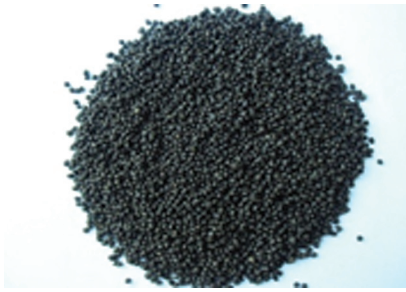
Harmonized Fertilizer Recommendations For Optimal Maize Production In Kenya








Nesbert Mangale, Anne Muriuki, Angela N. Kathuku-Gitonga and James K. Mutegi

OCTOBER 2016

KALRO
Kenya Agricultural & Livestock Research Organization

KSHC
Kenya Soil Health Consortium
Collating, Harmonizing, Disseminating
Soil Health Innovations

IPNI
International Plant Nutrition

AGRA
Growing Africa's Agricultre

Harmonized fertilizer recommendations for optimal maize production in Kenya

Published by:

Kenya Soil Health Consortium
KALRO, KABETE
P.O Box 14733-00800,
Nairobi, Kenya

Complied by:

Nesbert Mangale[1], Anne Muriuki[1], Angela N. Kathuku-Gitonga[1] and James K. Mutegi[2]

[1]KALRO-NARL Kabete, Po. Box 14730-00800, Nairobi
[2]International Plant Nutrition Institute (IPNI), P. O. Box 30772 - 00100, Nairobi, Kenya

Typesetting & Editing:
Nesbert Mangale, Anne Muriuki, Angela N. Kathuku-Gitonga

Design & Layout:
Nogrecia N. Mnene

Citation:

Mangale *et. al,* 2016.Harmonized fertilizer recommendations for optimal maize production in Kenya

Harmonized Fertilizer Recommendations For Optimal Maize Production In Kenya

OCTOBER 2016

Foreword

Per capita food production in Kenya has continued to decline in spite of the successful introduction of new crop varieties, associated fertilizer and pesticide packages coupled with excellent research outcomes. Natural disasters (increased incidences of floods and droughts); high incidences of pests and diseases and degradation of the soil resource base among others have been cited as the main reasons for the decline. Degradation of the soil resource base is directly linked to poor land management including land use without installation of appropriate erosion control measures and exportation of nutrients from farms through the plants and animal products without adequate replenishment of the removed nutrients. Additionally, harmonized soil fertility information collected by the Kenya Soil Health Consortium (KSHC) since 1925 (about 90 years) showed that most farmed soils were deficient in organic matter and are acidic. The decreased soil organic matter and widespread soil acidity is due to prolonged removal of crop residues, limited use of good quality organic manure and injudicious use of inorganic fertilizers. The rapid population increase, which currently stands at one million people per year, has put tremendous pressure on available arable land giving way to continuous cultivation, subdivision of agricultural land and migration from high potential areas to marginal ones. Thus the traditional way of maintaining soil fertility through shifting cultivation, application of suboptimal amounts of mineral fertilizers and/or manure and inclusion of grain legumes into the cropping systems is not sufficient to meet crop nutrients demands and ensure food security in the country. To deal with this problem both inorganic and organic fertilizers are essential and adequate quantities of the right types should be availed to a particular crop at the right crop stage following soil test recommendations.

A large body of research body to this effect is available such as the crop-soil and agro-ecological zone specific fertilizer recommendation developed by the Fertilizer Use Recommendation Project (1989 to 1994) and verified through the Fertilizer Extension Project (1994 to 1999), integration and optimization of organic and inorganic resources use and limiting nutrient trials carried out by Tropical Soil Biology and Fertility institute (1990's to 2000's) and within the last decade the International Plant Nutrition Institute and Alliance for a Green Revolution in Africa.

The results from these research efforts support *combined use of organic and inorganic fertilizers* popularly known as Integrated Soil Fertility Management (ISFM), which has proved to restore the soil resource capital base and significantly increase crop yields. ISFM is defined as the use of farming practices that involve the combined use of inorganic and organic inputs, improved seed and other planting materials combined with the knowledge on how to adapt these practices to local conditions so as to maximize the plant nutrient use efficiency while improving crop yields. All inputs need to be managed following sound farming principles.

This manual has been prepared by the Kenya Soil Health Consortium (KSHC) and features harmonized fertilizer use recommendations that were derived from ISFM research legacy data collected in Kenya. The legacy data covers research conducted between 1925 and 2015.

Acknowledgement

This harmonized fertilizer recommendation manual is the outcome of the joint effort of the Kenya Agricultural & Livestock Research Organization (KALRO) research staff in the Kenya Soil Health Consortium (KSHC) secretariat based at the National Agricultural Research Laboratories (NARL) Kabete; together with Dr. J. Mutegi of the International Plant Nutrition Institute (IPNI) who has been very instrumental in providing technical backstopping.

We are also grateful for the editorial comments provided by Dr. A. O Esilaba, of KALRO headquarters; Dr. C. N. Kibunja, of KALRO (NARL) Kabete; Dr. F. O. Ayuke, Soil Science Department, University of Nairobi (UoN) and Dr. S. Nguluu, South Eastern Kenya University (SEKU). The Kenya Soil Health Consortium is greatfull for the financial support provided by AGRA to facilitate the implementation of its activities, preparation and production of this manual.

Abbreviations and Acronyms

ACT	African Conservation Tillage Network
ACZ	Agro-Climatic Zone
AEZ	Agro – Ecological Zone
AGRA	Alliance for a Green Revolution in Africa
ARM	Athi River Mining
ASAL	Arid and Semiarid land
ASN	Ammonium Sulphate Nitrate
BCR	Benefit Cost Ratio
CAN	Calcium Ammonium Nitrate
CEC	Cation Exchange Capacity
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Centre for Tropical Agriculture
CL	Coastal Lowland zone
$CO(NH_2)_2$	Urea
DAP	Di-Ammonium Phosphate
DSP	Di-Sulphate Phosphate
ESP	Exchangeable Sodium Percentage
ECe	Electrical Conductivity of a Saturated extract
FAO	Food & Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistics
FURP	Fertilizer Use Recommendation Project
FYM	Farmyard Manure
GDP	Gross Domestic Product
GoK	Government of Kenya
ICRAF	International Centre for Research in Agro-forestry
IFDC	International Fund for Developing Countries
IL	Inner lowlands zones
IPNI	International Plant Nutrition Institute
ISFM	Integrated Soil Fertility Management

KALRO	Kenya Agricultural and Livestock Research Organization
KARI	Kenya Agricultural Research Institute
KCl	Potassium Chloride
KMDP	Kenya Maize Development Programme
KSHC	Kenya Soil Health Consortium
KUCC	Kenyatta University Conference Centre
L	Lowlands zones
LH	Lower Highlands zones
LM	Lower Midlands zones
MAP	Mono-Ammonium Phosphate
MOP	Muriate of Potash (KCl fertilizer grade)
NARL	National Agricultural Research Laboratories
NARS	National Agricultural Research Systems
NRM	Natural Resources Management
pH	Negative log of Hydrogen ion Concentration (A numerical measure of acidity)
SEKU	South Eastern Kenya University
TSBF	Tropical Soil Biology and Fertility Institute
NGO	Non – Governmental Organization
TA	Tropical Alpine zone
TOT	Training of Trainers
TSP	Triple Supper Phosphate
SSP	Single Supper Phosphate
UH	Upper Highland zones
UM	Upper Midland zones
UoN	University of Nairobi
UNEP	United Nations Environmental Programme
WAFC	World Agro-forestry Centre (Formerly ICRAF)

Table of Contents

List of tables

List of figures

Executive Summary

In Kenya, agriculture is and will continue to be the cornerstone of the economy for a considerable time in future. Agriculture directly accounts for 26 per cent of Gross Domestic Product (GDP) annually; and, indirectly 27 per cent through linkages with manufacturing, distribution and other service related sectors. It also accounts for 65 percent of total exports and provides 18 per cent and 60 per cent of formal and total employment, respectively. However, in spite of the importance of agriculture in the Kenyan economy, the sector's performance has continued to decline with time, leaving the country food insecure. This is because Kenya's food production has been the burden of small scale farmers who produce 65% of the total agricultural output. In these smallholder farms, poor soil health, and in particular low and declining soil fertility is a major constraint limiting agricultural productivity.

Many research institutions and organizations in the country, in particular, the national agricultural research system (NARs) encompassing local universities and research institutions, international organizations and non-governmental organizations (NGOs) have over the past several decades dedicated enormous research time and resources to developing soil fertility management technologies with the aim of improving crop productivity in smallholder farming systems. Their research efforts have over the years generated numerous technologies with potential for increasing food production and rural incomes. These range from use of organic and/or inorganic fertilizers, phosphate rock, lime, intercropping with legumes, inoculation of food legumes with appropriate rhizobia strains, agroforestry, biomass transfer, conservation tillage and combination of water harvesting techniques with fertilizers and/or manures.

This research information spanning over 90 years (1925 to 2015) was collected, collated, reviewed, synthesized, analysed and harmonized into crop and agro ecological zone specific ISFM practices by the Kenya Soil Health Consortium. The Consortium established a collaborative stakeholders' platform to improve access to ISFM legacy data from relevant institutions and reviewed the consortium's recommendations as presented in this manual. The outcome of this collaborative effort is presented in this *'Harmonized Fertilizer Recommendations for Optimal Maize Production in Kenya'* manual. It is intended to give soil fertility management practitioners in the country, more in depth understanding of the major issues to ISFM use. In the maps and tables, detailed harmonized ISFM recommendations and their economic implications in different regions of Kenya are provided. The tables also show the agro-ecological zones where the harmonized ISFM recommendations are most suitable.

1.0 INTRODUCTION AND PURPOSE OF THE MANUAL

The fundamental importance of agriculture in the development of Kenya's economy cannot be underscored. Agriculture is the backbone of Kenya's economy contributing 26% and 27% of the gross domestic product (GDP) annually directly and indirectly respectively. It also accounts for 65% of total exports and provides 18% and 60% of formal and total employment respectively. It is estimated that a 1% increase in the sector results in a corresponding 1.6% GDP growth in the overall economy. Evidence from a broad range of research impact studies show that returns on investment (ROI) from agricultural research in Kenya are two to three times higher than from all the other investments combined. Investments in agricultural research are therefore paramount to economic growth since the benefits it produces are widely and more equitably distributed.

However, per capita food production in Kenya has continued to decline in spite of the successful introduction of new crop varieties, associated fertilizer and pesticide packages coupled with excellent research outcomes. Natural disasters (increased incidences of floods and droughts due to climate change), a high incidence of pests and diseases and degradation of the soil resource base among others have been cited as the main reasons for the decline. Degradation of the soil resource base is directly linked to poor land management including land use without installation of appropriate erosion control measures and exportation of nutrients from farms through the crop and indirectly through animal products without adequate replenishment of the removed nutrients (Bationo *et al* 1997; Sanchez, *et al* 1997 & Sanchez, 2002)

The agricultural sector in Kenya is dominated by smallholder farmers who account for about 75% of the country's total output. Under smallholder farming systems, soil fertility has been maintained through application of farmyard manure and inclusion of grain legumes into the cropping systems. The rapidly increasing population has put great pressure on land (land holding per household in arable Kenya zones is estimated at less than 0.5 ha) making farming intensification the only alternative option. One of the most significant policy challenges is to find innovative ways of managing food insecurity and household incomes through improvement in crop germplasm, soil fertility inputs and sound agronomic practices. One of the options is to increase adoption of Integrated Soil Fertility Management (ISFM) in smallholder farming systems. ISFM is defined as *farming practices that involve the combined use of inorganic and organic inputs, improved seed or planting materials combined with the knowledge on how to adapt these practices to local conditions so as to maximize the plant nutrient use efficiency while improving crop yields. All inputs need to be managed following sound farming principles*, (KSHC, 2014; Vanlauwe and Giller 2006; Sanginga and Woomer 2009).

The Kenya government through the Kenya Agricultural Research Institute (KARI) presently known as the Kenya Agricultural and Livestock Research Organization (KALRO) and universities (e.g. Kenyatta, Egerton, Eldoret, Moi and Nairobi) and partnership with international institutions and organizations in the country such as the World Agro-forestry Centre (ICRAF), the Tropical Soil Biology and Fertility Institute (TSBF) presently CIAT Africa, and national non-governmental organizations (NGOs) has developed a range of soil fertility management technologies for use by smallholder farmers to improve crop productivity, food security and rural incomes. However there has been low adoption of these technologies by smallholder farmers. This is attributed to their incoherence and contradicting nature having been generated from different sources, institutions/organizations and through varied approaches. These technologies range from use of organic resources, combining organic and inorganic nutrients, phosphate rock, liming, integration of dual purpose legumes into cropping systems, inoculation of food legumes with appropriate rhizobia strains, agro-forestry, biomass transfer, conservation agriculture and combination of water harvesting techniques with fertilizers and/or manures (Lekasi *et al*,. 2001; World Agro-forestry Centre, 2008; TSBF, 2005; Ikombo, 1980; Jama *et al*., 2000; Okalebo, *et al*., 2007; Ojiem, 2006; Salasya, 2005; Misiko, 2007; AGRA, 2009; FAO, 2009; Rockstrom *et al*., 2009).

The Kenya Soil Health Consortium was formed by the Soil Health Program of AGRA, the Kenya Agriculture Research Institute (KARI) hereafter referred to as Kenya Agricultural & Livestock Research Organization (KALRO) and various ISFM stakeholders in the agricultural sector in Kenya. The consortium falls within the broader Soil Health Consortia Project working in eight (8) Eastern and Southern Africa states under the leadership of International Plant Nutrition Institute (IPNI). The Consortium collected, collated, reviewed, synthesized and harmonized agro ecological zone specific soil fertility management technologies that have the potential to improve soil health, revert land degradation and increase crop yields to close the yield gap. In particular, the combined use of inorganic and organic nutrient resources was identified as the best technology because of better crop yields and economic returns. The effectiveness of organic/inorganic combinations can be attributed to availability of crop nutrients throughout the crop growth period while organic resources are crucial for soil biological processes, moisture retention and improved soil physical characteristics. Thus an ISFM approach is advocated as the best way to overcome the problem of soil fertility depletion and restore crop productivity. This report provides an overview of effective and harmonized agro-ecological zone specific soil fertility management recommendations for maize in Kenya.

2.0 CHARACTERISTICS AND ROLE OF AGRICULTURE IN KENYA

Characteristic of Agriculture in Kenya

Only about 16 per cent of Kenyan land mass is of high and medium agricultural potential with adequate and reliable rainfall (GoK, 2009). The rest is ASALs not suitable for rain-fed farming but rather used by ranchers, agro-pastoralists and pastoralists.

Kenya has seven distinct ecological zones, including Tropical Alpine (TA), Upper Highland (UH), Lower Highland (LH), Upper Midland (UM), Lower Midland (LM), Lowland (L) and Coastal Lowlands (CL). The country is also divided into three main production zones based on rainfall. In the high rainfall zone, the productive agricultural land can receive more than 1,000 mm of rainfall annually. The region occupies less than 20 per cent of total productive agricultural land, but has approximately 50 per cent of the country's population. Using semi-intensive and intensive systems, this zone accounts for all the tea, pyrethrum, potato, coffee, vegetables and nearly 75 per cent milk production (GoK, 2009). The medium rainfall zone receives between 750 mm and 1,000 mm of rainfall annually and occupies 30 per cent to 35 per cent of the country's land area (GoK, 2009). It is home to about 30 per cent of the population. Farmers in this zone keep cattle, small livestock and grow drought-tolerant crops. The low rainfall areas receive 200 mm to 750 mm of rainfall annually and are home to about 20 per cent of the Kenyan population. They also contain 80 per cent of the country's livestock and 65 per cent of its wildlife (Gok, 2009).

Kenya's agriculture is mainly rain-fed, making the sector vulnerable to weather variability which leads to fluctuations in production and incomes, especially in rural areas (Alila and Atieno, 2006). Over reliance on rain-fed agriculture is one of the major causes of the country's food insecurity.

Most of farming in Kenya is usually at a small scale. About 75 per cent of total agricultural output and 70 per cent of marketed agricultural production comes from smallholder farmers who own farms ranging from averages of between 0.25 and 0.5 ha in high rainfall areas to 4 ha or more in the Arid and semi-arid areas (UNEP, 2014). Adoption of improved inputs such as hybrid seed, fertilizers and pesticides or machinery by small-scale farmers is less than 30% (GoK, 2009).

The agriculture sector has come under pressure due to the population increase and extreme weather changes. The sub-division of land, resulting from population pressure and the relative scarcity of productive agricultural land, has resulted in small uneconomic farm sizes, which cannot be managed sustainably (UNEP, 2014). The problem is expected to increase, with available land per capita in Kenya decreasing from the present area of approximately 1.5 ha to 0.3 ha by 2050 (GoK, 2007). In addition, the sector is vulnerable to more frequent and prolonged droughts and major floods due to climate change. The increased frequency of these weather extremes is leading to intensified soil erosion, deforestation, loss of soil fertility and reduced productivity.

Irrigation agriculture in Kenya is limited and mainly developed in the form of irrigation schemes and large-scale irrigation of crops like rice and coffee. Individual farmers have developed their own systems of irrigation, notably for export crops like coffee and horticultural produce. Large commercial farms account for 40 per cent of irrigated land, while the smallholder farmers and government-managed schemes account for 42 per cent and 18 per cent of irrigated land, respectively (GoK, 2009). Despite the enormous potential for irrigation, less than 17 per cent of total suitable land has been irrigated (GoK, 2004). This is mainly due to low utilization of water, lack of efficient technologies, destruction of rainfall catchment areas, poor management of government irrigation schemes, pollution of surface water, uncontrolled exploitation of underground water leading to a drop in the water table (Alila and Atieno, 2006).

The Role of Agriculture in Kenya

Agriculture is the mainstay of the Kenyan economy, contributing up to 53 per cent of national GDP directly and indirectly. The agriculture sector is not only the driver of Kenya's economy, but also the means of livelihood for the majority of Kenyan people. The sector provides income to more than 80 per cent of the population, employing over 40 per cent of the total population and over 70 per cent of the rural population. In spite of the importance of the agricultural sector in the Kenya's economy, farming in the country is predominantly small scale, rain-fed and poorly mechanized. Moreover, 85 percent of Kenya is classified as arid or semi-arid (leaving arable land at a mere 15 percent of the total land area) and over-dependence on rain-fed agriculture sector leaves the country vulnerable to the vagaries of weather. Hence, the sector is facing major challenges including stagnant or declining productivity levels due to low soil fertility coupled with the advancing climate change, under-exploitation of land due to lack of proper mechanization, inefficiencies in the supply chain due to limited storage capacity, lack of post-harvest services, poor access to input and output markets and low value addition of most agriculture exports. The agricultural sector is divided into four subsectors, namely, industrial crops, food crops, horticulture, livestock and fisheries. Food crops contribute to 32% of the agricultural GDP, with maize crops contributing 15%. The key players in Kenya's agricultural production are the small farmers; those cultivating less than 1 hectare of land to produce food mainly for home consumption with their surplus sold in local markets. These farmers are particularly vulnerable to unpredictable rainfall and seasonal rivers, streams and wells. Therefore crop failure is common, leading to food shortages and even to famine. However, with proper knowledge on crop intensification and integrated soil fertility management, sustainable crop production can be achieved.

Soil moisture influence on plant nutrient uptake

Nutrients in the soil are taken up by the plant through its roots. To be taken up by a plant, a nutrient element must be located near the root surface; however, the supply of nutrients in contact with the root is rapidly depleted. Plant uptake of nutrients can only proceed when they are present in a plant-available form. In most situations, nutrients are absorbed in an ionic form from (or together with) soil water. Although minerals are the origin of most nutrients, and the bulk of most nutrient elements in the soil is held in crystalline form within primary and secondary minerals, they weather too slowly to support rapid plant growth.

The nutrients adsorbed onto the surfaces of clay colloids and soil organic matter, provide a more accessible reservoir of many plant nutrients (e.g. K, Ca, Mg, P, and Zn). As plants absorb the nutrients from the soil water, the soluble pool is replenished from the surface-bound pool. The decomposition of soil organic matter by microorganisms is another mechanism whereby the soluble pool of nutrients is replenished - this is important for the supply of plant-available N, S, P, and B from soil.

There are three basic mechanisms whereby nutrient ions dissolved in the soil solution are brought into contact with plant roots: (1) *Mass flow of water*, (2) *Diffusion within water* and/or (3) *Interception by root growth*. For the most part, nutrient ions must travel some distance in the soil solution to reach the root surface. This movement can take place by *mass flow,* as when dissolved nutrients are carried along with the soil water flowing toward a root that is actively drawing water from the soil. In this type of movement, the nutrient ions are somewhat analogous to leaves floating down a stream. In addition, nutrient ions continually move by *diffusion* from areas of greater concentration toward the nutrient-depleted areas of lower concentration around the root surface. By this means, plants can continue to take up nutrients even at night, when water is only slowly absorbed into the roots as transpiration has almost stopped. Finally, *root interception* comes into play as roots continually grow into new, un-depleted soil.

3.0 SOIL FERTILITY CHARACTERIZATION IN KENYA

The agricultural sector in Kenya is dominated by smallholder farmers who account for about 75% of the country's total output. Before independence and for sometimes after, the demand for greater agricultural production was met primarily by opening new lands for cultivation while previously cropped lands considered to have become infertile were left fallow to re-generate soil fertility. However, with a rapidly increasing population, land pressure has increased tremendously in recent decades, and shifting cultivation has given way to continuous cultivation. Currently smallholder farmers in Kenya, being resources poor maintain soil fertility through application of negligible amounts of mineral fertilizers or organic animal manure or inclusion of grain legumes in cropping systems. It is therefore in these smallholder farms that the Kenya soil health consortium (KSHC) through over 1000 legacy data collection identified poor soil health and in particular low and declining soil fertility as a major constraint limiting agricultural productivity. The long time and continuous imbalanced use of inorganic fertilizers without addition of organic resources has led to increased soil acidity, mining of nutrients not supplied in the applied fertilizers and lowering of the soil organic matter content. Nutrients such as nitrogen (N), phosphorus (P), potassium (K), sulphur (S) and micro-nutrients Zinc (Zn), Molybdenum (Mo) and boron (B) have been depleted in the soils of smallholder farms in Kenya. Nutrients removed in the harvested plant parts of most cereals and legume crops grown in the country are not returned to the fields. The plant parts are exported off-farm and used as animal feeds or fuel wood or even as building materials. Animal manure produced from harvested plant parts is bulky and normally applied on the farm area nearest the animal kraals or housing. Many smallholder farmers in the country have not realized the value of using green manure and compost to maintain and improve soil fertility. The consequences of these actions for smallholder farms have been a progressive decline in yields and diminishing soil fertility.

3.1 Integrated soil fertility management

Integrated soil fertility management (ISFM) is a means to increase crop productivity in a profitable and environmentally friendly way and thus eliminate one of the main factors that perpetuates rural poverty and natural resource degradation. ISFM interventions include the combined use of organic manure and mineral fertilizers, dual-purpose legume–cereal rotations, green manure, or micro-dosing of fertilizer and manure for cereals in semiarid areas; in addition to using improved seeds/ planting materials and sound agronomic practices.

There is an urgent need to increase agricultural production in Kenya with a main focus on increasing the use of improved seeds and fertilizers by smallholder farmers. More importantly, an integrated approach to soil fertility management (ISFM) that combines the use of improved crop varieties with mineral fertilizers and organic resources, and good management is required to increase crop productivity while reversing soil fertility depletion and soil degradation. Nutrients are more effectively used when the right source of nutrients are applied at the right rate, right time and right place, in what is termed as the 4 Rights (4Rs) of nutrient management. In addition, other agronomic practices including land preparation, timing of planting and weeding and plant spacing should also be correctly implemented. (Zingore *et al* 2014).

A major challenge to effective nutrient management is the lack of site-specific fertilizer recommendations that are appropriate for the socio-economic conditions of farmers. Fertilizer recommendations are mostly generalized for all soil types and ecological conditions, irrespective of the huge biophysical, ecological and socioeconomic variability at different scales. This often results in a mismatch between nutrient application and actual crop requirements, translating into suboptimal agronomic and economic efficiency, low crop yields, food insecurity and wasted human, capital and financial investment.

General Maize Information - Production, Imports and Exports for Last 10 Years and Projections

Geographical Production Regions

According to Kenya Maize Development Programme (KMDP) maize is the primary staple food crop in the Kenyan diet with an annual per capita consumption rate of 98 kilograms contributing about 35% of the daily dietary energy consumption (FAOSTAT). Therefore maize is grown in many Kenyan agro ecological zones starting from the coast lowlands (1-1250 metres above sea level (masl)) to the high potential highlands (>2100 masl).

Overview of Kenyan Maize Production

Ninety percent (90%) of the rural households in Kenya grow maize and production is dominated by small scale farmers who produce 75% of the overall produced. The other 25% is grown by large scale farmers. In recent years there has been an expansion of land used for maize production as evidenced by 1.7 million hectares in 2008 and 1.8 million hectares in 2009. This was actually less than the 2009 Ministry of Agriculture targets which aimed for 2.2 million hectares producing 36 million bags. The available figures showed that 2009 production reached 2.4 million tonnes (27 million 90 kg bags).

Kenyan maize production has been fluctuating (increasing and decreasing) over the last 10 years but there has been an increasing demand due to the high rate of population growth in Kenya (estimated at 2.9% per annum). The national maize production ranges between 24 and 33 million bags per annum which does not keep pace with the domestic consumption levels (e.g. in 2008, the consumption was estimated over 36 million bags). This maize shortfall is because of the:

i) Increase in urbanization.
ii) High reliance on maize based diets as the staple food (evidenced by the high consumption figures of 98kg/capita/year).
iii) Low per capita production and changing lifestyles.

Kenyan Maize Importation Figures

In the last decade, the country has experienced years of heightened food insecurity, dependence on imports and emergency humanitarian assistance. The large maize deficit is met through the importation from other countries. The amount of maize that is imported fluctuates depending weather conditions with 314,000 Tonnes imported in 2001 and 243,000 T in 2009. However, aside from the weather the maize importations have increased just to keep up with Kenyan consumption patterns, increasing from 2.9% to over 12% in the period 1970 - 1991. In 2009, Kenya imported 16.8 million bags of maize (GoK, 2011).

Kenyan Maize Projections

Sadly the national maize supply is expected to further decline due to a combination of crop failure in the predominantly short rains dependent southeastern lowlands as a result of climate change coupled with pre- and post-harvest losses (20-30%) caused by lack of proper mechanization in Kenya's grain basket (Rift Valley). Food insecurity for farms and urban households outside these major production areas is also high due to the increase in population and conversion of farmland to urban housing and hence decreasing the size of land available for crop production and consequently low food production. Moreover, maize products prices have skyrocketed throughout the country. Already prices have nearly doubled, with the price of a 2 kg pack of maize flour going for 60-120 Ksh instead of the previous 50 Ksh. The price of maize in Kenya is among the highest in eastern and southern Africa, and the lowest income quartile of the Kenyan population spends 28% of its income on maize. With the country's population projected to be 43.1 million by the year 2020, the demand for maize is then likely to be 5 million metric tonnes. This means based on the prevailing maize production rates, that the maize deficit will be around 1.2 million metric tonnes in 2020. Increased reliance on imports implies that the foreign exchange reserves and resources earmarked for development will be likely diverted for the procurement of food for Kenyans. Increased productivity, more efficient markets, and rational government policies could dramatically alter the economic contribution of the maize sub-sector – from being a drag on the economy to becoming a key element in accelerated growth and poverty reduction.

4.0 AGRO-ECOLOGICAL CLIMATIC CHARACTERIZATION

Kenya has climatic and ecological extremes with altitude varying from sea level to over 5000m above the sea level. The mean annual rainfall ranges from less than 250 mm in arid and semi- arid areas to more than 2000 mm in high potential areas.

Kenya can be divided into 7 major agro-climatic zones (Table 4.0). The seven agro-climatic zones are each subdivided according to mean annual temperature to delineate areas suitable for growing each of the major food and cash crops. Most of the high potential land areas are located above 1,200 m altitude and have mean annual temperatures of below 18°C, while 90% of the semi-arid and arid zones lies below 1260 m and has mean annual temperatures ranging from 22°C to 40°C. The agro-climatic zones I, II and III have a very high to medium-high potential for cropping. The risk for maize failure is low to very low. The agro-climatic zones IV and V have a medium to marginal potential to grow crops. The risk for maize failure is higher particularly in zone V. These are sparsely populated areas representing 21% of the total land area but being home to 23% of the total population. The arid zones VI and VII are not suitable for rain-fed agriculture. They represent 67% of the total land area and supports only 5% of the total population.

Figure 4.0 below shows the distribution of the 7 agro-climatic zones (ACZ) in Kenya. The arid and very arid zones (VI and VII) are shown to occupy 67% of the total land area mostly in the North-Western, Northern, North-Eastern, Eastern and South-Western parts of the country. Agro-Climatic Zones I-V occupy Western, Central and coastal parts of the country.

Table 4.0: Agro-climatic zones (ACZ) of Kenya

ACZ	*r/Eo (moisture index)	Climate	Annual Rainfall mm	Potential for Plant Growth	Risk for maize failure as a result of climatic condition
I	>80	Humid	1100-2700	Very High	Extremely low 0-1%
II	65-80	Sub-Humid	1000-1600	High	Very Low 1-5%
III	50-65	Semi-Humid	800-1400	High-Medium	Fairly Low 5-10%
IV	40-50	Semi-Humid to Semi-arid	600-1100	Medium	Low 10-25%
V	25-40	Semi-arid	450-900	Medium-Low	High 25-75%
VI	15-25	Arid	300-550	Low	very high 75-95%
VII	<15	Very arid	150-350	Very Low	Extremely High 95-100%

*r/Eo represents ratio between rainfall and evapo-transpiration; modified from KSS 1982

This report focused on various agricultural regions in Kenya based on detailed soil fertility management research data collection, synthesis and harmonization for the period

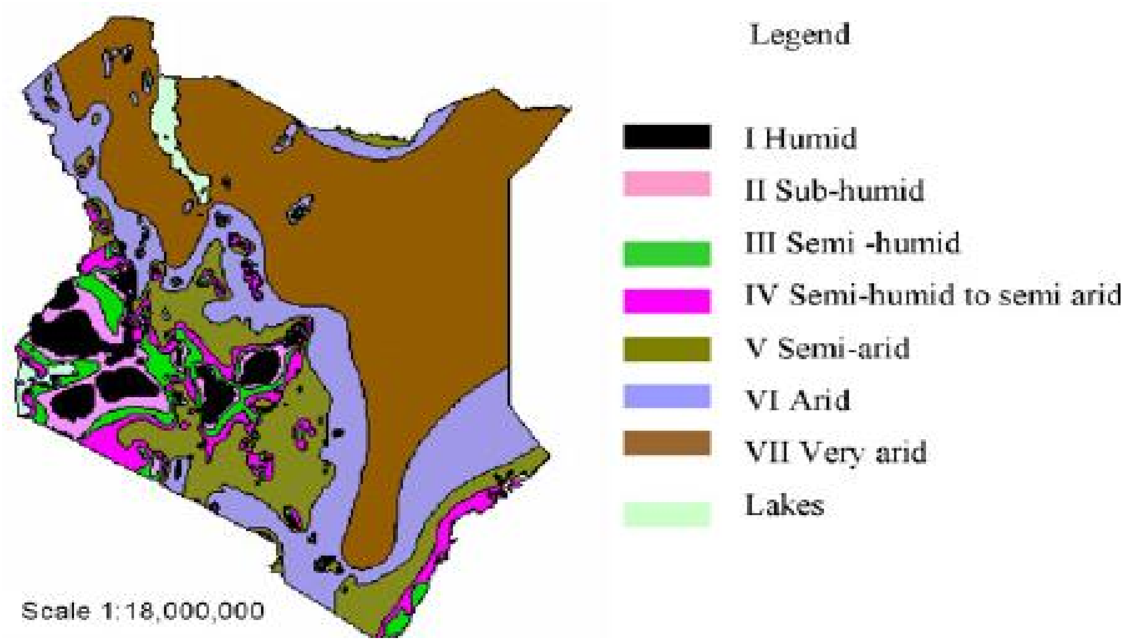


Figure 4.0: Agro-climatic zones of Kenya

ranging from 1980 to 2015. This work was done under the auspices of various partners who constitute the Kenya Soil health consortium (KSHC). The KSHC was formed to take a lead role in harmonization and identification of the best integrated soil fertility management practices disaggregated by crops and agro-ecological zones in Kenya. Generally, much of agricultural research in Kenya was carried out by various national and international organizations for the period between 1990 and 2015. The 1980 to 1990 period represent a duration when most of the baseline surveys regarding soil types and laboratory techniques were done. Table 4.1 shows how soil research has transformed over time. Generally Kenya can be divided into various distinct agro-ecological regions characterized by different agricultural potential.

Table 4.1: changes in tropical soil fertility management paradigms and their effects on farm resource management over the past five decades.

Period	Paradigm	Role of fertilizer	Role of organic inputs	Experiences
1960s and 1970s	1st external input paradigm	Use of fertilizer alone will improve and sustain yields	Organic resources played a minimal role	Limited success due to shortfalls in, supply infrastructure, policy and adoption
1980s	Organic input paradigm	Fertilizer plays a minimal role in land quality maintenance	Organic resources are the main source of nutrients and substrate	Limited adoption as organic matter production requires excessive land and labour
1990s	Organic, Inorganic paradigm	Fertilizer use is essential to alleviate the main nutrient constraints.	Organic resources serve as an entry point offering functions other than nutrient release.	Difficulties to access organic resources hampered adoption (e.g. improved fallows)
2000s	Integrated Soil Fertility Management	Fertilizer is a major entry point to increase yields and supply needed organic resources	Access to organic resources has social and economic dimensions	Entails not only organic and inorganic fertilizer inputs but also improved seeds and planting materials and appropriate farming practices

Source: modified from Sanginga and Woomer, 2009.

5.0 PROCESS OF SELECTING PERFORMING ISFM TECHNOLOGIES

5.1 The Criteria for Selecting AEZ Specific Technologies

The criteria used in selecting for the performing and AEZ specific ISFM technology were:

1. The Benefit Cost Ratio (BCR)
2. Practicability of the technology
3. The yield attained using the technology -food security

BCR

- BCR between 6 and 15 –Excellent technologies
- BCR between 4.0 and 5.9–Best technologies
- BCR between 2.0 and 3.9–good technologies
- BCR between 1.5 and 1.9–Marginal returns/Subsistence technologies
- BCR between 1.0 and 1.4–Unprofitable technologies
- BCR below 1.0 – Loss

The Process

- Consider carefully the yields versus the BCR. The higher the yield with corresponding higher BCR is more advisable than lower yield with higher BCR.
- Anything above a BCR of 2 is considered profitable.
- BCR represents a key driver for willingness to invest
- Also consider the practicability of the technology for easier adoption. The more practical a technology is the more advisable it is.
- Consider also the yields obtained and not just the BCR; higher yields determines food security
- BCR follows marginal analysis which gives a response curve; the dy/dx formula.

What is BCR and how it is calculated

The Benefit - Cost Ratio (BCR)

A BCR is the ratio of the benefits of a project or proposal, expressed in monetary terms, relative to its costs, also expressed in monetary terms. It is an indicator, used in the formal discipline of Cost-Benefit Analysis (CBA) that attempts to summarize the overall value of money of a project or proposal.

- In the absence of funding constraints, the best value for money projects are those with the highest net present value (NPV). Where there is a budget constraint, the ratio of NPV to the expenditure falling within the constraint should be used.
- In practice, the ratio of NPV to expenditure is expressed as a BCR.
- A major shortcoming of BCRs is that, by definition, they ignore non-monetized impacts. Attempts have been made to overcome this limitation by combining BCRs with information about those impacts that cannot be expressed in monetary terms
- A further complication with BCRs

concerns the precise definitions of benefits and costs. These can vary depending on the funding agency.

Cost-benefit analysis

- Cost-benefit analysis is a term that refers both to:
  - Helping to appraise, or assess, the case for a project or proposal, which itself is a process known as project appraisal; and
  - An informal approach to making decisions of any kind.

- Under both definitions the process involves, whether explicitly or implicitly, weighing the total expected costs against the total expected benefits of one or more actions in order to choose the best or most profitable option.
- The formal process is often referred to as either CBA (Cost-Benefit Analysis) or BCA (Benefit-Cost Analysis).

  The cost-benefit analysis is explicitly designed to inform the practical decision-making of enterprise managers and investors focusing on optimizing their social and environmental impacts.

Cost–benefit analysis is typically used by governments to evaluate the desirability of a given intervention.

- It is an analysis of the cost effectiveness of different alternatives in order to see whether the benefits outweigh the costs.
- The costs and benefits of the impacts of an intervention are evaluated in terms of the public's willingness to pay for them (benefits) or willingness to pay to avoid them (costs).
- Inputs are typically measured in terms of opportunity costs - the value in their best alternative use.
- The guiding principle is to list all parties affected by an intervention and place a monetary value of the effect it has on their welfare as it would be valued by them.

- The process involves monetary value of initial and ongoing expenses vs. expected return.
  - Constructing plausible measures of the costs and benefits of specific actions is often very difficult.
  - In practice, analysts try to estimate costs and benefits either by using survey methods or by drawing inferences from market behavior.

- For example, a product manager may compare manufacturing and marketing expenses with projected sales for a proposed product and decide to produce it only if he expects the revenues to eventually recoup the costs.
  - Cost–benefit analysis attempts to put all relevant costs and benefits on a common temporal footing.
  - A discount rate is chosen, which is then used to compute all relevant future costs and benefits in present-value terms.
  - Most commonly, the discount rate used for present-value calculations is an interest rate taken from financial markets.

5.2 Other Fertilizer Recommendations

Project(s)

5.2.1 FURP

FURP stands for Fertilizer Use Recommendation Project. It was started in 1985 after funds were initially secured from the Germany government through GTZ and later the European Union (EU) and was concluded in 1994. Before 1994 inorganic fertilizer recommendations for major food crops were based on “blanket recommendations” which were too broad and did not take into account the differences in soils, climate and economic environment associated with food crop production in Kenya. Thus the main objective of FURP was to develop crop, soil and agro-ecological zone specific inorganic (mineral) fertilizer recommendations for major food crops based on the smallholder farming scenario.

5.2.2 TSBF Institute of CIAT thereafter called CIAT-AFRICA

TSBF stands for Tropical Soil Biology and Fertility. This was a regional project that started in 1990s and was ended in the 2000s. The project main aim was to contribute to human welfare and environmental conservation in the tropics by developing adoptable and suitable soil management practices that integrate the biology, chemical and socio-economic processes that regulate soil fertility and optimize the use of organic and inorganic resources available to the land users.

5.2.3 The Kenya Soil Health Consortium (KSHC)

The Kenya Soil Health Consortium was formed through financial support of the Soil Health Program of AGRA, coordinated by the Kenya Agriculture Research Institute (KARI) hereafter referred to as Kenya Agricultural & Livestock Organization (KALRO). The Consortium established a collaborative stakeholders’ platform that collected, collated, reviewed, synthesized and produced harmonized ISFM technologies and innovations disaggregated by major food crops and agro-ecological zones (AEZ). In the Harmonization process, KSHC divided the country into 5 regions namely: ASALs, Central, Coast, Rift Valley and Western (Western & Nyanza provinces). Hence presented below are harmonized ***organic, inorganic, combined organic*** & ***inorganic fertilizer*** recommendations and water harvesting & in-situ storage technologies for maize production in all the 5 regions of Kenya.

6.0 FERTILIZERS AND SOIL AMENDMENTS

Organic Fertilizers

Organic fertilizers are materials containing carbon and one or more elements other than hydrogen and oxygen essential for plant growth. Organic fertilizers contain carbon, and more specifically, a carbon-hydrogen linkage. Organic fertilizers, whether natural or synthetic, have nutrient elements such as nitrogen, phosphorus or potassium attached to carbon. Because of the ***covalent bonding*** that shares electrons, the structures are quite stable. As the carbon structure is decomposed or hydrolyzed over time, the nutrient elements are released as ions such as ammonium (NH_4^+), which carry a positive or negative charge. It is in this form that nutrients are absorbed by plants since plants have no mechanism to attract uncharged nutrient sources including organic compounds.

Examples and sources

The main organic fertilizers are: peat, animal wastes (from slaughter houses, farmyard manure, goat droppings, chicken litter & bat-guano), and plant wastes from agriculture (crop residue, compost and green manure), urea (synthetic) and treated sewage sludge.

Peat

The main source of organic fertilizer is peat, an immature precursor to coal. Peat itself offers no nutritional value to the plants, but improves the soil by aeration and absorbing water. Peat is the most widely used organic fertilizer.

Animal sources

These materials include the products of the slaughter of animals. Blood-meal, bone meal, hides, hoofs, and horns are typical precursors. Fish-meal, and feather meal are other sources. Chicken litter, which consists of chicken manure mixed with sawdust, is an organic fertilizer that has been shown to better condition soil for harvest than synthesized fertilizer.

Plant Wastes

Processed organic fertilizers include compost, humic acid, amino acids, and seaweed extracts. Other examples are natural enzyme-digested proteins. Decomposing crop residue (green manure) from prior years is another source of fertility.

Treated sewage sludge

Bio-solids

Although night soil (from human excreta) was a traditional organic fertilizer, the main source of this type is nowadays treated sewage sludge, also known as bio-solids.

Urine

Animal sourced urea and urea-formaldehyde from urine are suitable for organic agriculture; however, synthetically produced urea is not.

Inorganic fertilizers

Inorganic Fertilizers are any materials of natural or synthetic origin that contain no carbon-hydrogen linkages and, thus, are not used as an energy sources by soil microorganisms. Although many inorganic fertilizers are naturally occurring as minerals such as potassium nitrate (KNO_3), they are often synthesized to reduce costs and contaminants. In inorganic fertilizers, the nutrient elements are attached directly together with *ionic bonding,* which separates or dissociates readily in water. For example, potassium nitrate dissociates into the potassium ion (K^+) and the nitrate ion (NO_{3-}) when dissolved in water. Thus, inorganic fertilizers are typically quick release, and have a *high burn and leach potential* compared to organic fertilizers. Because of the lack of carbon, inorganic fertilizers "feed the plant but not the soil."

Organic + Inorganic Fertilizers

There have been increased concerns expressed of the impact on environmental quality due to continuous use of chemical or inorganic fertilizers. Chemical fertilizers are typically *quick nutrients releasers*, but have *a high burn and leach potential*. On the other hand organic fertilizers are *slow nutrients releasers and soil health improvers.* This means that soil fertility management systems that rely on organic inputs as plant nutrient sources have different dynamics of nutrient availability from those involving the use of chemical fertilizers. The integrated nutrient management system is an alternative and is characterized by combined use of chemical fertilizers with organic materials such as animal manures, crop residues, green manure and composts. For sustainable crop production, integrated use of chemical and organic fertilizer has proved to be highly beneficial. Several researchers have demonstrated the beneficial effect of combined use of chemical and organic fertilizers to mitigate the deficiency of many secondary and micronutrients in fields that continuously received only N, P and K fertilizers for a few years, without any micronutrient or organic fertilizer. Also demonstrated in the integrated nutrient management system is the availability of balanced and adequate nutrients to crops throughout the growing season. When the integrated nutrient management system is used with improved crop varieties and good agronomic practices the whole system becomes what is popularly known as *"Integrated soil fertility management (ISFM)*. This is a system that is currently highly recommended for sustainable crop production.

Agro-forestry

Agro-forestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence. In agro-forestry systems there are both ecological and economical interactions between the different components. Agro-forestry can also be defined as a dynamic, ecologically based, natural resource management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels. In particular, agro-forestry is crucial to smallholder farmers and other rural people because it can enhance their food supply, income and health. Agro-forestry systems are multifunctional systems that can provide a wide range of economic, socio-cultural, and environmental benefits.

There are three main types of agro-forestry systems:

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

Soil and water management

ASAL areas cover approximately 80% of Kenya's land surface. In the recent past, there has been a substantial increase in settlements within these areas that were predominantly used for livestock production. In addition the ASAL areas are home to more than 35% and 50% of human and livestock population respectively. Rainfall in these areas is normally low, erratic and unreliable with frequent dry spells even within the rainy seasons. This unreliability and poor distribution of rainfall is the most limiting factor to agricultural production and human settlement. Smallholder crop production is the backbone of Kenya's agriculture and is mainly practiced under rain fed conditions. They produce over 80 per cent of food for the population and influence greatly the overall economical performance of the country. Approximately 74 percent of the economically active population is employed in agriculture.

Past studies have shown that agriculture in the ASALs of Kenya is mostly rain-fed. Therefore, moisture stress is a major constraint against food production in these areas. Demand for water use in agriculture will continue to increase as a result of growing population and economic growth. This poses a major threat to food security. To guarantee food security, proper management of water resources is absolutely necessary.

This encompasses taking all deliberate human actions designed to optimize the availability and utilization of water for agricultural purposes. This includes practices such as irrigation (supplemental or full), drainage, soil and water conservation, rainwater harvesting, soil fertility management, conservation agriculture and wastewater reuse among others.

Microbes

Microbes (microorganisms) can make nutrients and minerals in the soil available to plants, produce hormones that spur growth, stimulate the plant immune system and trigger or dampen stress responses. In general a more diverse soil micro biome results in fewer plant diseases and higher yield.

Farming can destroy soil's rhiziobiome (microbial ecosystem) by using soil amendments such as chemical fertilizer and pesticide without compensating for their effects. By contrast, healthy soil can increase fertility in multiple ways, including supplying nutrients such as nitrogen and protecting against pests and disease, while reducing the need for water and other inputs. Some approaches may even allow agriculture in soils that were never considered viable. The group of bacteria called rhizobia, live inside the roots of legumes and fix nitrogen from the air into a biologically useful form.

Mycorrhizae or root fungi form a dense network of thin filaments that reach far into the soil, acting as extensions of the plant roots they live on or in. These fungi facilitate the uptake of water and a wide range of nutrients. Up to 30% of the carbon fixed by plants is excreted from the roots as so-called exudates-including sugars, amino acids, flavonoids, aliphatic acids, and fatty acids-that attract and feed beneficial microbial species while repelling and killing harmful ones. *Stenotrophomonas rhizophila* increases drought tolerance in crops such as sugar beets and maize. The microbe excretes molecules that help plants withstand stress, including osmoprotectants, which prevent the catastrophic out-flux of water from plants in salty environments.

Microbes can affect the flavor of food plants: A bacterium called *Methylobacterium extorquens* increases the production of furanones, a group of molecules that gives strawberries their characteristic flavor. One approach is to apply microbes to plant seeds before planting instead of directly into soil.

7.0 SFM HARMONIZATION IN ARID AND SEMI-ARID LANDS (ASALS)

Counties from which KSHC was able to get ISFM legacy data for synthesis and harmonization in the ASAL region were: Kitui, Machakos, Makueni, Tharaka Nithi and Embu (Mbeere). However, the obtained and harmonized information is applicable to other similar agro-ecological zones within ASALs.

Semi-humid (IV), Semi-arid (VI) and Arid (V) land areas cover 51 million hectares or 88% of Kenya's land area. Arid and Semi-Arid land (ASALs) areas are presently defined as having rainfall to evapo-transpiration ratio of less than 50%. ASALs are characterized by hot climate (average temperature above I8˚C) altitude ranges of between 200 to 1200 meters above the sea level. The, annual evapo-transpiration is above 2000 mm and annual rainfall between 150 mm and 1000 mm, depending on the zones. Annual rainfall in arid areas ranges between 150mm and 550mm per year, and in semi-arid areas between 550mm and 900mm per year. There are important differences between arid and semi-arid areas. The agricultural economy of arid areas is dominated by pastoralism, while in the better watered and better-serviced semi-arid areas; a more mixed economy prevails, featuring rain-fed and/or irrigated agriculture, agro-pastoralism and conservation agriculture.

The ecology of semi-arid areas allows for better intensification of agricultural production systems in a way that arid areas do not. Nevertheless, both arid and semi-arid areas experience chronic food insecurity resulting from rapid population growth, poor soils, degraded ecosystems, low and erratic rainfall and changing seasonal patterns arising from climate change.

The soils of Kenyan ASALs include: Luvisols, Acrisols, Andosols, Arenosols, Cambisols, Chernosems, Ferralsols, Fluvisols, Gleysols, Lithosols, Nitosols, Solonetz and Vertisols. The predominant soil types are Luvisols, Acrisols and Vertisols (for a more detailed description see appendix I). The other soils are not of significant economic importance in terms of agricultural area they occupy. Their texture ranges from sandy loam to loamy sand with tendency to harden when dry but are friable when wet. They are deep and well drained in the drier areas due to presence of petroplinthite (murram) horizons. They have low organic matter (<1% C), mainly due to the poor growth of natural and human modified vegetation and removal of crop residues for livestock feed. They have low water holding capacity, are generally medium to slightly acidic (pH 5.0 to 6.5) in the surface horizons, poor structural development, are highly erodible and prone to surface sealing capping through the energies of high-intensity rainfall and solar radiation.

7.1 Harmonized Fertilizer Recommendations for ASALs

The following combinations of studies were harmonized in this region. The studies were carried out by different organizations as outlined below.

- Organic – CIAT, AGRA, ICRAF, KARI, Universities
- Inorganic –KARI, Fertilizer industries (MEA, ARM, Kel Chemicals), IFDC, IPNI, CIAT
- Organic + inorganic –CIAT, AGRA, ICRAF, KARI, Universities, IPNI
- Tillage + Inorganic –Universities, ACT, KARI
- Water harvesting + Organic + Inorganic –Universities, KARI

A meta-analysis of over 100 different studies carried out in the Kenyan ASALs for the period between 1980s and 2015 was carried out with an aim of identifying the best performing ISFM technologies for maize cropping system. These results were derived from on-station and on-farm researcher managed trials. The yield levels and economic returns presented here are therefore achievable

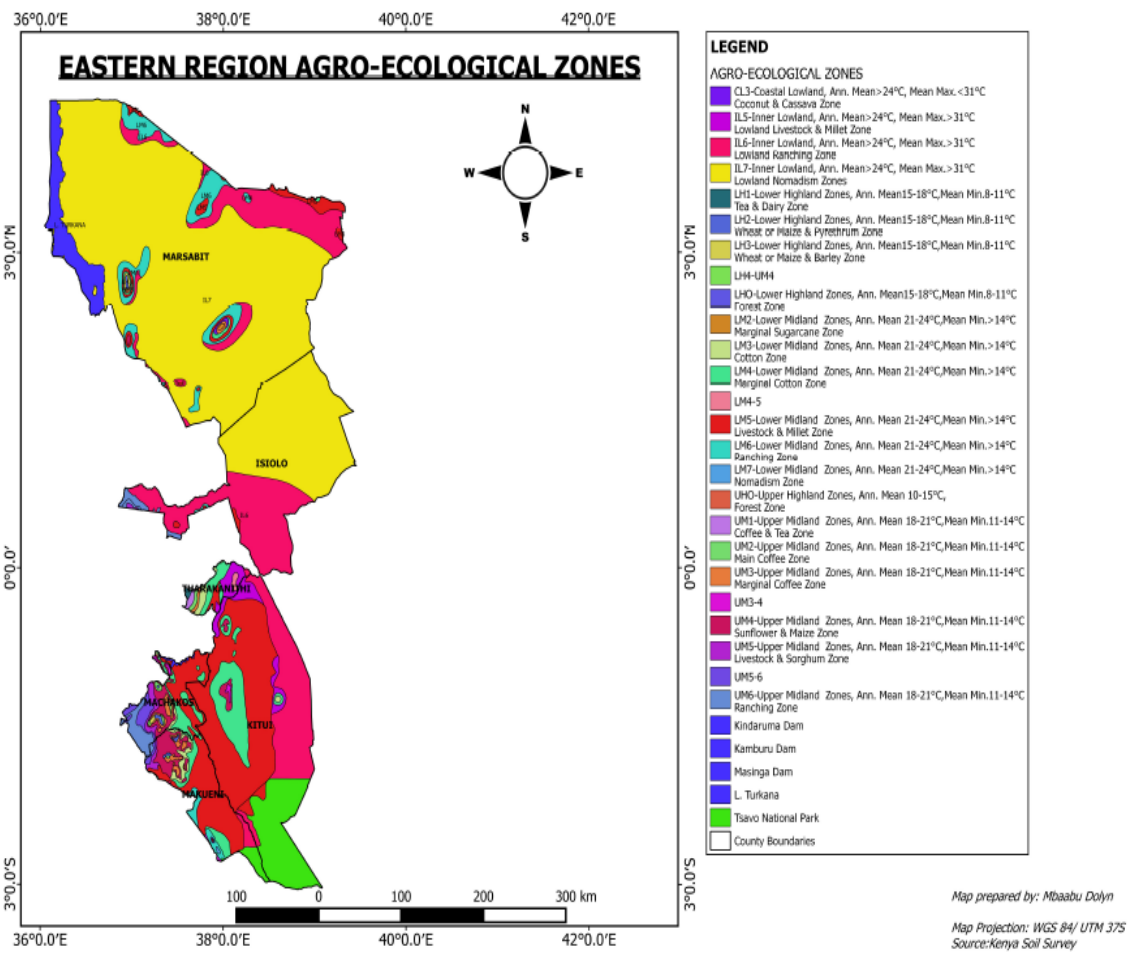


Figure 7.0: agro-ecological zones found in the Eastern Kenya Region

by farming households if such technologies are adopted and implemented in accordance with the principles of good agronomic practices. Good agronomic practices include use of improved seed and planting materials, application of the right nutrient source, at the right rate, at the right time and place, timely field operations.

The analysis targeted both the crop yields for food security and economic returns for wealth creation. The technologies presented in this chapter are those that stood the minimal criterion BCR of more than 2. A BCR of more than 2 implies a return of at least two shillings per every shilling invested. These results present a basket of profitable options from which farmers can choose.

In the ASALs farmers have a wide range of soils fertility enhancement options. The most common are organic resources, inorganic fertilizers and their various combinations.

The harmonization data showed that in the ASALs without external fertilizer inputs, it is difficult to harvest more than 1 t/ha of maize grain. However, with inputs it is possible to improve production by more than 300% up to 4 t/ha. A general observation showed that application of fertilizer and different types of organic resources yielded between 2 and 5 t/ha with a benefit cost ratio of between 2 and 14 implying that these technologies were profitable at a household level. As water is a limiting factor for rain-fed crop production in ASALs, combining water management technologies with fertilizer application presents an opportunity to boost yields further by up to 2 t/ha.

Manure is the most important resource for soil fertility management in this region. It is used either as a sole source of soil nutrients or in combination with inorganic fertilizer. Although, application of either goat or farmyard manure is profitable as indicated by BCR better profits are realized from goat manure as opposed to farmyard manure. This is because goat manure has higher nutrient concentration than farmyard manure. There are however challenges associated with getting sufficient goat manure. Over the 25 years of research highlighted in this report, application of goat manure and farm yard manure at 5 t/ha produced on average 5 t/ha and 2 t/ha of maize grain yield respectively.

Although inorganic fertilizers are not commonly used in the ASALs, they present an opportunity for increasing crop yields especially for households that do not have livestock. The various options for use of inorganic fertilizers include use of single nutrient source such as Urea or TSP, multiple nutrients source such as DAP or a combination of various inorganic fertilizer which could supply variety of nutrients such as macro and micro nutrients and trace elements. Combinations of various inorganic fertilizers address various nutrient limitations simultaneously. The data presented here shows that in cases where nitrogen was the only major element in the fertilizer (e.g. CAN and urea), the average yields did not exceed 3 t/ha in both cases. Combining nitrogen supply fertilizer with phosphorus supply fertilizers increased yields to between 3.3 and 4.3 t/ha (Table 7.0). Even much better yields and profits are realized when nutrient management interacts with water management because water is often the most limiting element of crop production in ASALs. The common methods for water management in the ASALs include irrigation, terraces, in-situ water

Table 7.0: ISFM technologies found profitable in UM3-4 of the ASALs

UM3-4: Machakos and Makueni Counties	ISFM Technology	Yield (t/ha)	90 kg Bags/acre	BCR
	Urea 30 kg N/ha	3.0	13	12.4
Machakos County -Machakos Central, Kimutwa, Kwa Vonza, Masii, Wamunyu, Katumani, Kangundo, Mitaboni, Kalama	Goat manure 5 t/ha	4.9	22	11.5
	TSP 20 kg P/ha + CAN 20 kg N/ha	3.6	16	6.8
	Farmyard manure 5 t/ha	2.2	10	3.3
Makueni County - Kampi ya mawe, Mbooni, Wote, Kilome	Farm yard manure 5 t/ha + CAN 20 kg N/ha	2.2	10	2.0
	No inputs	0.6	3	0.0

Table 7.1: Water harvesting technologies suitable for ASALs

UM4: Eastern region	Water management technologies	ISFM Technology	Yield (t/ha)	90 kg Bags/acre	BCR
Kitui, Machakos, Makueni, Tharaka, Embu(Mbeere, Mwea)	Irrigated	Irrigation only	3.8	17	13.3
	Irrigated	TSP 25 kg P/ha	4.3	19	7.3
	Sub-soiling	TSP 20 kg P/ha + CAN 20 kg N/ha	3.0	13	5.1
	Irrigated	TSP 20 kg P/ha + CAN 20 kg N/ha	5.8	26	3.5
	Sub-soiling	FYM 5 t/ha + TSP 10 kg P/ha + CAN 10 kg N/ha	2.8	12	2.3
	Rain-fed	No inputs	0.8	4	0.0

NB: Irrigation only will work for a short term but for long term nutrient replenishment is required.

Table 7.2: Nutrient management technologies suitable for LM4 in ASALs

LM4: Eastern Region	Technology	Yield (t/ha)	90 kg Bags/acre	BCR
Makueni County –Emali), (**Machakos County**- Mwala, Makutano, Ikiwe), (Kitui County-Mwingi, Kisasi, Mutomo, Kithioko, Ithookwe, Mutitu,)	CAN 20 kg N/ha	2.7	12	15.8
	Goat manure 5 t/ha	4.9	22	11.5
	SSP 20 kg P/ha + CAN 60 kg N/ha	3.3	15	3.3
Embu County -Mbeere	No inputs	0.8	4	0.0

NB: CAN is very soluble and availability of soil moisture for a short period solubilises and becomes available for crops unlike other fertilizer which take a longer time to solubilise.

*BCR values are calculated relative to the values for low input for similar treatment from the same trails.

Table 7.3: Combined water and nutrient management options suitable for LM4 in ASALs

LM4: Eastern region	Water harvesting	Fertilizer Technology	Yield (t/ha)	90 kg Bags/acre	BCR
Makueni County –Emali), (Machakos County-Mwala, Makutano, Ikiwe), (Kitui County-Mwingi, Kisasi, Mutomo, Kithioko, Ithookwe, Mutitu,) Embu County -Mbeere	Tied ridges	CAN 40 kg N/ha	2.3	10	4.4
	Normal tillage	Manure 2 t/ha	1.8	8	3.5
	Normal tillage	No inputs	0.8	4	0.0

Table 7.4: Nutrient management technologies suitable for LM4-5 in ASALs

LM4-5: Eastern region	Technology	Yield (t/ha)	90 kg Bags/acre	BCR
(Machanga, Mutuobare, Emali (Makueni))	Goat manure 5 t/ha	4.9	22	11.5
	Farmyard manure 5 t/ha	3.5	16	6.2
	TSP 40 kg P/ha + CAN 40 kg N/ha	4.3	19	4.3
	CAN 50 kg N/ha	3.0	13	3.8
	No inputs	0.9	4	0

NB: CAN is very soluble and availability of soil moisture for a short period solubilises and becomes available for crops unlike other fertilizers which take a longer time to solubilise.

8.0 SFM HARMONIZATION IN CENTRAL HIGHLANDS OF KENYA

The Counties encompassed under the central highlands of Kenya include: Kiambu, Nyeri, Nyandarua, Kirin¬yaga, Murang'a, Maragua and Meru. The central Kenya highlands contain unique agro-ecological zones and subzones as well as magnificent landforms that include forests and catchments. The pattern of the Agro-Ecological Zones starts on Nyandarua Range with the *Tropical Alpine Zones TA I* and *II*. They are currently used as National Park but some parts of TA I could possibly be opened up for seasonal grazing stock from the over-populated zones below the forest. The forest reserves are mainly situated in steep wet areas unsuitable for agricultural use (*UH 0* and *UH 1*). The row of Agro-Ecological Zones *LH 1, UM 1-5* and *LM 3-4* occurs at descending altitudes towards the foot-plains in eastward direction. Towards the Laikipia Plateau and the Rift Valley rain shadow occurs, therefore the zones UH 2, 3 and LH 2, 3, 4, 5 indicate decreasing rainfall already in higher altitudes.

The average annual rainfall increases from less than 400 mm in the low eastern plains to more than 2200 mm on the southeastern windward side of the Nyandarua Range in 2200-2700 m, the main altitude for condensation and rain from the clouds of the SE Trade winds. The distribution of rainfall is typically bimodal with two distinct rainy seasons, the first one with its peak in April and the second with the peak in November; the intervening dry season is distinct, except in the misty and cloudy altitudes above 1800 m, and west of the Nyandarua Range and Mt. Kenya where middle rains induced from Western Kenya occur.

8.1 Harmonized Fertilizer Recommendations for maize in Central Kenya region

Central highlands of Kenya refer to Kirinyaga, Nyeri, Meru, Embu, Muranga, Kiambu and Nyandarua. The soils are predominantly humic nitisols, deep and well drained with nitrogen as the main limiting nutrient for crop production. The soils are prone to acidification. Other than for the challenges that may be posed by climate change, rainfall is often sufficient for crop growth for most parts in the region. The maize potential production for this region varies between 6-10 t/ha but average yields in the farmers' fields is less than 3 t/ha owing to challenges presented by low quality seeds, low soil fertility, low fertilizer use, expansion of acidic soils and poor agronomic practices. A major impending factor to use of appropriate soil fertility enhancing technologies is lack of synthesized and harmonized information on appropriate technologies disaggregated by crop and regions. Tables 8.0, 8.1, 8.2, 8.3, 8.4 and 8.5 highlights a basket of profitable option of technologies that have been tested in central highlands of Kenya for the period between 1980s and 2015 by a variety of institution (NARS, Universities, CGIAR centres and

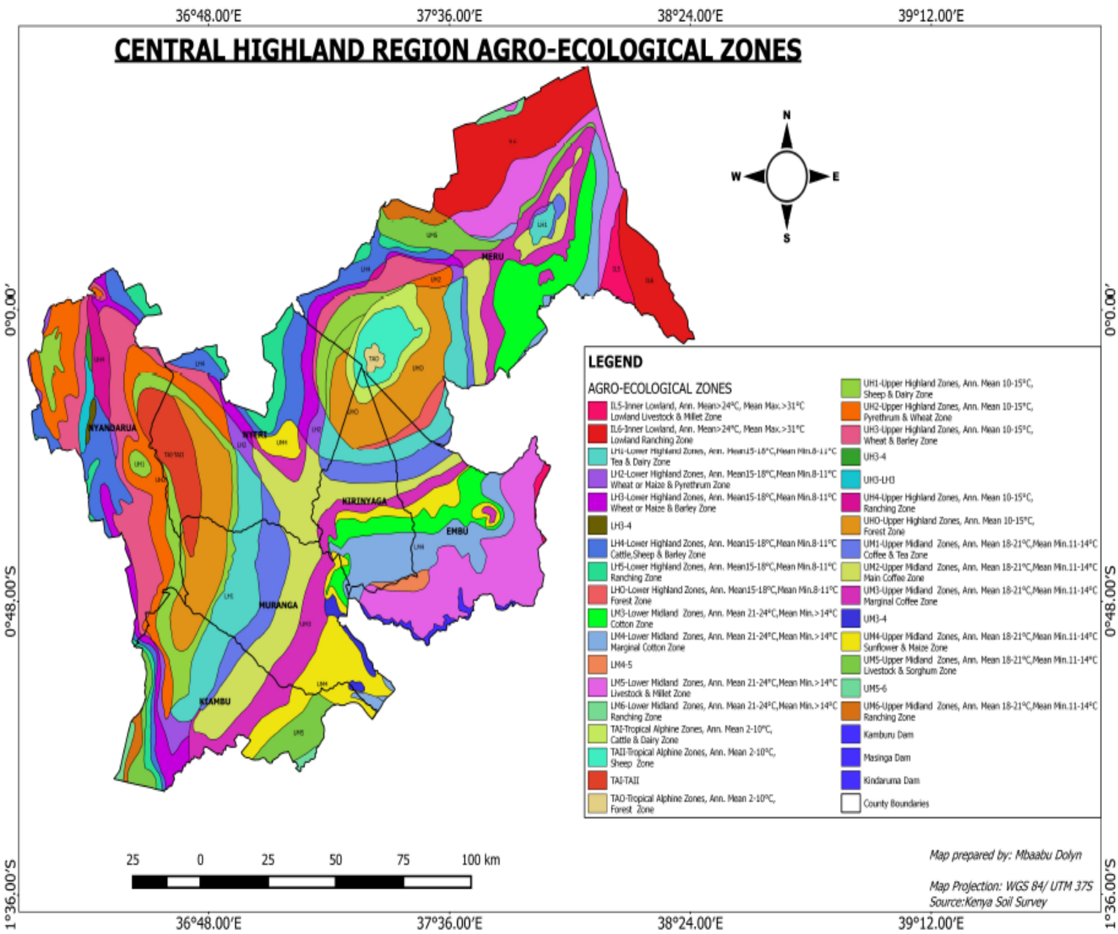


Figure 8.0 Agro-ecological zones found in central Kenya

Table 8.0 Harmonized ISFM technologies for UH1-2 in Central Kenya

UH1, 2	ISFM Technology	Yield (t/ha)	90 kg Bags/acre	BCR
Sasumua Dam, KALRO Oljororok Research Station, Geta Forest scheme, N. Kinangop, Mirangi-Ini, Silibwet, Dundori, Tulaga, Njabini, Kipipiri, Kinale, Lari, Karurumo	Lime 1 t/ha + SSP 100 kg P/ha	5.3	24	10.1
	Lime 1 t/ha + CAN 50 kg N/ha	4.6	20	3.2
	Lime 1 t/ha + Farm yard manure 5 t/ha	4.3	19	3.1
	No input	0.9	4	0

development organizations). The data was collected under the mandate of KSHC whose roles included consolidation synthesis and harmonization of all ISFM work that has been carried out in Kenya with the aim of identifying the right technologies for various regions in Kenya.

The data shows that for central highlands, with no external fertilizer inputs farmers would not produce more than 1.2 t/ha of maize grain. However, by use of various technology options, farmers could increase crop yields to between 3 and 8 t/ha.

- Organic-CIAT, AGRA, ICRAF, KARI, Universities
- Inorganic -KARI, Fertilizer industries (MEA, ARM, Kel Chemicals), IFDC, IPNI, CIAT
- Organic + inorganic-CIAT, AGRA, ICRAF, KARI, Universities, IPNI
- Tillage + Inorganic-Universities, ACT, KARI
- Water harvesting + Organic + Inorganic -Universities, KARI

The interaction between lime and either N or P fertilizer increased yields by more than 300% to between 4.5 and 5.4 t/ha. Economically, these technologies were profitable because the BCR was between 3 and 10 (Table 8.0 UH1, 2). This fertilizer lime interaction, was similar to farmyard manure and lime interactions whose yields were approximately 4 t/ha with a benefit cost ratio of about 3.

Research has used a variety of inorganic fertilizer and fertilizer combinations to address the nutrient deficiencies in the soil. The data shows that with various technologies farmers can achieve between 5 and 8 t/ha of maize grain if the fertilizers are used appropriately in addition to good seeds and good agronomic practices. This translates to benefit cost ration of between 6 and 17, beyond the minimum threshold of 2 which is an indicator of profitability within resource limiting environment. The data provides various options that the farmers can exploit based on fertilizer availability and economic returns (Table 8.1).

A common prescribed practice is to use both nutrient organic and inorganic resources. Organic resources are crucial in long run for wholesome soil health. They are however characterized by slow and unsynchronized release of nutrients which often does not match the crop demand phases. A healthy soil has favourable soil physical, chemical and biological characteristics. On the other hand inorganic resources ensure appropriate synchronization of nutrient supply with crop demand. A mix of the two is crucial

Table 8.1 Inorganic management technologies suitable for LH 1, 2-3 in Central Kenya

LH 1, 2-3	Technology	Yield (t/ha)	90 kg Bags/acre	BCR
Githunguri, Othaya, Kigumo, Limuru, Tigoni, Kijabe, Kikuyu, Mweiga, Karatu, Mwagu	MAP 20 kg P/ha	5.7	25	17.1
	DAP 40 kg P/ha + MOP 25 kg K/ha	6.5	29	14.0
	DAP 40 kg P/ha + CAN 25 Kg N/ha	6.1	27	8.7
	TSP 60 kg P/ha + CAN 30 kg N/ha	7.9	35	7.7
	DAP 40 kg P/ha + CAN 25 Kg N/ha + MOP 25 kg K/ha	5.9	26	7.1
	CAN 60 kg N/ha	5.5	24	6.8
	No input	1.2	5	0.0

for balancing a good synchrony of nutrients supply and demand and soil health. A combination of organic and inorganic sources of nutrients also ensures availability of nutrients throughout the crop growing period. In the data presented in table 8.2, shows that farmers could achieve an average of 4 t/ha of maize after application of 4 t/ha of farmyard manure. Applying a mix of manure and nitrogenous fertilizers could boost the yields to between 5 and 6.5 t/ha while retaining BCR of more than 4.

Biomass transfer seems to be a lesser effective method for boosting maize crop yields in central highlands of Kenya. The challenges presented by biomass transfer include the limitation of land sizes for establishment of biomass stand for transfer (average arable farm size of 0.25 ha). Additionally, the yield levels from commonly used biomass transfer systems such as agro-forestry spp, biomass transfer and green manure restitution is between 3 and 5 t/ha which is between 1 and 3 t/ha less than systems based on inorganic fertilizer, inorganic plus organic fertilizers and farmyard manure. However, the BCR shows that even with those low yields, the systems presented in table 8.3 are profitable

Certain areas in central highlands of Kenya face the challenges of moisture to crop growth. A requirement for crop production in such areas is water management. Farmyard manure

Table 8.2 Organic and inorganic technologies suitable for UM1-2 in Central Kenya

UM1-2	Technology	Yield (t/ha)	90 kg Bags/acre	BCR
Kangema, Karinga, Gakira, Kandara, Kagumo, Karatina, Mathira, Kerugoya, Gathuki-ini, Kirunda	FYM 4 t/ha	4.0	18	11.3
	FYM 5 t/ha + CAN 30 kg N/ha	5.2	23	6.3
	TSP 60 kg P/ha + CAN 30 kg N/ha	5.1	23	5.3
	FYM 5 t/ha + CAN 70 kg N/ha	6.4	28	4.7
	No input	1.0	4	0.0

Table 8.3 Biomass transfer, Agro-forestry and inorganic fertilizers in central Kenya

UM1-2	Technology	Yield (t/ha)	90 kg Bags/acre	BCR
Kangema, karinga, Gakira, Kandara, Kagumo, Karatina, Mathira, Kerugoya, Gathuki-ini, Kirunda	Leucaena 2 t/ha	3.6	16	20.8
	Lablab 1 t/ha + TSP 20 kg P/ha	3.1	14	11.5
	Calliandra 3 t/ha	3.1	14	11.4
	Tithonia 5 t/ha	4.5	20	9.7
	Tithonia 3t/ha + CAN 30 kg N/ha	4.7	21	7.6
	Mucuna 3 t/ha + TSP 20 kg P/ha	3.4	15	7.1
	Calliandra 3 t/ha + CAN 30 kg N/ha	3.7	16	5.8
	No input	1.0	4	0.0

NB: With appropriate machinery these technologies can be practised and are good soil resource base restoration.

Table 8.4 Nutrient management options suitable for UM2-3 in central Kenya

UM2-3, 4, 5	Technology	Yield (t/ha)	90 kg Bags/acre	BCR
Thika, Ruiru, Gatundu, Ndumberi, Makuyu, Kieni East, KALRO Kandara, Kiambu central	TSP 20 kg P/ha + CAN 20 kg N/ha	5.2	23	10.9
	CAN 30 Kg N/ha	4.2	19	10.6
	FYM 5t/ha + CAN 20 kg N/ha	5.9	26	7.3
	FYM 5t/ha	4.2	19	6.3
	No input	1.0	4	0.0

is a common resource in these agro-pastoral AEZs. Some of the most profitable practices involve an interaction between farmyard manure as a source of nutrient and water management techniques for water retention. The common practices include Zai pits, contour furrows, earth basins etc. Table 8.5 shows that even after application of manure at 5 t/ha in absence of water harvesting techniques farmers may not achieve more than 1t/ha of maize grain. With various water harvesting and application of 5 t/ha manure, farmers could achieve between 6 and 8 t/ha of maize grain.

Table 8.5 Water and nutrient management technologies suitable for LM4 in central Kenya

LM4	Water harvesting	Technology	Yield (t/ha)	90 kg Bags/acre	BCR
Gatuanyaga, Mbeere, Siakago, Mwea, Ngoliba, Wanguru, Kambiti	Road/compound runoff	FYM 5 t/ha	6.1	27	6.8
	Planting (Zai) pits	FYM 5 t/ha	8.1	36	6.7
	Earth basins	FYM 5 t/ha	7.7	34	6.3
	Camberred beds	FYM 5 t/ha	7.4	33	6.0
	Contour furrows	FYM 5 t/ha	6.4	28	6.0
	Tied Furrows	FYM 5 t/ha	6.3	28	5.8
	No Water harvesting	FYM 5 t/ha	1.0	4	0.0

9.0 SFM HARMONIZATION FOR COASTAL REGION

The counties covered under the coastal region are: Kwale, Kilifi, Lamu, Mombasa, Taita-Taveta, &Tana River. The coastal region falls into agro- ecological climatic zones sub-humid (II) to semi-arid (V) (Fig.2). Thus the coastal sub-humid zone II is considered having good potential (60-70% of optimum) for sugarcane-maize, zone III for coconut-cassava, zone IV for cashew nut-cassava and the semi-arid and zone V for Livestock/forages-millet enterprises. The rainfall is bimodal with long rains (March-July) and short rains (October-December) (Jaetzold and Schmidt, 1982).

The important soils are sandy Acrisols, Arenosols, Ferralsols and deep well drained eutric and thionic Fluvisols, and imperfect to poorly drained Cambisols and Vertisols with saline-sodic phases. The predominant soil types are Acrisols, ferralsols and Vertisols. The well drained soils occurring in Zones II and III are fairly well suited to small scale arable farming - sugarcane, coconut (light soils) cashew, mango with maize, cassava and vegetables and poorly drained soils for grazing.

The deep to moderately deep, well drained relatively fertile soils (Ferralsols, Arenosols, Luvisols) in Zones III and IV have good potential for small scale arable/mixed farming with intermediate technology (Jaetzold and Schmidt, 1982). The main tree crops are coconuts (light soils only), cashew, mango, bixa and avocadoes with food crops –maize, cassava, sorghum, legumes and vegetables. The potential for food crops is much lower during short rains for Zone IV. The soils of the vast semi arid to arid Zones V and VI (Fluvisols, Cambisols, Planosols, Luvisols, Vertisols, Solenetzs with sodic phases), particularly on the north east coast, have low potential for arable farming and best used for Livestock, pasture and forages and draught resistant crops such as millet, sorghum, beans, peas and green grams.

Table 9.0 Nutrient management options suitable for CL3-4 AEZ of Coastal Kenya

CL3-4	Basket of Option Technologies	Yield (t/ha)	90kg bags/acre	BCR
Malindi, Lamu, Kwale, Kilifi, South-Eastern Tana River	TSP 20 kg P/ha + CAN 20 kg N/ha	4.9	22	10.8
	FYM 2.5 t/ha	3.8	17	10.7
	FYM 2.5 t/ha + DAP 25 kg P/ha + CAN 30 kg N/ha	4.5	20	5.0
	Goat manure 4 t/ha	3.3	15	4.4
	No inputs	1.7	8	0.0

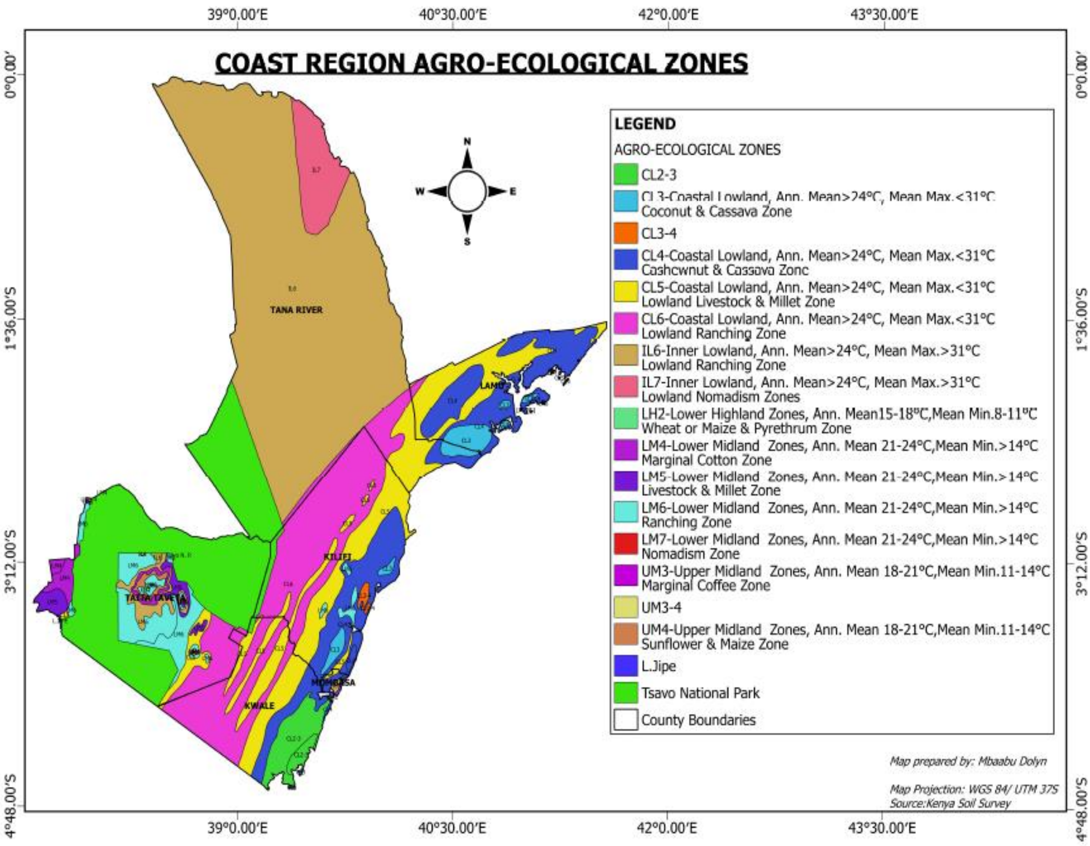


Figure 9.0 Agro-ecological zones found at the Kenya coastal region

9.1 Harmonized Fertilizer Recommendations for Coastal region

The level of research on various agricultural practices at the coastal region is much lower than most of the other regions in Kenya. Nevertheless, there are a number of technologies that have proved effective for boosting crop yields in the coast region. They include inorganic fertilizers, organic resources and a combination of organic and inorganic fertilizers. Table 9.0 highlights a basket of profitable technology options that farmers may rely on to boost crop yields by between 1.5 and 3 t/ha at a BCR of between 4 and 10.

Table 9.1: Nutrient management technologies suitable for M5 in Coastal region

LM 5	Technology	Yield (t/ha)	90 kg Bags/acre	BCR
Taveta, Wundanyi	Goat manure 5 t/ha	4.9	22	11.5
	Farmyard manure 5 t/ha	3.5	16	6.2
	TSP 40 kg P/ha + CAN 40 kg N/ha	4.3	19	4.3
	CAN 50 kg N/ha	3.0	13	3.8
	No inputs	0.9	4	0

10.0 SFM HARMONIZATION FOR RIFT VALLEY REGION

In the earlier administrative boundaries where Kenya was divided into eight provinces, Rift valley was the largest of the eight running from northern to the southern part of Kenya. It was the largest and one of the most economically important provinces. Currently the area formerly referred to as rift valley province is now divided into 14 counties namely: Turkana, West Pokot, Samburu, Trans Nzoia, Uasin Gishu, Elgeyo-Marakwet, Nandi, Baringo, Laikipia, Nakuru, Narok, Kajiado, Kericho and Bomet. In this manual Rift Valley is divided into 3 sub-regions namely North Rift, Central Rift and South Rift. The sub-regions and counties are shown in Table 10.0 and cover many agro-ecological zones.

North Rift

North Rift is divided into the following counties: Turkana, West Pokot, Samburu, Elgeyo Marakwet and Baringo. However Turkana has not been included in this manual because there is almost no farming in the county. The dominant agricultural activities there are ranching or livestock keeping & some fishing in Lake Turkana. Soils found in the remaining 4 counties (West Pokot, Samburu, Elgeyo Marakwet & Baringo) include: Acrisols, Cambisols, Ferralsols, Luvisols, Nitosols, Phaeozens, Solonetz and Vertisols with Nitosols, Cambisols, Acrisols, Luvisols, Ferralsols and Verisols occurring in most parts of the 4 counties. Detail description

Table 10.0 Agro-ecological zones as distributed across the counties in Rift valley

County	Agro-ecological zones
	North Rift
Turkana	UM6, LM6, LM7, IL7
West Pokot	UH1, UH2,LH1,LH2,LH3,LH4,UM3,UM4,UM5,LM4,LM5,LM6,IL6
Samburu	UH2,LH2,LH3,LH4,UM3,UM4,UM5,LM5,LM6,LM7,IL7
Elgeyo-Marakwet	UH1,UH2,UH3,LH1,LH2,LH3,UM3,UM4,LM4,LM5,IL6
Baringo	UH1,UH2, LH2, LH3, UM3, UM4, UM5, LM4, LM5, LM6
	Central Rift
Trans Nzoia	UH1,UH2,LH1,LH2,UM2,UM3,UM4,UM5
Nandi	UH1,LH1,LH2,LH3,UM1,UM2,UM3,UM4,LM1, LM2
Uasin Gishu	UH1,UH2,UH3,LH2,LH3,LH4,UM3,UM4
Kericho	UH1,UH2,LH1,LH2,LH3,UM1,UM2,UM3,UM4,LM2,LM3
Bomet	LH1, LH2,LH3,UM3,UM4
Laikipia	UH2, LH2, LH3, LH4, LH5, UM4, UM5, UM6, LM6
Nakuru	UH1, UH2, UH3, LH2,LH3,LH4,LH5,UM4,UM5,UM6,LM5
	South Rift
Narok	UH1,UH2,UH3,LH1,LH2,LH3,LH4,UM1,UM2,UM3,UM4,UM5,UM6, LM1,LM2,LM3,LM4,LM5,LM6
Kajiado	LH2,LH3,UM1,UM3,UM4,UM5,UM6,LM4,LM5,LM6,IL6

of all these soil types is given in appendix I

Central Rift

Central Rift is made up of: Trans Nzoia, Nandi, Uasin Gishu, Kericho, Bomet, Laikipia and Nakuru counties. Soils found in these 7 counties include: Acrisols, Andosols, Cambisols, Ferralsols, Histosols, Luvisols, Nitosols, Phaeozens, Planosols, Regosols, Solonchaks and Vertisols, with Nitosols, Cambisols, Acrisols, Luvisols, Ferralsols and Verisols occurring in most parts of the 7 counties. Histosols are found only in the Tropical-Alpine zones I and II on Mount Elgon in Trans Nzoia County. Planosols are found in the southwestern part of Bomet County that borders Narok County while Regosols are only found around Menengai crater in Nakuru County. Detail descriptions of all these soil types can be found in appendix I

South Rift

South Rift is composed of only 2 counties namely: Narok and Kajiado. Soils that are found in these 2 counties are: Andosols, Arenosols, Cambisols, Luvisols, Phaeozems, Planosols, Solonchaks and Vertisols with Cambisols, Luvisols and Vertisols being the dominant soil types in the 2 counties.

In general the soils in most counties of the Rift Valley region are fertile due to volcanic origin and other young parent materials.

10.1 Harmonized Fertilizer Recommendations for maize in Rift Valley region

The maize potential production for this region varies between 5-10 t/ha but average yields in the farmers' fields is less than 3 t/ha owing to challenges presented by low quality seeds, low soil fertility, low fertilizer use, acidic soils and poor agronomic practices. A major impending factor to use of appropriate soil fertility enhancing technologies is lack of synthesized and harmonized information on appropriate technologies disaggregated by crop and agro-ecological zones in the region. Tables 10.1, 10.2, 10.3, 10.4 and 10.5 highlight a basket of profitable option of technologies that have been tested in the Rift Valley region of Kenya for the period between 1980s and 2015 by a variety of institution (NARS, Universities, CGIAR centres and development organizations). The data was collected under the mandate of KSHC whose roles included consolidation synthesis and harmonization of all ISFM work that has been carried out in Kenya with the aim of identifying the right technologies for various regions in the country.

The data shows that for Rift Valley, with no external fertilizer inputs farmers would not produce more than 1.2 t/ha of maize grain. However, by use of various technology options, farmers could increase crop yields to between 3 and 8 t/ha.

- Organic – CIAT, AGRA, ICRAF, KARI, Universities
- Inorganic –KARI, Fertilizer industries (MEA, ARM, Kel Chemicals), IFDC, IPNI, CIAT
- Organic + inorganic –CIAT, AGRA, ICRAF, KARI, Universities, IPNI
- Tillage + Inorganic –Universities, ACT, KARI
- Water harvesting + Organic + Inorganic –Universities, KARI

The interaction between lime and either N or P

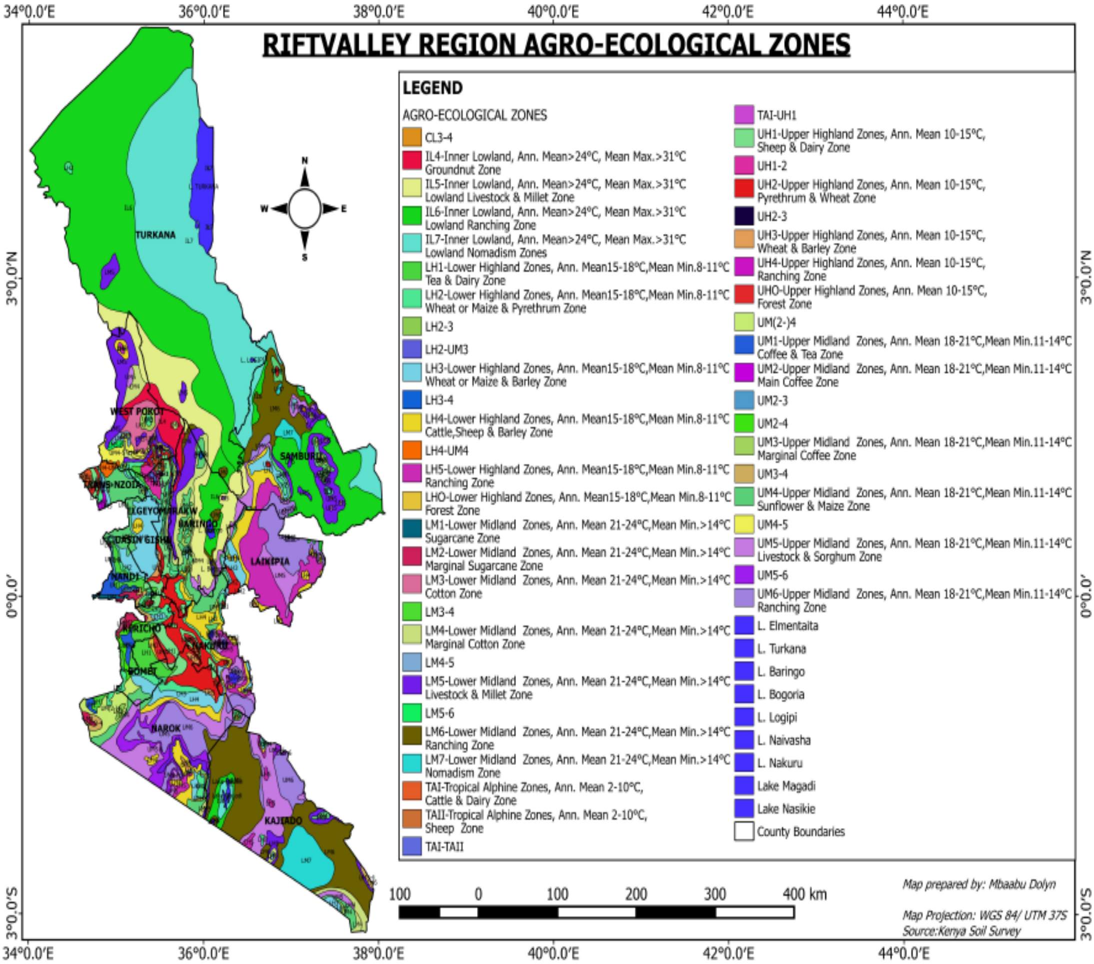


Figure 10.0 Agro-ecological zones found in rift valley region

Table 10.1 Inorganic fertilizer application rates suitable for TAI in Rift Valley

TAI-II	Technology	Yield (t/ha)	90 kg bags/acre	BCR
Laikipia –Aberdares , Trans Nzoia-Mt Elgon	SSP 56 kg P/ha	6.7	30	4.5
	SSP 56 kg P/ha + ASN 80 kg N/ha	7.9	35	3.7
	No input	1.5	7	0.0

fertilizer increased yields by more than 400% to between 5.4 and 6.5 t/ha. Economically, these technologies were profitable because the BCR was between 2.7 and 31.8 (Tables 10.2 & 10.3 LH2 & 3).

Research has used a variety of inorganic and organic fertilizers, and organic + inorganic fertilizer combinations to address the nutrient deficiencies in the soils. The data shows that with various technologies farmers can achieve between 4.5 and 10 t/ha of maize grain if the fertilizers are used appropriately in addition to good seeds and good agronomic practices. This translates to benefit cost ratios of between 2.7 and 31.8, beyond the minimum threshold of 2 which is an indication of profitability within resource limiting environment.The data provides various options that the farmers can exploit based on fertilizer availability and economic returns (Tables 10.1 - 10.5). Combined use of organic and inorganic sources of nutrients ensures availability of nutrients throughout the crop growing period. In the data presented in Tables 10.3-10.5 shows that farmers could achieve an average of 6.8 t/ha of maize after application of 2 t/ha of chicken manure. Applying a mix of the manure and nitrogen (N) and phosphate (P) fertilizers could boost the yields to 7.4 t/ha while application of a mix of farmyard manure and N and P fertilizers could push maize grain yield to an average of retaining BCR of more than 4.

Table 10.2 Inorganic fertilizer application rates suitable for LH2-3 in Rift Valley

LH2-LH3	Fertilizer Technology	Yield (t/ha)	90kg bags/acre	BCR
Kapsabet, Sangale, Bomet, Longisa, Ndanai, Londiani, Tambach, Njoro, Nandi hills,Kipkelion	DSP 60 kg P/ha	7.2	32	12.0
	CAN 60 kg N/ha	5.4	24	5.7
	M.A.P 75 kg P/ha + CAN 15 kg N/ha	5.7	25	5.7
	DAP 120 kg P/ha	6.6	29	4.7
	Lime 1 t/ha + DAP 60 kg P/ha	5.8	26	4.7
	SSP 56 kg P/ha	5.6	25	3.7
	Mono-calcium phosphate 75 kg P/ha	6.7	30	3.6
	TSP 60 kg P/ha + CAN 30 kg N/ha	5.1	23	3.6
	Di-calcium phosphate 60 kg P/ha	5.4	24	2.7
	No inputs	1.3	6	0

* Crotalaria is mainly used as vegetable in western Kenya and often farmers do not plough back the biomass.

Table 10.3 Organic and inorganic nutrient management options suitable for LH3 in Rift Valley

LH3	Technology	Yield (t/ha)	90kg bags/acre	BCR
Nakuru, Naivasha,kaiboi, Kingwal, Lessos, Kilibwani, Chemundo, Kosirai, Bahati, Enabelbel, Ololungu, ildamat, Eldama-Ravine, Mosop, Sigor, Endebess, Moiben, Eldoret, Masaba, Kaptagat	Chicken manure 2 t/ha	6.8	30	31.8
	Lime 2 t/ha + DAP 30 kg P/ha	5.4	24	19.6
	Compost 2.5 t/ha	5.4	24	18.8
	Chicken manure 2 t/ha +TSP 30 kg P/ha + CAN 40 kg N/ha	7.4	33	9.8
	FYM 2 t/ha +TSP 30 kg P/ha + CAN 40 kg N/ha	8.7	39	7.9
	FYM 5 t/ha + CAN 25 kg N/ha	7.2	32	7.8
	TSP 40 kg P/ha + CAN 40 kg N/ha	7.3	32	7.1
	Lime 5 t/ha + DAP 80 kg P/ha + CAN 80 kg N/ha	7.0	31	3.0
	DAP 80 kg P/ha + CAN 80 kg N/ha (FURP recommended rate)	6.6	29	2.8
	No inputs	1.1	5	0

Table 10.4 Organic and inorganic nutrient management options suitable for UM1-3 in Rift Valley

UM1-3	Technology	Yield (t/ha)	90kg bags/acre	BCR
Tindinyo, Kaptumo, Kapkangani, Waldai,Soin, Emarti, Siria, Kilgoris, Saboti	FYM 2 t/ha + DAP 15 kg P/ha	4.6	20	13.0
	FYM 2 t/ha +TSP 30 kg P/ha + CAN 40 kg N/ha	8.7	39	7.9
	DAP 60 kg P/ha + CAN 60 kg N/ha (FURP recommended rate)	5.1	23	2.8
	No input	1.0	4	0.0

Table 10.5 Organic and inorganic nutrient management options suitable for UM4-5 in Rift Valley

UM4-5	Technology	Yield (t/ha)	90kg bags/acre	BCR
Kapkaren, Kabiyet, Kaboson, Kitale, Cherangani, Lembus, kakamor, Solai, Subukia, Kwanza, Moi's bridge, Turbo, Kapenguria, Riwaa, Chepareria, Loboi, Ewaso Narok, Mosiro	TSP 20 kg P/ha + Urea 60 kg N/ha	9.8	44	15.6
	Lime 2 t/ha + DAP 30 kg P/ha	6.5	29	12.6
	*Crotalaria 5 t/ha	6.1	27	10.6
	FYM 5 t/ha + CAN 30 kg N/ha	8.5	38	9.0
	CAN 50 kg N/ha	6.1	27	8.7
	TSP 30 kg P/ha + CAN 30 kg N/ha + Zinc Sulphate 9 kg Zn/ha	6.4	28	7.1
	TSP 60 kg P/ha + CAN 60 kg N/ha (FURP recommendation)	8.9	40	5.8
	No input	1.1	5	0

11.0 WESTERN REGION (WESTERN AND NYANZA)

Western

Western consists of eight districts namely: Bungoma, Busia, Mt. Elgon, Kakamega, Lugari, Teso, Vihiga and Butere-Mumias. With a total land area of 8,264 km2, it is one the most densely populated re-gions and has the most evenly distributed rainfall in Kenya.

The annual averages range between 900 and 2200 mm. The reason is that after the convectional rainfall of the first rainy season (March - May), the normally long dry season (June - October) receives heavy rains too with a peak in August - September. They are caused by a convergence of the daily Lake winds, attracted by the daily heating up of the land, with the Trade winds from the East. This circulation causes dry component near the Lake, and thus the rainfall is much smaller than in Nyanza because the shore is stretching mainly parallel to the Trade winds.

Nyanza

Nyanza comprises of various agro-ecological zones and rainfall areas, distributed as follows:

- Kisii group of districts (Marani, Masaba South, North Masaba, Kisii, Manga, Borabu, Nyamira, Nyamache, Kenyenya, Gucha)- LH1, LH2, UM1, UM2 (rainfall 1300-2100 mm)
- South Nyanza group of districts (Homa Bay, Ndhiwa, Suba, Mbita, Rachuonyo, Nyatike, Rongo, Uriri, Migori, Kuria) - UM1, UM2, UM3, UM4, LM1-5 (rainfall 700-1800 mm)
- Kisumu group of districts (Kisumu, Nyando and Nyakach)- UM1, UM2, UM3, LM1-4 (rainfall 980-1800 mm)
- Siaya group of districts (Bondo, Rarieda, Siaya and Ugenya) - UM1, UM2, LM1-5 (rainfall 800-1900 mm)

In western Kenya the following soil types are found: Acrisols, Arenosols, Cambisols, Ferralsols, Fluvisols, Gleysols, Histosols, Lithosols, Luvisols, Nitosols, Planosols, Regosols, Solonchaks and Vertisols.

Various soil types are found in Nyanza including sandy clay in the lower zones, Mbuga or black cotton soils in the plains and loamy clay soils of the Kisii highlands. Soils here vary greatly according to the prevailing parent material. In higher regions, soils are dark red clays which are fertile and well drained. In the Kavirondo Gulf, soils are sandy loam formed from sedimentary rocks. Alluvial deposits of eroded material from uplands are common along flood plains of rivers such as Nyando, Yala, Nzoia, and Kuja. In plains such as the Yala and Kano plains, peat swampy soils and black cotton soils dominate. Volcanic soils interspersed with fertile peat swampy soils are found in the uplands. Soils in these regions are generally productive. The soils are in most places not fertile due to the widespread absence of adequate volcanic or other young parent material. Areas with sedimentary rocks occur in the lowlands at an altitude ranging from 1000 m and have loamy sandy soils.

The annual average rainfall increases from 700 mm near Lake Victoria to more than 2200 mm on the high plateaus of the Kisii Group of Districts. The distribution during the year is not typically bimodal in two rainy seasons as in East Kenya but tends to be tri-modal. The reason is, that after the convectional rainfall of the first rainy season, the normally long dry season gets heavy rains too, the "middle rains", because they occur in the middle between the first and the second rainy season with a peak in August – September. These middle rains may be called already second rainy season where they are sufficient enough for crop growing. The eastern type of it with the main rainfall in November-December is almost disappearing in West Kenya, only a small peak remains. But here the rainfall and the stored moisture in the soil are generally so high that in humid areas there are permanent growing conditions or almost permanent ones Near the Lake shore, in the West and in the Southwest, the rains from October to December are small and unreliable. This may cause semiarid conditions up to February, changing Zone IV to Zone V.

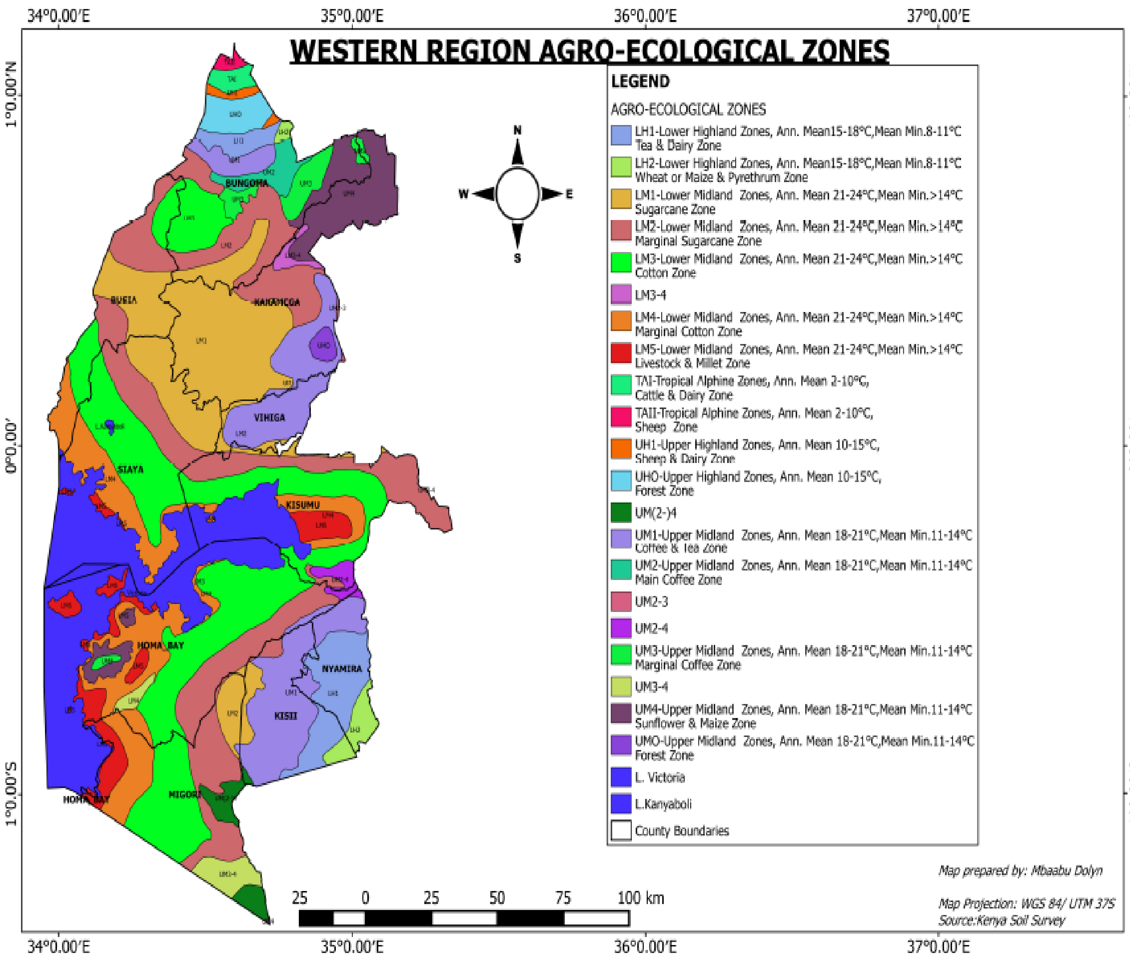


Figure 11.0 Agro-ecological zones found in Western Kenya

11.1 Harmonized Fertilizer Recommendations for maize in Western Kenya region

The maize potential production for this region varies between 3-7 t/ha which is lower than that of Central (6 - 10 t/ha) and Rift Valley (5 - 10 t/ha) regions despite the higher rainfall received in this region. The average yields in the farmers' fields is less than 1 t/ha again lower than 3 t/ha of the other 2 regions of Central and Rift Valley. This is attributed to challenges presented by low quality seeds use, low soil fertility, low fertilizer, manure and lime use, highly leached acidic soils and poor agronomic practices. A major impending factor to use of appropriate soil fertility enhancing technologies is lack of synthesized and harmonized information on appropriate technologies disaggregated by crop and agro-ecological zones in the region. Tables 11.0, 11.1, 11.2, 11.3, 11.4 and 11.5 highlight a basket of profitable options of technologies that have been tested in the Western Kenya region including Nyanza for the period between 1980s and 2015 by a variety of institutions (NARS, Universities, CGIAR centres and development organizations).

The data was collected under the mandate of KSHC whose roles included consolidation synthesis and harmonization of all ISFM work that has been carried out in Kenya with the aim of identifying the right technologies for various regions in the country. The data shows that for Western Kenya, with no external fertilizer inputs farmers would not produce more than 1 t/ha of maize grain. However, by use of various technology options, farmers could increase crop yields to between 3 and 7 t/ha. As in Rift Valley region research has used a variety of organic fertilizers, inorganic fertilizers and organic + inorganic fertilizer combinations to address the nutrient deficiencies in the soils. The data shows that with various technologies farmers can achieve between 3 and 7.7 t/ha of maize grain if the fertilizers are used appropriately in addition to good seeds and good agronomic practices. This translates to benefit cost ratios of between 2.1 and 19.5, beyond the minimum threshold of 2 which is an indication of profitability within resource limiting environment. The data provides various options that the farmers can exploit based on fertilizer availability and economic returns (Tables 11.0 - 11.5).

Table 11.0 Organic and inorganic nutrient management options for LH1 in Western Kenya

LH1	Technology	Yield (t/ha)	90kg bags/acre	BCR
Nyamira, Keroka, manga, Kiamokama, Nyamchemange, Masaba, Borabu, Kapsakwony, Chemweisus	Tithonia 5 t/ha	6.3	28	11.9
	FYM 5 t/ha + DAP 30 kg P/ha	6.2	28	7.2
	FYM 5 t/ha	4.3	19	7.2
	Lime 2.5 t/ha	5.0	22	4.2
	DAP 60 kg P/ha + CAN 60 kg N/ha	6.0	27	3.9
	No input	0.7	3	0.0

Table 11.1 Nutrient management options suitable for UM1 in Western Kenya region

UM1	Technology	Yield (t/ha)	90kg bags/acre	BCR
Kisii, Ogembo, Kenyenya, Nyamira North, Etago, Magenche, Gucha, Nyamache, Otamba, Nyamarambe, Maseno, Kibingei, Chavakali, kaimosi, Vihiga, Hamisi, Luanda, Emuhaya, Sabatia, Tiriki, Khayega, Kabras east, Muhandi, Igunga, Jepkoyai	Tithonia 5t/ha	7.4	33	14.7
	Crotalaria 5 t/ha + TSP 30 kg P/ha + Urea 20 kg N/ha	7.1	32	5.6
	TSP 60 kg P/ha + Urea 60 kg N/ha	5.8	26	4.3
	FYM 5 t/ha + TSP 30 kg P/ha + Urea 20 kg N/ha	5.2	23	4.0
	TSP 60 kg P/ha + Urea 60 kg N/ha + MoP 60 kg K/ha	6.3	28	3.9
	DAP 60 kg P/ha + CAN 60 kg N/ha	5.7	25	3.3
	Mavuno 30 kg P/ha + CAN 60 kg N/ha	4.5	20	2.7
	17:17:17 60 kg P/ha + $MgSO_4.7H_2O$ 20kg Mg/ha + $ZnSO_4.7H_2O$ 20 kg Zn/ha + $Na_2B_4O_7.10H_2O$ 5 kg B/ha +Urea 60 kg N/ha	7.7	34	2.3
	No inputs	1.1	5	0.0

Table 11.2 Nutrient management options suitable for UM1-2 in Western Kenya

UM1-2	Technology	Yield (t/ha)	90kg bags/acre	BCR
Kabondo, Kimilili, Sirisia, Kamakoiwa	MAP 40 kg P/ha	6.1	27	19.5
	DAP 50 kg P/ha	6.1	27	12.9
	TSP 30 kg P/ha + CAN 30 kg N/ha + Zinc Sulphate 5 kg Zn/ha	6.4	28	7.3
	TSP 60 kg P/ha + CAN 30 kg N/ha	7.0	31	6.6
	TSP 40 kg P/ha + MAP 30 kg N/ha + CAN 60 kg N/ha	6.5	29	4.0
	Lime 2 t/ha + DAP 20 kg P/ha	4.0	18	3.1
	No inputs	0.7	3	0.0

The interaction between lime and DAP fertilizer increased yields by more than 400% to between 4.0 and 4.5 t/ha from 1 t/ha. Economically, these technologies were profitable because the BCR averaged at 3.2 (Tables 11.2 & 11.4 UM1-2 & LM1-2).

Table 11.3 Organic and Inorganic Nutrient management options suitable for LM1 in western Kenya

LM1	Technology	Yield (t/ha)	90kg bags/acre	BCR
Rongo, Nyamarambe, Sega, Rangala, Yala, Sigomere, Matete, Kiboswa, Nambale, Butula, Busia, Mayende, Buchenya, Akobwait, Butsotso, Kakamega, Malava, Mumias, Lurambi, Bukura, Butere, Munami, Marama, Khwisero, Matungu, Navakholo, Ikolomani	Tithonia 1 t/ha + TSP 50 kg P/ha	4.2	19	17.2
	Tithonia 5t/ha	4.6	20	7.5
	FYM 5 t/ha + DAP 30 kg P/ha	5.0	22	5.2
	TSP 60 kg P/ha + Urea 60 kg N/ha	5.8	26	4.6
	Tithonia 5 t/ha + TSP 40 kg P/ha	5.3	24	4.1
	TSP 60 kg P/ha + Urea 60 kg N/ha + MOP 60 kg K/ha	6.2	28	4.0
	No inputs	0.9	4	0.0

Table 11.4 Inorganic nutrient management options suitable LM1-2 in Western Kenya

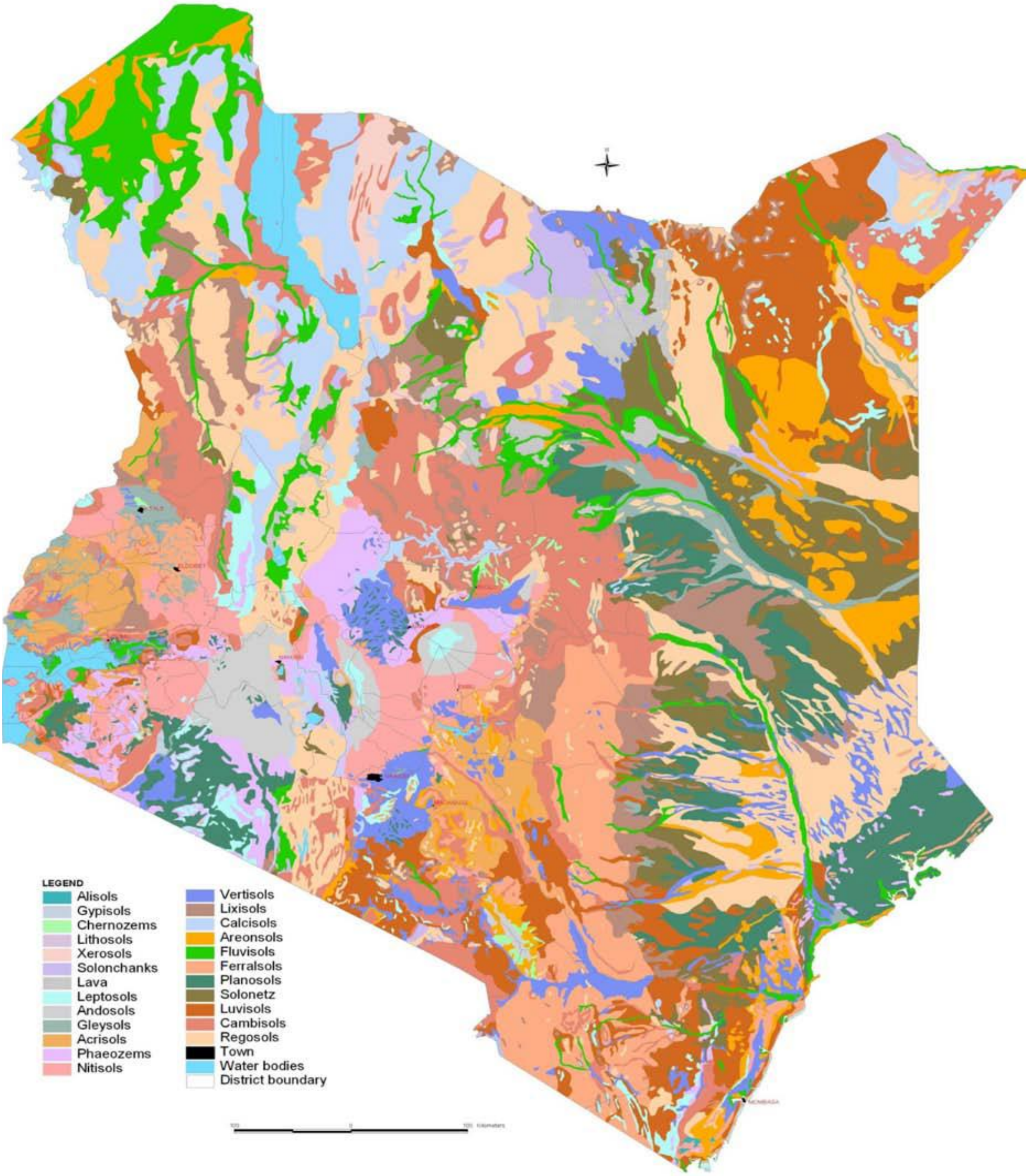
LM1-2	Technology	Yield (t/ha)	90kg bags/acre	BCR
Marinde, Rangwe, Mirogi, Oyugis, Uriri, Rongo, Chwele, Kuria, Siaya, Ukwala, Akala, Boro, Umala, Mugai, Malakisi, Ugenya, Miwani, Muhoroni, Kibigori, Sondu, Namasanda, Amukura, Alupe, Busia, Malaba, Matayos, Matsakha, Esikulu, Bungoma, Webuye, Sangalo, Bumula, Kanduyi	DAP 30 kg P/ha	4.6	20	14.5
	TSP 50 kg P/ha + Urea 30 kg N/ha + MOP 60 kg K/ha	6.3	28	6.6
	TSP 30 kg P/ha + CAN 40 kg N/ha	4.1	18	4.0
	Lime 1 t/ha + DAP 60 kg P/ha	4.5	20	3.4
	DAP 30 kg P/ha + CAN 60 kg N/ha	3.6	16	2.1
	No inputs	1.0	4	0.0

Table 11.5 Inorganic nutrient management options suitable for LM3-4 in Western Kenya

LM3-4	Technology	Yield (t/ha)	90kg bags/acre	BCR
Kendu Bay, Kosele, Ndhiwa, Magunga, Homa Bay, Nambale, Suba, Migori, Mbita, KenduBay, Tongaren, Rachuonyo, Nyatike, Kadenge, Bodo Madiany, Rangengni, Asembo, Usenge, Rarienda, Ajigo, Nyawita, Nyavita-Maranda, Nyamonge, Kibos, Awasi, Kisumu, Ahero, Nyakach, Nyando, Gem Nam, Budalangi, Funyula, Amagoro, Teso, Nagina, Sio Port, Hakati, Port Bunyala, Osieko, Angurai, Bukiri, Bulemi, Kamolo, Katalepai, Kimaeti, Tongaren, Myanga, Ndivisi	DAP 15 kg P/ha + CAN 15 kg N/ha	5.4	24	15.4
	TSP 10kg P/ha + CAN 20 N/ha	4.5	20	10.9
	No inputs	1.0	4	0.0

The technology that resulted in the highest maize grain yield of 7.7 t/ha (17:17:17 60 kg P/ha + $MgSO_4.7H_2O$ 20kg Mg/ha + $ZnSO_4.7H_2O$ 20 kg Zn/ha + $Na_2B_4O_7.10H_2O$ 5kg B/ha +Urea 60 kg N/ha) indicates that soils of this region are deficient not only in the traditional N, P, K nutrients but the micro-nutrients as well. This may be attributed to the highly leached soils of this region due to the high rainfall received in the region.

Kenya Soil map



Source: Sombroek *et al*.1982; FAO, 2006

12.0 THE LINK BETWEEN SOIL FERTILITY, CROP YIELD, FOOD AND NUTRITION SECURITY

The causes of food insecurity are very diverse and interconnected, but poverty and food shortage are the main drivers. Improvement of crop yields especially through integrated soil fertility management will lead to increases in the supply of food, nutrition and raise household incomes. The yield gap of cereal is 4 t/ha while the yield gap of legumes stands at about 1 t/ha. There are three levels of yield gaps. The first one is yield gap 3 which is due to soil nutrient imbalance, inappropriate germplasm and poor farm management practices. The second yield gap is mainly caused by economic imbalances and climatic variations while the last yield gap is due to germplasm performance potential in a given climatic condition (Fig 12.0). Closing this yield gap is crucial for checking the food insecurity and malnutrition. At the heart of food insecurity is poor crop yields largely caused by use of inappropriate crop germplasm, weeds, pests, diseases and degraded soils. Crop diversification, balanced soil fertilization taking into account economic profitability are important measures for addressing food and nutritional insecurity without depleting ecological biodiversity.

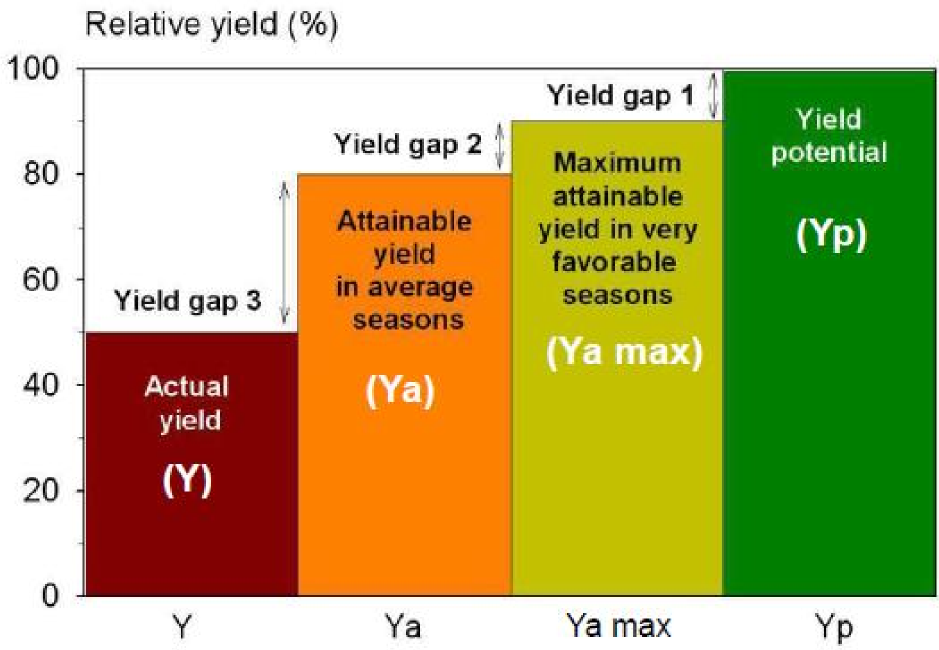


Figure 12.0 Three yield gap levels as influenced by varied indicators

Source: Zingore *et al* 2013

Effective ISFM approaches are based on adapting crop and nutrient management practices to local soil, climatic and socio-economic conditions. The performance of different ISFM technologies is location specific. Significant and sustainable adoption of appropriate technologies is a function of farmers' access to appropriate inputs (fertilizer and seeds), access to appropriate information and availability of favorable output markets.

12.1 The Link between Fertilizers, Soil Fertility and Soil Health

Mineral fertilizer use is essential to modern agriculture and ensuring food security for mankind. In addition to enhancing crop yields, fertilizers can indirectly affect soil properties or soil health, either positively or negatively. The key to ensuring positive effects on soil lies in good science-based nutrient management practices; adoption of such practices ensures that economic crop production is compatible with minimizing environmental effects. Wherever possible, available organic manures and other organic materials should be used in an integrated fashion with mineral fertilizers to ensure efficient and effective nutrient use as well as better soil health.

12.2 Soil fertility gradients/variability

Smallholder farms in Kenya exhibit a high degree of heterogeneity, determined by a complex set of socio-economic and biophysical factors. The farms consist of multiple plots managed differently in terms of allocation of crops, nutrient inputs and labour resources, making within-farm soil fertility gradients caused by management strategies a common feature. Variability in soil fertility at farm scale may be associated with topography, soil types, land degradation intensities, sharp physical discontinuities (e.g. rocky outcrops), land-use history or distance from the homestead and livestock facilities. In most cases, nutrient inputs are preferentially allocated to home fields, whilst outfields are neglected. As nutrient use efficiency varies strongly along these gradients, such heterogeneity must be considered when designing soil management strategies, aimed at improved overall resource use efficiency at farm scale.

12.3The Four R Nutrient Stewardship Site specific nutrient requirement (types, and rates)

Fertilizer application recommendations are often based on crop response data averaged over large areas, though farmers' fields show large variability in terms of nutrient-supplying capacity and crop response to nutrients. Thus, blanket fertilizer application recommendations may lead farmers to over-fertilize in some areas and under-fertilize in others, or apply an improper balance of nutrients for the crop. An alternative to blanket guidance, Site-Specific Nutrient Management (SSNM) aims to optimize the supply of soil nutrients over time and space to match the requirements of crops through four key principles (Table 1). The principles, called the "4 Rs", date back to at least 1988 and are attributed to the International Plant Nutrition Institute (Bruulselma *et al*. 2012). They are:

Right product: Match the fertilizer product or nutrient source to crop needs and soil type to ensure balanced supply of nutrients.

Right rate: Match the quantity of fertilizer applied to crop needs, taking into account the current supply of nutrients in the soil. Too much fertilizer leads to environmental losses, including runoff, leaching and gaseous emissions, as well as wasting money. Too little fertilizer exhausts soils, leading to soil degradation.

Right time: Ensure nutrients are available when crops need them by assessing crop nutrient dynamics. This may mean using split applications of mineral fertilizers or combining organic and mineral nutrient sources to provide slow-releasing sources of nutrients.

Right place: Placing and keeping nutrients at the optimal distance from the crop and soil depth so that crops can use them is key to minimizing nutrient losses. Generally, incorporating nutrients into the soil is recommended over applying them to the surface. The ideal method depends on characteristics of the soil, crop, tillage regime and type of fertilizer.

Benefits of site-specific nutrient management

Higher profits: Site-Specific Nutrient Management can increase and maintain yields by optimizing the balance between supply and demand of nutrients and providing more balanced plant nutrition (Wang *et al*. 2007). In general, it improves nutrient-use efficiency and provides greater returns on investments in fertilizer (Ortiz-Monasterio and Raun 2007).

Reduced nitrous oxide emissions: Agriculture contributes 70-90% of nitrous oxide (N_2O) emissions, mostly from N fertilizer. Site-Specific Nutrient Management reduces N_2O emissions by reducing total N application and/or timing applications to crop needs, thus avoiding N losses to volatilization, leaching and runoff.

Improved disease resistance: The more balanced NPK nutrition that comes with SSNM may lead to improved resistance

Table 12.1 Examples of key scientific principles and associated practices of 4R nutrient stewardship

SSNM principle	Scientific basis	Associated practices
Product	Ensure balanced supply of nutrients Suit soil properties	Commercial fertilizer, Livestock manure , Compost, Crop residue
Rate	Assess nutrient supply from all sources Assess plant demand	Test soil for nutrients Balance crop removal
Time	Assess dynamics of crop uptake and soil supply Determine timing of loss risk	Apply nutrients: Pre-planting , At planting, At flowering At fruiting
Place	Recognize crop rooting patterns Manage spatial variability	Broadcast, Band/drill/inject Variable-rate application

to plant diseases (Pasuquin *et al*. 2014).

Challenges to adoption of site-specific nutrient management

Technology and knowledge requirements: Site-Specific Nutrient Management requires knowledge of underlying soil properties and the ability to monitor crops' nutrient status and adjust fertilizer inputs accordingly. While the need to conduct on-farm nutrient trials and soil tests has historically been a barrier to implementation of Site-Specific Nutrient Management, the development of decision support systems and farmer-friendly tools and techniques that use proxy information to calculate nutrient requirements make Site-Specific Nutrient Management more accessible to farmers and farm advisors.

Availability of fertilizers: Cost and access to fertilizers-whether synthetic or organic-is not universal. Development of input markets or identification of on-farm nutrient sources may be a necessary precursor to adoption of Site-Specific Nutrient Management. Site-Specific Nutrient Management can help farmers make best use of limited nutrient resources.

Variable economic benefit: For Site-Specific Nutrient Management to increase farmers' profits, it must deliver either a) savings from reduced fertilizer use without a reduction in yields, or b) yield increases that are valued higher than the costs of acquiring and using Site-Specific Nutrient Management technology. Farmers are more likely to see positive net returns with high-value crops, where yield increases can substantially increase profits, or when fertilizer prices are high.

12.4 Site specific fertilizer recommendations

Current fertilizer recommendations in Kenya are standard, mainly based on blanket application across very large areas of farm land not taking into account localized variations in soil fertility in different farms. Crop productivity and suitability of crop and nutrient management options at the farm level are influenced by complex heterogeneity in farm types and soil fertility. As such, any crop and nutrient management options developed should be based on a good understanding of farm heterogeneity. However, yields achieved are very low, mostly as a result of poor soil fertility and inadequate nutrient use and management. Attempts to improve soil fertility and the associated crop productivity using fertilizers have had limited success for both legume and cereal crops due to blanket fertilizer recommendations that are inappropriate for the heterogeneous soil fertility conditions found in most farms. To reverse the current trend of soil fertility depletion and low crop productivity, there is urgent need to develop effective strategies for sustainable maize production intensification based on balanced nutrient management and crop residue management.

13.0 CONCLUSIONS

Per capita food production in Kenya has continued to decline in spite of the successful introduction of new crop varieties, associated fertilizer and pesticide packages coupled with excellent research outcomes. Natural disasters (increased incidences of floods and droughts); high incidences of pests and diseases and degradation of the soil resource base among others have been cited as the main reasons for the decline. Degradation of the soil resource base is directly linked to poor land management including land use without installation of appropriate erosion control measures and exportation of nutrients from farms through the plants and animal products without adequate replenishment of the removed nutrients. Additionally, from the harmonized soil fertility information collected by the Kenya Soil Health Consortium (KSHC) covering about 90 years of research showed that most of the farm soils are deficient in organic matter and are acidic. The soils data is not presented in this particular report but can be found in the subsequent reports. The decreased soil organic matter and widespread soil acidity is due to removal of crop residues to feed livestock, limited use of livestock manure and long time use of inorganic nitrogenous fertilizers, particularly those with acidifying elements. The rapid population increase, which currently stands at one million people per year, and conversion of farmland to commercial rental housing has put tremendous pressure on available arable land giving way to continuous cultivation, subdivision of agricultural land and migration from high potential areas to marginal ones. Thus the traditional way of maintaining soil fertility through shifting cultivation, application of suboptimal amounts of mineral fertilizers and/or manure and inclusion of grain legumes into the cropping systems is not sufficient to meet crop nutrients demands and ensure food security in the country. To deal with this problem both mineral and organic fertilizers are essential and adequate quantities should be obtained from the right source, availed and applied at the right time and place in the farm. However mineral fertilizers are expensive and as such out of reach to most smallholder farmers who contribute 75% of total agricultural output in Kenya

Soil fertility management research in Kenya on food crops was started in the 1920s and before 1990, only blanket fertilizer recommendation existed. Between 1990 and 1994 the Kenya government through the Kenya Agricultural Research Institute (KARI) initiated and implemented the Fertilizer Use Recommendation Project (FURP) whose main objective was to develop crop-soil - agro-ecological zone specific Inorganic Fertilizer recommendations. The FURP *inorganic fertilizer* recommendations were successfully validated through the Fertilizer Extension Project (FEP) that ran from 1994 to 1999.

The FURP recommendations focused on nitrogen (N), phosphorus (P) and potassium (K) as the main limiting nutrients for crop production, leading to countrywide recommendations for use of fertilizers that supply nitrogen, phosphorus and to limited extent potassium, namely: Di-Ammonium Phosphate (DAP), Triple Superphosphate (TSP), , Calcium Ammonium Nitrate (CAN), Urea and minimal Murate of potash (MOP). Plants source 13 other nutrients from the soil namely, the major elements potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S) and the microelements Iron (Fe), manganese (Mn), boron (B), molybdenum (Mo), copper (Cu), Zinc (Zn), Nickel (Ni), Chlorine (Cl), Cobalt (Co). Increasing the supply of nitrogen and phosphorus not only results in higher yields, but also leads to greater removal of the 13 nutrients not supplied by fertilizers. Thus continued application of these four (4) inorganic fertilizers supplying nitrogen and phosphorus has resulted in the mining of the other nutrients to deficient levels, lowering of organic matter and increased soil acidity. Unlike 30 years ago, today, nutrients such as potassium, sulphur, copper, boron and zinc have become more widely deficient even in soils previously considered fertile. As a result, there has been a rising trend in soil acidity, a decrease in soil organic matter and biodiversity all resulting in declining crop yields and compromised soil health. This led soil fertility management research involving the use of *organic, inorganic, combined use of organic and inorganic fertilizers and improved seeds* popularly known as **Integrated Soil Fertility Management (ISFM)**. ISFM has proved to restore the soil resource base (soil Health) and significantly increase crop yields. Integrated Soil Fertility Management (ISFM) is defined as the use of farming practices that involve the combined use of inorganic and organic inputs, improved seed and other planting materials combined with the knowledge on how to adapt these practices to local conditions so as to maximize the plant nutrient use efficiency while improving crop yields. All inputs need to be managed following sound farming principles. On other hand **Soil health** (or soil quality) is defined as the capacity of a soil to continue to function as a vital living ecosystem that supports and sustains plants, animals, and humans. Ecosystem is described as a community of living organisms (plants, animals and microscopic life forms) in conjunction with the non-living components of the soil such as air, water and nutrients interacting as a system.

For this reason, appropriate soil health management is necessary through application of soil health inputs such as organic and inorganic fertilizers, and soil amendments (liming). Declining soil health in Kenya has been caused by continuous cultivation without adequate replenishment of plant nutrients and organic matter in soil, lack of access to sufficient quantities of quality inputs, compounded by the adverse effects of climate change and variability. Various studies have shown that Integrated Soil Fertility Management (ISFM) can reverse this declining trend in soil health. Appropriate use of soil health inputs increases yields by 100 - 300%, but farmers are not likely to achieve such high yields due to inaccessibility of ISFM inputs, poor extension service, un-coordinated research and development programs. There is need to improve access to and adoption of appropriate ISFM knowledge, information and innovations by smallholder farmers. For sustainability purposes, there is need for creation of a platform for collection, collation, synthesis, harmonization, sharing and dissemination of harmonized ISFM knowledge, information and innovations among stakeholders.

While excellent progress has been made in improved seeds and planting materials and crop pests and diseases control, limited access to and low adoption of ISFM innovations has continued to hinder achievement of optimal agricultural production. This manual therefore is a significant step to facilitating access to ISFM practices by smallholder farmers in Kenya.

14.0 WAY FORWARD

This manual will remain just a booklet unless a harmonized fertilizer extension project (HFEP) similar to Fertilizer Extension project (FEP) of the Fertilizer Use Recommendation Project (FURP) is formulated and implemented.

15.0 REFERENCES

Alliance for a Green Revolution in Africa (AGRA) (2009). Building on the New Momentum in African Agriculture. AGRA in 2008, Nairobi, Kenya:

Alila, P. & R. Atieno (2006). Agricultural Policy in Kenya: Issues and Processes. Paper presented during the Future Agricultures Consortium workshop, IDS, March 20-22, 2006.

Bationo A., Ayuk E., Ballo D. and Kone M. 1997. Agronomic and economic evaluation of Tilemsi phosphate rock in different agroecological zones of Mali. Nutrient cycling Agrosyst. 48: 179–189.

Bruulselma TW, Fixen PE, Sulewski GD (eds) (2012) 4R Plant Nutrition Manual: A Manual for Improving the Management of Plant Nutrition. International Plant Nutrition Institute (IPNI), Norcross, GA, USA

FAO (2009). Scaling up conservation agriculture in Africa: Strategies and approaches

GOK, (2009). Economic Survey. Nairobi: Government Printer.

Ikombo B, M. (1994). Effects of farmyard manure on maize in semi-arid areas of eastern Kenya. East Africa Agriculture and Forest Journal 44: 266-274.

Jama, B., Palm, C. A., Buresh, R. J., Niang, A., Gachengo, C., Nziguheba, G. & Amadalo, B. (2000). Tithonia diversifolia as a green manure for soil fertility improvement in western Kenya: A review. Agroforestry Systems: 49:201-221.

Kenya soil health consortium (KSHC), 2014. Soil health research and development in Kenya: Challenges, Opportunities and Policy Options. Policy brief No. 4.

Lekasi, J.K., Tanner, J.C., Kimani, S.K. & Harris, P.J.C. (2001). Managing manure to sustain smallholder livelihoods in the East African highlands.

Misiko, M. (2007). Fertile ground: soil fertility management and the African smallholder. PhD Thesis, Wageningen University, Wageningen, the Netherlands

Muriuki A. W. and J. N. Qureshi (2001). Fertiliser Use Manual: a comprehensive guide on fertiliser use in Kenya. Kenya Agricultural Research Institute, Nairobi, Kenya. ISBN: 9966-879-40-4.

Ojiem, J.O. (2006). Exploring socio-ecological niches for legumes in western Kenya smallholder farming systems, PhD Thesis, Wageningen University, Wageningen, The Netherlands.

Okalebo, J.R., Othieno, C.O., Woomer, P.L., Karanja, N.K., Semoka, J.R.M., Bekunda, M.A., Mugendi, D.N., Muasya, R.M., Bationo, A. and Mukhwana, E.J. (2007). Available technologies to replenish soil fertility in Eastern Africa, In: Bationo A, Waswa B, Kihara J and Kimetu J (eds.) Advances in integrated soil fertility management in sub-Saharan Africa: challenges and opportunities. Springer. pp. 45-62.

Omiti, J.M., Freeman, H.A., Kaguongo, W. and Bett, C. (1999), Soil fertility maintenance in eastern Kenya: Current practices, constraints, and opportunities. CARMASAK Working Paper Number 1, KARI/ICRISAT, Nairobi, Kenya

Ortiz-Monasterio, J. I and W. Raun. 2007. Reduced nitrogen and improved farm income for irrigated spring wheat in the Yaqui Valley, Mexico using sensor based nitrogen management. Journal of Agricultural Science 145 (3) 1-8.

Palm, C. A., Gachengo, C. N., Delve, R. J., Cadisch, G and Giller, K. E. (2001). Organic inputs for soil fertility management in tropical agroecosystems: application o fan organic resource database. Agriculture, Ecosystems and Environment 83: 27-42.

Pasuquin JM, Pampolino MF, Witt C, et al (2014) Closing yield gaps in maize production in Southeast Asia through site-specific nutrient management. F Crop Res 156:219–230. doi: 10.1016/j.fcr.2013.11.016

Rockstrom,J., Kaumbutho, P., Mwalley, J., Nzabi, A.W., Temesgen, M., Mawenya, L., Barron, J., Mutua, J. and Damgaard-Larsen, S. (2009). Conservation farming strategies in East and Southern Africa: Yields and rain water productivity from on-farm action research. Soil and Tillage Research 103: 23-32.

Sanchez P. A., R. J. Buresh, R. R. B. Leakey,Philos. Trans.R. Soc. London Ser. B352, 949 (1997); R. J. Buresh et al., Eds., Replenishing Soil Fertility in Africa (Spec. Publ. No. 51, Soil Science Society of America, Madi- son, WI, 1997); E. M. A. Smaling (Guest Ed.), Agricult. Ecosyst. Environ. 71 (1998).

Sanchez P. A. (2002). Soil Fertility and Hunger in Africa. SCIENCE'S COMPASS. POLICY FORUM: ECOLOGY. 15 MARCH 2002. VOL 295

Sanginga N. and Woomer P. L. (eds) 2009. Integrated Soil Fertility Management in Africa: Principles, Practices and Developmental Process. Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture. Nairobi. Pp. 15.

Tittonell, P., A. Muriuki, K.D. Shepherd, D. Mugendi, K.C. Kaizzi, J. Okeyo, L. Verchot, R. Coe and B. Vanlauwe. 2010. The diversity of rural livelihoods and their influence on soil fertility in agricultural systems of East Africa – A typology of smallholder farms. Agricultural Systems 103(2): 83-97.

TSBF-CIAT (2005). Integrated soil fertility management in the tropics: From knowledge to implementation; TSBF-CIAT's strategy and work plan, 2005-2010. International Centre for Tropical Agriculture TCIAT): Tropical Soil Biology and Fertility (TSBF) Institute. CIAT Publication No. 343: 48. Cali, Colombia

United Nations Environment Programme (UNEP), (2014). Natural Resource Management & Land Tenure in the Rangelands Lessons Learned from Kenya and Tanzania, with Implications for Darfur. January 2014

Vanlauwe, B. and K.E. Giller. (2006). Popular myths around soil fertility management in sub-Saharan Africa. Agriculture Ecosystems & Environment 116:34-46.

Vanlauwe, B., Palm, C. A., Murwira, H. K. and Merckx, R. (2002). Organic resource management in sub-Saharan Africa: validation of a residue quality-driven decision support system. Agronomy for Sustainable Development 22: 839-846 AGRA 2007. Agricultural Development

Initiative II: Increasing small scale farmer productivity through improved inputs and management system. A Proposal for a Soil Health Program of the Alliance for a Green Revolution in Africa, pp 60

Wang G, Zhang QC, Witt C, Buresh RJ (2007) Opportunities for yield increases and environmental benefits through site-specific nutrient management in rice systems of Zhejiang province, China. Agric Syst 94:801–806. doi: 10.1016/j.agsy.2006.11.006

World Agroforestry Centre (WAC). 2008. Transforming lives and landscapes. Strategy 2008-2015. World Agroforestry Centre, pp 39. Nairobi, Kenya

Zingore, S., Wairegi L., Ndiaye M. K. (2014) Rice systems cropping guide. Africa Soil Health Consortium, Nairobi.

APPENDIX I: SOILS IN KENYA

ACRISOLS (Very acid soils)

These are soils with an ABC sequence of horizons, of which the A-horizon (topsoil) is relatively low in organic matter and/or is acid. The B-horizon (subsoil) is characterized by illuviation of silicate clay minerals (argillic horizon). Usually the horizon has an angular blocky structure, in which clay skins are present on at least some of the ped faces and in the fine pores. The illuviation usually shows a distinct increase of texture over a relatively short distance. Acrisols are strongly weathered soils with a low pH (very acid) and a base saturation of less than 50%. Chemically they are poor. Their cation exchange capacity (CEC) is usually greater than 16me/100g clay. The moist consistence is normally friable to firm and the structural stability is moderate. Some Acrisols contain large amounts of indurated plinthite. Preservation of the surface soil with its all-important organic matter and preventing erosion are preconditions for farming on Acrisols. Acidity-tolerant cash crops such as pineapples, cashew and tea can be grown with some success.

ANDOSOLS (Volcanic soils)

These are soils that are formed from recent volcanic material. They are soils with a thick, loose, granular, dark grey to black A-horizon over a yellowish brown or brownish C horizon. These soils may be coarse or fine textured but has usually high silt content. They are very porous, have a low bulk density (less than 0.85g/cm3), high organic matter content and a high water storage capacity. The clay is characterized by the dominance of allophane (amorphous hydrated aluminum silicates of varying composition). Although differences in parent material may influence the fertility of the Andosols, they have in general a high natural fertility and good physical characteristics. However, phosphate fixation and problems with micronutrients do occur. The strong phosphate fixation of Andosols (caused by active Al abd Fe) is a problem. Ameliorative measures to reduce this effect include application of lime, silica, organic material and phosphate fertilizer.

ARENOSOLS (Sandy soils)

Arenosols are weakly developed soils with an ABC sequence of horizons. They are characterized by a sandy texture with less than 15% clay. These soils commonly occur on quartz-rich crystalline or sedimentary rocks or unconsolidated sediments derived from them. The topsoil is low in organic matter content. The soils have a very low cation exchange capacity and a low moisture storage capacity. The natural fertility of these soils is in general very low. All Arenosols have common characteristics such as coarse texture, accounting for their generally high permeability and low water and nutrient storage capacity. On the other hand, Arenosols offer ease of cultivation, rooting and harvesting of root and tuber crops.

CALCISOLS (Calcium rich soils)

These soils have substantial secondary accumulation of lime. They are common in highly calcareous parent materials and widespread in arid and semi-arid environments. Vast areas of natural Calcisols are under shrub, grasses and herbs and are used for extensive grazing. Drought-tolerant crops (e.g. sunflower) can be grown under rain-fed conditions. Some vegetables have been grown successfully on irrigated Calcisols when fertilized with nitrogen, phosphorus and trace elements (iron and zinc). Furrow irrigation is superior to basin irrigation on slaking Calcisols because it reduces surface crusting/cracking and seedling mortality.

CAMBISOLS (Young soils)

These are "young" and little weathered soils. They have an ABC sequence of horizons, the B-horizon being"Cambic". The B-horizon is an altered horizon which shows already a soil structure with significant amounts of weatherable primary minerals. Cambisols have a relatively high natural fertility. They have in general a CEC of more than 24 me/100g clay. The texture of these soils is variable but usually finer than sandy loam. Cambisols generally make good agricultural land and are used intensively.

CHERNOZEMS (Dark coloured soils rich in organic matter)

These are soils with dark coloured topsoil that is relatively rich in organic matter and is non-acid. The subsoil (B-horizon) is usually dark brown and has an accumulation of free carbonates, increasing with depth. The topsoil has a granular structure while the subsoil has a blocky structure. These soils are little weathered and have a high natural fertility. In general they have a CEC of more than 24 me/100 g clay. The texture is usually clay. The preservation of the favorable soil structure through timely cultivation and careful irrigation at low watering rates prevents ablation and erosion.

FERRALSOLS (Highly weathered soils)

These are mineral soils with an "Oxic" B-horizon from which weathering has removed or altered a large part of the silica. The result of the weathering is the concentration of clay-sized minerals consisting of sesquioxides (Fe + Al oxides) mixed with varying amounts of silicate clays having a 1:1 lattice (e.g. kaolinite). These soils are strongly weathered, strongly leached and have an indistinct soil horizon differentiation. The oxic B-horizon has more than 15% clay-sized particles (texture of sandy loam or finer). The colour of the oxic horizon is widely variable: from dark red to brown. They are very friable, highly porous and permeable. The structure is weakly coherent massive to subangular blocky and is characteristically stable (high flocculation index). These soils have very low cation exchange capacities (CEC less than 16 me/100g clay) and low base saturation. Weatherable minerals like feldspars, mica and ferromagnesian minerals are nearly absent. Chemically these soils are poor. The natural fertility of many of these soils is restricted to the A-horizon and related to the organic matter content. Maintaining soil fertility by manuring, mulching and/or adequate (i.e. long enough) fallow periods oragroforestry practices, and prevention of surface soil erosion are important management requirements. Further, fertilizer selection and the mode and timing of fertilizer application determines to a greater extent the success of agriculture on Ferralsols.

FLUVISOLS (Alluvial soils)

These are young soils that have developed on alluvium of recent origin. They do not include soils developed from old alluvial deposits that now reflect the influence of climate and vegetation. They have no horizon differentiation due to soil forming processes but they show stratification due to sedimentary deposition. They have an organic matter content that decreases irregularly with depth and they receive fresh sedimentary material at regular intervals. The fertility of these soils varies widely, depending on their texture and on the nutrient content of soils and rocks in the watershed from which the alluvial deposits originate. However, in general most of the Fluvisols are well supplied with plant nutrients. Paddy rice cultivation is widespread on tropical Fluvisols with satisfactory irrigation and drainage. Many dry land crops are grown on Fluvisols as well, normally with some form of water control.

GLEYSOLS (Poorly drained soils)

These are poorly drained mineral soils which are periodically waterlogged. Periodic or permanent saturation by groundwater is reflected by greyish colours or prominent mottling. These soils have B-horizons that are weakly developed (cambic rather than argillic). They have no clear textural differentiation. The fertility of these soils is widely variable. Some of these soils have high contents of organic matter in the topsoil and therefore are relatively fertile, whereas others are very acid. The main obstacle to utilization of Gleysols is the necessity to install a drainage system to lower the groundwater table. Liming of drained Gleysols that are high in organic matter and/or of low pH value creates a better habitat for micro- and meso-organisms and enhances the rate of decomposition of soil organic matter and the supply of nutrients.

GREYZEMS (Soils rich in organic matter having a grey colour)

These are soils with an ABC sequence of horizons, of which the A horizon is dark coloured and relatively rich in organic matter. The B-horizon usually has a prismatic or angular blocky structure showing bleached coatings on the ped surfaces. The texture ranges from friable clay loam in the topsoil to very firm, cracking clay in the subsoil. They have a moderate to high natural fertility.

HISTOSOLS (Bog and Marsh soils)

These are poorly drained soils with thick topsoil that contains a high percentage of fresh or partly decomposed organic matter. The topsoil (Histic horizon) is at least 40 cm thick and is dark coloured (sometimes black). The physical and chemical characteristics of these soils are strongly determined by the environment and the type of plants that accumulated to give rise to the organic matter content. It is desirable to protect and conserve fragile peat lands because of their intrinsic value, especially their common function as sponges in regulating stream flow and unique species of animal(s). Their prospects for sustained agricultural use are meager.

LEPTOSOLS (Soils with hard rock at very shallow depth)

These are shallow soils with an AR sequence of horizons. The topsoil is not rich in organic matter and there is no B-horizon of any kind. These soils have continuous coherent and hard rock (R-horizon) within 10 cm of the surface. Most of the Lithosols are found in hilly and mountainous areas on slopes with excessive and often erosive run-off. The fertility of these soils is widely variable, depending on the parent material. Erosion is the greatest threat to Leptosol soils, particularly on sloping populated lands. Steep slopes with shallow and stony soils can be transformed into cultivated land through terracing, the removal of stones by hand and their use as terrace fronts.

LITHOSOLS- LEPTOSOLS (Soils with hard rock at very shallow depth)

These are shallow soils with an AR sequence of horizons. The topsoil is not rich in organic matter and there is no B-horizon of any kind. These soils have continuous coherent and hard rock (R-horizon) within 10 cm of the surface. Most of the Lithosols are found in hilly and mountainous areas on slopes with excessive and often erosive run-off. The fertility of these soils is widely variable, depending on the parent material. Erosion is the greatest threat to Leptosol soils, particularly on sloping populated lands. Steep slopes with shallow and stony soils can be transformed into cultivated land through terracing, the removal of stones by hand and their use as terrace fronts.

LIXISOLS (Highly weathered and poor soils)

They comprise soils that have higher clay content in the subsoil than in the topsoil as a result of clay migration. They have a high base saturation and low activity clays at certain depths. Preservation of surface soil with its all important organic matter is of utmost importance. Tillage and erosion control measures such as terracing, contour ploughing, mulching and use of cover crops help to conserve the soil. Growing of perennial crops is preferred to annual crops, particularly on sloping land. Rotation of annual crops with improved pasture is recommended in order to maintain or improve the content of soil organic matter.

LUVISOLS (Soils with illuvial accumulation of clay)

These are soils with an ABC sequence of horizons, of which the A-horizon is relatively low in organic matter. Luvisols have similar morphological characteristics as the Acrisols. They are separated from each other solely on the base saturation of the lower part of the B-horizon. The

Luvisols have a base saturation of more than 50% whereas the Acrisols have a base saturation of less than 50%. Luvisols are moderately to strongly weathered soils. Due to their relatively high base saturation and the presence of weatherable primary minerals, they have a moderate natural fertility. They have a tendency to form a strong sealing on the surface which may cause a strong run-off of water leading to severe erosion. Most Luvisols are fertile soils and are suitable for a wide range of agricultural uses. Luvisols on steep slopes require erosion control measures.

NITISOLS (Deep, red friable clays)

Nitisols accommodate those soils that are more than 150 cm deep, show evidence of clay movement and have conspicuous shiny ped surfaces throughout the subsoil (B-horizon). They have a clay texture and show gradual to diffuse soil horizon boundaries. The colour is often dark red, dusky red or dark reddish brown. These soils show a very gentle clay illuviation resulting in a gentle clay bulge over a traject of at least 150 cm. They usually have topsoil with a moderate to strong sub-angular blocky structure underlain by subsoil with a moderate angular blocky structure. The soils are friable or vey friable and are porous throughout. They have marked structure stability. The chemical properties of these soils vary widely. The organic matter content, cation exchange capacity (CEC) and percentage base saturation range from low to high. The soils are known to have a high degree of phosphorus sorption. Nitisols are among the most productive soils of the humid tropics. The deep and porous solum and the stable soil structure of Nitisols permit deep rooting and make these soils quite resistant to erosion. High P sorption calls for application of P fertilizers, usually provided as slow-release, low-grade phosphate rock (several tones per acre, in maintenance, doses every few years) in combination with smaller applications of better soluble phosphate for short term response by the crop.

PHAEOZEMS (Dark coloured soils rich organic matter)

These are soils with dark coloured topsoil (mollic A-horizon) that is relatively high in organic matter and is non-acid. The base saturation of the topsoil is over 50%. These soils usually have an ABC sequence of horizons. The subsoil (B-horizon) usually has a well developed blocky structure with a high porosity. These soils have a high natural fertility due to the high organic matter content and an abundant supply of mineral nutrients. Their CEC is usually over 24 me/100g clay. Phaeozems are porous, fertile soils and make excellent farmland. Wind and water erosion are serious hazards if they are left uncontrolled.

PLANOSOLS (Vlei soils)

These are imperfectly drained soils with a pronounced and abrupt transition between relatively light textured topsoil, part of which is whitish (“albic or E-horizon”) and a heavy textured, compact and hard B-horizon. They have a very slow vertical and horizontal drainage and are therefore often waterlogged. The natural fertility varies widely, depending on texture and organic matter content of the topsoil. Natural Planosols areas support sparse grass vegetation, often with scattered shrubs and trees that have shallow root systems and can cope with temporary water-logging. Vast areas of Planosols are used for extensive grazing.

RANKERS (Shallow, acid soils rich in organic matter)

Rankers are shallow soils with an ACR or AR sequence of horizons, on siliceous parent material. They are acid and rich in organic matter. They are usually associated with steep slopes. The texture and natural fertility vary widely, both depending on parent material and degree of weathering.

RENDZINAS (Shallow soils over limestone, rich in organic matter)

These soils are developed form calcareous material. Calcium carbonate (CaCo3) usually occurs throughout the soil profile. They have an AC sequence of horizons. The A-horizon is dark coloured, rich in organic matter and is not more than 50 cm thick. Its thickness and organic matter content is greater than that of Lithosols and Regosols developed from calcareous material. The A-horizon contains or overlies calcareous material, with a calcium carbonate equivalent of more than 40%. The soils have a high base saturation and are relatively fertile.

REGOSOLS (Weakly developed soils of loose material)

These are shallow soils with an AC sequence of horizons. The topsoil is low in organic matter and there is no B-horizon of any kind. Directly below the A-horizon is a weathering rock material that is unconsolidated (C-horizon). Very often, these soils are stony and rocky. Their natural fertility varies widely, depending on the parent material. Many Regosols are used for extensive grazing. Others are planted with small grain variety crops and fruit trees. Regosols in mountainous regions are delicate and best left under forest.

SOLONETZ (Alkali soils)

These are soils with an ABC sequence of horizons characterized by the presence of a natric B-horizon. A high level of sodium on the exchange complex causes the clay to disperse and to move from the A to the B-horizon. Usually a characteristic columnar structure develops. Upon wetting, this natric B-horizon becomes virtually impermeable. The soils have a pH between 8.5 and 10. Their natural fertility is low to moderate, due to relatively low organic matter content in the topsoil. The deeper subsoils are often saline. Most reclamation attempts start with incorporation of gypsum or exceptionally calcium chloride in the soil. Traditional reclamation strategies begin with planting of a sodium-resistant crop, e.g. Rhodes grass, to gradually improve the permeability of the soil. Once a functioning pore system is in place, Na ions are carefully leached from the soil with good-quality (Ca-rich) water.

SOLONCHAKS (Strongly saline soils)

These soils contain a lot of soluble salts that are harmful to the growth of agricultural crops, mainly because of the high osmotic pressure of the soil solution, which reduces the availability of water. Soils that have an electrical conductivity of the saturation extract (ECe) greater than15 mmhos/cm are considered to be Solonchaks. Solonchaks usually occur in association with saline-alkali soils. Saline-alkali soils are characterized by an electrical conductivity of the saturation extract of more than 4 mmhos/cm (saline) combined with an exchangeable sodium percentage (ESP) of more than 15 (alkali). Their pH may vary widely, but usually is between 8.0 and 8.5. The clay disperses easily upon wetting. Solonchaks are used for extensive grazing of sheep, goats, camels and cattle, or are left as idle land.

VERTISOLS (Dark coloured, strongly cracking clay soils)

These soils are popularly known as "Black cotton soils". The texture is clay throughout (more than 35% clay) and the clay minerals are of the montmorillonite type. This is reflected in great plasticity and stickiness of the soils when they are wet and a pronounced hardness when dry. They are usually imperfectly drained or poorly drained. A sticking feature of these soils is their capacity to expand and contract with changes in moisture content. During the dry season, they shrink markedly and large cracks develop sometimes up to a depth of 1 metre. As a result of these soil movements, slickensides (large, shiny, grooved ped surfaces) develop in the subsoil and gilgai micro-relief (small mounds) is formed at the surface. The natural fertility of these soils is moderate. Physical properties are adverse: low infiltration rate, low permeability and difficult tillage. These soils have considerable agricultural potential, but adapted management is a precondition for sustained production. Their physical soil characteristics and, notably, their difficult water management is a cause of tillage problems. Building and other structures on Vertisols are at risk, and engineers have to take special precautions to avoid damage. Cotton is known to perform well on Vertisols, allegedly because cotton has a vertical root system that is not damaged severely by cracking of the soil. Tree crops are generally less successful because tree roots find it difficult to establish themselves in the subsoil and are damaged as the soil shrinks and swells.

XEROSOLS (Soils with an aridic soil moisture regime)

These are soils developed under dry climatic conditions. They have a weak A-horizon which is low in organic matter. The drainage condition of these soils ranges from well drained to poorly drained. Most of these soils are calcareous and have textures ranging from loamy sand to clay. In many places, these soils are saline and/or sodic.

Kenya Soil Health Consortium (KSHC),
P.O Box 14733-00800, KALRO- Kabete, Waiyaki way, Nairobi,
www.kenya.soilhealthconsortium.org