swahili English: Late potato blight Scientific: *Phytophthorainfestans*	Use varieties that have high levels of late blight resistance
		Always cover tubers with soil during hilling to prevent tuber infection
		Before harvesting destroy leaves that are infected
		Harvest tubers when fully mature
	Symptoms on potato stem	**Pesticides**
		Susceptible varieties- Spray mancozeb after emergency and every 7 days later
		Resistant varieties – spray *Metalalyx* when symptoms appear and alternate with mancozeb 7 days
	Local:	**Pesticides**
	Swahili English:Early blight on potato leaves Scientific:Alternariasolani.	Use preventive fungicides like *Mancozeb* as above

Figure 43: Black leg in the field stem becomes black rot and exudes slime

Figure 44: Symptoms of soft rot on potato tubers

4.2.13.11.2 Bacterial diseases

The major bacterial diseases attacking potato include the bacterial wilt *(Ralstonia solanacearum)* and the blackleg or soft rot *Pectobacterium atrosepticum* (Figure 36 and 37). Major symptoms of bacterial wilt include wilting, stunting growth and yellowing of the foliage while the blackleg include blackening of the stem and tubers. The major sources of bacterial causing agents include infected seeds or tubers, contaminated soils, infected crop residues, volunteer plants, contaminated irrigation water, contaminated tools, machinery or equipment and alternative hosts (weeds). The major transmission routes include wounds or damaged skins caused by tools, nematodes and insects.

Simple test for bacterial wilt

Procedure: Cut a 2-3 cm piece of stem from the base of the suspected plant. Discard the lower and upper parts; Tie the piece with the string provided; suspend the piece of stem horizontally in the glass full of clean clear water as illustrated in Figure 38 and wait for about 15 minutes. If the plant was infected with bacterial wilt, it will exude white smoky liquid / milky threads down wards from one or both ends of the cut stem.

Figure 45: Bacterial disease identification *Source: GIZ TOT potato production manual (2017)*

The main management of bacterial diseases include IPM approaches using practices such as crop rotation, use of certified seeds, controlling injuries, bruises and mechanical damage and control of nematodes. The store should be ventilated and kept cool. Before storage the tubers must be sorted to remove the cut and the rotting, dried and cured. The infected plants should be removed and destroyed away from the field through burying 3-4 feet deep in a pit or burying completely.

Figure 45 summarizes the key management practices of bacterial diseases.

Physical Symptoms of Disease	Name Bacterial Disease	Management
	Local: Swahili English: Bacterial wilt infected plant Scientific: *Ralstonia solanacearum*	IPM Plant disease free tubers Crop rotation Avoid injury of roots, stolons and tubers Control nematodes Destroy infected plants
	Local: Swahili English: Black leg bacterial on seedlings Scientific: *Erwinia caratova*	Avoid suspected seeds Avoid excessive soil moisture before harvesting Dry tubers before storage Proper curing of tubers

Figure 46: Summary presentation on bacterial diseases *Source: GIZ TOT manual (2017)(Photo KALRO Tigoni)*

4.2.13.11.3 Viral diseases

Viral diseases do not have cure and they don't kill potato. They gradually degenerate seeds and tuber yields. The major virus affecting potato include the Potato virus Y (PVY), Potato leaf roll virus (PLRV), Potato Virus X (PVX), Potato virus S (PVS) and Potato virus A (PVA). Viruses are transmitted through infected seed tubers by aphids and through contact (farm machinery, tools and equipment, plants, human movement). Transmission of virus is mainly through aphid feeding characteristics. The major symptoms of virus attack on potato include upward curling and rolling of leaves, yellowing of leaves and necrosis of tubers, purple-red discoloration. Figures 40 to 44 shows symptoms of viral infection on potato. The viral diseases management practices include use of certified seeds, rogueing diseased plants/tubers, use monitoring traps of traps and use of insecticides at the recommended rates.

Figure 47: Symptoms of PVY infection in tubers *(Photo: Judith Oyoo, KALRO Tigoni)*

Figure 48: Chlorosis or yellowing of foliage due to PVY *(Photo: Judith Oyoo, KALRO Tigoni)*

Figure 49: Mottling and shiny leaves due to PVA *(Source: (www.teagasc.ie/Crops/Potato/knowledge transfer)*

4.2.13.12 Potato Pests

The common important insect pests affecting potato include aphids, cutworms, PMT and nematodes as well as white flies and *Tuta absoluta*. Insect pests especially aphids also transmit viral diseases from attacked plants to healthy ones. The insect pests affect physical quality of tubers and accelerate entry of pathogens. The temperature rise as a result of climate change is the major cause of outbreaks of insect potato pests. With rising temperature, lifecycles of insects become more increasing population and severity of attack on crops. Migratory patterns, host –insect populations and natural enemy populations may respond differently to changes in temperature and rainfall. There will be intense impacts on insect management strategies with changes in climate. Insects will expand their geographic ranges, increase reproduction rates and over wintering process.

4.2.13.12.1 Aphids management practices

There are three types of wingless or winged aphids namely *Myzus persicae, Aphis gossypii* and *Macrosiphum euphorbiae* affecting potatoes. Aphids are suckers, damage leaves, flowers, stems and sprouting by sucking the sap which is plant nutrients and they are also vectors of viral diseases. This will cause curling or stunting of net growth. Sticky leaf or honey dew secretion are signs of aphid infestation. The major economic effect results when aphids transmit and spread diseases. The biological control of using natural enemies such as lady birds' beetles (coccinelidae), birds and wasps can keep the population of aphids under control. Crop rotation, use of certified seeds, farm hygiene, rogueing and as a last resort use insecticide.

4.2.13.12.2 Cutworms management practices

There are three major species of cutworms. They include *Terricolous cutworms* (develop in soil), *defoliator cutworms* (develop on leaves) and stem *borer cutworms* (develop in the stems). They are very active at night and hibernate during daytime. Females lay on grass or weeds and eggs hatch in 5 to 10 days. Cutworms attacks young plants (seedlings) by cutting stems at the soil level. The damaged points become entry points of pathogens especially bacteria that cause soft rot. The plant cover is reduced or emergence of plants from the soil fail. The management practices include regular scouting and use of contact or systemic pesticides.

4.2.13.12.3 Potato Tuber Moth (PTM) management practices

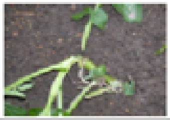
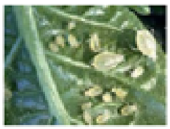
Potato tuber moth (PTM) *Phthorimae operculella* infest tubers while in the field and store. No potato variety is resistant to PTM attack. The warm and dry weather favors the insect. Rising temperature will increase its infestation or outbreak. The larvae worms of the moth bore through stems, leaf petioles, shoots and tubers. They cause transparent blisters and move into the stem tissues causing death. The larvae burrows through the cracked soil and enter to the tubers through the eye. The most common way of larvae entry into the tuber is when the moth lays eggs direct on the exposed tubers. The larvae create tunnels and excreta on tubers enhancing rotting of the tubers or leading to infection with dry rot and soft rot.

The PTM management practices include covering soil well, selecting a variety that sets its tubers deep in the soil, farm hygiene, sorting tubers, applying Eucalyptus or *lantana camara* as repellants, store tubers in the diffused light stores, early and proper earthing/ hilling and use dusting insecticides to tubers in the store.

4.2.13.12.4 Nematodes management practices

There are two major types of nematodes which are endoparasite. They include the Root Knot Nematodes (RKN) and Potato Cyst Nematodes (PCN). The RKN include M*. arenaria, M. hapla, M. incognita and M. javanica* while PCN include *Globodera rostochiensis* and *Globodera pallida.* Nematodes attack roots and tubers. The attacked parts develop knotty swellings and galls. Nematodes cause poor plant development and stunted growth, the leaves (yellowing) premature early and fall off and wilt particularly during hot periods and the affected plants appear to be in patches which are yellowing. The lesions created, creates avenues for bacteria and fungal infestation of the crop. Nematodes are spread by planting infested seed, or from soil washed down slopes or after sticking to farm implements and foot ware. They may also be spread by irrigation water. The nematodes are most serious on light, sandy soils and in furrow irrigated areas. The management practices for RKN include crop rotation, long fallow periods on affected soils, planting of trap crops such as mexican marigold, soil sterilization, use of tolerant/resistant varieties and use of soil nematicides. Management practices for PCN include early and proper preparation of the land, use of certified seed potato free of PCN, soil testing, crop rotation (5 years or 10 seasons), farm hygiene, use night shades to trap and burning of both trap and infected plants and bio-fumigation. Additional information on potato diseases and pest can be found in the training kit of pests and disease and is provided in Annex 7.

Table 33: The signs of the common pests, their identity and management options

Signs of Pests /Pest Damage	Name of Pests	Management Options
	Local	**Pesticides**
	Kiswahili	Spray with Alphacypermethrin or Dimethoate at 30-40 mls per 20 liters water)-10 days after germination
	English:cut worm	
	Scientific: *Agrotis spp*	
	Local	**IPM**
	Kiswahili	Rogue destroy infested plants
	English:adult aphids	**Pesticides**
	Scientific: *Myzuspersicae*	Spray with Alphacypermethrin or Dimethoate at 30-40 mls per 20 liters water
	Local	**IPM**
	Kiswahili	Examine seeds before use
	English: Root knot nematodes	Rotation with brasiccas
	Scientific: *Meloidogynejatvanica* and *Mincognita*	Spray Bio nematicides
		Chop brasicca crop residue and mix with soils
		Long fallow periods
		Destroy crop residues
		Removal of volunteer plants
	Local	**IPM**
	Kiswahili	Crop rotation
	English: Potato tuber moth larvae	Use clean seeds
	Scientific: *Phthorimaeoperculleld*	Hilling
		Destroy infested tubers
		Use moth repellents in store
		Store potato in a store with diffused light
		Pesticides
		Spray with Alphacypermethrin or Dimethoate at 30-40 mls per 20 litres water
		Spray store walls and floor as below
		Spray potato tubers in store *Diazinon*,

Source: GIZ TOT Manual potato production (2017a)

4.2.13.13 Judicious use of pesticides

Pesticides (insecticides, fungicides, miticides, bactericides, herbicides and nematicides) should only be used as a last resort, when other measures have failed to maintain pests at acceptable levels. When pesticides are needed, preference should be given to IPM-compatible selective pesticides that have little or no effect on natural enemies. These include bio pesticides and botanical pesticides (those derived from plants such as the neem tree). Neem-based pesticides are effective for the control of a broad range of pests (insects, mites, fungal diseases and nematodes) and are not usually harmful to natural enemies. However, products based on neem oil have stronger side effects on non-target pests than do oil-free products. Amending the soil with neem leaves or neem cake is a common method used against root-knot nematodes. Neem-based products deter feeding in many insects. This is particularly important in the case of vectors of viral diseases such as aphids and whiteflies. Since neem products do not have a “knock-down effect” and take longer to kill insect pests compared with synthetic pesticides, many small-scale farmers perceive them as not being effective. Therefore, farmers should be informed about the mode of action of neem products.

When using pesticides, the instructions on the product label must be strictly followed. This includes using the right product for the target problem; safe handling and storage of pesticides; use of protective clothing when spraying; use of equipment properly calibrated and maintained; use of the right dosage and application frequency; proper record keeping; and proper disposal of pesticide containers. Children, and pregnant or breastfeeding mothers must not be allowed to handle pesticides.

4.2.14 Potato stakeholders

The key stakeholders in the potato value chain are farmers (women, men and youth), input and service providers, extension agents, researchers, academia, aggregators, market off takers, National and County governments, and private sector organizations like NPCK, development partners such as GIZ among others (see figure 5). Farmers with an interest to venture into sustainable potato production are advised to consult with such stakeholders for several reasons. First is to have a better understanding of the distinct functions along the value chain and what each actor is doing or can offer support in service. Secondly, the stakeholders have in their possession experiences and insights on challenges and potentials of the value chain and lastly, the stakeholders have knowledge of the various value chain actors and can easily link one to the network hubs. Stakeholders should carryout sustainable potato activities along the entire value chain using good agricultural practices and inclusive approaches to increase productivity, resilience and mitigation of climate change. All stakeholders should be concerned about reducing use of pesticides and chemical fertilizers so that environment and biodiversity is conserved

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ANNEXES

Annex 1: Percent daily nutritional value from potato tuber

Potato (Baked, Flesh with Salt): Percent Daily values are based on a 2,000 calorie diet				
	1 Cup (122 g)		2 Cups (244 g)	
	Nutrients	% Daily Value		% Daily Value
Calories	113	5.65%	227	11.35%
Total Fat	0	0%	0	0%
Cholesterol	0	0%	0	0%
Sodium	294 mg	12%	588 mg	25%
Total Carbohydrate	26 g	9%	53 g	18%
Fibre	2 g	7%	4 g	15%
Sugars	2 g		2 g	
Protein	2 g		5 g	
Vitamin A		0%		0%
Vitamin B_1 (Thiamin)	0.13 mg	9%	0.26 mg	17%
Vitamin B_2 (Riboflavin)	0.03 mg	2%	0.05 mg	3%
Vitamin B_3 (Niacin)	1.7 mg	9%	3.4 mg	17%
Vitamin B_5 (Pantothenic acid)	0.68 mg	7%	1.4 mg	14%
Vitamin B_6 (Pyridoxine)	0.37 mg	18%	0.73 mg	37%
Vitamin B_9 (Folate)	11 mcg	3%	22 mcg	5%
Vitamin B_{12} (Cobalamin)	0 mcg	0%	0 mcg	0%
Vitamin C	15.6 mg	26%	31.2 mg	52%
Vitamin D	0 mg	0%	0 mg	0%
Vitamin E	0.05 mg	0%	0.01 mg	0%
Vitamin K	0.37 mg	0%	0.73 mg	1%
Calcium	6.1 mg	1%	12.2 mg	1%
Iron	0.43 mg	2%	0.85 mg	5%
Magnesium	30.5 mg	8%	61 mg	15%
Phosphorus	61 mg	6%	122 mg	12%
Potassium	477 mg	14%	954 mg	27%
Zinc	0.35 mg	2%	0.71 mg	5%
Copper	0.26 mg	13%	0.52 mg	26%
Manganese	0.2 mg	10%	0.39 mg	20%
Selenium	0.37 mcg	1%	0.73 mcg	1%
Water	92 g	75.4%	184 g	75.4%

Annex 2: Uses of potato tubers in Kenyan market

Use	Suitable varieties
Table	Shangi, Kerr's pink, Acoustic, ambition, Annet, Arizona, Arvona, Asante ,Carolus , Challenger, Chulu, Connect , Derby, Desire, El Mundo, Evora ,Faluka, Jelly,Kenya Baraka, Kenya Karibu, Kenya Mavuno, Kenya Mpya, Kenya Sifa, Konjo,Kuroda, Lady Amarilla , Manitou , Mayan Gold ,Milva ,Musica , Nyota , Panamera ,Rodeo, Royal ,Rudolf, Sagita, Sarpo Mira ,Saviola , Sherekea , Shifra , Tigoni, Toluca , Unica,Voyager, Zafira,
Chips	Rosalin Tana , Wanjiku, Shangi, Sherekea , Annet ,Arizona, Arvona, Carolus, Caruso,Challenger, Chulu , Connect , Derby, Desire , Jelly, Kenya Baraka, Kenya Mavuno, Kenya Mpya, Kenya Sifa, Kerr's pink, Konjo, Kuroda, Lady Amarilla , Laura ,Lenana, Manitou , Markies , Mayan Gold , Musica , Royal , Rudolf, Sagita, Sarpo Mira, Toluca , Unica, Voyager,
Crips	Wanjiku, Sherekea ,Caruso, Chulu, Derby,Destiny , Dutch Robijn, Kenya Karibu, Kenya Mavuno, Kerr's pink, Konjo, Lady Amarilla , Lenana, Markies , Purple Gold ,Rumba , Rudolf, Sagita, Taurus, Toluca , Unica,
Dehydrated products	Caruso, Royal , Sarpo Mira,
Mashing	Kerr's pink, Kenya Chaguo, Kenya Dhamana,
Frozen chips	Arizona, Tigoni,

Annex 3: NPCK Viazi Soko platform

VIAZI SOKO: A Digital marketing platform for seed and ware potatoes

HOW TO REGISTER

1. Go to your mobile phone messaging service, type: NPCK #REGISTER#Your Name #Your County and send to 22384
   EXAMPLE: NPCK #REGISTER #ESTHER KAMAU #NAKURU
   Note:
   - There is a space between NPCK and the first #.
   - Use at least two of your names separated by a space.

EXAMPLE:
NPCK #ANDIKISHA #ESTHER KAMAU #NAKURU

2. You will receive a feedback confirming your registration 'Welcome to NPCK SMS Services. Your account has been created'. If registration was not successful, you will receive an SMS with instructions on how to register

HOW TO QUERY FOR SEED POTATO INFORMATION

1. Go to your mobile phone messaging service and type: NPCK seed potato variety and send to 22384
   EXAMPLE:
   NPCK #SEED #SHANGI (Note there is no space between NPCK and the first #)
   Alternatively you can use the following in place of **SEED: SEEDS, MBEGU, MBENGU, SEEDLINGS, POTATO, QUERY, TAFUTA and SEARCH**
   EXAMPLE:
   NPCK #TAFUTA #SHANGI
2. You will receive a reply that will include details of: Seed variety, if seed is certified or an alternative, seed size, amount available in Kgs, price per Kg, seed producing company, its contact number and County.

HOW TO QUERY FOR MARKET PRICES

On your mobile phone messaging service;
Type **NPCK #PRICE** and send to the number 22384
You will receive Information with market prices in all major towns in Kenya
Note there is a space betwen NPCK and the first #

HOW TO MARKET WARE POTATO

To market through the platform a farmer should be in a group that has an MOU/AGREEMENT with NPCK. The group will have a farmer coordinator who will market on behalf of the members. However, farmers who attain a production of more than 10 tons per season can market individually through the system.

1. When a group member is about to harvest, the farmer coordinator will be responsible for uploading the required information as below; **NPCK #MARKET#POTATO VARIETY #PRICE PER KG#AVAILABLE KG# DAY#MONTH** send to 22384
   EXAMPLE:
   NPCK #MARKET#SHANGI#30# 5000#15#5
   Note: There is a space between NPCK and the first#.
   DAY means the harvesting date from 1st to 31st. Month means harvesting month from 1-12.
2. The coordinator will receive a reply that the group's stock record has been created and will be valid for a period of two weeks.
   This record is made available to registered potato buyers on the Viazi soko platform who can then place an order for the potatoes.
3. Upon an order placement, the coordinator collects potatoes from the selling members and updates the quantities and prices per Kg in the connected farmer software. The members involved will receive a digital receipt with transaction details and there after M-pesa payment.

For more details on requirements and procedure contact NPCK marketing department through

Phone: 0799739578/0712338633
Email: npck@npck.org

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CIP INTERNATIONAL POTATO CENTER
german cooperation giz

Annex 4: Additional information on Nutrient requirement

Primary macronutrients

Nitrogen (N)

When planting is delayed, a heavy application of nitrogen will not necessarily compensate for the truncated growing season and may provide immature tubers with low dry matter at harvest. Nitrogen application rate should therefore take account of the expected length of the growing season. Optimal application rate will vary depending on soil type and previous cropping history. The crop demand for nitrogen is highest during the critical tuber bulking phase and if the crop is showing early symptoms of nitrogen deficiency this can be corrected by top dressing prior to tuber bulking. Heavy rain, when the crop is young (40 to 50 days after planting) and the demand for nitrogen is low, can result in loss of nitrogen due to leaching towards lower soil strata or through run off. Splitting the application of nitrogen should be considered if this phenomenon is considered a risk. Care should be exercised when applying urea to supply nitrogen as a top dressing. Do not apply the urea granules to the whole field and then start to incorporate it into the topsoil. Urea should be spread only minutes before it is incorporated into the soil.

The end use of the crop should also be considered when determining the nitrogen application rate. A crop destined for processing will require tubers having high dry matter and therefore should receive less nitrogen. Early maturing cultivars require less nitrogen that the late maturing types, because the canopy is shorter lived.

The form of nitrogen applied will affect plant growth and tuber quality. Chemical fertilizers supply nitrogen to the soil in one of two forms: ammonium-nitrogen and nitrate-nitrogen. Potato roots can only take up the nitrate form directly. When nitrogen is supplied in the ammonium form it must first be converted to the nitrate form by soil micro-organisms during the growing season through a process known as nitrification. The young plant requires a balance of nitrate and ammonium in the root zone. However excess ammonium should be avoided as it reduces pH in the root zone (a serious issue when crops are growing in low pH soils) and facilitates the development of the *Rhizoctonia* organism. As the crop progresses from tuber initiation on through tuber bulking, nitrate nitrogen is more preferable as is it more readily available during this period of intense demand

Phosphorus (P)

Phosphorus is an essential element in every metabolic process and is also required during early plant growth for proper early root formation and tuber initiation and at the end of the growth cycle, to promote tuber maturity. It is crucial in photosynthesis, energy production and transfer, storage, respiration, cell division and enlargement. The primary role of phosphorus is to facilitate the transfer of sugars synthesized in the leaves to their storage site in the tubers and their inter conversion to sugars and starch. It is a component of the nucleic acids, Deoxyribonucleic acid (DNA) and Ribonucleic acid (RNA) which regulate protein synthesis. As a constituent of Adenosine Tri-Phosphate (ATP) it is commonly regarded as the “power supply” in the plant. P provides a major stimulus to root development, especially through promoting root branching and root hair formation. N and P complement each other; N facilitates the trapping of energy from sunlight, while P permits the utilization of this energy. N is a major component of plant protein while P regulates protein synthesis. N and P compete for uptake sites on the root hairs and excess nitrogen can mitigate against phosphorus uptake.

At tuber initiation phosphorus stimulates formation of many tubers but plays only an indirect role in tuber enlargement. A large number of tubers per plant are a desirable trait in crops grown for seed. P also helps the plant to survive harsh cold conditions and enhances efficient use of water.

Since the potato roots explore only 30% of the cultivated area, place the fertilizer within this area. Many soils, especially those with low organic matter 'lock up' phosphorus, reducing its availability to the plant roots. This problem can be addressed by accurate placement close to the plant roots. Low pH values in the soils reduce the availability of phosphorus. An advantage accruing from the lack of mobility in the soil is that it is not readily lost by leaching. Deficiency symptoms manifest in purple coloration on the edges of the potato leaves. This phenomenon is a symptom of the accumulation of unutilized sugars not transported to the storage site in the tubers.

Potassium

Potassium has various roles in the potato plant. In the photosynthesis process, K regulates the opening and closing of stomata, and thereby regulates Carbon dioxide CO_2 uptake. K plays a related role through the regulation of water loss in plants (known as osmo-regulation). It regulates both water uptake through the potato plant roots, water circulation within the plant and its subsequent loss from the leaves through the stomata. Furthermore K has been shown to improve drought resistance. It triggers enzyme activation and is the element essential for production of ATP. ATP is a primary energy source for crucial chemical processes occurring in plant tissues. K is essential for both protein and starch synthesis and is important in metabolism, breakdown and distribution of sugars within plant tissues. K also enhances photosynthesis and disease resistance.

Potatoes absorb K in its ionic form, K^+ and they absorb more of it from the soil than any other nutrient; by week 6 from planting, over 70% of the season's requirement has been absorbed rapidly. Potato is a luxury consumer of K, takes up 10kg/ha per day however, excessive supply beyond the recommended rates leads to low dry matter content. As the plant matures and dies, some potash is returned to the soil. By harvest time, 75% of the uptake is found in tubers, which contain approximately 5.8kg K_2O per ton of tubers. This figure is assumed to be constant over the normal yield range and the maximum supply should be 300kg/ha. Deficiency symptoms include inter-venial chlorosis from older to younger leaves, dark-green or silver colorations on leaf margins and stunted growth. K deficiency causes severe chlorosis in young leaves when soil levels of iron are low. It is advised that K should range between 90 to 130ppm in solution in the soil. Although most soils in Kenya have this level of K, farmers are advised to add a little K to soils exhibiting deficiency. Potato crop grown in K deficient soil exhibit hollow hearts though this may vary with variety and size. Large tubers (>100mm diameter) are more susceptible to hollow hearts than smaller tubers (<100mm diameter). K is sometimes referred to as the "quality nutrient" and the form of K applied will affect tuber dry matter. Sulphate of potash (potassium sulphate) can provide higher dry matter values than muriate of potash (potassium chloride). Crops destined for processing should be grown using the sulphate form in preference to the chloride form.

Secondary macronutrients

Sulphur (S) is traditionally regarded as a secondary element, but now many plant nutritionists regard sulphur as the 4th major nutrient due to its importance in the plant.

Sulphur along with N is a key element in the amino acids, cysteine and methionine, two essential protein building blocks. Unlike magnesium, S is not a constituent of chlorophyll, but it is essential in the formation of chlorophyll as it is a major component of an enzyme responsible for the synthesis of chlorophyll. It helps to reduce incidences of common scab (*Streptomyces scabiei*) and improves tuber dry matter content. It is also readily leached from the soil surface layers to lower strata. The S requirements of the potato crop can often be provided through the breakdown of soil organic matter. When additional S is required it can be provided by the application of either ammonium sulfate or potassium sulfate. Avoid excess application rates as sulphate can be oxidised to sulphuric acid and this will further reduce soil pH in already acid soils. In the past, sulphur was supplied to the soil as a contaminant of chemical fertilizers. The new high purity formulations do not contain S as a contaminant and farmers must plan for its inclusion in a crop nutrition program.

Calcium (Ca) is also regarded as a secondary nutrient, nonetheless it is critical to crop growth and development. In the plant it is required in large amounts as calcium pectate for sustaining cell wall structural rigidity and cell adherence, providing stability through a process known as cross linking. Furthermore it maintains the integrity of cell membranes, where low calcium concentrations increase the permeability, resulting in solute leakage. Calcium can only move upwards with water through the xylem transport system and when sequestered in plant parts, cannot be remobilized to new expanding tissues, unlike for example nitrogen.

In the soil it is regarded as an ameliorant and is essential for sustaining soil structure. It assists crumb formation – a process known as flocculation. This makes the soil more friable, permits water to drain down through the large pores created and also enhances soil water retention. Soils deficient in Ca permit poor water penetration due to dispersion of clay particles. High potassium levels in the soil can inhibit Ca uptake due to competition for uptake sites on the plant roots. The cation exchange properties of the soil (a function of soil pH) influence the retention of calcium and facilitate its role as a balancing agent. Potatoes have their highest requirement for Ca during the rapid phase of tuber bulking, when cell division and expansion rates peak and there is a high requirement for products to manufacture new cell walls.

Calcium is very important in cell division, improved plant resistance to diseases and enhanced nitrogen metabolism. Deficiency leads to internal brown spots, hollow hearts and poor colour development in red skinned varieties. On tubers, deficiency may manifest as severe cracking of the tuber. On foliage, particularly on young leaves deficiency manifests as a pale green colour, leaves are small in size and curling downwards of leaf ends. Calcium deficiency is readily manifest in stored tubers, and results in tissue blackening due to bruise damage or under severe deficiency, in tuber tissue breakdown.

Magnesium (Mg) is the central atom in the chlorophyll molecule hence its role in chlorophyll production. Only some 20% of the plant Mg occurs in chlorophyll, the remainder is involved in metabolic reactions. It facilitates the utilization and mobility of phosphorus and promotes uniform tuber maturity. Magnesium in the soil is held on clay particles and organic matter and is readily available to the potato plant. Magnesium, N and K all influence tuber dry matter content. Low levels of Mg will reduce the starch content of tubers and research has confirmed the positive benefits of Mg on tuber dry matter and specific gravity. Its deficiency will have a negative effect on quality before it has an effect on yield. Low P levels or high K levels in the soil will exacerbate Mg deficiency. Magnesium should be supplied to the soil when soil test result shows concentrations of <50ppm. Fresh poultry manure is a valuable source of Mg.

Zinc (Zn) acts as a binding agent in enzymatic reactions and thus protects proteins from denaturing. It has a major role activating enzymes involved in nitrogen assimilation, so deficient crops will have lower levels of protein, Zn deficient crops will also have lower starch content. Deficiency is usually observed on alkaline soils or is associated with excessive applications of P. Deficiency symptoms include stunting, leaf malformation and rolling of young leaves. The latter symptoms resemble those caused by infection with PLRV, so caution with diagnosis is required. Many fungicides used for the control of late blight (*Phytophthora infestans*) contain zinc and that would be sufficient to fulfill crop requirements. Zinc also reduces incidences of powdery scab (*Spongospora subterranean,* Wallr).

Micronutrients

Boron (Bo) has both a functional role and a structural role in the plant, where it is localized mainly in the cell wall. It is required for essential growth process such as, cell membrane and cell wall development to proceed. It is also involved in fructose metabolism and carbohydrate transport. It has a further role in optimizing calcium utilization. Boron deficiency has a detrimental effect on the ultrastructure and physical properties of plant cell walls. It prevents internal browning in tubers. A deficiency results in plants having a 'bushy' appearance due to the necrosis of growing points and the consequent compensatory growth of lateral branches.

Copper (Cu) has a role similar to iron where they provide a site for reaction with molecular oxygen during photosynthesis. It plays a key role in the electron transport system and is also involved in lignification of plant cell walls. It promotes the production of Vitamin A in potato tubers and also facilitates protein synthesis. Copper enhances Mn uptake which also reduces incidences of common scab (*Streptomyces scabiei*).

Manganese (Mn) is both a constituent and an activator of enzymes involved in metabolism and energy transfer. It has a critical role in the photosynthesis reaction where it is associated with the photosystem II reaction center. Deficiency is usually observed only on high pH soil (greater than 8.0) while toxic levels may be encountered in acidic soils (pH < 5.0). A deficiency in the plant can be moderated by the compound Mancozeb, where Mn and Zn are two of the molecules in the fungicide applied to control late blight (*Phytophthora infestans*) disease in potatoes.

Iron (Fe) has a homeostatic role in the potato plant and offers protection against abiotic stress such as temperature extremes. Deficiency is associated with either water logged or high pH soils; it is readily available in acid soils. Excess water during furrow irrigation can induce anaerobic conditions in the root zone and promote iron deficiency. The typical symptom is interveinal chlorosis. Deficiency can be ameliorated by foliar applications of chelated iron.

Molybdenum (Mo) is one of the least abundant elements required for plant nutrition. It has chemical properties similar to sulphate and phosphate. This feature allows the three elements to interact in assimilation and metabolism reactions. Molybdenum shares a root uptake mechanism with P. It is required by major enzymes such as nitrate reductase to carry out reactions where it converts nitrate to nitrite and then to ammonia before the N is assimilated into amino acids. The Mo deficiency in plants is rare, but can be important in low pH soils. Molybdenum availability can be improved by the application of lime.

Chlorine (Cl) has only been considered an essential micronutrient since 1954. In plants it is found as the free anion or else bound to organic molecules. Like Mn, it is associated with photosystem II where it is involved in catalyzing the oxidation of water, which provides the oxygen required to sustain life on the planet. In plant cells it helps maintain turgor through osmoregulation, while at the leaf level, it has a role in stomatal functioning. It is applied to plants either in the form of ammonium or potassium chloride. However excess application will lead to chlorine toxicity which is a problem to potatoes.

Nickel (Ni) is regarded as the 17th element required for plant growth. It is important in plant nitrogen metabolism where it is a functional constituent of eight enzymes, including the urease enzyme. Urease is a nickel-dependent enzyme, which catalyzes the hydrolysis of urea to produce ammonia and carbon dioxide. Hydrolysis of one molecule of urea results in the release of two molecules of ammonia and one molecule of carbon dioxide. When Ni is not present, urea conversion is impossible, allowing toxic levels to accumulate, leading to chlorosis and necrosis. It is required in only trace amounts, with the critical level suggested as about 0.1 parts per million. Nickel availability is reduced in soils with high pH.

Growers are advised to exercise caution when considering the application of micronutrients. It is essential that a deficiency is confirmed through laboratory analysis. The application rate of the micronutrient must be chosen so as to raise the availability of the micronutrient in the soil to produce optimum yields but not elevate its concentration to toxic levels. If an application is recommended, adhere rigorously to the advice since some micronutrients are phytotoxic at excess rates.

Organic matter

Although organic matter is not strictly a plant nutrient, it is considered one of humanity's most important natural resources and its value to crop nutrition has been appreciated by our farmer ancestors since the dawn of agriculture. Farmers have always recognized that soil fertility can be maintained or improved through the addition of organic material. Organic matter content can be used to classify soil as mineral of organic, with mineral soils having up to 30% organic matter, while organic soils may have up to 95% organic matter. Productive soils generally have between 3 and 6% organic matter.

Plants can acquire nutrients from two natural sources: organic matter and minerals. It is useful to consider the organic matter fraction in the soil under two headings, the fraction comprising decomposed plant debris from preceding crops combined with soil microbiota and then the recently acquired fraction, generally consisting of plant material from the most immediately harvested crop and farm yard manure. This freshly acquired fraction might better be described as organic material or sometimes as detritus. Such organic material is unstable and the major portion disappears rapidly due to decomposition, especially in a warm wet climate. The former major, more stable organic matter fraction is known as humus. It is derived from material that has been decomposed and is resistant to further decomposition. Decomposing plant tissue already contains all the nutrients required for plant growth; while the humus stores nutrients in a plant available form. Successive cropping will deplete these resources unless they are constantly replenished. The valuable nutrients may also be lost through leaching or erosion.

In addition to its role as a nutrient reserve, organic matter helps reduce crust formation and soil compaction when it contributes to soil particle aggregation, which improves drainage and water holding properties. Organic matter further provides a crucial role when it helps to reduce soil loss due to erosion. Increasing the soil organic matter content from 1% to 3%

helped reduce erosion loss by 20 to 33% through improving water infiltration and providing stable aggregate formation. Most of the soil organic matter resides in the topsoil and when this is lost to erosion the organic matter is also lost.

What factors does the potato crop require to grow and produce a high yield of tubers?

- Sunlight
- Carbon Dioxide (CO2)
- Water (H2O)
- Nutrients
- Correct Temperature

The plants absorb water through their roots and in the process they also absorb nutrients from the soil. Soil and air temperature can affect the levels of H_2O absorption and nutrient intake. The plant has a system of veins in the stems and leaves that allows the water and nutrients to move to all parts from the root tip to the shoot tip.

Photosynthesis is the process by which plants synthesize their food using sunlight, water and carbon dioxide. Photosynthesis takes place in the leaf cells, in microscopic structures known as chloroplasts. These chloroplasts contain a green pigment, known as chlorophyll, which absorbs energy from the sunlight. Chlorophyll is the compound that provides the green color in leaves. The CO_2 from the air enters the leaves through tiny openings known as stomata. The energy absorbed from the sunlight is used to split the CO_2 and H_2O molecules to produce the sugars mainly glucose and fructose and also oxygen. The oxygen is released to the atmosphere through the stomata. Some of the sugar is broken down to produce structures such as cell walls in new leaves, some to produce metabolic products, which sustain the plant, helping it to grow; while the remaining sugar is transported to the tubers, where it is converted to starch and stored.

How to explain differences in tuber yield between fields and seasons

Farmers often ask “why did my neighbors field yield a bigger crop of tubers than mine?” or “why did I have a bigger crop of potatoes last season?”

Recent developments in crop growth analysis have provided a basis whereby differences in tuber yield may be examined against a set of measurable criteria. Tuber yield is determined by:

- The amount of sunlight intercepted by the canopy
- The efficiency with which this sunlight is converted to dry matter and
- The proportion of accumulated dry matter partitioned to the canopy and the tubers.

The amount of sunlight intercepted: This is determined by the date of planting, the time from planting to emergence and the time from emergence to the attainment of full ground cover by the shoots - which means that all the sunlight falling on the field is intercepted by the canopy and not wasted by simply hitting the soil. The next most important factor is to maintain a healthy canopy, which is long lived; this requires the planting the seed tubers at the correct depth and spacing, applying the appropriate amount of nutrients, a plentiful supply of water and efficient protection against pests and diseases. Attention to these parameters will maximize the amount of sunlight intercepted by the canopy.

The efficiency of sunlight conversion: This is largely a function of variety – different varieties will have different conversion efficiencies. However, the process requires that the entire parameters essential for growth (water, nutrients and plant protection) are available at the appropriate time and in the correct amounts.

The proportion of accumulated dry matter partitioned to the canopy and the tubers: This factor is heavily influenced by variety, but the type of plant nutrient, the amount applied and the timing of application, combined with the availability of water, all combine to influence dry matter partitioning. Application of excessive levels of nitrogen will promote the development of a luxurious canopy, where the dry matter is partitioned to producing longer stems, more leaves and new branches at the expense of partitioning to the tubers. Dry matter invested in the canopy can be recovered however, if the canopy can be protected against pathogens and pests, then sufficient water is available to allow it to grow on to maturity. If the crop-growing season is cut short by infestation with late blight or due to scarcity of water, then the investment into a luxurious canopy will be wasted, resulting in a yield of small tubers having low dry matter content.

Annex 5: Some recommended soil testing laboratories in Kenya

Name of laboratory	Location	Contacts
SGS Kenya Limited	SGS House Shimazi Mombasa	P.O Box 72118-00200 Nairobi Tel:020 2733693 Email: sgsinquiries-kenya@sgs.com
University of Nairobi PublicHealth Engineering Laboratories	University of Nairobi-Main Campus	P.O Box 30197-00100, Nairobi Tel:020318262 Ext 28394
University of Nairobi Chemistry Department-Pesticide Research Laboratory	University of Nairobi Chiromo Campus, Riverside Drive	P.O Box 99376-00100, Nairobi Tel:020 4446138
University of Nairobi Department of Land Resource Management and Agricultural Technology	University of Nairobi, Upper Kabete Campus	P.O Box 29053-0625 Nairobi Tel:020 631225 Fax:020 631253 Email: larmat@gmail.uoni.ac.ke
Kenya Bureau of Standards (KEBS)	KEBS Centre Popo Road, South C, Nairobi	P.O BOX 54974-00200,NAIROBI Tel:+254 020 605490, 605506 Email: info@kebs.org
Mines and Geological Department, Chemistry Laboratory	Machakos Road, Industrial Area Nairobi	P.O Box 30009-00100,Nairobi Tel:020 558034 Fax:020 554366 Email: cmg@bidii.com
Kenya Industrial Research and Development Institute (KIRDI) Laboratories	Ndungu Road, Industrial area Nairobi	P.O BOX 30650-00100,NAIROBI Tel:020 535966 Fax:020 555738 Email: dir@kirdi.go.ke
Kenya Agricultural Research Institute National Agricultural Research Laboratories	Waiyaki Way Kabete, Nairobi	P.O Box 14733-00800,Nairobi Tel:020 4444144/4444251 Email: ed@iconnect.co.ke
Kenya Plant Health Inspectorate Services (KEPHIS)	Karen Ololua Ridge, Nairobi	P.O BOX 49592,Nairobi Tel:882933 Fax:882265 Email: director@kephis.org

Annex 6: Registered Seed potato producers

	Name	Country/ County	Contacts	Varieties
1	ADC-Molo	Nakuru	0721-202565 Judith, adcmolo@gmail.com	Shangi, Sherekea, Dutch Robijn, Kenya Karibu, Kenya Mpya, Bvumbwe, Asante, Desiree, Kenya Mavuno, Rolin Tana, Kenya Sifa, Tigoni,
2	Aberdare Technology Limited	Muranga	0716177086	Shangi, Dutch Robijn, Unica, Asante, Kenya Karibu
3	Agrico East Africa	Nakuru	0722-206179- Amina or 0741788380- Josphat or info@agrico.co.ke	Markies, Destiny, Manitou, Rudolph, Arizona, Arnova, Carolus, Faluka, Zafira, Kuroda
4	Baraka Agricultural College	Nakuru-Molo	0724-775769- Majanga	Shangi
5	Benjamin Cheruiyot	Uasin-Gishu	0726-619426	Dutch Robijn
6	Charvi Investment/ EuroPlant Aardappel B.V	Nakuru- Mau Narok	0724-739739 Jajpal Tejpal.singh@xflora.net	Shangi, Dutch Robijn, Jelly, Rumba, Milva, Laura
7	Clabham Investment limited - Frontier farm	Nakuru	0710607935 Boniface, bonifacetoday@yahoo.com	Shangi, Dutch Robijn
8	Den Hartigh	The Netherlands	Br.Krijger@denhartigh-potato.nl	Connect, Caruso
9	Gene Biotech seeds LTD	Kajiado	0739-532993-Nayarani, narayanimanatan@yahoo.com	Shangi
10	GTIL (Apical cuttings and minitubers only)	Nairobi	0722-662037 kae@africaonline.co.ke	Dutch Robijn, Shangi and Konjo
11	Grace Rono	-Trans-Nzoia	0722-460326	Shangi

	Name	Country/ County	Contacts	Varieties
12	IPM & Kevian Kenya seeds (Kirinyaga seeds)	Kiambu	0705-729755-Koome info@keviankenya.com	Shangi, Unica and Dutch Robijn
13	Julius Kandie	Trans-Nzoia	0720-874575	Dutch Robijn
14	KALRO-Tigoni	Kiambu	0727031783/0735458481 kalro.tigoni@kalro.org	Shangi, Tigoni, Unica, Kenya Karibu, Sherekea, Kenya Mavuno, Wanjiku, Nyota, Lenana, Annet, Chulu, Dutch Robijn and Kenya Mpya
15	Kenya Highland Seeds (Royal seed)/ Danespo	Nairobi	0706 825555 - Peter Peter.francombe@khs.co.ke	Royal, Sarpo Mira
16	Kisima Farm	Meru	0716968766/0722509830- Abuid Saidi potatoes@kisima.co.ke	Tigoni, Asante, Sherekea, Kenya Mpya, Shangi,Dutch Robijn, Unica, Farida,Derby ,Sagitta, Taurus, Challenger, Evora, Panamera, Rodeo, Sifra, Voyager, Zarina
17	Leah Rono	Nandi	0727566988	Dutch Robijn
18	Savannah Fresh Hort. Farmers' Cooperative Society Ltd	Meru	0708347959- Patrick	Asante, Sherekea, Unica, Dutch Robijn and Konjo
19	Seeds2B Africa Ltd	Meru	james.wathiru@syngenta.com	Shangi
20	Sigen Hortipruse Ltd	Elgeyo Marakwet	Isaac Letting 0728621222	Shangi, Dutch Robijn
21	Singus Enterprises	Nakuru- Molo	Ann Mbugua 0722691245 anniekoimbori@gmail.com	Shangi, Dutch Robijn, Unica

	Name	Country/ County	Contacts	Varieties
22	Spring valley (Moiben)	Uasin Gishu	0723916161-Samson Chebutuk	Shangi, Dutch Robijn,
23	Stockman Rozen Ltd	Naivasha	0720-603990 info@srk.co.ke	Apical stem cuttings and mini-tubers of Shangi, Unica, Konjo, Dutch Robijn, Wanjiku, Asante
24	Starlight Cooperative society	Nakuru- Molo	0721109200	Shangi and Sherekea
25	Stet Holland B.V	The Netherlands	Holtslaghenk- Henk. Holtslag@stet-potato.com	Elmundo
26	Suera Farm/C. Meijer B.V	Nyandarua	0706-186579 Suera.flowers@gmail.com	Musica, Lady Amarilla, Acoustic, Lady Terra, Rock
27	Wanfa Technologies	Nyandarua	Teresia Mbeere 727622385 tmbeere@yahoo.com	Shangi, Unica

As at July 2018

Annex 7: Additional information on potato diseases and pest management

Potato diseases management

- Bacterial diseases
- Bacterial Wilt

Transmission route

Ralstonia solanacearum (Rs) causes bacterial wilt of more than 200 species and 50 families of plants. Strains of Rs differ in host range, geographical distribution, pathogenicity, epidemiological relationships, and physiological properties. Classification of the pathogen relies on two different approaches, race and biovar, where race places emphasis on host range characterization and biovar classification relies on the use of selected biochemical properties. Thus five races and six biovars have been described and designated; races, according to the hosts primarily affected and biovars, to the metabolism of different carbon sources. The potato race (race 3; biovar 2) is a low-temperature-adapted biovar and it survives at cool temperatures in plant debris and latently infects potato tubers. In terms of disease spread, the heavily infected tuber is not a serious problem since these generally rot away, but of course serving to maintain contamination of the land in which they were grown. However, slightly infected tubers, which show no visible symptoms, pose a serious threat of spreading the disease to new areas.

Soil types have been differentiated as being either conductive or suppressive to bacterial wilt; their indirect influence on soil moisture determines the population size of antagonistic microorganisms, which affect, in turn, the persistence of *R. solanacearum*.

Various cultural practices, whether deliberate or not, have been effective in reducing the occurrence of bacterial wilt. Rotation to a non-host crop forces pathogens to persist as survival structures and/or as saprophytes. Starvation of the pathogen is a key mechanism of crop rotation.

Viral diseases

- **Potato Virus Y**

Transmission of PVY by aphids occurs in a non-persistent, non-circulative manner, which suggests a less intimate interaction between virion and vector than with PLRV. Since the virus Y particles are transmitted in a non-persistent fashion, it means that viral replication does not occur within the aphid vector and that, unless the aphid feeds on infected plants, it loses its ability to infect plants after two to three feedings. Virus Y is transmitted when the virions attach to the aphid stylet in a matter of seconds and may remain infectious for four to seventeen hours. Because the virions are attached to the outside of the stylet they can be rubbed off it when the aphid feeds on other plants growing close by, like for example maize. This explains why the transmission is referred to as non-persistent. Virus Y concentration in an infected potato plant is high and this significantly increases the chance of uptake by aphids.

The green peach aphid (*Myzus persicae*) has been found to be most effective in its role as viral vector. Other aphid spp. such as the potato aphids (Macrosiphum euphorbiae) is also capable of viral transmission; some 25 species have been identified as having the capability to function as PVY vectors. Species differ significantly in their ability to act as vectors.

Potato pest and management

- Nematodes
- Root Knot Nematodes

Juveniles (young nematodes) penetrate the root tips and occasionally invade roots in the zone of root elongation. Invading nematodes initiate the development of giant cells in the root tissues and galling of roots occurs. Eggs are laid inside roots and may number up to 1000. Reproduction does not require males. The juvenile emerges from the egg and is the infective agent penetrating roots. Juveniles will repeatedly infect roots and may infect tubers as well. They enter tubers through the lenticels.

Environmental factors that influence development of *Meloidogyne spp.* are moist soils and relatively warm temperatures. Temperature and moisture may directly or indirectly affect nematode abundance and distribution. Temperature directly affects different nematode processes such as rate of feeding and root penetration, while nematode infection rate is directly impacted by moisture. Plant penetration by root-knot nematodes occurs over a wide range of temperatures, between 10 and 35 ^{0}C, with the optimum at about 27 ^{0}C depending on the species. Eggs are not laid when temperatures are lower than 14.2 or higher than 31.7 ^{0}C. Under average conditions a female produces 300 to 800 eggs. A new generation can arise within 25 days, but under less favourable conditions, the time may be prolonged to 30 to 40 days. Root-knot nematodes measure about 0.5 mm to 1.5 mm in length.

Management

Note: Several plants show a resistance to nematodes and this is attributed to the presence of certain active compounds, such as flavonoids and isothiocyanates. These plant extracts have shown potential as raw material for the production of natural nematicides. The efficiency of the nematicidal activity can depend on the plant used for the preparation of the extract and the extraction method. Plant derived compounds achieve their nematicidal effect, through the presence of naturally occurring glucosinolates present in brassica species such as cabbage and rapeseed (*Brassica napus*). The enzyme myrosinase hydrolyses the glucosinolates, to release the nematicidal compounds. The development of naturally occurring nematicides is a worthwhile activity and deserves investigation.)

- **Potato Cyst Nematode (PCN)**

A strategy to control PCN

Since PCN cysts are extremely long lived in soil, even in the absence of suitable host plants, eradication of PCN from an infested site is not possible in the short term. However, eradication remains as the long term objective for all infested land. Research studies have shown that cysts may survive longer than 20 years, even in the absence of suitable host plants. Ongoing management of PCN outbreak sites should aim to progressively reduce PCN populations, eventually to the point where PCN may be considered to be eradicated. In some countries there is a major emphasis on the use of resistant cultivars to suppress soil populations of PCN.

Growing a potato variety, which has complete resistance to the Ro1 strain of *Globodera rostochiensis* reduces the number of cysts in soil over a season by the order of 80-90% reduction after each crop. This is because exudates from the potato roots stimulate the eggs to hatch and while the juvenile nematodes still invade the potato roots, they do not develop and therefore further production of cysts is prevented. Resistant cultivars can cause up to 90% of PCN eggs in the vicinity of potato plants to hatch, but the Ro1 strain of PCN cannot encyst on resistant cultivars. This is a more effective way to reduce PCN soil populations compared to just using a rotation with no potato crop in which the natural decline in number of cysts in soil per season is only 20-30%. The growing of other non-PCN resistant potato crops in infested fields is inappropriate as these will increase or maintain PCN populations. Tomato and eggplant crops may also increase PCN levels and these also should not be grown.

Annex 8: General market assessment tool

Market information needed	Player 1	Player 2	Player 3	Notes
• Type and name of the market person (consumer, collector or retailer)				
• Name of the market and distance from your farm				
• Telephone number of the respondent				
• What kind /type of tuber variety they prefer?				
• What size of the tubers do you prefer?				
• What quantities do they require and when?				
• How much is paid for the potatoes and how (cash, MPESA)				
• When are payments made (advance, on delivery, after delivery)				
• Is the player willing to purchase potato from you				

Annex 9: Price trends charts for variety A

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Market Name 1												
Market Name 2												
Market Name 3												
Market Name 4												
Market Name 5												
Market Name 6												

Annex 10: Soil Testing and Amendments

Today in the planet the use of fertilizer has been inappropriate. It has led to pollution of water and contributed to generation of GHGs and other air pollutants. Soil testing is the only proper justification of the use of fertilizers. It helps to establish the rates or quantities of nutrients already available in the environment (water, soil and air) and any amendments where necessary.

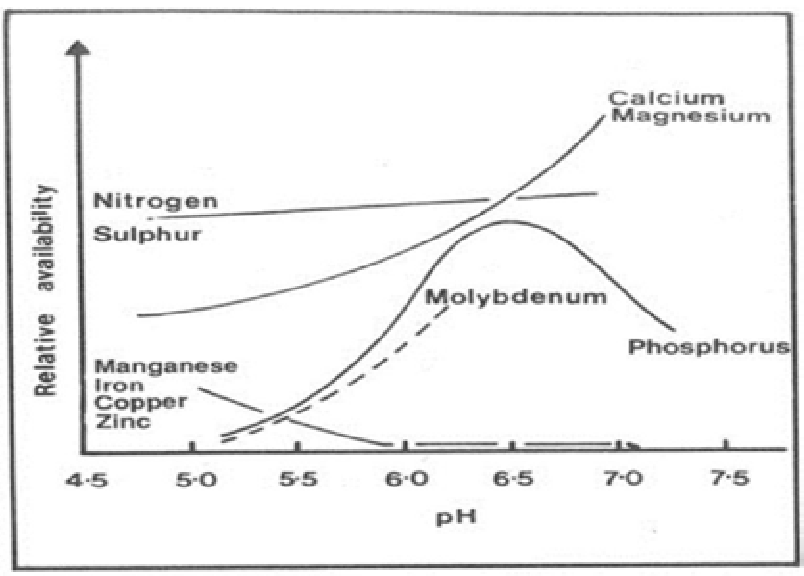
Annex 11: Determination of soil pH, Macro Nutrients and Micronutrients

Quick testing of soil pH, pH meter or litmus paper (cheaper) is used to measure the level of the acidity in the soil. On the Soil pH meter, the values span the range from 0 to 14 where a value of 7 is neutral, below 7 acidic and values above 7 alkaline. The pH value of a soil defines the concentration of hydrogen ions present in the soil solution. Acidic substances release hydrogen ions (H^+) whereas alkaline or base substances release hydroxyl ions (OH^-). Determining soil pH is the primary step that a farmer or entrepreneur should undertake at the site selection stage. Since there are no region-specific recommendations on fertilizer use for potatoes soil analysis helps to determine the fertility status of the soil (level of macro and micro nutrients) and form the basis for recommending the type and rate of fertilizer to apply

What is the significance of soil pH in potato growth?

Potato grows best when the pH is slightly acidic to neutral (5.5 – 6.5) since most soil derived mineral nutrients required for plant growth are in chemical forms that roots can absorb at this pH range. Soil pH is a critically important chemical property, which has a major influence on potato nutrient availability. The higher the concentration of hydrogen ions in the soil relative to the basic ions the lower the pH, at low soil pH values, the levels of exchangeable aluminum in the soil solution may become toxic to potato roots.

The figure below illustrates the effect of pH on the availability of essential nutrients required by the potato crop. Long term use of urea and ammonium sulfate fertilizers as well as leaching of cations from the root zone can cause soils to become more acidic. Fortunately, potatoes can be grown successfully in soils with pH values as low as 5.5. This is particularly helpful as low pH discourages the development of *Streptomyces scabies*, the organism responsible for causing common scab. Caution is required as low pH values can induce magnesium deficiency and the fore mentioned aluminum toxicity.



The relative availability of plant nutrients as affected by soil pH

If soils are acidic (lower pH) use of organic input practices such as composting, green manure, mulching and animal manure and application of lime is recommended to increase pH towards 7.0. Farmers should start reducing use of urea and ammonium sulfate fertilizers to get good quality tubers and conserve soils where possible.

Soil testing procedure

Soil testing is a necessary procedure used to identify presence of pests, diseases and nutrients levels in the soils and determine soil pH. Farmers regularly apply soil nutrients such as fertilizers and manure following blanket recommendations. Soil testing results are also used to confirm deficiency symptoms that visual method was unable to resolve. Soil testing should be done following the steps outlined below:

- **Soil sampling -** Collection of soil samples from the field by the farmer or extension officer and packaging ready for dispatch.
- **Chemical, physical or health analysis –** The process of determining the soil characteristics and health and is usually done by registered laboratories.
- **Correlation and calibration of results** - Interpretation of soil analysis results and includes calculation of nutrients required.
- **Correction/remedial process -** This is done by the farmer and includes acting based on the results of soil analysis.

Soil sampling

A farmer can sample soils and interpret test results with assistance from an agronomist or soil experts using the following as a guide. The timing for sampling is very important and should be done:

- As close as possible to the planting period because most tests take 1 to 2 weeks to complete. A farmer should therefore take samples 2-3 weeks before planting.
- When soils are dry since it is easier to collect samples. It is not recommended to submit wet samples to the laboratory because this may interfere with the results.
- Where a field designated for a potato crop is suspected to have low pH, this field should be sampled in the preceding season and lime applied if necessary. This will help reduce the infestation of common scab on tubers, which is promoted by freshly applied lime.

Materials and tools required for sampling include: Auger, tape measure, paper bags, felt pens, masking tape, clean bucket and data sheet.

Caution when preparing for soil sampling

- Avoid sampling hot spots like ant hills, terrace channels or where burning has taken place or manure was heaped.
- Do not use galvanized tools or containers since they may contaminate the sample with Zinc.
- Use clean tools always between samples.
- Keep tools and containers away from fertilizers and manures because of contamination.
- Use new paper bags to package soil samples.
- It is important to take a representative sample as possible.

Soil sampling steps

Step 1 – Field preparation

- Randomly select 3 sampling sites per acre of land and mark with wooden pegs.
- Remove trash from the sampling sites selected.

Step 2 -Auguring and compositing for topsoil

- Dig out 20 cm depth of soil using panga or augur tool and place in a bucket.
- Repeat procedure in other sites selected and place in same bucket.
- Mix the soil samples uniformly to form a composite.
- Package ½ kg of the composite soil sample in a sampling bag and label properly as topsoil.

Step 3 -Auguring and compositing for sub soils

- Dig out the sub soil 20-50 cm depth.
- Repeat procedure as outlined above and label as sub soil.

Step 4 -Packaging

- Package the soil sample into a carton ready for sending to the testing laboratory indicating field and farmer details.
- Address the package to the laboratory and send.

Documentation and record keeping

The soil samples should be accompanied with the following information: Depth (top or sub soil), depth in centimeters, date of sampling, samplers name, field number, farmer name, recent history on use of the site on crops grown, yields, fertilizer used, reason for analysis and a sketch map showing farm layout and marked sites sampled. The names of some of the recommended laboratories for soil testing are provided for in Annex 5.

Results, interpretation and remedy

Nutrients required by the potato crop may be supplied either through organic (commercial organic fertilizers, farmyard manure, compost, liquid tea, green manure and mijingu rock phosphate) or inorganic fertilizers.

A summary table of soil test interpretation chart

Nutrient	Recommendation	Remedial action
Nitrogen (N)	Deficient-apply N	Use basal fertilizers at planting like DAP or NPK. Top dressing with nitrogen will only increase yield if the crop can benefit from an extended growing season.
Phosphorus (P)	Deficient	A warm, moist and well-aerated soil at a pH of 6.5 optimizes the release of this element. If recommended apply a straight inorganic P containing fertilizer or a compound like NPK.
Potassium (K)	Optimal levels	Apply a straight fertilizer containing K or a compound like NPK. For remedial purposes, supply K through foliar fertilizers that contain the element.
Calcium (Ca)	Less than optimal	Liming is necessary. Gypsum (Calcium Sulphate) may be used.
Magnesium (Mg)	Low	When liming is required use dolomite lime. When it is not required Epsom salt (Magnesium Sulphate) is used.
Sulphur (S)	Low	Apply gypsum and Potassium Sulphate Compost or manure
pH	Below 5.2 (acidic) Availability of N, P and K is reduced. There are usually low amounts of Ca in the soil	Apply agricultural lime
pH	High 7.0 (Alkaline)	Use acidifying fertilizers like DAP

A fertile soil for potato production is the one with the capacity to receive, store and supply different forms of nutrients required for sustainable potato growth and development. A productive soil stores enough nutrients and makes them available for the potato plant to absorb. Such soil requires very minimal inorganic fertilizers or external chemicals to make soil suitable to supply nutrients to the crop. Other than plant nutrients being abundant in the soil, the soil should be protected from moisture loss, soil erosion and becoming acidic or alkaline. The soil structure should be improved to allow nutrients flow, dissolve in water and be supplied to the crop.

Use of soil amendments

Soil amendments are the practices used to improve soil quality in terms of its structure and biochemical function. Generally, the chemical properties of soils are easier to improve than the physical ones. With increasing intensity of cropping, many methods of soil improvement have become available and proved profitable. Among the soil chemical properties, the soil reaction (soil pH) of many soils must be optimized in order to create favorable conditions for plant growth, nutrient availability and to eliminate harmful toxic substances. Optimizing soil pH is a precondition for the success of nutrient management in potato production. It entails either raising the pH of acid soils or lowering the pH of alkaline soils. Among the soil physical properties, the improvement of soil structure is of great concern to farmers. The texture of sandy, clay or stony soils may also be improved but to a very limited extent.

Amendments for raising the soil pH (liming)

Sometimes soils become acidic due to overuse of fertilizers, mono-cropping and depletion of soil organic matter stocks. One of the most common ways of neutralizing soil acidity to achieve the required pH for potato production is application of agricultural lime. The most common liming material is ground natural limestone (CaCO3) with a definite fineness, depending on the hardness of the rock. When liming is advised to increase the pH, it is advisable to apply lime in the previous crop before planting potato to reduce the risk of infection by common scab. Gypsum is also commonly used to decrease soil pH by bonding high sodium salts and lime or limestone to decrease the soil pH.

Amendments for alkaline soils

Intentional acidification to lower the soil pH may be required on alkaline soils for various reasons. These include removal of negative factors such as micronutrients deficiencies, and removal of excess Na. Soils that have been over limed may require acidification to improve the availability of Fe, Mn and Zn. A certain degree of acidification can be obtained by using N fertilizers that produce an acidic effect where these are cost-effective. However, on soils with a high buffering capacity, this effect may be minimal. Amendments for effective acidification are either acids or those that produce acids after decomposition in soil. The most effective substance is diluted sulphuric acid, but its use is technically difficult, costly and inconvenient.

Amendments for improving soil texture and structure

In addition to adequate nutrient supplies, a precondition for optimal plant growth is an optimal water supply, adequate aeration of the soil and root penetrability, both in the topsoil and subsoil. Soil physical properties can be improved by creating better soil structure as a precondition for optimal water supply and aeration, and a more favorable soil texture for water retention, root growth and proliferation.

Amendments for soil texture improvement: Light sandy soils lack adequate fine clay particles, whereas heavy clay soils lack enough coarse particles. The consequences of extremely coarse or fine particle sizes are a low potential for natural structure formation. The obvious measures for altering the particle size composition of soils are to supply clay particles to light soils, and sand particles to heavy soils. The key issue is the quantity to be applied and its practical feasibility.

Amendments for soil structure improvement: An important measure for improving the structure and opening up the subsoil is correct tillage. However, this results in only temporary improvement, and it should be supplemented by creating favorable conditions for the structure-forming processes in the soil. Several amendments have been developed specifically to improve soil structure. These are usually called soil conditioners and are applied to increase the water holding capacity (WHC) and resistance to erosion of soils. In fine-textured heavy soils, these are used for creating a crumb structure, chiefly for better aeration. Farmers can use fresh organic matter which can increase SOC and N content, soil biological activity, and crop yields.

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