Smart Fertilization and Water Management – Kenya-Netherlands Aid-and-Trade Opportunities

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Developing Agriculture from the Ground Up

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Contents

List of Tables

List of Figures

Acronyms and Abbreviations

ACGS	Agricultural Credit Guarantee Scheme
ADC	Agricultural Development Corporation
AFC	Agricultural Finance Corporation
AfSIS	Africa Soil Information Service
AGRA	Alliance for a Green Revolution in Africa
ARM	Athi River Mining
AS	Ammonium Sulfate
CAN	Calcium Ammonium Nitrate
CDF	Constituency Development Fund
CEC	Cation Exchange Capacity
CGA	Cereal Growers Association
CMA	Cereal Millers Association
DAP	Diammonium Phosphate
DFI	Development Finance Institution
DGIS	Directorate-General for International Cooperation
EAGC	East African Grain Council
EMT	European Machine Trading
ETG	Export Trading Group
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FBO	Farmer Business Organization
FGI	Fertile Grounds Initiative
FOT	Fertilizer Optimization Tools
FURP	Fertilizer Use Recommendation Project
G4AW	Geodata for Agriculture and Water
GDP	Gross Domestic Product
ICL	Israel Chemicals Limited – ICL the Netherlands
ICM	Integrated Crop Management
ICRAF	World Agroforestry Center
ICT	Information and Communication Technology
IDA	Iron Deficiency Anemia
IDD	Iodine Deficiency Disorders
IFAD	International Fund for Agricultural Development
IFDC	International Fertilizer Development Center
IPNI	International Plant Nutrition Institute
ISFM	Integrated Soil Fertility Management
ISRIC	International Soil Reference and Information Center
KALRO	Kenya Agricultural and Livestock Research Organization
KCEP	Kenya Cereals Enhancement Project
KDHS	Kenya Demographic and Health Survey
KEPHIS	Kenya Plant Health Inspectorate Service
KNGD	Kenya-Netherlands Green Deal
KSAP	Kenya Smart Agricultural Project

MAP	Monoammonium Phosphate
MOP	Muriate of Potash
NAAIAP	National Accelerated Agricultural Inputs Access Program
NARS	National Agricultural Research System
NCPB	National Cereal and Produce Board
NDVI	Normalized Difference Vegetation Index
NFP	National Fertilizer Platform
NGO	Non-Governmental Organization
NIR	Near Infrared
NPCK	National Potato Council
ODA	Official Development Assistance
OFRA	Optimizing Fertilizer Recommendations in Africa
PAPR	Partially Acidulated Phosphate Rock
PFI	Participating Financial Institution
PPP	Public-Private Partnership
QUEFTS	Quantitative Evaluation of the Fertility of Tropical Soils
R&D	Research and Development
RMSE	Root Mean Squared Error
SACCO	Savings and Credit Cooperative Organizations
SOM	Soil Organic Matter
SSA	Sub-Saharan Africa
SSP	Single Superphosphate
STAK	Seed Trade Association of Kenya
TSP	Triple Super Phosphate
TTFA	Toyota Tsusho Fertilizer Africa Ltd
VAD	Vitamin A Deficiency
WaPOR	Water Productivity through Open access of Remotely sensed derived data
WUE	Water Use Efficiency
WUR	Wageningen University and Research Centre

1. Summary

This report describes the outcome of a feasibility study for demonstrating the development of a trade-and-aid relationship between Kenya and the Netherlands for sustainable agricultural intensification. Such intensification can be achieved by means of knowledge-intensive location-specific fertilizer and water management practices, driven by increased input-output agribusiness, with the ultimate aim to sustainably improve food and nutrition security in Kenya and create local jobs in the country. The outline and support for the study resulted from discussions between the project team and the Ministries of Economic Affairs (the Directorate-General for Agriculture), the Ministry of Infrastructure and Environment, and the Ministry of Foreign Affairs (the Directorate-General for International Cooperation – DGIS) of the Kingdom of the Netherlands.

The governments of the world have agreed to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture by 2030 as one of the ambitious Sustainable Development Goals (SDGs). Several studies show that investment in small-scale sustainable agriculture is an effective and proven way to reduce hunger and poverty in low-income countries, where agriculture may contribute up to 70% of the gross domestic product (GDP). Yet, public investment in agriculture is dismally low, with governments allocating less than 2% of their central government expenditures to agriculture and 6-8% of their total official development assistance. Apart from public investments, public-private partnerships (PPPs) are considered essential in development cooperation to achieve sustained and widespread impact on poverty reduction. PPPs are partnerships between the government, the private sector, research institutions, and civil society organizations.

The Kenya-Netherlands Green Deal (KNGD) PPP team, consisting of actors in agriculture, fertilizer, water management, logistics, and business development, proposes location-specific agronomic interventions to accelerate the agricultural productivity of maize and potato, important food security crops in Kenya. The interventions can be achieved by: (1) activating and gathering the contribution of PPP partners in the Netherlands and Kenya in the design of the interventions; (2) integrating practical experiences from past and current field operations with recent advanced big-data analytical methodologies for spatial extrapolation of the agronomic interventions; (3) generating information about business opportunities for actors along the entire value chain; and (4) creating instruments to develop enabling conditions for widespread adoption of the interventions.

The proposed intervention is at the heart of the basic requirements for sustainably increasing agricultural productivity. Its validity has been proven in other parts of the world but needs to be adapted for local production, ecological, and socio-economic conditions. The nature of this intervention and the proposed approach for its implementation are not meant merely to be a one-time effort that ends after a project period but to be an integral part of the business and institutional environment. The team recommends two additional phases after this feasibility study – a demonstration phase, which is outlined in this document, and an implementation phase to mainstream the demonstrated effects in businesses and institutions. These two phases can also be smoothly merged.

For decades, point-based agronomic experiments have been carried out to determine the impact of fertilization and other measures on crop response, but this information could not be extrapolated to larger areas because of specific soil and water conditions. This is especially true for Kenya. Current agro-ecological knowledge, combined with advanced IT- and satellite-based big-data analytical methodologies, allows for such specification and extrapolation. In this case, it will generate information about the total amount of specific nutrients (macro and micro) and other inputs required at local and regional scales. Chain actors can use the information to enhance their businesses. For example, farmers can select the most appropriate business solutions. Fertilizer companies can understand the potential market size and the exact formulation of fertilizer products required in their region; they also can explore available local sources of nutrients (recycle material). Logistics companies will be able to design optimal logistical solutions, and agro-dealers can tailor their distribution networks. Governments will be able to better direct their policies by stimulating the use of specific products. With advancements in the analytical methodology, the information may also lead to more accurate estimates of expected harvest volumes to inform buyers and to guide policymakers in their decisions about the amount and timing of food imports, if needed.

This study reveals that accelerating maize and potato productivity and nutritional quality is feasible because: (1) the agro-technical opportunities to sustainably boost productivity, particularly smart fertilizers and water management, are large; (2) the Kenyan market has most basic elements in place, but (3) many relevant actors in Kenya run solitary operations to provide farmers with (their) specific products but lack the capacity to assess and develop the market, for which they call upon public sector support; (4) supporting Kenyan knowledge and governmental institutions already have basic understanding about the need for the proposed approach but lack oversight and capacity to generate the required information, (5) which can be created in collaboration with Netherlands knowledge institutions; (6) industry parties in Kenya and beyond are eager to develop the Kenyan market; (7) financial parties are willing to provide services to chain actors under transparent market conditions; and (8) policy regulations could be adapted in support of the interventions informed by multi-stakeholder governing platforms, such as a National Fertilizer Board.

The uniqueness of this methodology goes beyond approaches and initiatives that take part of the equation into consideration. We propose to develop a ***science-supported implementation program*** that combines advanced agro-technical insights for sustainable intensification with business opportunities for chain actors and the creation of enabling conditions. While this case has been developed specifically for Kenya, the approach is applicable for any other country in sub-Saharan Africa.

Methodological innovations contained in the proposed demonstration/implementation phase include the following:

- Bottom-up agro-technical approach with farm participation and top-down advanced satellite and big-data analyses:
    - Advanced geo-spatial extrapolation methodologies of soil data points (FAO-endorsed).
    - Advanced, rapid, and automated (spectroscopic) soil testing.
    - Satellite imaging and processing for spatial-temporal water use optimization (FAO-endorsed).
    - Modeling and expert judgement-based analytical methodology for fertilizer recommendations.

  - Location-specific fertilizer and water management within the context of farm practices.
  - On-farm and on-station trials for ground-truthing and verification of fertilizer responses.
- Business cases:
  - Enhanced business opportunities for agro-dealers.
  - Increased farm-level food and nutrition security and household income.
  - Contracts and agreements between farm producers and buyers.
  - International opportunities for trade in fertilizers and improved seeds.
  - National business opportunities for blended fertilizers.
  - Portfolio of financial services and credit facilities for chain actors.
- Enabling conditions:
  - Facilitate development of a National Fertilizer Platform (NFP) with PPP actors.
  - NFP to agree on actions to stimulate the development of the novel fertilizer market.
  - Inform value chain actors about volumes of region-specific fertilizers for investment decisions.
  - Inform about water management practices to increase water use efficiency.
  - Enhance national capacity for seed production and testing.

Outcomes include:

- National awareness among actors to jointly unlock the potential of innovative fertilization.
- Joint creation of enabling conditions.
- Value chain actors acting in harmony.
- Learning by combined theory and practice.
- Optimized use of natural resources, improvement of soil health, and an end to soil degradation through use of organic and inorganic fertilization.
- Increased maize and potato production for improved nutritional quality and reduced losses.
- Increased on-farm food and nutrition security and income.
- Enhanced international trade in agro-inputs.
- Vibrant value chains in maize and potato.

2. Background

This report assesses the feasibility of demonstrating the development of a trade-and-aid relationship between Kenya and the Netherlands for sustainable agricultural intensification by means of knowledge intensive location-specific fertilizer and water management practices, driven by increased input-output agribusiness, with the ultimate aim to sustainably improve food and nutrition security in Kenya. Participants representing a knowledge network in the Netherlands, Kenyan research institutions, agribusinesses, and implementing organizations understand that many technologies introduced are often not widely adopted and that any new endeavor should be embedded in favorable enabling conditions for large-scale uptake. This assessment therefore comprises: (1) agro-technical aspects of production, (2) socio-economic dimensions of farmers and business perspectives of actors in the food value chain, and (3) policy and institutional conditions. It moreover aims to introduce the improved location-specific agronomic practices in the context of a food value chain. Farmers should have access to inputs and credit and a secure outlet for their increased produce. Comparable conditions for secured input delivery and market conditions hold for other actors in the chain as well.

Chapter 2 describes the challenges and opportunities in food and nutrition security for sub-Saharan Africa in general and Kenya in particular. Current insecurities drive migration, which is undesired from both the migrants' perspective and recipient countries, linking the African and European continent but causing great human suffering. Unlocking the agricultural potential on the African continent, particularly in Kenya, to improve livelihoods requires location-specific agronomic and business interventions that are knowledge-intensive. The availability of this required knowledge in Netherlands institutions and private sector can, in cooperation with Kenyan counterparts, be utilized to improve food and nutrition security in Kenya.

Chapter 3 describes the current available status of the agricultural system and identifies the knowledge gaps and additional information needed to arrive at location-specific soil and water interventions, complemented with a description of the market conditions in chapter 4. The agro-technical, socio-economic, and institutional feasibility to introduce specific interventions are outlined in chapter 5 based on a scoping mission, with the chain actors separately listed in chapter 6. Chapter 7 describes proposed business cases in the demonstration / implementation program following this feasibility study. It is a description based on the current state of art and to be adjusted during the next steps in the process to craft the program. Details about the maize and potato value chains have been detailed in the appendices.

The team, therefore, perceives that the ultimate goal of this project will be to improve food and nutrition security in Kenya through sustainable agricultural intensification by means of data- and knowledge-intensive fertilizer and water management, distribution and marketing catalyzed by increased agribusiness between the Netherlands and Kenya, and eventually toward an economically self-supporting system creating more jobs and welfare in Kenya.

2.1 African Agriculture

For decades, the African continent relied on heavy industry, primarily mining, for its economic development, but the budget deficit of the continent is at record high of U.S. $200 billion today because of plummeted prices of raw materials and increasing food imports. A recent think tank placed sustainable agricultural intensification as a most important driver for overall development for the African continent that will experience an unprecedented population growth from 1.1 billion today to 2 billion in 2050 and 4-5 billion by 2100, with more than half of the population below the age of 20 today. Demand for food will continue to grow in both rural and urban areas, and food supply chains should be tuned to these markets.

The agricultural production potential of the African continent is large under optimal agronomic management, but Van Ittersum et al., (2016) stress that the entire yield gap (the difference in yield under optimum rainfed management compared to current yield levels) will have to be closed by 2050 to maintain 80% of the cereal self-sufficiency rate when food demand triples. Total food volumes have increased over the past decades but at the expense of natural ecosystems due to expansion of the cultivated acreage, with the area occupied by permanent crop land doubling over the last 50 years (World Bank, 2017). Yield increases even have been negative in some countries, like Kenya and Tanzania at about -4 and -9% per year from 1991 to 2014, respectively (Van Ittersum et al., 2016). To prevent further encroachment into natural lands at the expense of biodiversity and increased emission of greenhouse gases (GHG) due to land clearing, sustainable agricultural intensification will have to be pursued to accelerate the rate of yield increase while maintaining the productive capacity of the ecosystem base.

Investments in agriculture in SSA countries have been low over the past decades, and while this constraint received increasing attention from the African Union, country budgets are still modest. Globally, governments are allocating less than 2% of their central government expenditures to agriculture, which is even less in African countries (FAO, 2018a), and their official development assistance (ODA) is only approximately 6-8% of total assistance (OECD-DAC, 2015). While the production potential is substantial, the continent suffers from unfavorable agro-ecological and socio-economic conditions that seriously challenge agricultural intensification (InterAcademy Council, 2004). Recently, the African Development Bank presented its comprehensive perspective in "Increasing African Agricultural Productivity through Promotion of Efficient Input Use" (AfDB, 2016; Figure 1). The Bank emphasizes the need for affordable agro-inputs and their efficient use in boosting agricultural productivity and proposes to orchestrate, design, scale, and replicate transformation through seven enablers that address the barriers to feed Africa. These enablers include agro-technical aspects, value-adding activities, hard and soft infrastructure improvement, increased financing, improved agribusiness environment, and inclusiveness and sustainability.

Under-performing value chains	Limited coordination of research and development	Insufficient utilization of inputs and mechanization	Limited reach of extension to boost on-farm production	Poorly organized post-harvest aggregation and transport	Inconsistent capacity for effective value addition	Poorly developed market linkages and trade corridors
Insufficient infrastructure	Insufficient transport, energy, water, waste management and other hard infrastructure, leading to uncompetitive cost structures			Underdeveloped soft infrastructure, including aging smallholder farmers and a lack of skills for commercial agriculture and agro-allied industries		
Limited access to agricultural finance	Real and perceived risk limiting private sector investment		High service cost due to small deal sizes, lack of credit data, and low capacity in agricultural lending		Limited market attractiveness relative to perceived higher returns outside of the agriculture sector	
Adverse agribusiness environment	Unfavorable market access and incentives limiting trade and capacity to produce high-quality products		Ineffective sector regulation creating long lead times for new technologies and inconsistent trade policies		Unsupportive business enabling environment restricting land tenure and general ease of doing business	
Limited inclusivity, sustainability and nutrition	Insufficient inclusivity of women and youth in agricultural development		Limited incentives to ensure sustainability and climate-resilient practices		Limited access and affordability of commodities with high nutrition levels	

Figure 1. Barriers Crippling Africa's Agriculture Sector

A fundamental barrier throughout the continent that is globally acknowledged is poor and variable soil fertility, including limited rootable depth (Guilpart et al., 2017). Together with erratic rainfall, poor soils severely hamper productivity increases and the overall development of the food sector. In the former green revolution areas, including Europe and North America, the Indo-Gangetic plains, the coastal zones of China and southeastern Asia, fertilizer application of the macro nutrients nitrogen (N), phosphorus (P), and potassium (K) could be a major driver for yield increase on the relatively fertile soils and better-endowed agro-ecological conditions.

Padwick (1983) presented an overview of 50 years of experiments about the soil fertility of tropical Africa and suggested the need for organic matter to improve soil characteristics and inorganic fertilizers to increase yield. In the early 1990s, Vlek (1990) called for African countries to improve the efficiency of fertilizer procurement and distribution in order to raise fertilizer use for increasing crop production; at the time, fertilizer was applied at an average rate of 8 kilograms per hectare per year (kg ha^{-1} y^{-1}). Still today, the continent is using the lowest amount of fertilizers in the world, averaging 13 kg ha^{-1} y^{-1}, which is mostly used on cash crops and on large farms. This amount and the even lower quantities used by smallholder famers are insufficient to replenish the soil with nutrients withdrawn by the crops. A wheat and maize crop of 2 tons (t), for instance, extracts about 25 and 40 kg N ha^{-1}, respectively. It is estimated that continuous cropping leads to the depletion of over 50 kg ha^{-1} y^{-1} of N, P, and K combined on the continent (Chianu et al., 2012). Soil mining leads to degradation and loss of soil production capacity, which then leads to shortening of the fallow period and further expansion into natural lands, pushing farmers into a negative spiral of poverty.

McArthur and McCord (2014), in their cross-country economic analyses, observe a clear role for fertilizers, modern seeds, and water in boosting cereal yields. They find that a half-ton increase in staple yields generates 13 to 20% higher GDP per capita, a 3.3 to 3.9%-point lower labor share in agriculture five years later, and approximately 20% higher non-agricultural value added per worker a decade later. A country with yields of 1 t ha^{-1} that jumps from 15 to 65 kg ha^{-1} of fertilizer used would see an average yield jump of 147 to 470 kg ha^{-1}; an increase from 10 to 50% in the use of modern seed would increase yields by 480 kg ha^{-1}. These empirical links in developing economies between increased agricultural yields and economic growth, with the specific role of fertilizers, suggest a strong role for agricultural intensification as a driver for overall development.

Several organizations argue that most of the employment in African countries must be created in agriculture. Of the projected 450 million additional persons in the working-age population by 2035, only 100 million are expected to find a stable paying job. Central to job creation is a move from the more “static,” classic view of agricultural development as increasing the small farmers’ productivity to a more dynamic approach that fosters food value chain development and includes multiple aspects, such as increased access to inputs, credit, and markets. Moreover, “Truly unlocking Africa’s agricultural potential will require complementing these efforts with those to sustainably transform the sector from low-productivity small farms producing mainly for household local consumption, into larger farms and more intensive agro-processing activities” (World Economic Forum, 2017).

Box 1. The African Soils Conundrum

Farmers' low use of fertilizers is partly due to the low agronomic effectiveness of the fertilizers and associated high investment risks. In addition to the need for NPK, which boosted yields in the former green revolution areas, much of the arable land on the African continent is affected by multiple micronutrient deficiencies, resulting in low to no yield responses to NPK fertilizers. Dramatic crop yield increases, in some cases up to 70% or more, have recently been observed with the addition of several micronutrients (Zingore et al., 2008; Vanlauwe et al., 2014; Voortman and Bindraban, 2015). More appropriate, micronutrient-containing NPK fertilizers should therefore be brought to the market to raise yields, improve nutritional quality, and maintain soil productivity (Bindraban et al., 2015; 2018). Another major constraint is the highly variable rainfall that poses high risk for investment in fertilizers, as nutrient uptake by crops is low in dry years. This implies that effectiveness of any fertilizer should be enhanced in an integrated approach with other agronomic practices, primarily water availability, but also timely sowing, use of improved seeds, soil organic matter (SOM) management, proper weeding, and sufficient disease control. Agronomic practices can again be optimized only under properly functioning (fertilizer) input chains, as untimely supply one of the most salient reasons for non-adoption.

2.2 Kenya

The agriculture sector is the mainstay of the Kenyan economy. It directly contributes 24% to GDP and another 27% indirectly to GDP through linkages with other sectors. The sector accounts for 80% of total employment, 60% of industry raw materials, and a further 50% in export earnings. The sector is dependent on rainfed production that is characterized by low productivity and low processing with up to 91% of Kenya's total agricultural exports sold in their raw, crude, or semi-processed form (Government of Kenya [GoK], 2007; GoK, 2010). The agribusiness sector involves agricultural production, including farming and contract farming, seed supply, agrochemicals, farm machinery, wholesale and distribution, processing, marketing, and retail sales; the potential for agribusiness in Kenya is enormous. The objectives of the national agribusiness strategy in Kenya are to (1) remove barriers and create incentives for the private sector to invest in agribusiness and related business opportunities; (2) invest public resources more strategically to trigger growth in agribusiness; (3) make agribusiness systems more competitive, easily adaptable, and "fleet-footed" in order to deal with dynamic markets and the opportunities they bring; and (4) encourage institutional frameworks, which enable all actors to utilize market opportunities (GoK, 2012).

2.2.1 Food Security

Almost half of the Kenyan population lives on less than U.S. $1 a day, and one-third is food insecure. According to the 2008-09 Kenya Demographic and Health Survey, 35% of children under the age of five are stunted, 16% are underweight, and 7% are wasted; progress for improvement has been poor. According to a 1999 national micronutrient survey in Kenya, the most common deficiencies include vitamin A deficiency (affecting 84.4% of children under five), iron-deficiency anemia (affecting 69% of children ages 6-72 months and 55.1% of pregnant women), iodine deficiency disorders (affecting 36.6 of the population), and zinc deficiency (affecting 52% of mothers and 51% of children under five). The Ministry of Public Health and Sanitation has therefore outlined a National Nutrition Action Plan 2012-2017 to improve nutrition security. This initiative for location-specific water and fertilization management aims to make a contribution through agronomic fortification, i.e., the application of micronutrient fertilizers to increase the nutritional content of food crops (Dimkpa and Bindraban, 2016), to help resolve nutrition insecurity, particularly related to mineral micronutrients, including Zn and Fe (Bindraban et al., 2018).

According to the Famine Early Warning Systems Network (FEWS NET, 2017), food insecurity remained precarious for 2017 because of a poor 2016 cropping season and a prolonged drought in many parts of the country (Figure 2; from FEWS Net downloaded December 2017). The decline in staple food availability across most markets, which is also attributable to reduced imports from Tanzania and Uganda, results in rising prices of food commodities. Wholesale maize prices in the urban consumption markets of Nairobi, Mombasa, Kisumu, and Eldoret increased 19-39% between January and March 2017, with current prices being 30-54% above five-year averages.

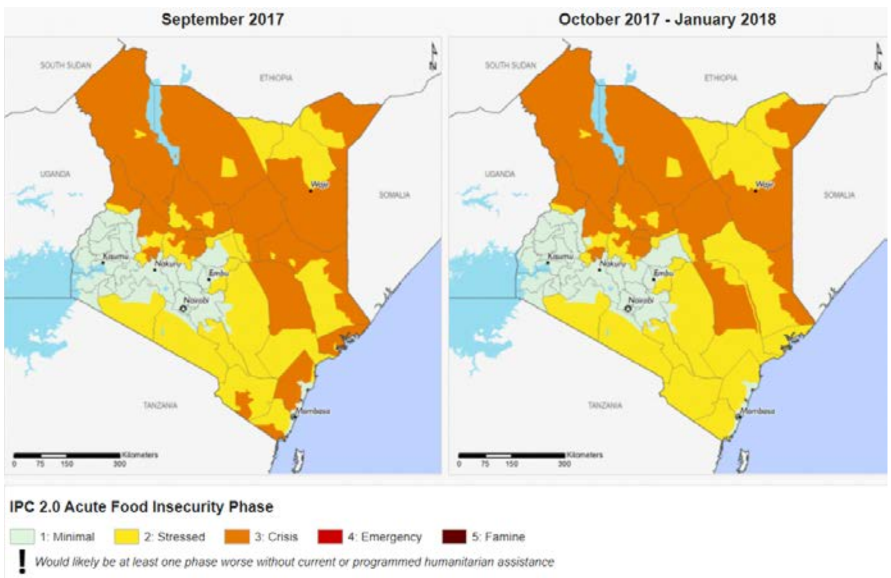


Figure 2. FEWS NET

In January 2018, FEWS reported production in Uasin Gishu, Trans Nzoia, and Nandi to be about 10-25% below average due to the combination of a dry spell during the development stages, fall armyworm infestations, and extended rains through October that delayed harvesting and drying. Overall, production from high and medium rainfall areas was estimated to be 15% below average. This information reveals that food and nutrition in Kenya remains highly insecure.

Food crops contribute 32% to agricultural GDP and are important for food security, with maize being by far the largest staple crop (Figure 3; FAOstat, May 2017). Annual production of maize was 3.6 million tons against a national requirement of 3.8 million tons in 2013 (Economic Survey 2013, Kenya National Bureau of Statistics). The production of the most important food crops is estimated for beans at 185 ktons, rice (225 ktons), potatoes (500 ktons), wheat (162 ktons), sorghum (170 ktons), and millet (90 ktons).

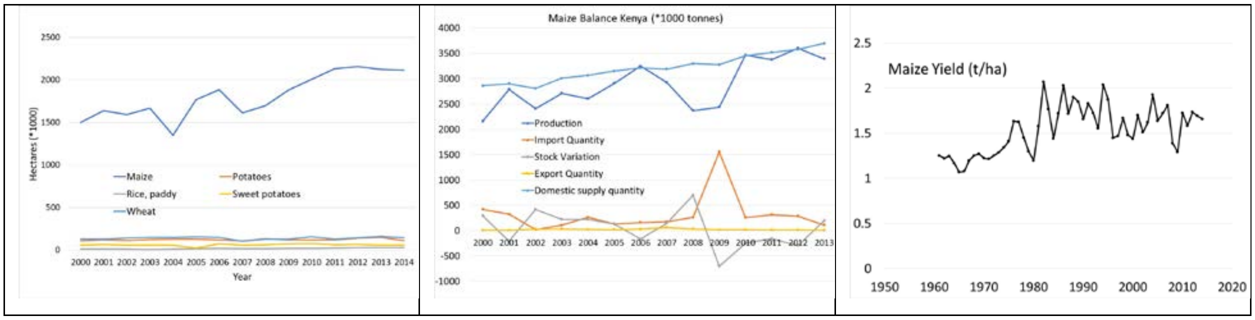


Figure 3. Acreage of Largest Food Crops in Kenya (left) and the Maize Balance Sheet (middle) Revealing the Volatility in Maize Production and Imports, with Highly Varying Yields (right)

Food production increases over the past decades have resulted from expansion of the cultivated land rather than yield increase (Figure 3). The production volume of maize is thereby highly variable and lower than the national demand, necessitating food import. Combined with high price volatility on the international market for maize (FAO, 2018b), food security is highly sensitive and claims on national budgets high and variable. The low and highly variable yields affect household livelihoods and continue to trap farmers in poverty. Apart from a low land effectiveness, the use efficiency of water, nutrients, and crop varieties is low as well, which implies ineffective use of already scarce resources.

Whereas potato is not a priority crop, it is in high demand and will become an important food crop and diversify the food basket. However, progress in potato development has been poor with yields at around 20 tons of fresh potato per hectare and at constant acreage (Figure 4; FAOstat, May 2017). Gildemacher et al. (2009) investigated opportunities for potato system improvement and found through participatory stakeholder meetings that seed potato quality management, bacterial wilt control, late blight control, and soil fertility management were key technical interventions needed to raise productivity.

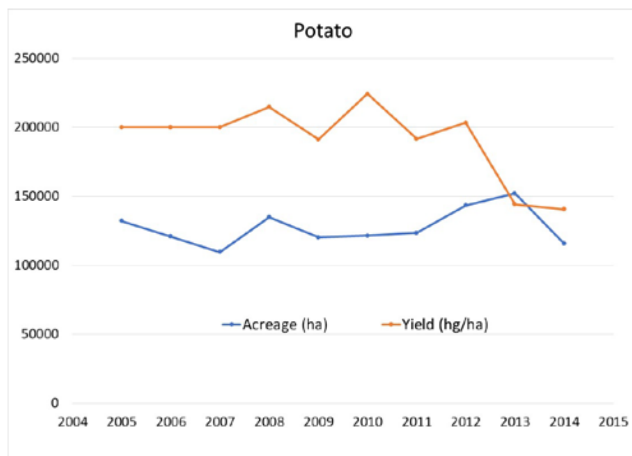


Figure 4. Potato Yield and Acreage

Under business as usual and continuing trends in agricultural productivity, Kenya's food and nutrition security will likely exacerbate, given that most food consumed by humans is produced locally, and double or even triple the amount of national food production is needed by 2050 to meet demand. Changing climate is expected to worsen the growth conditions with increasing drought, changing planting times, and shortened growth periods resulting in further increasing yield variability (Kabubo-Mariara and Kabara, 2015).

2.2.2 Agricultural Potential and Policy

The production potential of agriculture, i.e., the yields that can be obtained when crops are grown under optimal conditions (Bindraban et al., 1999; 2000), is calculated to be much higher than actual yield levels for the African continent. Applying this mechanistic modeling approach based on production ecological principles, Van Ittersum et al. (2016) present an overview of yields for a range of crops worldwide, including rainfed maize yields in Kenya and surrounding countries. These yield levels can be obtained when fertilization and crop protection are optimal and not limiting yield, while water availability sets a ceiling to the yield levels. In Kenya, yields can reach 10 t ha^{-1} and more in the high rainfall areas in the western part of the country, while they can be as low as 5 t ha^{-1} (red grids) and 3 t ha^{-1} (brown grids) in drier zones in eastern areas where soils are shallow (Figure 5). Current yields of 1-2 t ha^{-1} can be increased by an additional 6-8 t ha^{-1} in high rainfall areas under optimized fertilization, water harvesting, and crop protection. These practices will also be needed to close the yield gap of 2-3 t ha^{-1} in the drier areas but supplemental irrigation, if available, will be needed in these low rainfall and low yielding areas to further push up yields and reduce variability. Yet, the identification of optimal fertilization and other agronomic practices calls for advanced insights in production ecology (van Ittersum and Rabbinge, 1997).

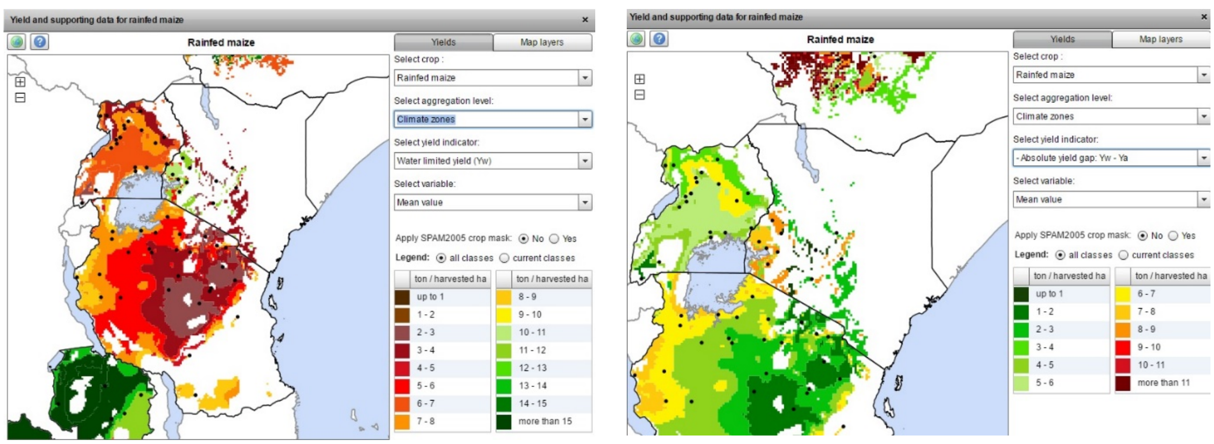


Figure 5. Water-Limited (rainfed) Maize Yield (left) and Gap with Current Yield Levels (right) (Yield Gap Atlas)

These theoretical yield gap assessments for maize have been confirmed in field experiments by Ngome et al. (2013) to be 4-5 t ha^{-1} on Nitisol and about 6 t ha^{-1} on Acrisol and Ferralsol, at current farm yields of 1.5-3.0, 0.8-1.0, and 0.9-0.5 t ha^{-1}, respectively. Yields were strongly determined by rainfall, weed infestation, and fertilization, and yield responses to inputs were heavily dependent on soil type. The authors discuss the implications of different management practices on the three soils in greater detail.

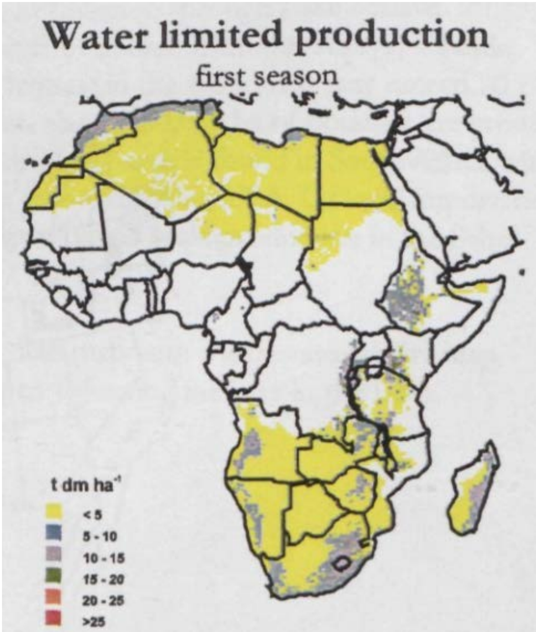


Figure 6. Potato Yields under Rainfed Conditions

Potato yields under rainfed conditions can reach 10-15 t dry matter ha^{-1} (Figure 6; MacKerron and Haverkort, 2004), which is equivalent to 50-75 t fresh potatoes ha^{-1}. This reveals a significant potential for productivity improvement given current fresh potato yields of 10-15 t ha^{-1}.

The InterAcademy Council (2004) presented a comprehensive set of agro-technical practices, institutional conditions, and policy measures needed to unlock these potentials. More specifically, Wineman et al. (2017) report periods of drought to be the most consistently negative weather shock that reduces income from both on- and off-farm sources, primarily in lowland areas, and that on-farm production must be increasingly complemented with food purchases. Excess water in the highlands can negatively affect yield and farm income. Water-harvesting technologies, intercropping, optimal planting period, and drought-tolerant short-duration varieties are proposed adaptation technologies to mitigate the impact; these bring about significant challenges that hinder farmers' ability to adopt the practices (e.g., Mati, 2000; Iizumi and Ramankutty, 2016; Mulwa et al., 2016). Access to credit and a more diverse income base seem to render a household more resilient. The current insecure food situation, along with the growing population and changing climate, necessitates developing sustainable, high-productive, and resilient agricultural systems that can cope with drought and other biotic and abiotic stresses.

The Ministry of Agriculture, Livestock and Fisheries of the Republic of Kenya (2015) aims to modernize its agriculture through innovation and commercialization. The plan reveals several global and national constraints and identified six strategic objectives: (1) create an enabling environment for agriculture development; (2) increase productivity and outputs in the sector; (3) enhance national food and nutrition security; (4) improve market access and trade; (5) strengthen institutional capacity; and (6) enhance the role of youth in agriculture. The Ministry established the National Accelerated Agricultural Inputs Access Program (NAAIAP) to empower resource-poor smallholder farmers in increasing their maize production through the provision of grants for farm inputs, because of the high input costs. The program promotes sustainable public-private sector partnerships through subsidized credit aimed at ensuring that smallholder farmers and businesses along the maize value chain can access farm inputs.

2.3 Migration

Migration is a global phenomenon that is driven by limited economic opportunities, civil unrest, and other insecurities. However, at a more conceptual level, De Haas (2010) finds that rather than the neoclassical migration theory and popular push-pull model in which people migrate from low- to high-income countries to improve their lives, migration is better conceptualized as a function of people's capabilities and aspirations. He observes, based on empirical findings, that economic factors as proxied by GDP per capita, but also the Human Development Index, strongly explain that outmigration exceeds immigration until about 5,000-10,000 euros/capita (Figure 7; from De Haas, 2010). This exemplifies the need to conceptualize migration as an integral part of the broader processes of development and social and economic change rather than an isolated problem to be solved.

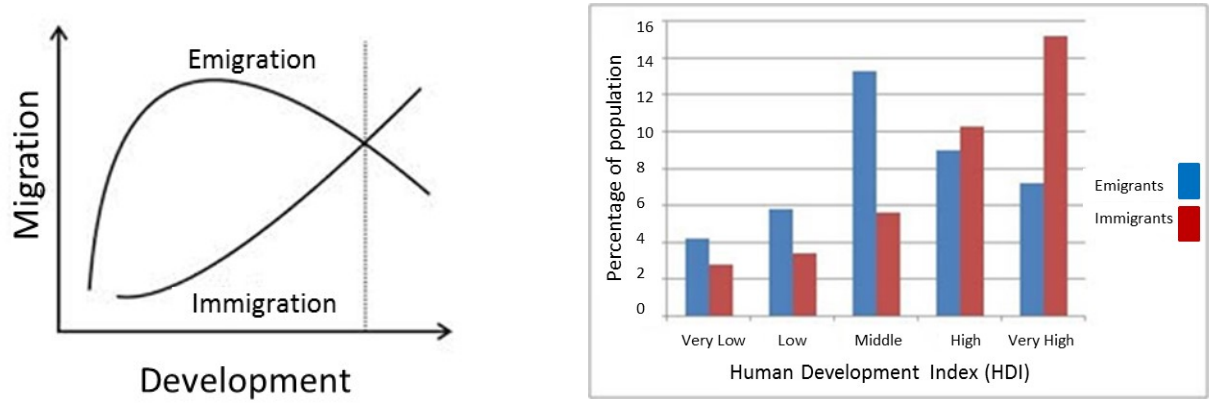


Figure 7. Graphic Representation of Migration Transition Theory (left) and Empirical Evidence (right)

However, these generic development-based migration movements may not represent migration caused by insecurities. In 2013, sub-Saharan Africa’s emigrant population was estimated to be about 23.2 million people, or close to 2.5% of the population. About half of Africa’s migrants stay within the continent and the other half are concentrated in France, Saudi Arabia, the United Kingdom, and the United States. According to the International Organization for Migration (IOM, 2015), about 15,000 Kenyans immigrated to European countries in 2009, of which over 400 relocated in the Netherlands. Larger flows of people (estimated at about 300,000) from the Sahelian regions, with even higher levels of insecurity, migrated to Europe from January to November 2016; almost all were male (IOM, 2016).

Several studies have found that climate extremes can exacerbate human migration, such as the migration of millions in Nigeria due to civil unrest, exacerbated by climate change that reduces the asset base for livelihoods, e.g., near Lake Chad (Webber, 2017). But the bigger effects of climate variability on migration are larger for short-distance or temporary moves, often from better-off households sending migrants as a form of investment, while reverse effects can occur in which climate extremes trap vulnerable populations in place (Gray and Wise, 2016, and reference therein). In local migration, households that had a family member who migrated to nearby centers for formal and informal employment could overcome barriers by employing high-cost agricultural innovations payed for from remittances and thus enhanced their self-protection against climate-related shocks (Ng'ang'a et al., 2016).

The dialogue about migration, particularly from the African continent to Europe, has surfaced at the top of the political agenda of the European Union (EU); the EU is taking measures to halt “irregular migration” through agreements with countries bordering the EU (Webber, 2017). In East Africa, for instance, the EU aim is to close a Mediterranean route to Europe by pushing border controls as far into Africa as possible with countries on the Horn of Africa (Somalia, Eritrea, and Ethiopia) and transit countries (including Sudan and South Sudan, Tunisia, Kenya, and Egypt).

There is, however, growing consensus that it is essential to address the root causes of irregular migration and forced displacement. The EU realized that these ambitions can only be reached through close and sustained cooperation between the EU and its Member States, in partnership with the countries of origin and transit of migrants.

2.4 Netherlands' Development Approach and Knowledge Base

Development of the agriculture sector is the most important, if not only, avenue to move out of poverty for most African countries, including Kenya. The Netherlands is internationally recognized as an expert and innovative partner in agricultural development and food security. In its development policies, it focuses on (1) eradicating existing hunger and malnutrition, (2) promoting inclusive and sustainable growth in the agriculture sector, and (3) creating ecologically sustainable food systems.

The Netherlands is particularly knowledgeable about high-productive agricultural systems and water management. It houses the highest ranking agricultural university in the world and several high-performing technical R&D institutes in soil and water management and logistics. It has extensive knowledge about optimized use of fertilizers for its high-intensity arable and animal farming, about specialty fertilizers that serve the high-value horticultural production systems, and about extraction and recycling of excess nutrients from air, liquid, and waste. The Netherlands production systems are also knowledge-intensive with the use of close- and remote-sensing technologies combined with mechanistic modeling that support decision making at the national level down to field applications. With 26% of the Netherlands territory below sea level and 29% susceptible for flooding from rivers, the country has centuries of advanced knowledge in water management. Moreover, the Netherlands thrives on a dense and highly effective logistical network nationally and internationally.

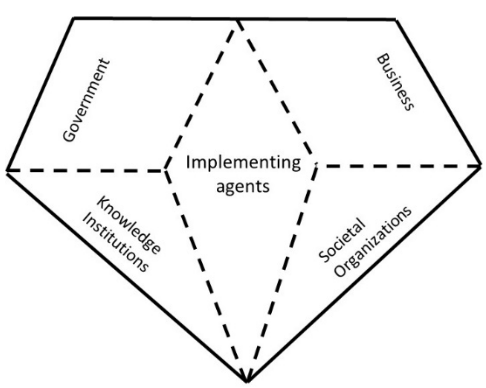


Figure 8. A Public-Private Partnership Approach (PPP) for Sustainable Development Cooperation (the Dutch Diamond Approach)

The insights about development cooperation have evolved from providing (agro-)technical support towards stimulation of public-private partnerships (PPPs) as a major driver for the implementation of development policy. These are partnerships between the government, the private sector, research institutions, and civil society organizations, also known as the Dutch Diamond Approach (Figure 8; Government of the Netherlands, 2011). Through this approach, the Netherlands Government is supporting development of the African continent by shifting from aid to trade and investment in Africa (Government of the Netherlands, 2011) as a vehicle for long-term cooperation and sustainable growth with optimal use of scarce resources. The ministry identified and supported new inroads in development based on these principles (Ministry of Foreign Affairs, 2013). One of the leading programs is 2SCALE, led by the International Fertilizer Development Center (IFDC), an agricultural research and development organization. 2SCALE seeks to improve rural livelihoods and food security in nine African countries by accelerating inclusive business in agri-food industries through PPPs (Box 2).

Box 2. 2SCALE – Business as Unusual

2SCALE is a Netherlands-supported development initiative that works with inclusive business champions – of African or foreign origins – and other relevant private and public partners to develop partnership and business models that promote inclusiveness, develop (new) competitive edge, and have potential for scaling in nine sub-Saharan African countries. Activities of 2SCALE include the identification of market opportunities; support to technology and organizational innovations in farming, post-harvest handling, and processing; capacity strengthening of farmer groups and small enterprises; brokering, trust, and relationship building within agribusiness clusters and value chains; financial intermediation; and targeted interventions for base-of-the-pyramid consumers.

In Kenya, 2SCALE provides support to 1) strengthen government certification agencies for the introduction of new high-yielding potato varieties; 2) introduce drip irrigation to cope with unreliable rainfall in chili production to be supplied a guaranteed market with advance contracts; 3) introduce blended fertilizers and application technologies in rice for higher yields; 4) support an agribusiness cluster to provide new sorghum varieties, training, and access to credit and link farmers to markets; 5) improve feed/fodder production by cattle owners, introduce new dairy products for the poor and IT systems to track deliveries, quality, and payments to secure supply to two independent dairy companies; and 6) explore ways to improve the marketing of fresh and dried vegetables to low-income families produced from newly introduced varieties.

Source: https://ifdc.org/2scale/ and Pers. Comm. IFDC staff

2.5 Kenya-Netherlands Green Deal

The agricultural potential and the shifting Netherlands aid-and-trade policies have already led to an intense trade-and-aid relationship between Kenya and the Netherlands, e.g., with farmers growing flowers and vegetables for the local and global market, creating local employment and prosperity. Experience has been building over the past few years for the PPP value chain approach in the 2SCALE program led by IFDC and supported by the Netherlands Ministry of Foreign Affairs. IFDC and partners have been building public-private relations within Kenya and between Kenyan and Netherlands actors.

Actors of the Netherlands can also support the sustainable rise in productivity of the staple food crops to more directly ensure food and nutrition security that enhances the resilience of rural livelihoods, which helps to stabilize migration dynamics while fostering robust urban-rural supply chains and trade opportunities. Several Dutch actors, most with long-term experience in sub-Saharan Africa in general and in Kenya in particular, have therefore bundled their expertise to explore the feasibility for location-specific fertilizer and water management approaches to boost agricultural productivity and income for the value chain actors sustainably. The team aims to supply farmers in predetermined pilot regions with location-specific (blended) fertilizers, as a component in a more complete agronomic package, that will result in significant yield and quality gains and profit. The fertilizer specifications (ISRIC – World Soil Information and IFDC) will be based on innovative analyses that integrate rapid soil observations (SoilCares) and remotely sensed water information (eLEAF) in crop-soil models to arrive at the recommendations. Specific emphasis will be placed on simple but seamless logistics (ATTRO logistics), international fertilizer trade (ICL with sufficient capacity for the Kenyan market of commodity, semi-specialty, and specialty fertilizers but also with experience to use locally available resources as nutrient suppliers to local agriculture), and local blending and coating facilities (ICL Fertilizers and EMT) to minimize cost build up (Wageningen UR – economics) while producing a wide range of products and optimizing delivery to local agro-dealers and farmers (IFDC). The approach should yield viable businesses for the actors in the supply chain, including fertilizer producers and importers, blending companies, and agro-dealers. Farm productivity and profitability should increase to improve farm household food security and livelihoods, while traders and retailers should be ensured of continuous and high-quality products. Good business may be found in more fertilizer supply but more likely in improved and tailored formulation, broader product ranges, and smart fertilizers, and in improved distribution and timely delivery. Developing and implementing a sound business model can ensure an economically self-supporting system over time. Obviously, an effective team in Kenya should mirror the Netherlands' efforts and expertise that will be laid out following a feasibility assessment.

3. Agro-Technical Production Aspects

The project team proposes to focus on maize-based systems, because maize is the most important food security crop of Kenya and 60% of all fertilizers in the country are used on maize. Potato, with several ecological benefits and a potentially high-volume staple crop with an international link, deserves specific attention to diversify the food basket of Kenya. These choices do not exclude other crops, like beans or vegetables, that are often also grown in maize- and potato-based cropping systems.

This consortium has prioritized counties in southwestern Kenya, because this area forms the grain basket of Kenya. In addition, various actors in Kenya and in the Netherlands have emphasized the favorable opportunities and significant potential to raise productivity here.

- Counties for maize: Uasin Gishu, Trans Nzoia, Nandi
- Counties for potato: Nyandarua, Nakuru, Elgeyo Marakwet

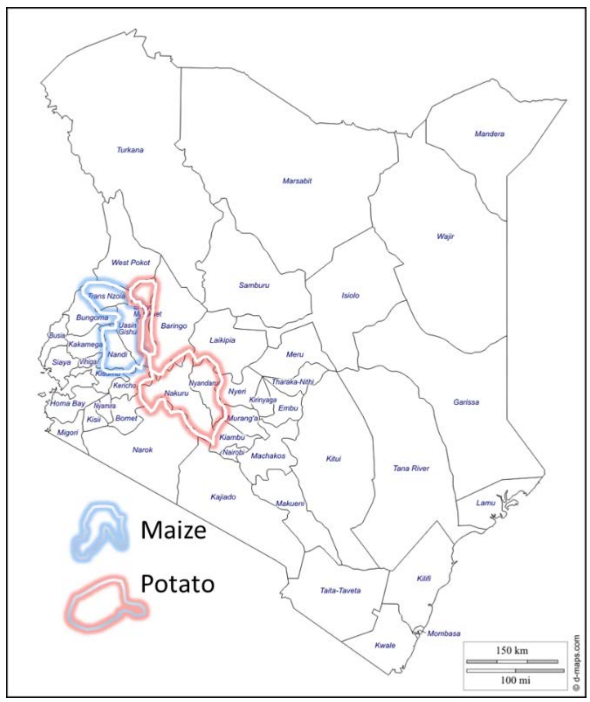


Figure 9. Selected Counties for Maize and Potato Demonstrations

Detailed descriptions of the maize and potato value chains are given in Appendices 3 and 4, respectively.

3.1 Crop Productivity, Nutrition, and Fertilization

Current maize yield levels of 1-2 t ha^{-1} y^{-1}, under production conditions that allow up to 10 t ha^{-1}, are an indication of insufficient or ineffective use of inputs. Given the low inherent productivity of most soils on the African continent (Voortman and Bindraban, 2015) and low use of fertilizers, the Kenyan Ministry of Agriculture conducted a soil fertility evaluation program that included 9,600 soil samples from 4,800 farms across 164 sub-counties to develop fertilizer recommendations for maize (Department of Kenya Soil Survey, 2014). The Ministry warns that blanket recommendations may acidify soils, leading to land degradation, and encourages farmers and other stakeholders to use the current information and, in the long-term, to test farm soils to determine the most appropriate fertilizer types and quantities.

The nutrient elements analyzed in the soil sampling scheme included total organic carbon (C), pH, N, P, K, calcium (Ca), magnesium (Mg), manganese (Mn), iron (Fe), zinc (Zn), copper (Cu), total nitrogen, and exchangeable acidity where the pH of the soil was ≤ 5.5. In devising fertilizer recommendations, emphasis is placed on maintaining the soil pH within the range of 5 to 8, which is desired for maize and because deficiency or toxicity of micronutrients is least likely to occur at that pH, presuming that the soil contains sufficient nutrient stocks. The report recognized micronutrient deficiencies and recommended application of organic matter sources to balance the offtake and specific fertilizers to control pH. Acidifying fertilizers, such as diammonium phosphate (DAP), monoammonium phosphate (MOP), ammonium sulfate (AS), and urea, are recommended to prevent further increase of pH on farm soils with pH greater than 6.5. On farm soils with pH ≤ 6.5, neutral fertilizers such as triple superphosphate (TSP), single superphosphate (SSP), compound fertilizers N:P:K 17:17:17, 15:15:15, 23:23:0, 20:20:0, and calcium ammonium nitrate (CAN), should be preferred to avoid further acidification. On acidic soils, special fertilizers with neutralizing effect, such as Partially Acidulated Phosphate Rock (PAPR), and conventional liming agents, such as lime stone, could be used. A typical recommendation at the county level is application of 5-8 t ha^{-1} of manure, between 150 and 250 kg ha^{-1} NPK fertilizers at planting, and around 125-200 kg ha^{-1} as split application during growth.

Table 1 presents the percentage of samples (60 soil samples from 30 farms per sub-county) that were under the critical level for specific soil characteristics. The sub-county general fertilizer recommendations show little difference, and no mention is made of the target maize yield for which the recommendation applies. The report does make a generic remark that zinc or copper sulfate at 5-10 kg/ha can be added to soils with Zn or Cu deficiency, or through foliar application for high-value crops, but it does not further specify this recommendation.

Table 1. Percent Soil Samples Below the Critical Level and Recommendation for Maize Fertilization

		Uasin Gishu County			Trans Nzoia County			Nandi			Nyandarua		Nakuru		Elgeyo Marakwet County			
Soil Parameter	Critical Level	Eldoret East	Eldoret West	Wareng	Kwanza	East	West	North	South	Tinderet	Kipipiri	North	Naivasha	North	Keiyo North	Keiyo South	Marakwet East	Marakwet West
pH	>5.5	83	80	93	20	30	67	95	57	22	25	27	2	12	35	67	2	23
Total Org. C. (%)	>2.7	88	100	89	83	97	100	75	48	27	65	67	90	37	57	42	67	23
Total Nitrogen (%)	>0.2	62	87	43	25	63	95	22	20	2	20	13	53	17	23	18	67	5
Available P (ppm)	>30.0	86	95	96	13	93	97	62	55	13	28	57	63	7	57	55	53	70
Potassium (me %)	>0.24	0	0	0	0	83	40	7	35	0	7	3	2	0	0	0	22	15
Calcium (me %)	>2.0	1	37	5	8	57	87	35	0	0	27	5	0	0	0	0	0	0
Magnesium (me %)	>1.0	11	28	13	0	7	3	35	5	0	0	0	0	0	0	18	0	0
Manganese (me %)	>0.11	0	0	0	0	0	0	5	0	0	0	0	2	0	0	0	0	0
Copper (ppm)	>1.0	0	0	0	0	0	0	23	20	8	70	3	87	18	0	48	3	0
Iron (ppm)	>10.0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Zinc (ppm)	>5.0	40	78	25	79	93	42	93	57	67	57	28	0	10	45	53	7	85
Recommendation																		
Manure (t/ha)		5	6	5	5	7	7	5	5	6	5	5	6	4	5	5	6	3
Planting N:P:K: 23:23:0; {17:17:17}: [SSP] kg/ha		250	250	250	150	250	300	250	200	0	250	200	250	50	250	200	250	250
Topdressing (CAN) kg/ha		150	150	150	100	150	200	125	125	125	125	125	125	125	125	125	125	125

Source: Department of Kenya Soil Survey, 2014.

While these recommendations aim to better suit soil conditions, the team has observed a number of challenges and improvements to further adjust fertilizer recommendations to farm needs:

1. Current fertilizer application rates in maize vary from zero to over 200 kg ha^{-1} y^{-1}, with the highest amounts mostly used on large farms.
2. The recommended fertilizer quantities of the Department of Kenya Soil Survey (2014) total 300-500 kg ha^{-1} y^{-1}, containing approximately 50-80 kg of N and of P, with mostly no K. Crop nutrient uptake must be compensated by nutrient input from fertilizers and organic matter to prevent degradation. Recovery of 50% of the applied fertilizer N and fertilizer P, which actually varies from 20 to 50% (Vanlauwe et al., 2011), implies crop uptake of 25-40 kg N and P. With maize grains containing about 20 kg N t^{-1} grain, yields of 2.5-4 t ha^{-1} can be attained (Ciampitti and Vyn, 2014). The N:P:K[1] content ratio in maize is 5:1:5, which implies a total of about 10-16 kg P and 50-80 kg K are contained in the grain. Application rates of 50-80 kg P ha^{-1} may therefore be too high unless much P is fixed to the soil matrix, which may be significant under low (<6) and high (>8) soil pH, justifying higher P application rates because of the low recovery. Clearly, lack of K application is likely to hamper yield, if not now then in future.
3. The recommended application of 5-8 t ha^{-1} of manure would suggest the application on average of roughly 13, 3, 13, 10, 4, 6, and 0.5 kg ha^{-1} of N, P, K, Ca, Mg, Fe, and Mn, respectively, if the recommended amount is expressed on a dry weight basis at 25% dry matter content, and 3,

[1] N:P varies from 17:1 (maximum N accumulation) to 1.25:1 (maximum N dilution). N:K ratio varies from 2.5:1 to 0.25:1).

1, 3, 2, 1, 2, and 0.1 kg ha^{-1}, respectively, if expressed on a fresh weight basis (Table 1). Manure application does not contribute significantly to macronutrient application but may be relevant for supply of micronutrients.

4. In addition to nutrients, manure is desired to improve soil structure through increased soil organic matter (SOM) that in turn helps, for instance, to retain nutrients and increases water-holding capacity. Yet, the application of 5-8 t ha^{-1} of manure is not likely to be feasible for most farmers. Apart from use for other functions, such as for fuel, the logistics of moving around this large amount of manure is unlikely at a significant scale. Current available amounts, on average, are in the order of 1-4 t ha^{-1} and not available to all farmers (Box 3).
5. It should be noted that increasing maize yield should come with a comprehensive agronomic package of simultaneous integrated water management, use of improved seeds, optimal tilling of soil, adequate protection of the crop, and many other agronomic measures.

Table 2. Indicative Nutrient Contents (on Dry Weight Basis) of Manure

Nutrient	Lupwayi et al. (2000)		Harris and Yusuf (2001)		Lekasi et al. (2003)	
	Mean	Min – Max	Mean	Min – Max	Mean (%)	Min – Max
N	18.3	11.7 – 27.4	30	25 – 38	1.12	0.33 – 1.91
P	4.5	2.2 – 7.0	19	14 – 28	0.3	0.06 – 0.75
K	21.3	10.6 – 54.4	80	40 – 97	2.38	0.43 – 7.0
Ca	16.4	10.1 – 24.6	84	45 – 91	0.26	<0.01 – 1.34
Mg	5.6	3.2 – 12.4	24	20 – 32	0.51	0.05 – 1.19
	(mg kg^{-1})	(mg kg^{-1})				
Fe	10,776	3,693 – 22,477				
Mn	777	271 – 1904				
Cu	24	8 – 86				
Zn	92	49 – 217				

Box 3. Fertile Grounds Initiative (FGI)

The FGI is a collaborative effort between actors in nutrient management to increase nutrient use efficiency at various spatial levels to maintain or improve soil health and productive capacity of land. The program emphasized the use of compost. Farmers, however, do not exceed producing 1 t of compost while up to 8 t ha^{-1} may be needed to maintain soil health. Explorations about the recycling of waste from urban areas and other concentrated production sites, such as for rose greenhouses or sugarcane, reveal a myriad of challenges, including insufficient supply, toxic levels of heavy metals and agro-chemicals, high salinity, and lack of standards. While composting could contribute to reducing on-farm nutrient imbalance, and some specific local efforts could help to reduce the nutrient gap, scalability of the approach will be a challenge as the balanced crop nutrient requirements cannot be met and logistics are very demanding, making business cases weak.

Source: FGI, 2017. Remko Vonk, Pers. Comm.

The need for better-specified location-specific fertilization is also found by Kihara et al. (2016), for instance. Based on 310 fields trials in Kenya, Malawi, Mali, Nigeria, and Tanzania, they found high variability in maize yield responses to fertilization which they categorized in four clusters. These include: (1) 25% of the soils with low and high inherent yield levels that are hardly or nonresponsive to any nutrients or soil amendments; (2) 35% of the soils that more than double yield on which soil amendments (+40%) and multi-nutritional fertilization (+23%) further enhanced yields; (3) 28% that have a poor response; and 4) 11% of the soils in which N strongly limits yield and PK hardly adds to improvements, while soil amendments and multi-nutrients further increase yield. Regrettably, they were not able to relate these differences in responsiveness of soils with differences in soil properties, possibly also because soil-water characteristics were not measured nor included in the analysis.

Based on fertilizer experiments carried out in the late 1960s in Kenya by the Food and Agriculture Organization (FAO) of the United Nations, Okalo and Zechernitz (1971) demonstrate N and P to significantly increase maize yield while yields tended to respond less on K application. Based on 100 fertilizer trials in 1968 and 1969 in the Trans Nzoia and Uasin Oishu districts of Western Kenya and smaller numbers in Embu and Kakamega, Allan (1971) reports that S application increases maize yield in Trans Nzoia and Uasin Oishu by 1 t on top of yield of 5 t ha^{-1} obtained with NPK. Recently, Keino et al. (2015) found Mg, K, P, and Ca as important limiting nutrients for soybean growth for Kenyan soils (Figure 10; from Keino et al., 2015).

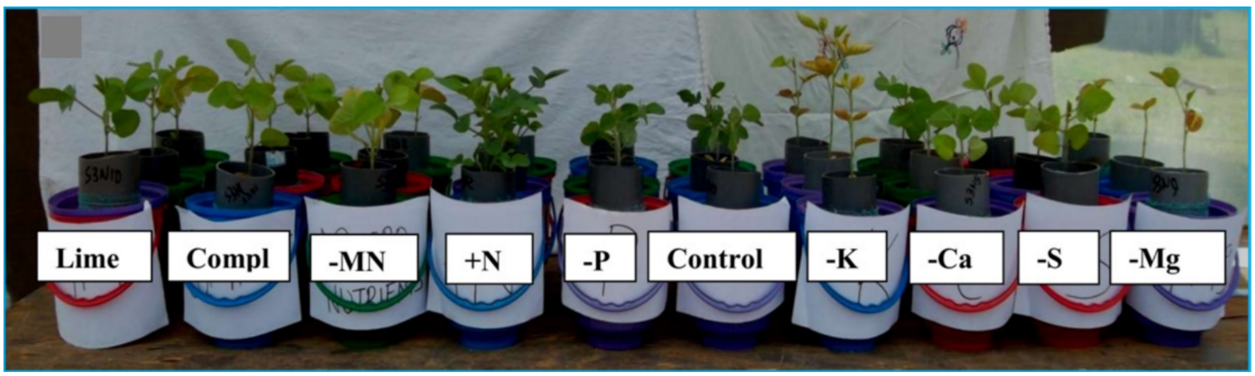


Figure 10. Illustration of the Impact of Various Nutrients on Soybean Growth

Box 4. On-Farm Maize Trial ICL-Kenya

ICL-Kenya performed fertilizer trials on maize in Western Kenya and found balanced fertilizers to significantly increase yield. Apart from adding K to the N and P, they also included S because it is considered to be deficient in most parts of Kenya, and Mg because it was available in the blend and because Mg deficiencies have been observed in other crops like tomatoes in the region. Maize farmers use subsidized fertilizers that come as DAP (N + P) and CAN (Ca + N) and sometimes NPK 23:23:0 (N + P), which makes it challenging for farmers to adopt more balanced fertilizers through the private sector market.

Maize trials conducted by ICL in Western Kenya in Trans Nzoia, Uasin Gishu, and Bungoma

Treatment	Fertilizer Rate (kg ha^{-1})	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	Yield (t ha^{-1})
Farm practice	360 DAP basal 24-360 CAN top	130-360	170	0	2.0 – 3.5
FP + 60 kg MOP	360 DAP + 60 MOP basal 240-360 CAN top	130-360	170	88	4.5 – 5.5
FP + 120 kg MOP	360 DAP + 120 MOP basal 240-360 CAN top	130-360	170	176	2.5 – 4.0*
ICL slow release N + $2MgO+21SO_3$		190	170	50	5.2 – 7.0

**Note that yields decreased at higher K rate, likely due to soil acidity or too high K relative to other nutrients.*

These trials reveal the actual opportunities to raise maize yields through more balanced fertilization. The trial design does not, however, allow to systematically disentangle the contribution of each nutrient given the confounding effects of multiple nutrients and to arrive at location-specific required nutrient combinations.

Source: Lilian Wanjiru Mbuthia; ICL-Kenya

Njoroge et al. (2017) conducted 24 on-farm maize omission trials with NPK in Siaya, Western Kenya, during six growing seasons from 2013 to 2016. They found widespread and consistent yield response to N, arguing that it was linked to relatively low soil organic matter contents. According to AfSoilGrids (discussed in Section 3.2.1), however, the SOM content in that study area is in the order of 4%. Hence, the widespread response in Siaya suggests little need for spatial-temporal optimization for nitrogen use efficiency, and application rates should compensate for the offtake by the maize crop, irrespective of location, SOM content, and seasonality. The omission of P in the treatments (NK) resulted in significantly lower yields compared to NPK fertilization that further decreased over time. This indicates a difference in P status which calls for spatial specification and for replenishment of P over time, as the residual effect of P, i.e., the supply from a previous season, occurs over a very short period. The strong spatial-temporal response to K with K limitation became stronger with increasing NP fertilization, suggesting hot spots of K deficiencies and K depletion even in regions considered sufficient in K. These authors found soil organic matter, soil available P, and soil exchangeable K to relate only weakly to responses to N, P, and K, respectively, and argued that fertilizer recommendations cannot be solely based on field-level soil analysis. This observation is not new nor surprising, given the multiple factors that determine ultimate crop response to fertilization (see Section 3.4). For instance, no attention has been paid to ratios between nutrients in soil that act antagonistically or synergistically (e.g., Rietra et al., 2017).

Little is known about fertilizer recommendations for potato. Based on farm surveys in 2005, Gildemacher et al. (2009) found the vast majority of farmers to use substantial quantities of mineral fertilizers in potato farming, though on average at less than half of the recommended amounts of nitrogen and phosphorous in the form of DAP (18:46). In addition, farmyard manure was used by 45% of the farmers and contained 48 kg N and 13 kg P (which seems excessively high). They found potato farmers received positive return on their cash investment, providing them with some cash income as well as food from their potato production, but return on their labor was lower than the opportunity cost. Based on long-term experiments from 1987 to 1994, Recke et al. (1997) found potato yield to respond linearly to N and P fertilization, but to be less responsive to K, and optimal agronomic and economic application rates to be almost similar, with yields exceeding 20 t ha^{-1}.

Box 5. On-Farm Potato Trial ICL-Kenya

ICL-Kenya recently performed a survey among potato farmers and conducted 30 demonstration trials during two seasons in the counties Murang'a, Nyandarua, and Narok to experiment with fertilization. Currently, farmers apply three to mostly five bags per acre (50 kg each; 370-620 kg ha^{-1}) of DAP at planting; 500 kg DAP ha^{-1} (18-46-0) is equivalent to 90 kg N and 230 kg P ha^{-1}. Some farmers will topdress with mostly one, sometimes two, bags of CAN (8% Ca and 21-27% N); 120-250 kg CAN ha^{-1} is equivalent to 10-20 kg Ca and 25/32-50/67kg N ha^{-1}. Some farmers may even apply foliar fertilizers. Current farm yield levels reach 10 t potato ha^{-1}, varying from 6-14 t ha^{-1}. As potato requires large amounts of potassium, ICL experimented with application rates of 90-100 kg N, 60-70 kg P, and 170-190 kg K ha^{-1} to compensate NPKS removal for attaining 30 t ha^{-1}. Combining DAP with MOP (muriate of potash, 0-0-60) and a control release NPK fertilizer, which also contains S and Mg, an average yield of 27 t ha^{-1} was obtained, varying from 18 to 34 t ha^{-1}. Most farmers adapted these novel practices and purchased the fertilizers, as the more than two-fold yield increase doubled their income with a value-cost ratio of $23 for every extra $1 spent on fertilizer. MOP is currently also available in the major towns but had to be brought down to the communities for the last mile. Farmers are able to obtain the fertilizers on time and on credit through their cooperatives.

Source: Lilian Wanjiru Mbuthia; ICL-Kenya

Bindraban and colleagues (2018; see references herein) provide an overview of a forgone opportunity that is not considered in fertilization, which is the possibility to increase the nutritional content of food crops. Due to the prime use of NPK fertilizers, the contents of micronutrients in grains of cereal crops and in shoots of vegetables have declined, sometimes by more than half. This decline may be attributed to the dilution of micronutrients in shoot and grain biomass due to breeding and the continuous mining of soil micronutrients because of non-replenishment by fertilization, especially in resource-poor countries. Through the application of mineral micronutrient fertilizers to soil or plant leaves, the micronutrient content of edible plant parts can be increased, contributing to human nutrition (Table 3). Use of Zn-containing NPK fertilizers in crops, such as wheat, rice, sorghum, and soybean, with specific timing and application techniques, has resulted in dramatic improvements in crop yield and nutritional quality. For instance, soil- and foliar-applied Zn has been found to increase median Zn concentration in maize, rice, and wheat grains by 23%, 7%, and 19%, and 30%, 25%, and 63%, respectively. But while the concentrations of the macronutrients N, P, and K are generally confined to upper and lower limits governed by the metabolic functions of the nutrients and their storage capacity, the concentration of micronutrient can increase multifold. Agronomic fortification, therefore, has a widespread reach across crops and regions and is not discriminatory to specific groups of the population. Current nutrition interventions, including diversity of diets, nutritional supplementation, fortification of processed food, and biofortification through breeding of crops with higher contents of micronutrients, lack full coverage, and their reach varies depending on the conditions and circumstances of the target group.

Table 3. The Decline in Crop Nutrient Content Over the Past Decease Can Be Reverted and Increased Through Fertilization Along with Increasing Yield and Biomass

Crop	Nutrient Applied	Application Method	With/ Without NPK	% Change in Nutrient	Yield Increase (%)	Biomass Increase (%)	Remarks
Rice	Zn	Soil	-	+70 to +210 Zn	+97	-	
	Fe	Liquid Soil	-	+54 Fe			-51 Zn
	Cu	Soil	-	+40 Cu		+8.5	
	Mo	Soil	-	+30 Zn; +48 B	+13	+24	
Maize	Zn	Soil & foliar	+	+66 to +98 Zn	+24 to +39		
	Mn	Soil	-	+69 Mn		+16	
Bean	Zn	Soil	-	+329 Zn			+12 Fe; +18.5 Mn
	Fe	Foliar	-	+588 Fe	+133		-12 Mn; -59 Cu; -27 Zn
	Cu	Soil	-	+77 Cu			
	Mn	Soil	-	+643 Mn		+19	
	B	Soil & foliar	+	+94 to +161 B	+24 to +36		
Soybean	B	Soil	-	+111 B		+13	
Wheat	Cu	Soil	-	+29 Cu; +9 Mn; +5 Zn	+63	+26	
	Fe	Soil	+	+73 Fe	+7		
	Zn	Soil	+	+116 to +317 Zn	+3 to +23		
	Fe + Zn	Soil	+	+64 Fe; +66 Zn	+17		
	Cu	Soil	+	+16 to +24 Cu	+7 to +63		
	B	Soil	+	+169 B	+26		
	B + Zn	Soil	+	+175 B; 147 Zn	+26		
	Mn	Foliar	+	+0 Mn	+11		

Source: Dimkpa and Bindraban (2016).

3.2 Soils – Understanding the Production Base

The findings presented in the previous section clearly demonstrate the potential for more than just current standard fertilizers to boost crop yields. Based on this status of fertilizer recommendations and the general findings about the need to derive crop- and location-specific fertilization strategies, the project team proposes to refine the recommendations for soil, fertilizer, and water management to arrive at better agronomic and economic options.

3.2.1 Soil Property Data and Maps

Soil information is at the base of fertilizer recommendations. Direct sampling of farm fields may provide the most reliable and accurate soil property data, but this approach is limited due to high costs and lacks the ability to extrapolate findings to other soils, farms, and regions. Therefore, the team proposes to use existing spatial soil information that will have to be improved over time, such as through additional sampling, to continuously improve the accuracy of the data and fertilizer recommendations.

ISRIC has developed a collection of gridded soil property maps (SoilGrids) that represent estimated soil property values for the world (Hengl et al., 2017a). These are calculated and interpolated using machine learning algorithms from increasingly large quantities of georeferenced soil profile data projected upon stacks of geographic covariates. SoilGrids maps are available at a spatial resolution of 250 meters (m) and includes estimates for six depth intervals over the full profile depth, i.e., 0-5 (cm), 5-15 cm, 15-30 cm, 30-60 cm, 60-100 cm, and 100-200 cm. The current version of SoilGrids provides validated estimates of both soil physical and bio-chemical properties for sub-Saharan Africa (Hengl et al., 2015), here called AfSoilGrids.

Derived from these AfSoilGrids and particularly relevant for location-specific yield gap analysis are maps of aggregate soil characteristics, including the plant-available water-holding capacity, the soil fine earth fraction, and the rootable depth (Leenaars et al., 2015). The pedotransfer functions prepared and used by Leenaars et al. (2015) have been used by Hengl et al. (2017a) to map soil water retention, including available water-holding capacity for the world. Recently added to the AfSoilGrids are maps of the soil nutrient contents (of the fine earth of 0-30 cm) of sub-Saharan Africa (Hengl et al., 2017b), including N, P, total P, K, Ca, Mg, Cu, Zn, Mn, Fe, boron (B), aluminum (Al) and sodium (Na). Figure 11 (from Hengl et al., 2017b) illustrates the accuracy of the nutrient assessment, which varies from one nutrient to another, indicating that the uncertainty of each prediction can be very considerable. For example, for a given, predicted, value on the Y axis (imagine a horizontal line through the graph), the corresponding measured value can be any value within the range as distributed in the cloud along the X-axis. The uncertainty graphs in Figure 11 apply for the entire sub-Saharan African continent and can be reduced – or the accuracy can be increased – by making updated predictions for a target area using additional data from additional soil samples collected from that area.

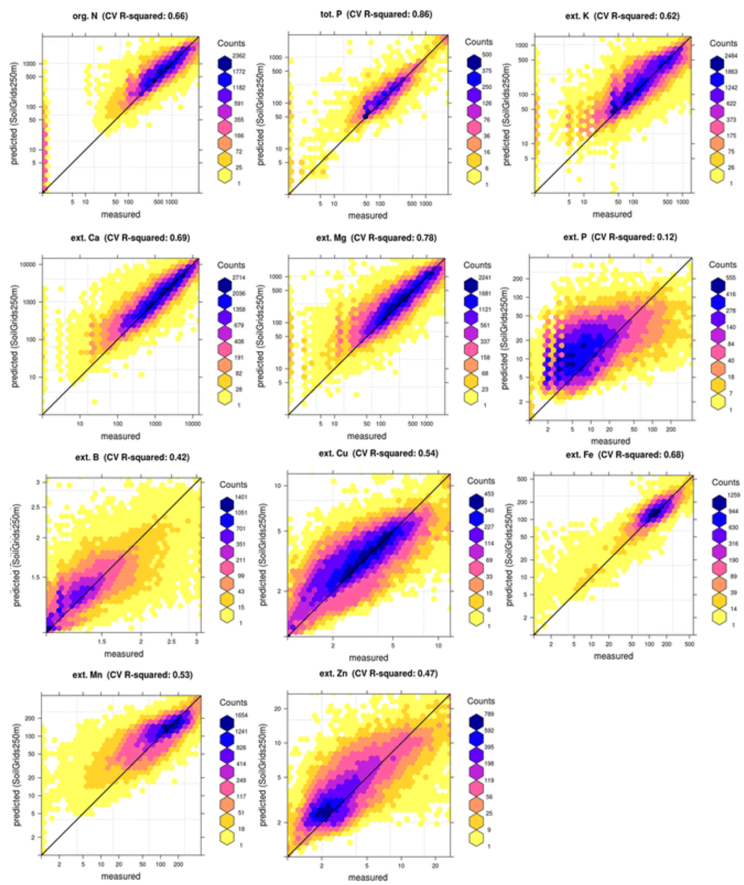


Figure 11. Accuracy Assessment Plots for All Nutrient Maps Using Five-Fold Cross-Validation for Sub-Saharan Africa. All values are expressed in ppm and displayed on a log-scale. Note that no map is available for S given the critically low accuracy.

Figure 12 presents two examples of the AfSoilGrids, depicting the spatial variability in Kenya of extractable (Al) and rootable depth. The Al content is relatively high near the areas targeted for maize and potato, but it does not reach toxic levels. Concentrations are considered excessive beyond 2,500 parts per million (ppm) with total root growth restriction beyond 7,000 ppm (Landon, 1991; Sanchez et al., 2003). Another measure for Al toxicity for common crops is when exchangeable Al saturation exceeds 60% of the cation exchange capacity (CEC), but the current Al concentration remains at or below 20% for the CEC values of 10-15 cmol/kg and higher in the target counties (data not shown). The rootable depth appears to be severely restrictive for maize in the north of Kenya and variable in the target counties with patches of shallow depths. Appendix II lists all soil property maps, including metadata, available through this study for Kenya.

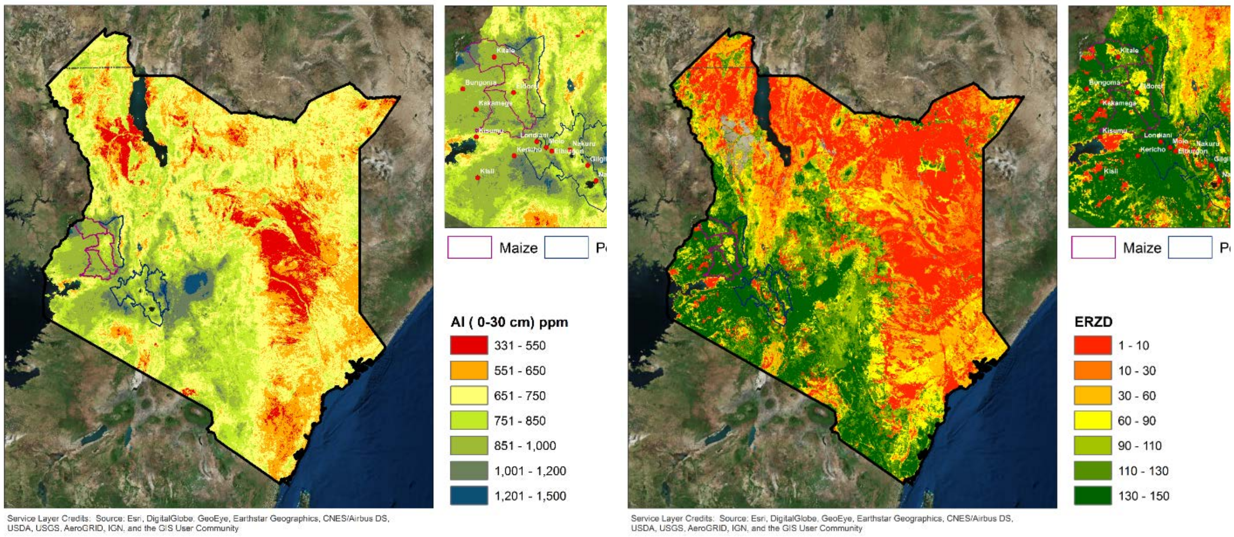


Figure 12. Examples of AfSoilGrids indicating soil constraints to crop growth. Left: extractable aluminum (mg kg^{-1}); Right: maize rootable depth (cm)

3.2.2 Interpreting Soil Property Data

Interpretation of soil properties as an indicator for nutrient availability and ultimate uptake by plants is not a straightforward transformation and requires careful consideration of several factors.

First, the representativeness of the soil sample taken from the field might vary for a variety of reasons, including the number of samples per field, the depth of soil sampling, the timing during, before, or after a growth period, and many more errors that might occur during handling and processing of the sample.

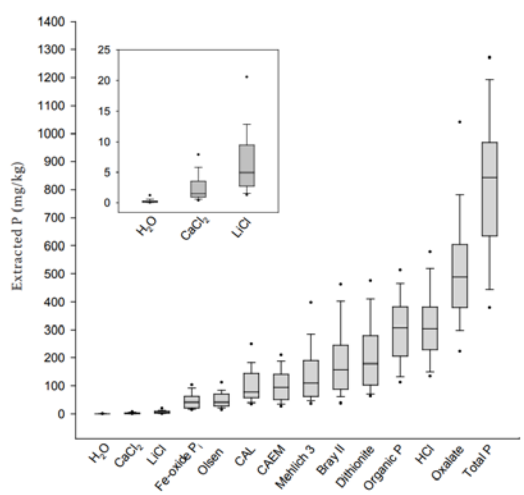


Figure 13. Phosphorus (P) Extracted by the Different Extraction Methods in the Order of Increasing Extraction Yield (n = 50)

The second factor is the extraction method in laboratories to determine the amounts in the soil. Depending on the extractant, a smaller or larger portion of the total amount of a nutrient can be detached from soil particles and other compounds nutrients adhere to (Figure 13; from Wuenscher et al., 2015). Hence, the same soil sample with a different extractant will result in different values. Phosphorus, for example, can be extracted by a mixture of chemicals; most known are P-Bray, P-Melich-3, and P-Olsen. P-Bray and P-Olsen tend to be strongly correlated in soils with a pH of less than 7.5, while the relationship breaks down at higher pH values. Total P is obtained by converting organic P in the soil into inorganic P by heating and extraction with a strong hydrochloric acid. Therefore, critical levels for available P for crop growth will depend on the extraction method. Based on Melich-3, P contents of less than 10 might be considered “very low”; up to 15 is considered “low”; “optimal” is between 15-20; “high” is 21-30; and “very high” is above 31.

The third factor is the ability of a crop to extract the “available” nutrient from the soil. Crops differ in the extent of excreting organic acids (exudates) to dissolve nutrients from soil particles for uptake. Some crops, like lupin, can thrive on soils with lower P amounts, while others like maize excrete less exudates and need higher available soil amounts. In addition, the ultimate amount of a nutrient taken up depends on other growth parameters as well, such as the radiation intensity, temperature and water availability or occurrence of pests and diseases that drive crop growth rates and, with that, affect uptake capacity.

Then there are other factors that further affect ultimate uptake. The extractable amounts may differ among soil types due to differences in P sorption properties. The acidity of the actual in situ soil (pH) strongly determines availability of nutrients as illustrated in Figure 14. The rootable depth of the soil and the rooting depth of a crop are important determinants for the thickness of the soil column that can be mined for nutrients as well as for water required to grow. The relative availability of different nutrients might result in synergistic or antagonistic effects in soil and plant uptake processes (Rietra et al., 2017). And the wetness or rather dryness of the soil has a large impact on nutrient uptake.

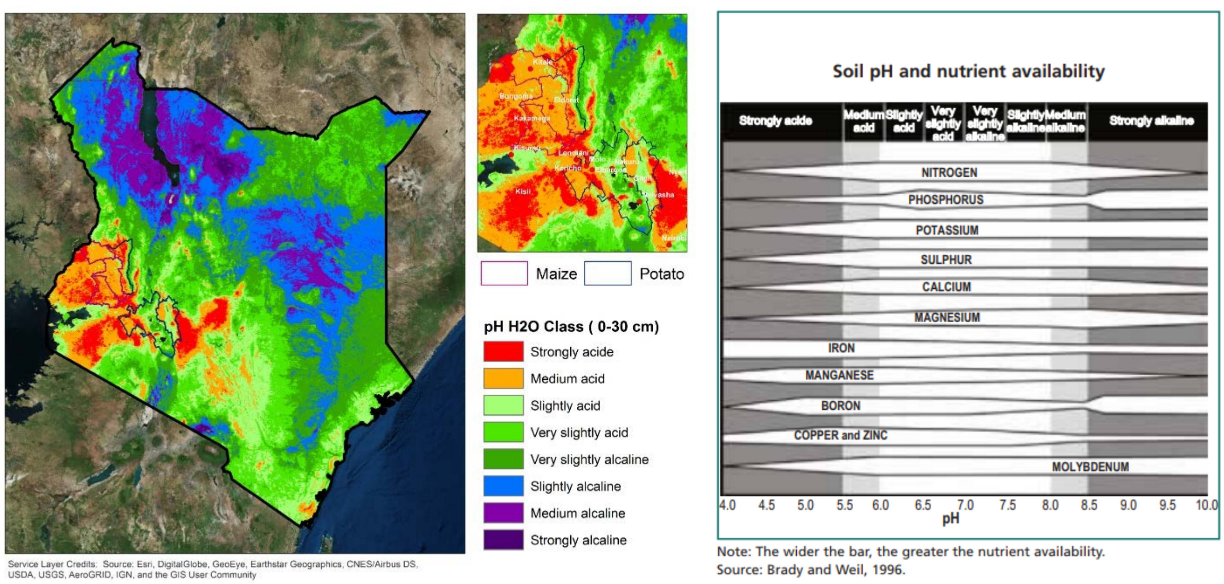


Figure 14. SoilGrids in Kenya (pH-water) Evaluated Relative to Suggested Criteria for pH-Water. Left: AfSoilGrids pH-water soil map revealing values varying from strongly acidic to strongly alkaline; Right: Relative impact of soil pH on nutrient availability

For this feasibility report, the project team has taken a rather generic range of “critical” soil nutrient contents that are not crop- nor condition-specific, as indication for the methodology. Based on data obtained from different soil-crop conditions and a variety of specific extraction procedures, Dimkpa et al. (2017) present a range of values for critical levels of different nutrients, with most data relevant for the top 30 cm of the soil, which is most intensively rooted and mined (Table 4).

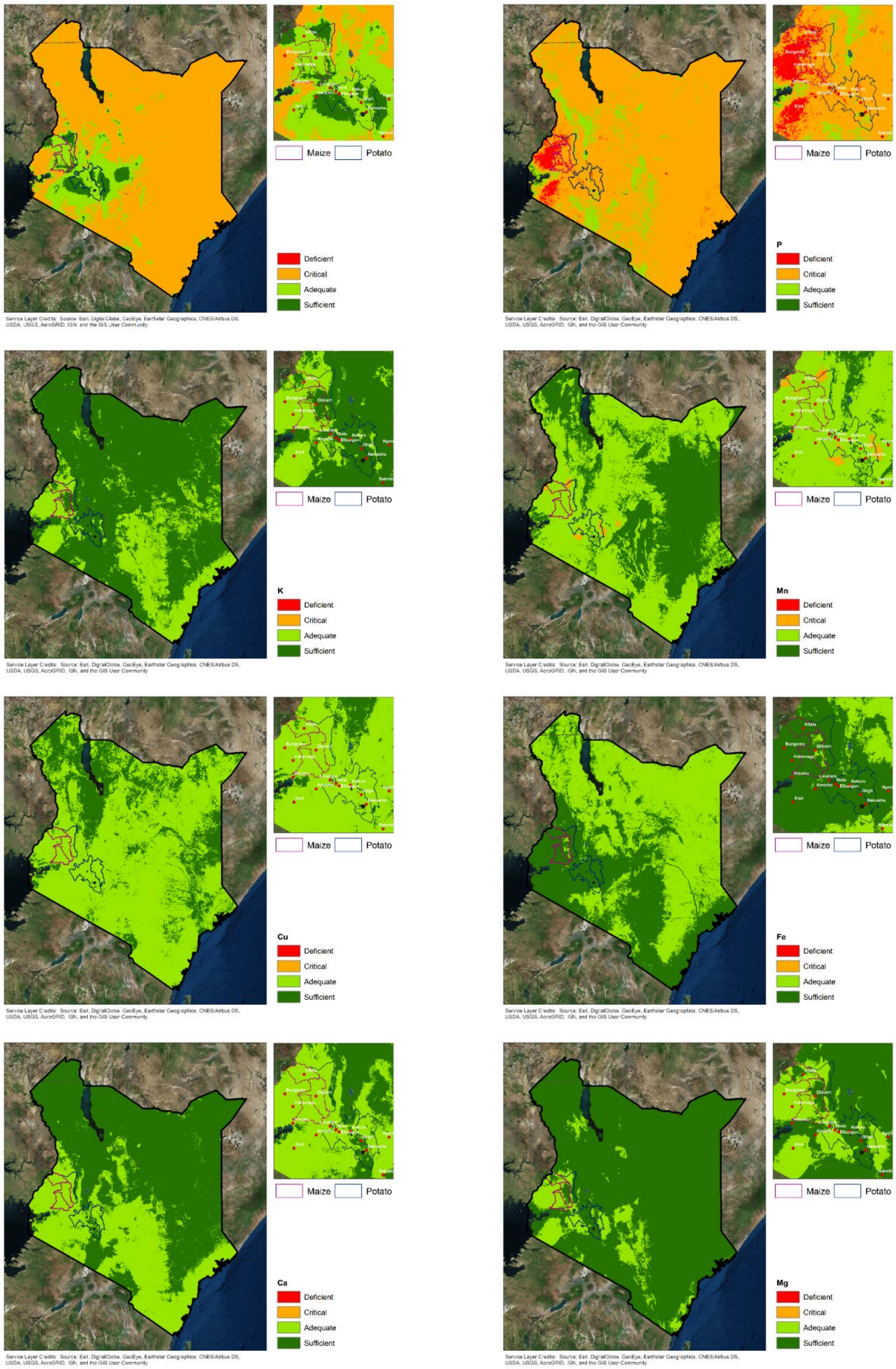
The extraction methodologies were compared with the methods used for the data for development of the AfSoilGrids maps, whereby "y" refers to similar, which holds for N, P-available, K, Ca, and Mg, "n (y)" refers to different methods but considered more or less comparable for B, Zn, Mn, Cu, and Fe, and "n" refers to incomparable. Added to Table 4 are the AfSoilGrids median values, with associated Root Mean Squared Errors (RMSE), to allow comparison of the orders of magnitude of the critical levels.

Table 4. Extraction Methods and Critical Nutrient Levels (Generic)

Element	Critical Level[α] (range)[β]	(methods)	AfSoilGrids (median)[β]	(rmse)	(methods)	Similarity y / n
N total	400 – 1500[+]	[+] unspecified	600	558	Wet oxidation	y
P total	-	-	132	284	Unspecified	n
P available	11 – 31[a]	[a] M3	6	43	M3	y
K	17 – 74[a]	[a] M3	130	201	M3	y
Ca	308 – 504[a]	[a] M3	1,162	1,950	M3	y
Mg	23 – 42[a]	[a] M3	242	241	M3	y
S	8 – 10*	KCl40-S	[9]	[78]	[M3]	n
Zn	0.5 – 1.0[b]	[b] DTPA	2.1	4	M3	n (y)
B	0.25 –0.5[c]	[c] Hot water	0.3	0.47	M3	n (y)
Mo	0.10 – 0.15[d]	[d] NH_4OAc	-	-	-	n
Mn	50 – 100[b]	[b] DTPA	124	69	M3	n (y)
Cu	0.1 – 0.2[b]	[b] DTPA	2.2	2.1	M3	n (y)
Fe	2.5 – 4.5[b]	[b] DTPA	121	5	M3	n (y)

Extractant: [a] M3 = Mehlich-3; [b] DTPA; [c] hot water; [d] NH4OAc; + unspecified (but $CaSO_4$ or KCl commonly used); [ ] Not available: critically low accuracy.
α. Dimkpa et al., 2017; β. All data in ppm (mg kg^{-1}).

Despite some differences in comparability of the methodologies and the lack of crop- and location-specificity to the data, the team evaluated the critical values with the AfSoilGrids data for this study to present the methodological abilities of the approach and to serve as a first indication. The nutrients N, P-available, K, Ca, Mg, B, Zn, Mn, Cu, and Fe have been evaluated relative to the critical levels (Figure 15). It is noteworthy to repeat that these maps are a first indication but need to be further specified by more accurately determined crop-specific evaluation criteria. Red indicates areas where the soil nutrient is deficient and orange where it is critical, suggesting that yields are likely limited by lack of the nutrient that might be resolved through fertilization. Light green indicates adequate availability, where fertilization with this nutrient is not likely to increase yield per se but is advisable to maintain soil nutrient status, prevent depletion and ultimate degradation. Dark green indicates sufficient availability, where fertilization might not directly increase yield, but fertilization may be needed to sustain soil productivity. In any case, soil nutrient availability should be regularly monitored, even and especially when sufficiently available, to prevent soil mining and degradation.


Maize
Potato
P
K
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Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

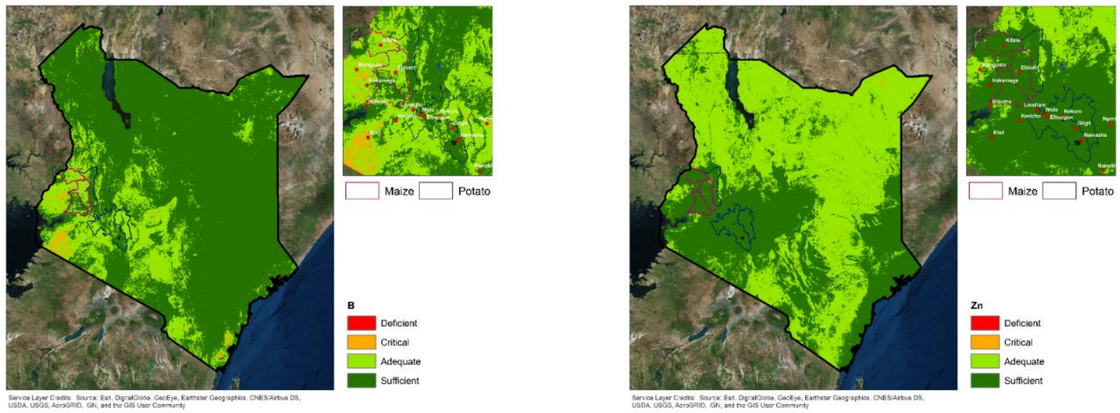


Figure 15. Soil Nutrient Contents in Kenya, Categorized Using Table 4, for N, P, K, Mn, Cu, Fe, Ca, Mg, B, and Zn (red-deficient; orange-critical; light green-adequate; dark green-sufficient)

Surrounded by the uncertainties, we can still arrive at some generic remarks. The soil N content is critical throughout Kenya, while it seems to be mostly adequate and sufficient in the targeted counties. The spatial pattern corresponds with the pattern for soil organic carbon (organic matter), suggesting high SOM contents in the highland soils. The team reflected on these findings in a little more detail (Table 5). SoilCares considers a critical total N level of 1.1 grams per kilogram (g kg^{-1}), which is within the range of 0.4-1.5 from Table 4. This suggests that a substantial number of data points would be below the critical level as considered by SoilCares. Other data sources arrive at contents that are in the same order of magnitude. The critical level method hence, provides a generic indication of fertilizer requirements only, that may for instance differ between high lands and low lands. Nitrogen fertilization will remain essential to obtain high yields and to maintain soil productivity by replenishing the amounts of nitrogen removed by the crop.

Table 5. Comparison of C and N Data from Various Sources

# Samples		SoilCares[a] 1100				Africa Soil Profiles Database[b] 600		Africa Soil Nutrient Maps (Total SSA)[c] 60,000			AfSoilGrids[d]		
		Min	Median	Mean	Max	Average	SD	Min[e]	Average	Max[e]	Min[e]	Median	Max[e]
C Total	g kg^{-1}	0.51	12	14	82	11.6	18.8	0.75	7.5	75	0	7.0	70
N Total	g kg^{-1}	0.04	0.91	1.1	10	1.9	2.0	0.065	0.65	6.5	0	0.6	4.2
C/N				12.7		10.1	6.0		12			12	

a. SoilCares data (pers. comm.): Samples distributed across Kenya all west of approximately 40° longitude.
b. https://doi.org/10.1007/s10705-017-9870-x; http://www.isric.org/index.php/projects/africa-soil-profiles-database-afsp
c.Africa SoilGrids http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0125814
d. This study.
e. Approximate.

The soil available P content is also mainly within the critical range but varies from deficient to sufficient, also in the target counties. Clearly, a significant impact of P fertilizers could be expected on these soils and indeed reported as the second major nutrient required following N.

The soil contents of K, Ca, Mg, Zn, Mn, Cu, and Fe appear adequate to sufficient throughout Kenya according to the evaluation criteria of Table 4, which suggests little response to fertilization with these nutrients. However, a critical level of 5 ppm that is generally used for Zn, specifically for maize, would alter the picture, suggesting Zn to be within critical limits on most parts of the maize growing counties (Figure 16). A similar effect would occur for Cu that is considered critical below 2 ppm for maize, which would paint the map less favorable, though with smaller pockets of Cu deficiencies.

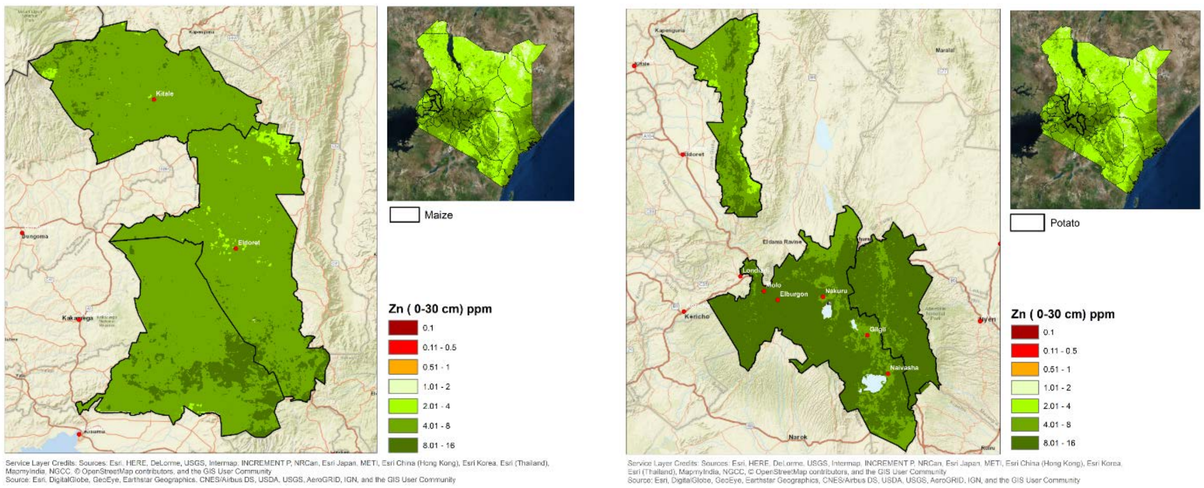


Figure 16. Soil Zinc Contents for Targeted Maize (left) and Potato (right) Counties (darkest green 8-16; less dark 4-8; light 2-4)

There are small spots in the target counties where Mn and B are within the critical range, and the addition of the needed nutrient might increase yield. The critical level used for Mn in Table 4 is higher than the 20 ppm that may be used for maize, suggesting Mn to be less deficient than apparent from Figure 17.

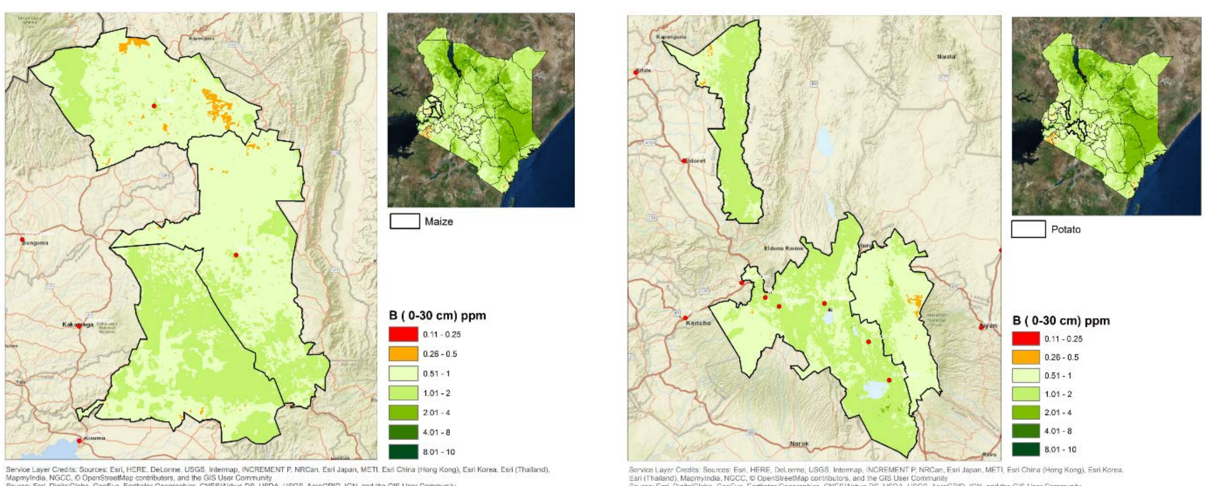


Figure 17. Soil Boron Contents for Targeted Maize (left) and Potato (right) Counties, Categories Using Table 4

The maps of boron, on the other hand, are categorized around the critical levels 0.25-0.5 ppm. Mahendran et al. (2016) found a linear increase in yield response for groundnut with B fertilization up to the critical limit of hot water extracted B of 0.4 ppm. Debnath et al. (2015) found yields of cowpea to respond strongly until 0.5 ppm with a lower response rate thereafter, while Debnath and

Ghosh (2014) found linear yield responses up to levels of 0.8 ppm for peas. Wasaya et al. (2017) found foliar application of B to be highly effective in raising maize yield and kernel weight and revealed synergistic effects with Zn application, a synergism reported by Rietra et al. (2017) as well. Tamene et al. (2016) found significant maize yield response in Malawi with soils containing less than 0.1 ppm B. Therefore, soil boron concentrations of below 1 ppm might also limit yield, turning the picture more orange, suggesting a more widespread deficiency. Given interactions with other soil properties, including other nutrients, soil pH, type of clay, etc., field trials will have to be conducted to verify crop responses to fertilization based on soil data maps.

Finally, as mentioned earlier, fertilizer strategies may also address the nutritional quality of food. A simultaneous increase in yield and nutritional quality is often reported, but either a yield or a nutritional increase only has been observed as well, depending on soil and crop conditions. Any additional cost incurred with the use of micronutrient-containing fertilizers is likely to be recovered by the increase in yield, with the nutritional improvement as a collateral benefit.

3.3 Water Availability and Biomass Production – Satellite-Derived Information

Water is important for biomass production and yield because it serves to cool the plant through transpiration and is a medium for plant growth processes. Soils again play an essential role as a medium to store water for uptake by plants. Soil water is replenished primarily by rainfall and in some situations from capillary rise and run-on, while evaporation from bare soils, transpiration by plants, run-off, and seepage are the largest depleting forces. In most cases rainfall and evapotranspiration are the two foremost factors affecting the water balance and, with that, plant growth and yield. The capacity of soils to hold water depends on soil physical characteristics, such as texture and soil depth, but also organic matter content. As a result, water capacity and availability are highly location-specific (Figure 18).

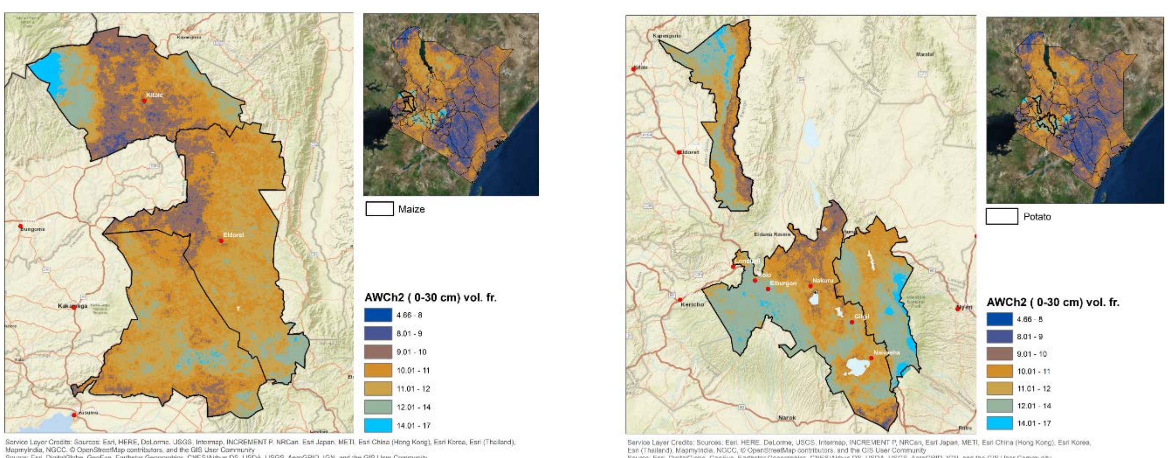


Figure 18. Derived Available Water-Holding Capacity as Volumetric Fraction (%) of Fine Earth (Field Capacity at pF 2.3), Aggregated for 0-30 cm

Satellite imagery can be used as a powerful tool to get insight in the water balance and crop conditions over vast areas at once. Publicly available data sets are used for the initial analysis in this study. Recently, the FAO launched the beta release of the WaPOR database (Water

Productivity through Open access of Remotely sensed derived data) with the aim to monitor and report on agriculture water productivity over Africa and the Near East (FAO, 2017). The WaPOR database contains information on the actual evapotranspiration as well as the actual dry matter biomass production of crops. The FAO WaPOR database is produced by the Dutch company eLEAF in cooperation with VITO from Belgium.

The following parameters are analyzed for the year 2016:

- Actual evapotranspiration in millimeters per year (mm y^{-1}). The ETLook algorithm is used to determine the actual crop water consumption ET_{act} on a 10-day basis. The algorithm uses satellite imagery and weather data in combination with the Penman Monteith evapotranspiration equation.
- Annual dry matter biomass production in kg ha^{-1} y^{-1}.
- Biomass water productivity in kg m^{-3}. The amount of dry matter biomass produced per m^3 water consumed.
- Precipitation surplus in mm y^{-1}. This is determined by subtracting the ET_{act} from the available precipitation (P). Areas where ET_{act} is higher than P have a negative precipitation surplus while areas where less water is evaporated than available through rainfall have a positive precipitation surplus. Precipitation used for this analysis is based on a combination of satellite data and local measurements. The original resolution of this data is 5 kilometers (km). The accuracy at pixel level is limited. Nonetheless, the precipitation surplus provides a first indication of water availability.

Figure 19 shows all four parameters for 2016 covering the entirety of Kenya. The maps provide an instant overview of Kenya as well as the regional dynamics. As expected, the annual biomass production shows higher growth rates for the agricultural regions in the southwest as well as along the rivers.

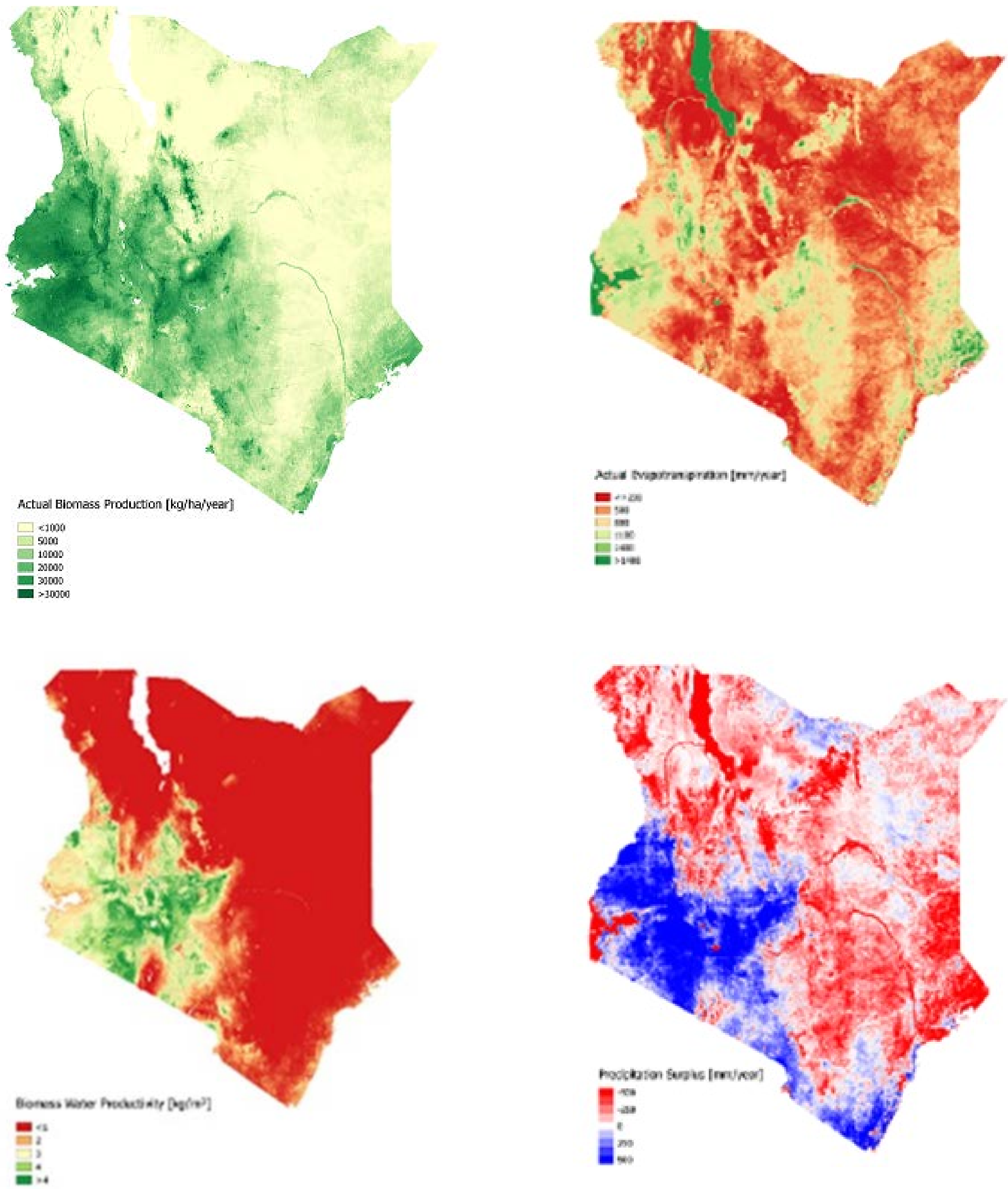


Figure 19. Satellite-Derived Data for Water- and Biomass-Related Parameters

The annual actual evapotranspiration follows the main spatial pattern in the biomass production, and the relationship becomes even more apparent through the biomass water productivity. Yet, the areas with higher biomass show quite a range of values for evapotranspiration.

The Biomass Water Productivity is very low for a large part of Kenya, where virtually no agricultural production takes place. More interesting is the southwestern region where Biomass Water Productivity varies significantly. This suggests room for improvement by raising the Water Productivity in the entire agricultural areas to the highest observed values of 4, which is most optimal.

Finally, the annual Precipitation Surplus shows both areas in red and blue. Evapotranspiration is higher than the rainfall as an indication of drought in red areas. The agricultural production area generally shows up blue, which indicates precipitation to be higher than the actual evapotranspiration. For those areas, crop production is not limited by water, which suggests its inefficient use, creating an opportunity to raise agricultural productivity through agronomic interventions emphasizing, e.g., water harvesting in combination with soil fertility.

The data is further analyzed for the selected counties in the southwestern region. The pictures below show the actual evapotranspiration and the precipitation surplus displayed on top of a 3D model. The topography of the land is shown through the 3D effect, whereas the values of the parameters are shown through their color (Figure 20).

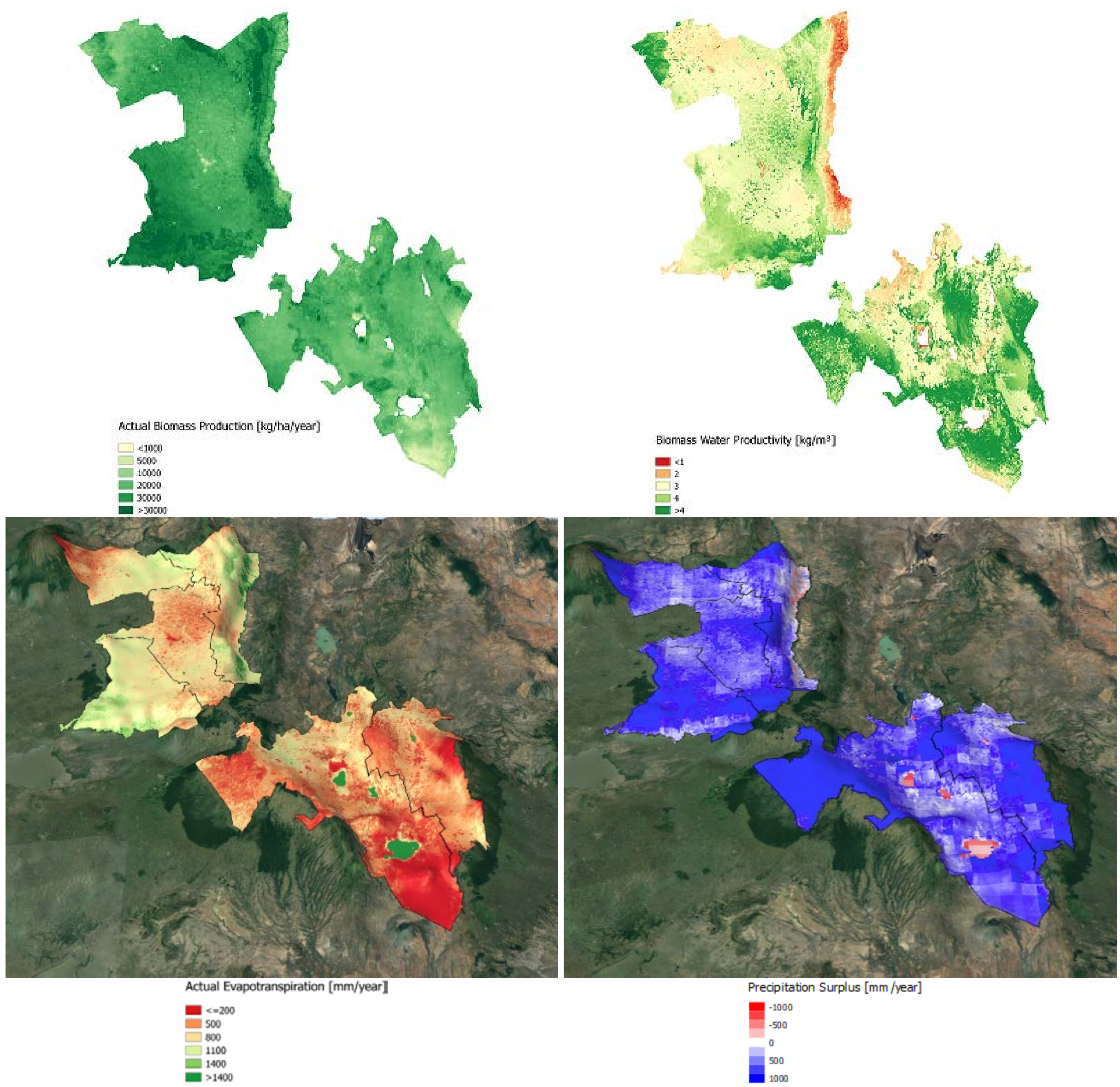


Figure 20. Satellite-Derived Data on Water and Biomass for the Target Countries as 2D and 3D

By combining the actual evapotranspiration map with a Digital Elevation Model, the impact of mountains becomes clear. At higher altitudes, water consumption is less efficient, likely due to run-off, suggesting lower actual evapotranspiration associated with surplus precipitation. Vice versa, high actual evapotranspiration is seen near slopes with an apparent precipitation deficit, likely caused by water run-on. Overall, the annual precipitation surplus over this region is positive, which suggests room for raising biomass production without additional irrigation from surface or underground waterbodies, but with water management practices. Whereas the course resolution of the precipitation products might not take the orographic influences on rainfall patterns fully into account, the data layers are useful as it gives a first understanding of the hydrological cycle.

The maps shown above provide information for all pixels regardless whether the underlying land is used for crop production, forestry, urban, or a mixture of those. A more detailed analysis can be made when zooming in on an agricultural production region (Figure 21). The aerial photograph on the top left shows the small agricultural fields of this area. The actual crop water consumption and biomass production show quite some variation over this small piece of land, as can be identified through the high resolution of 100 m x 100 m pixel size. Overall the biomass water productivity is at the lower spectrum and rather homogeneous.

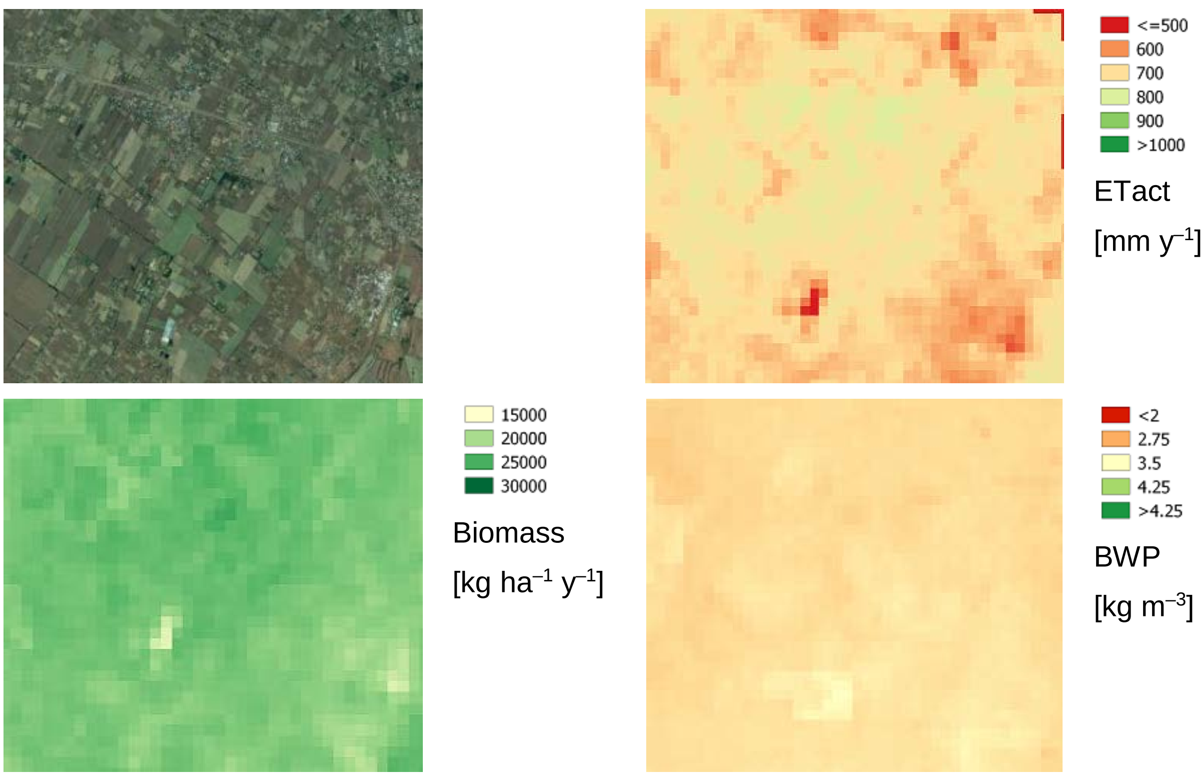


Figure 21. Water and Biomass Characteristics for a 2.5 km x 2.5 km Area at a Resolution of 100 m x 100 m

Therefore, the available satellite-derived information provides a first impression of agricultural and water-related issues. The annual precipitation surplus for the agricultural production regions, combined with the low biomass-water productivity indicates sufficient availability of water to further increase agricultural productivity. Combined with elevation data, we might conclude that some of the water may run off the field at higher altitudes and slopes, which suggests contour technique to maintain water on the field. As the data relate to annual balances, off-season rainfall might get lost for agricultural production reducing the biomass-water productivity and raising the rainfall surplus.

Maps of the monthly precipitation surplus can be used to get a better understanding of the dynamics through the year (Figure 22). The maps below all use the same legend, which covers the range of -150 to +150 mm/month. Values beyond that range will show as -150 or +150. In red areas, the evapotranspiration is higher than the rainfall, whereas the blue areas show a surplus of precipitation. From March to May, a high rainfall surplus is observed, which correlates to the main rainfall season. The following months show higher water consumption than rainfall, which is caused by water storage in the ecosystem. Crop production also takes place in months where the crop water demand is higher than the available precipitation. Saving water during the wet months to irrigate in the following months might lead to increased production potential.

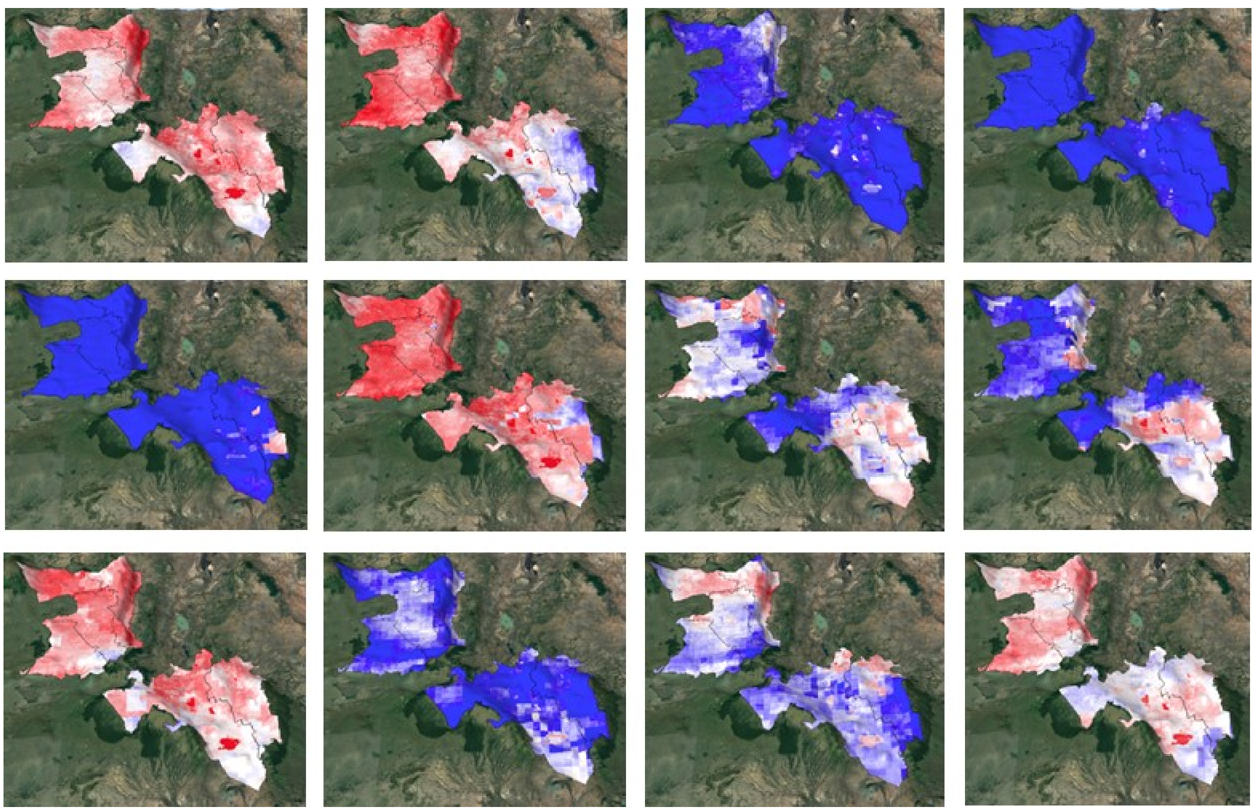
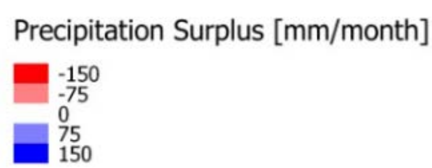


Figure 22. Monthly Precipitation Balance (from upper left corner to lowest right corner: From January 2016 to December 2016)



These findings suggest that measures to improve the use of the available (rain) water could be detected with satellite-derived products at higher spatial and temporal resolution. Satellite technology can already provide a spatial resolution of up to 10 m and a temporal resolution of five days, adequate to arrive at location- and time-specific agronomic interventions. Areas that perform better in terms of biomass or yield productivity, both per unit of land (land productivity [kg ha^{-1}])

and per unit of water (water productivity [kg m^{-3}]), can be detected and analyzed in order to identify the main drivers for the good performance. Lessons learned from these high-productive areas can serve to design interventions for poorly performing areas.

Smallholder farmers will be rather reluctant to use modern inputs, such as fertilizer and improved seeds, when water is not properly managed, creating a major production risk, which can partly be overcome with water-harvesting technologies in drier regions (e.g., Wakeyo and Gardebroek, 2013). Miriti et al. (2012), for instance, found cropping systems with manure treatments to increase maize grain yield, grain water use efficiency (WUE), and dry matter WUE by 36%, 30%, and 26% respectively, compared to treatments without manure. The strong water-nutrient interaction is also reported by Barron and Okwach (2005) who find supplemental irrigation obtained from collected surface run-off to improve maize yields by mitigating dry spells but only in combination with N fertilizer. Higher maize yields with NPK application were found by Njoroge and colleagues (2017) in the long rainy seasons than the short season in Siyaya, Western Kenya. This suggests that the efficiency of fertilizer use can be increased by tuning application rates to in-season rainfall amounts. Therefore, a comprehensive and location-specific set of agronomic interventions must be devised to improve yield and resource use efficiency.

3.4 Interpretation of Water and Soil Data for Fertilizer Recommendations

Inherent soil fertility is related to soil-forming processes, including geomorphology, local climate, and vegetation but also past soil management and cropping intensity. Along with methodological issues and measurement errors elaborated above, soil property values become merely an indication of the extent to which nutrients might be readily available to crops and, therefore, the extent to which growth might be hampered without nutrient addition. Soil property data allow us, though, to move away from the complete dark to the twilight in search of fertilizer recommendations. A generic conceptual relationship among soil nutrient level, fertilizer recommendation, and crop yield is given in Figure 23 (from Dimkpa et al., 2017).

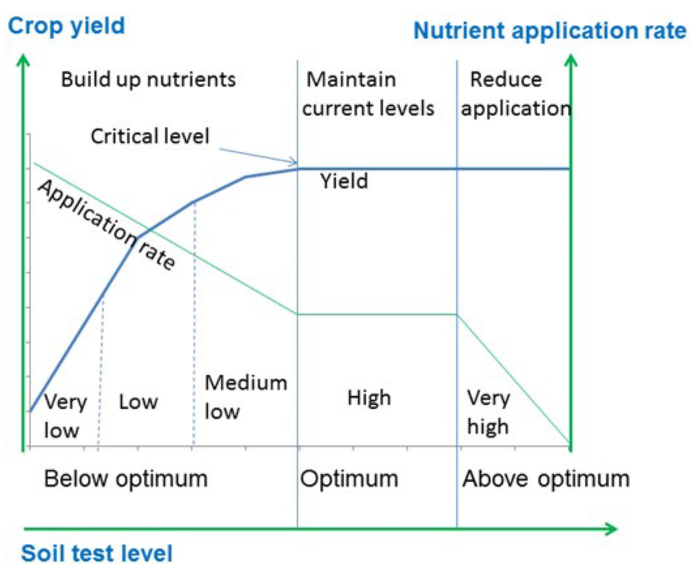


Figure 23. Conceptual Relationships among Soil Nutrient Level, Fertilizer Recommendation, and Crop Yield

Figure 23 suggests that even under "optimal" soil property values, fertilizers should be applied to prevent soil mining and loss of productivity over time, ultimately leading to soil degradation. Table 6 provides an indication of the amount of nutrient removed from the soil by maize yielding 5 t ha^{-1} of grains and stubble. These amounts will have to be restored in the soil to prevent degradation.

Table 6. Amount of Nutrients Removed in Grain and Stubble by 5 mt ha^{-1} of Maize

Nutrient	N	P_2O_5	K_2O	Ca	Mg	S	Zn	B	Mn	Fe	Cu
kg ha^{-1}	120	45	120	13	20	13	0.25	0.25	0.70	0.40	0.10

Table 7 illustrates the relationship between soil test outcomes and the recommended amounts of P_2O_5 and K_2O (Mallarino et al., 2013). The application rate for the optimum soil test category is based on the approximate nutrient removal for the harvested yield, based on 11 t ha^{-1} maize in the table, and can be adjusted higher or lower for other yield levels. Other factors like method of application, soil drainage conditions, soil temperature, and crop residues all affect application rate. This is where expert judgement and practical experience become important in recommendation estimates, given the complexity of the systems. P fertilization might be omitted under high values but need to be regularly monitored to prevent soil degradation through continuous mining. Other nutrients face comparable challenges.

Table 7. Interpretation of Soil Nutrient Values in Relation to Fertilization Recommendations – The Case of P and K*

Soil Test Category	Very Low	Low	Optimum	High	Very High
P-Bray & P Melich-3	0-8	9-15	16-20	21-30	31+
P-Olsen	0.5	6-10	11-14	15-20	21+
P_2O_5 application rate (kg ha^{-1})	110	85	60	0*	0*
K-Melich-3	0-90	91-130	131-170	171-200	201+
Fine textured soil (kg ha^{-1})	145	100	50	0*	0*
Sandy textured soil (kg ha^{-1})	125	80	50	0*	0*

* Recommendations apply to a maize yield of 11 t ha^{-1} in the United States. See text for further interpretation.

Source: Mallarino et al., 2013.

A clear example of soil mining, even for micronutrients that are extracted from soils in small quantities, is presented for continuous cropping without replenishment of Zn in India (Figure 24; from Shukla et al., 2015). Application of Zn fertilizers would not affect yield levels two decades ago given soil Zn contents far exceeding 1 ppm, but a yield response would be obtained today with Zn levels having declined far below 1 ppm. In Kenya, Muriuki and Kanyanjua (1995) report soil pH, organic carbon content, K, Ca, and Mg to all decline after continuous cropping over half a decade; the P content declined in unfertilized soils, while it increased in P-fertilized soils.

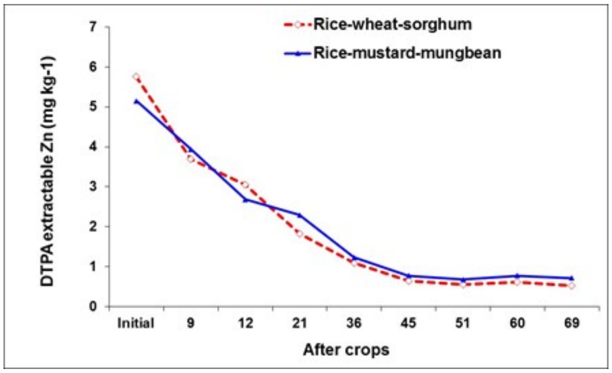


Figure 24. Decline in Soil Zn Content from 6 to 0.7 mg kg^{-1} (ppm) in 23 Years across 69 Crops in Bihar, India, Due to Continuous Cropping Without Replenishment

More systematically, the deficiencies of an increasing number of nutrients will become apparent under continuous cultivation with associated off-take of nutrients from the field when nutrients are not replenished through fertilization (Figure 25).

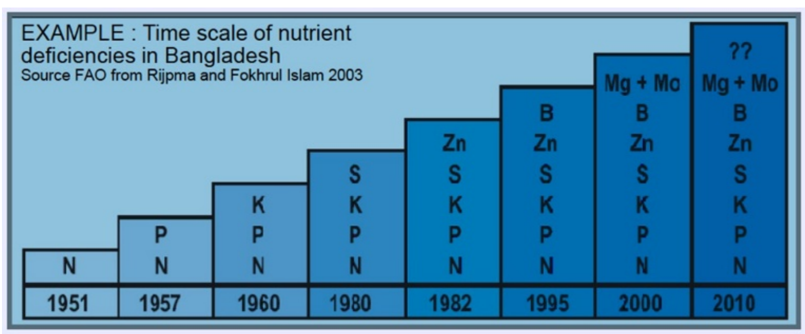


Figure 25. Continuous Cultivation Without Replenishment Leading to Deficiencies of Increasing Number of Nutrients

Clearly, crop specificity is another predominant determinant for fertilizer recommendations. For our analysis, maize with rainfed yield levels varying from 3 to 10 t ha^{-1} and potato with yield levels from 10 to15 t ha^{-1} have highly different characteristics. Maize can root up to 150 cm while potato has a rooting depth of about 50 cm, affecting the total soil depth that can be mined for nutrients. Tuber crops, in general, contain double or triple the amounts of K than cereal crops, which demands higher K availability from soil and fertilizers.

The availability of soil nutrients furthermore depends strongly on soil pH. Acidic soils may need to be neutralized by addition of lime when too strong (pH < 5.5). Figure 14 depicted acidity and alkalinity distributed in Kenya. Much of the acidic soils are located within the targeted areas for maize and potato.

Water-related variables from satellite images combined soil information will guide the search for location- and time-specific water and fertilizer interventions, given the strong interactions between water availability and utilization efficiency of fertilizers. Maize, for instance, can extract soil water from a root zone depth of 150 cm and to a soil moisture potential of 17.000 cm (pF 4.2); i.e., relatively dry soils. Potato is more sensitive to drought because of its rooting depth of maximally 50 cm, while it already starts to wilt at a moisture potential of 7.000 cm (pF 3.8) (Driessen and Konijn, 1992). Combined with the need for different nutrients, the crop- and location-specific water-nutrient interventions are likely to have a large impact on productivity.

The amount of fertilizers to be applied may also depend on the type of fertilizers. The most elementary form of combining nutrients is through blending whereby granules are thoroughly mixed. Often, relatively high quantities are then applied to the field. Also, blended fertilizers may disaggregate during transport, leading to heterogeneous distribution in the field (Figure 26).

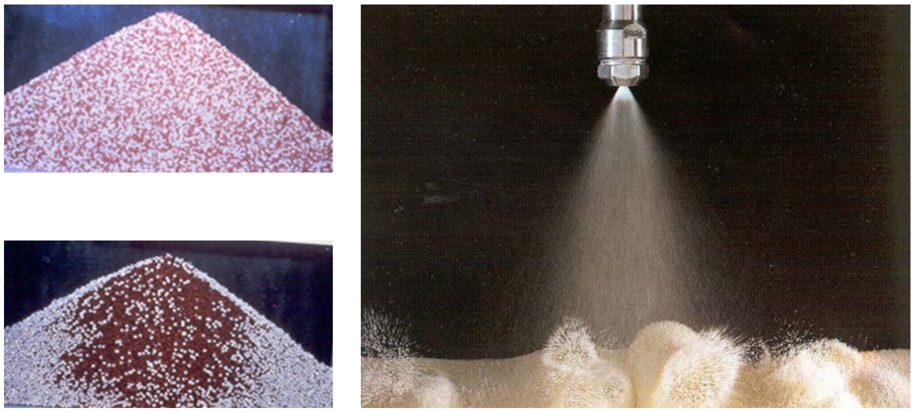


Figure 26. Blended Fertilizers with Risk of Disaggregation (left) and Coating of Macronutrient Granules with Micronutrients

As micronutrients are required in small quantities, coating of micronutrients onto macronutrients, like NPK granules, eliminates disaggregation, drastically reduces the total application amounts, and results in monogenous distribution. However, abrasion could potentially release the trace elements from the surface of the granules and accumulate in the bottom of the bag where high concentrations can be formed. Therefore, the ideal supply of trace elements is when they are incorporated into the NPK granules. Santos et al. (2016) found through pot experiments that coating of NPK granules with micronutrients was better than separate mixtures of B, Cu, and Zn in the soil. Dry matter production of maize shoots and the accumulation of B, Mn, Cu, and Zn were greater when the fertilizer was coated with micronutrients, therefore also increasing the use efficiencies of the NPK. Wani et al. (2015), for instance, demonstrated that balanced fertilizers, (NPK plus S+B+Zn based on soil analyses) increased yields of maize, soybean, and sorghum across India and increased the use efficiency of nitrogen, resulting in benefit-cost ratios ranging from 1.4 to 5.9. Special attention should be paid to the quantity of micronutrients applied and taken up to prevent accumulation in soils, such as with Zn (e.g., Montalvo et al., 2016). Foliar application of fertilizers, especially of micronutrients, can be a highly effective approach under specific conditions (e.g., Wasaya et al., 2017). Based on physiological evidence of overlaps in root and shoot uptake pathways, Dimkpa and Bindraban (2016) arrived at options for root or shoot application of micronutrients (Figure 27; from Dimkpa and Bindraban, 2016).

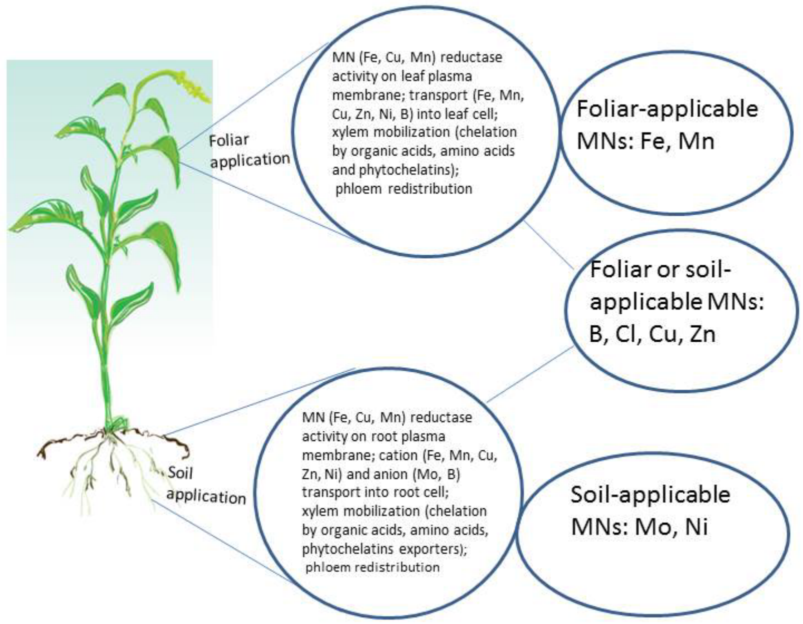


Figure 27. Feasible Delivery Pathways of Micronutrients for Uptake Based on Physiological Evidence

Overall, initial indications suggest the need for location-specific fertilizer application given the spatial variability. The below overview describes a reflection of our findings and expert judgements from soil scientists from the Kenya Agricultural & Livestock Research Organization (KALRO) and IFDC that have not been published and are often based on data gathered over past years but not systematically nor complete enough to arrive at conclusive statements.

- Nitrogen and P requirements must be met first to observe crop responses to other nutrients. However, current recommendations that include DAP and CAN supply too much P and not enough N for balanced nutrition.
- Soil acidification is primarily caused by N-containing fertilizers with nitrate-based products generally being less acidifying than ammonium-based products, but this may vary depending on other soil and weather conditions; this calls for judicious use of fertilizer and also is based on measurements over time and field experience.
- Application of lime products and PAPR may help to modify soil pH and, with that, alleviate deficiencies, especially of micronutrients, but data are scarce, not systematically analyzed, and inconclusive.
- Potassium is often overlooked in fertilizer recommendations and appears to be in adequate ranges in the target counties. Potassium responses have been found to be inconsistent, with K response sometimes observed on high K soils (>120 ppm) and sometimes not in low K soils (<80 ppm) in cereal crops. Potassium is known to be required in higher amounts in root crops, such as potato.
- As discussed, soil tests for S are not always a good predictor for crop response, but about 10-15 kg is required for a medium maize yield level. Ammonium sulfate (AS) is the most common S source, but S may be oversupplied when AS is used as the sole source for N. Single superphosphate (SSP) and potassium sulfate are other S suppliers.

- Low Zn levels in maize ear-leaf samples have been observed even on soils with moderate to high Zn. Omission trials (trials that supply all required nutrients except the one diagnosed) with Zn oxide and Zn sulfate fertilizers are required to validate crop responses.
- Boron may be deficient for crop growth, but no information is available about the impact of B on crop responses, which requires more experimentation.
- Several micronutrients, such as Zn, Cu, and Mg, may show little response when soil-applied and may be better delivered through foliar applications.
- The role of (green) manure is recognized, but it is available in insufficient amounts and not able to boost yields to high levels, which implies the supplementary need for mineral fertilization that can target specific deficiencies.

4. The Fertilizer Market in Kenya

4.1 Fertilizer Market

The Kenyan government withdrew from the fertilizer market and abandoned price controls in 1993, which improved farmers' access to the input through the expansion of private retail networks (Freeman and Omiti, 2003). The cash crop sectors, which include tea, coffee, and sugarcane, secured a high and stable level of demand for fertilizer (Jayne et al., 2004), and government involvement had increased farmers' awareness for use of fertilizers. The fertilizer importers and distributors in the country made investments in facilities to import and store fertilizers, which reduced retail prices and created a stable demand for fertilizers. It led to an increase in the maize/fertilizer price ratio, percentage of farmers using fertilizer and hybrid maize seed, maize yield and production, and percentage of farmers selling maize (Ariga and Jayne, 2009). However, only a limited number of fertilizer products are imported (mainly NP-based), storage capacity is still poor, and distribution networks are costly with incidences of fertilizer adulteration, which make the fertilizer farm-gate price almost double the landing price at the port of Mombasa.

In recent years, the government has, therefore, re-introduced fertilizer subsidies through Vision 2030 in order to reduce the cost of fertilizer. Under the government's flagship project "The Fertilizer Cost Reduction Strategy," a total of 445,000 t of fertilizer was procured between 2009 and 2014 as a price stabilization mechanism (Table 8). This intervention was aimed at contributing cheap fertilizer into the market to prompt private dealers to reduce their profit margins, hence making fertilizer cheaper. The initiative contributed 22.8% of the conventional fertilizer requirement in the country for the last five years. Under the bulk procurement initiative, the governmental body National Cereals and Produce Board (NCPB) procures quantities that are sold at subsidized prices to farmers through their network. Recently, the government announced to further stimulate the use of (subsidized) fertilizers to boost food security (Coastweek, 2018).

Table 8. Quantities of Fertilizer Procured under Government Bulk Procurement Initiative

Financial Year	Total Fertilizer Requirement (*1,000 t)	Quantity of Conventional Fertilizers Required (*1,000 t)	Quantity Procured (*1,000 t)	Conventional Fertilizers Procured (%)	Treasury Allocation for Fertilizer Procurement (million U.S. $)
2009/10	503.8	384.4	16.6	4.3	7.6
2010/11	505.5	365.6	96.0	26.3	30.0
2011/12	539.9	387.4	94.2	24.3	33.2
2012/13	542.8	379.9	66.3	17.4	31.5
2013/14	568.0	431.7	171.8	39.8	39.0
Total	**2,660.0**	**1,949.0**	**444.8**	**22.8**	**141.2**

Source: State Department of Agriculture Kenya.

The currently subsidized fertilizers (DAP, CAN, urea) reach the farmers too late in the planting season, and quantities are smaller than required. The nutrient contained in the fertilizers often is not what the crop needs, and fertilizer quality is a concern. In addition, the subsidy administration is far too complex. The procurement of subsidized fertilizer is often not synchronized with the cropping season. The late arrival leads to late planting, contributing to low yields. Table 9 shows a price comparison of different types of fertilizer when procured as subsidized or not subsidized. The difference in prices is massive; hence, most farmers could wait arrival of subsidized fertilizer and plant late rather than plant on time but buy a more expensive fertilizer that is not subsidized but available in the market when needed.

Table 9. Fertilizer Subsidies

Fertilizer Type	Market Price per Ton (U.S. $) Non-Subsidized Fertilizer a	Market Price per Ton (U.S. $) Subsidized Fertilizer b	Difference in Price per Ton (U.S. $) a-b	% Subsidy
DAP	680	360	320	47
CAN	540	300	240	44
Urea	560	300	260	46
NPK	630	360	270	43
AS	360	260	100	28

Source: Ministry of Agriculture, Livestock and Fisheries: Economic Review of Agriculture, 2015.

Despite the mixed government stance toward maize market liberalization during the past decades, evidence of increased private sector investment is tangible. The private sector mainly participates in procurement of fertilizer from different parts of the world. There are over 20 companies that import fertilizers. The major ones are YARA East Africa Ltd, Export Trading Group (ETG), MEA Ltd, and Devji Meghji and Bro. Ltd. Traders buying maize directly from farmers have penetrated more deeply into smallholder areas. Increased competition and efficiency in maize milling and retailing are also evident in the significant decline in maize marketing margins. There is also strong evidence of increased state investment in public goods supportive of private sector investment, especially since the creation of the Constituency Development Fund (CDF) in 2003. The combination of supportive policy changes in the fertilizer, foreign exchange, and maize markets, coupled with improved access to markets and services made possible by public good investments, appears to have stimulated investment by the private sector in both maize and fertilizer marketing. These factors have worked synergistically to bring about important gains in maize productivity and benefits to smallholder farmers and consumers in Kenya.

Box 6. E-Fertilizer Subsidy Management System

In late May 2015, the Government of Kenya took a revolutionary step in streamlining their farming subsidy paradigm by selecting a mobile phone company (Safaricom Company) to launch a pilot program that will give the farmers of Kenya access to government funds and materials for farming through their mobile phones. The E-Fertilizer Subsidy Management System allows farmers to use electronic vouchers to request fertilizer for their farmland using their mobile phones. This gives farmers immediate access to farming materials they need, and it will provide ministerial officials with clearer data regarding the amount and quality of farming subsidies required in the years to come. The program invited over half a million farmers to take part in this new pilot, but state officials plan to expand the program to include over 3.5 million farmers that use mobile phones. Furthermore, the Ministry aims to stabilize fertilizer prices in the coming years to protect farmers from fluctuations in the cost of fertilizer.

4.2 Fertilizer Recommendation Initiatives

Despite the programs, most small-scale farmers in Kenya apply little or no mineral fertilizers to their crops. They incorporate sub-optimal organic matter into the soil because manure and compost are available only in limited amounts and used for animal feed or bedding, as thatching materials, or as fuel for cooking. In addition, organic matter is bulky and therefore expensive to transport and handle. The result is low farmer crop yields. This leaves the farmers food insecure and prevents them from generating cash incomes from the sale of surplus crops – locking them into a cycle of poverty, certainly so as continually cropping land without returning the nutrients leads to nutrient mining, resulting in degraded and impoverished soils. Even if farmers wish to apply some mineral fertilizer to their crops, they often lack knowledge on the type and rate of fertilizer to apply, when, and how. Applying the wrong fertilizer, applying it to the wrong crops, or applying it at the wrong rate results in poor yields (low response) and waste of hard-earned money. Indeed, most existing fertilizer recommendations are often blanket recommendations covering large areas that encompass several agro-ecological zones, without consideration of inherent soil variability.

Substantial research in soil fertility status and restoration was carried out under the Fertilizer Use Recommendation Project (FURP) from 1987 to 1993, which resulted in 24 district-based fertilizer recommendations for major crops including maize, sorghum, bean, cowpea, finger millet, and other crops (Kibunja et al., 2017), but the recommendations were for N and P only (Muriuki and Kanyanjua, 1995).

The recommendations developed in 2014 by the Department of Kenya Soil Survey for maize per sub-county has been described in Section 3.1.

Recently, 37 trials were conducted, under the auspices of the Optimizing Fertilizer Recommendations in Africa (OFRA) project for various crops in four regions of Kenya, with mean responses to N, P, and K across these trials of 39%, 5%, and 17%, respectively (Kibunja et al., 2017). Existing data and data from these trials were used to create the parameters for a Fertilizer Optimization Tool (FOT) that is based on asymptotic curvilinear yield response functions to fertilizer application rates for several crops, specified per agro-ecological zone (Kaizzi et al., 2017). The Microsoft Excel-based tool is to be used by extension workers to generate fertilizer recommendations that reflect the farmer's specific circumstances, including hectares of a specific crop grown, fertilizer prices, expected crop output prices, and how much the farmer can afford to spend on mineral fertilizer that growing season. Through linear optimization, a recommended application is generated for the farmer, with the solution being the maximum financial return on the money spent on fertilizer. The nutrients included in the tool are N, P, and K and either S or Zn, and the fertilizer products include urea, SSP, DAP, KCl, and $ZnSO_4$. FOTs have been developed for different crops in the agro-ecological zones: Central Kenya; Coastal; Eastern above 1,200 m; Eastern below 1,300 m; Rift valley above 2,200 m; Rift valley below 2,300 m; Western above 1,500 m; and Western below 1,600 m above sea level. However, the fertilizer recommendations do not account for specific practices, such as manure application, rotation with a legume, intercropping, and use of a green manure crops, nor does it consider soil information explicitly. In the specific case of Kenya, maize yields obtained in the trials were well below 5 t ha^{-1}. These low yields will be reflected in the recommendations through the response functions, which will therefore be constrained and not able to arrive at application rates for higher yield levels.

These fertilizer recommendation initiatives have not been able to close the large yield gaps, suggesting substantial opportunities for the development of location-specific fertilizer recommendations, in combination with other agronomic practices that use the most recent data and advanced methodologies available. Clearly, the availability of a limited number of fertilizer products, primarily DAP and CAN, hampers optimization of nutrient application rates. Fertilizer import, export, and consumption in Kenya is listed in Annex 1.

5. Feasibility Assessment

The Netherlands Government has an intense trade-and-aid relationship with Kenya in which Netherlands farmers grow flowers and vegetables for the local and global market, creating local employment and prosperity. Actors of the Netherlands could also support the rise in productivity of the staple food crops to ensure food and nutrition security that enhances the resilience of rural livelihoods and helps to stabilize rural-urban migration dynamics while fostering robust urban-rural supply chains and trade opportunities. Experience has been building over the past few years for the value chain approach in the 2SCALE program (Box 2), supported by the Netherlands Ministry of Foreign Affairs, in which the International Fertilizer Development Center (IFDC) and partners have been building public-private relations within Kenya and between Kenyan and Netherlands actors.

The Netherlands Government has commissioned the Kenya-Netherlands Green Deal consortium of researchers, private sector partners, and development partners to perform a feasibility study with the objective to review experiences, identify opportunities, and make practical recommendations for agricultural input business development in Kenya. Three delegates from the project team went on a fact-finding mission to assess the feasibility of smart fertilization and water management to boost productivity. The findings have been summarized here, with major outcomes of meetings with actors in fertilizer value chain concisely presented in boxes.

The team traveled to Nairobi and the following counties: Uasin Gishu (Eldoret), Trans Nzoia (Kitale), Kakamega (Kakamega), Nakuru (Nakuru and Naivasha), and Nyandarua (Haraka Market). The group met with research and development organizations (KALRO and IFDC), soil fertility consultants (CropNuts), fertilizer importers and blenders (Toyota Tsusho, ICL, ETG, and Amiran), maize and potato farmers, and actors in policymaking implementation (National Cereals and Producer Board, Netherlands Embassy, and the EU Delegation to Kenya).

5.1 Soil Data and Fertilizer Recommendations

The Kenya Agricultural and Livestock Research Organization (KALRO) Centre at Kabete is host to the national agricultural research laboratories where soil, agrichemicals, water, and plant analyses are done and reported to concerned clients. The center also houses the Kenya Soils Survey Mapping Facility. Several efforts have been undertaken in the past to generate and disseminate soil analysis information to relevant stakeholders. In particular, the Fertilizer Use Recommendation Project (FURP), a collaborative initiative of GTZ-Kenya, generated region-specific fertilizer recommendations (mainly NP) for key food and horticultural crops through country-wide field experimentation (1988-1992). Given the dynamic nature of soils and changes to general biophysical and socio-economic environments over time, the recommendations need to be updated. More recent regional/continental efforts have been made to develop up-to date fertilizer recommendations through the OFRA project and Africa Soil Information Service (AfSIS), among others. Significant amounts of soil data also are available at the International Plant Nutrition Institute (IPNI) in Nairobi and the soil-plant laboratories of CropNuts (private) and World Agroforestry Center (ICRAF).

Box 7. KALRO, Kabete – Current Programs and Prospects

Currently, the Kenya Cereals Enhancement Project (KCEP), a collaborative IFAD project, aims at increasing farmer yields by working with several stakeholders: Equity Bank which provides credit through an e-voucher system to identified farmers; Agmarc which comprises the agro-dealers; Seed Trade Association of Kenya (STAK) and East African Grain Council (EAGC) which handle post-harvest issues; and KALRO which conducts on-center and on-farm trials and demonstrations on good agricultural practices that enhance productivity. The Kenya Smart Agricultural Project (KSAP) is an upcoming project that will address low productivity, food insecurity, and high poverty incidences in light of climate changing conditions.

The scientists further informed the team that there are many fertilizer distribution companies and retail outlets, mainly for NPK fertilizers in Kenya. In addition, there are five blending fertilizer companies: Export Trading Group (ETG), Toyota Tshusho, MEA Ltd, Minjingu, and Athi River Mining (ARM). These companies blend fertilizer based on soil tests and requests made mainly through large-scale farming operations. The main micronutrient additions to the NPK products are S, Zn, Cu, Ca, Mg, and Mn.

Despite all the efforts and settings, fertilizer use in Kenya is low and, hence, farmers' crop productivity is low. Causes for this include:

- Low accessibility due to high prices for resource-poor farmers.
- Lack of region- and crop-specific fertilizer use recommendations (only blanket NPK recommendations are available; there is limited access to available soil maps as an input to fertilizer recommendations).
- Limited access to fertilizer information for the wider farming community (inadequate recommendations and packaged information, e.g., leaflets on fertilizer use).
- Inadequate farmer information on accompanying good agronomic practices and market information.

After some discussion, it was agreed that as a way forward, the following should be done:

- KALRO should contact ISRIC to give the organization access to available soil maps to be used as an input into refining fertilizer recommendations but capacity may be lacking to effectively utilize the information.
- A platform for stakeholders, as initially planned by Dr. Man'gale (KALRO), should be set up and supported for information sharing and voicing fertilizer use concerns.
- Further experimentation should be conducted to refine fertilizer recommendations in light of the fact that organic carbon is less than 1% in most soils.
- On-farm and off-farm fertilizer demonstrations should be conducted specifically for fertilizer blends to generate information on region/crop-specific fertilizer blends that enhance yields.

Source: Dr. Anthony Esilaba and Dr. Catherine Kibunja, Lead Soil Scientists, KALRO.

Soil tests are considered expensive because soil laboratory services are concentrated around Nairobi (CropNuts and KALRO). Current fertilizer recommendations for most crops (potato and maize included) are blanket recommendations because they cover large regions and are not based on recent soil tests. Only a few farmers undertake soil tests, and some fertilizer trials are being conducted, currently by blending companies, even without prior soil testing. Even with soil data, it is not evident how to arrive at fertilizer recommendations. According to fertilizer distributors and blenders, they acquire the recommendations from the Crop Nutrition Lab. However, specialized farmers (high-value crops such as flowers) often apply fertilizers after conducting soil tests.

Box 8. Crop Nutrition Laboratory Services (CropNuts)

CropNuts offers crop laboratory services mainly to large-scale farmers (food, horticulture, floriculture, and industrial crops) in Kenya. The company has a network of agents in the country who assist farmers to send their samples to the Nairobi-based laboratory using courier services at farmers' cost. They also undertake fertilizer trials with large-scale farmers (based on farmer demand) with a view of providing soil test prescriptions and soil mapping. The large-scale maize farmers that work with CropNuts cultivate at least 40 ha. The company also works with other input suppliers, such as ETG (for fertilizers) and Syngenta (for seeds). Delivery of laboratory results is often done within seven days. The company charges U.S. $20 per soil sample. Other company activities include quality agriculture and soil moisture management (dryland risk mitigation). In partnership with other stakeholders, CropNuts undertakes fertilizer use dissemination activities through television shows, such as "Shamba Shape UP" and "Daktari wa Udongo" (Soil Doctor). However, required data and resources are key constraints.

Despite the available services and other initiatives from stakeholders, there is no rational fertilizer use, partly due to:

- Fertilizer subsidy program. Subsidized fertilizers reach farmers late. There is need for SMART subsidies.
- Soil acidity issues in the "grain basket counties" of Uasin Gishu and Trans Nzoia. There is no subsidy for lime; hence, crop response is low.
- No clear soil management policies for counties. There is no synchrony of fertilizer recommendations and availed subsidized fertilizers.

Opportunities Available for Scaling Up Fertilizer Use:

- Need to outscale and upscale fertilizer use services to smallholders through technology. There is need to establish a platform for information sharing that will have software for agronomic information (fertilizer use, plant nutrition, soil risk, and water-holding capacity, etc.), among others.
- Conduct on-farm demonstrations on blended fertilizers and develop region/crop-specific fertilizer recommendations (through a PPP arrangement).

Opportunities Available for Agribusiness (through a PPP Arrangement):

- Utilize available and to-be-generated (from demonstrations) plant and soil analyses reports to refine fertilizer use recommendations, taking into consideration accuracy of recommendations and price of recommended fertilizer blend as critical factors.
- Aggregate fertilizer recommendations (in terms of types and respective volumes) to justify economic viability of the blends.
- Develop appropriate (region, crop) fertilizer blends and promote their use.

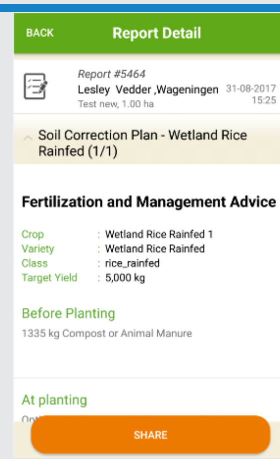
Source: Jeremy Cordingley, Managing Director, CropNuts

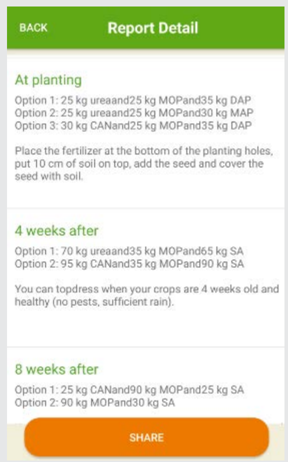
Box 9. SoilCares

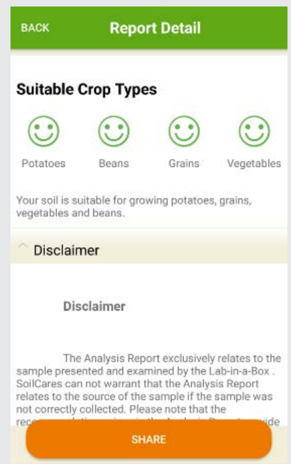
For many farmers, soil is a puzzling black box, to which they apply fertilizers without knowledge of what the soil actually needs. SoilCares made it possible to easily read and identify the needs of soil through near infrared (NIR) spectroscopy. SoilCares was founded in 2013 to put knowledge into the hands of farmers worldwide. It therefore developed a handheld Soil Scanner to give smallholder farmers, even the most secluded, access to reliable and affordable technology that will improve the productive capacities of their soils. With the Soil Scanner on the spot and customized soil management recommendations can be generated within 10 minutes using the locally available fertilizers. This approach also raises farmers' awareness and strengthens their capacity regarding soil management.

A review of methods for rapid testing of plant and soil nutrients is given by Dimkpa et al., 2017.

Source: Christy van Beek, SoilCares Foundation







Currently, there are no clear linkages between soil data and fertilizer use, including for blended fertilizers. There is no full coverage of quantitative location- and crop-specific fertilizer demand and not all required blends can be provided. Several actors, especially fertilizer importers and blenders, will conduct on-farm demonstration trials to introduce their products, which leaves farmers without objective comparisons between different products. Often also, several agronomic measures are introduced simultaneously, which from the farm perspective may be relevant but does not allow to disentangle the magnitude of the impact of each intervention. The use of improved seed potato is one prominent confounding factor in fertilizer trials, as famers generally use their own potatoes for planting. There are several challenges that need to be overcome, therefore, if large-scale adoption of smart fertilization is the goal. A G4AW project "Geodatics – Innovative advisory services to smallholder farmers" generates more generic recommendations for NPK fertilization.

Box 9. Geodatics – Innovative Advisory Services to Smallholder Farmers

A current project funded by the Geodata for Agriculture and Water (G4AW) mechanisms of the Ministry of Foreign Affairs in the Netherlands uses satellite images to observe the greenness of the Kenyan surface (normalized difference vegetation index, NDVI), soil sample data, and farmers' opinions for assessing fertilizer recommendations. An empirical model, QUEFTS, is used to estimate NPK requirements to attain 80% of the yield levels at long-term median rainfall. This "maximum" yield level remains at 80% when NDVI is good and is reduced to 60-70% when greenness is lower. This is the only use of satellite data. An additional adjustment is made based on the farmer's judgement of whether the soil is good or poor. The recommendations are limited to NPK application and pragmatically composed of amounts that can be combined from locally available fertilizers. CAN is sold in bags of 50 and 25 kg and DAP in bags of 50, 25, and 12.5 kg, which then are blended to arrive at the next closest recommendation rate. At present, about 1.2 million kg of fertilizers are dispensed at a turnover of about 2 million euros in this project to about 20,000 farmers at an average of about 60 kg per farmer. About 25% of the farmers have up to 0.25 acres, and 50% have up to 0.5 acres, all applying fertilizer at about 200 kg ha^{-1}. Farmer yields are found to increase from less than 1 t ha^{-1} to about 2 t ha^{-1} or slightly more. Hence, farm size in Western Kenya is small and competition in the fertilizer market is high, because many operate in this area with similar products. On some experimental trials, yields of around 5 t ha^{-1} were found in line with expected QUEFTS outcomes.

Geodatics conducts the fertilizer assessments, with input from Wageningen UR, and Agrics implements the fertilizer business; both entities are owned by ICS. The team identifies two critical phases in realizing increased use of fertilizers and associated yield increase. Reaching the first farmers is hardest as they must be convinced that this "magic" works to increase their yields. Once demonstrated at some farms, villagers will be eager to acquire the "magical" products as well. The next difficult step is to scale up from 10,000-15,000 farmers to hundreds of thousands. This requires significant upfront investment by agro-dealers in purchasing stocks and developing the proper logistical tools, such as larger warehouses, trucks, and blending machines.

Source: Raymond Chepkwony, Regional Project Manager, Geodatics; Tom Schut, Wageningen UR.

While several farmers indicated organic manure to be essential, there is no systematic overview of available amounts nor quantities used by farmers. In any case, the recommended amounts by the Kenyan Ministry of Agriculture (Department of Kenya Soil Survey, 2014) seem much higher than amounts readily available for farmers to use.

Box 10. KALRO-Kitale

The center is the headquarters of the Food Crops Research Institute, the largest of the 16 institutes that comprise KALRO. The center was one of the 10 sites of the multi-locational trials of the Kenya Cereals Enhancement Project. There were several projects using maize and beans as test crops. The main ones were:

- Conservation Agriculture trial in which effects of liming were sought using conventional and zero tillage methods.
- Optimization fertilizer trial with organic fertilizer in addition to blends such as use of zinc (as a micronutrient).
- Organic and inorganic fertilizer trial with and without lime.
- Potassium trial with and without lime.

The researchers observed that as much as they could wish to conduct fertilizer trials where micronutrients are incorporated, the blended fertilizers were not easily available. In the first year of data collection, no discernible yield differences have been reported (no discernible response). At the center, maize yields of 6-8 t ha^{-1} can be realized using the fertilizer recommendation (60 kg P_2O_5 and 60 kg N ha^{-1}) against 1.5-2.5 t ha^{-1} realized by farmers in the community. Yet, the discrepancy between the high yields and the low fertilizer levels suggest testing on prior uncultivated lands or lands that received high rates of fertilizer in previous seasons; yields can be expected to decline over time when continuously cultivated. Yields of 12-16 t ha^{-1} have been reported with higher levels of fertilization in Kenya. The yield gap between farmers and researchers can be attributed to:

- Sub-optimal use of fertilizers due to inadequate access to and affordability of fertilizers.
- Untimeliness of farm operations due to labor constraints.
- Low output prices (exploitation by middlemen – basically, the aggregators of maize given the geographically scattered small-scale production).

Source: Soil scientist Dr. Keziah Magiroi and agricultural economist Dr. Japhether Wanyama (KALRO-Kitale).

The current approaches of fertilizer testing are inadequate for up- or out-scaling and do not allow assessment of total required volumes of specific fertilizers for specific regions. There is, therefore, a need to formulate crop- and/or location-specific fertilizer blends based on soil tests, as is proposed in this study through a collaborative effort among KALRO, CropNuts, SoilCares, IFDC, AfSIS, fertilizer blending companies, etc.

Box 11. Toyota Tsusho Fertilizer Africa Ltd.

Toyota Tsusho Fertilizer Africa Ltd (TTFA) is a newly established fertilizer blending station close to Eldoret with a capacity of 150,000 mt y^{-1}. Apart from a blending and packaging installation, TTFA also has a coating facility that enables it to supply fertilizer with integrated trace elements, though limited in varieties. The business is clearly still in its introduction and growth stage. The station still runs well below capacity.

In the Kenyan fertilizer market, TTFA sees a strange contradiction. It is an obvious buyer's market with fierce price competition and overcapacity. So, the buyers would normally have power to enforce product improvements that are clearly needed, since in most cases fertilizer products obviously do not meet expectations. The market apparently seems unable to translate economic incentives to product improvement. TTFA considers certain challenges in the fertilizer value chain as the main cause for this:

- Lack of information flow in the chain.
- Lack of knowledge and skills among agro-dealers: While the widespread abundant network of agro-dealers is an advantage for Kenya (with 4,000 agro-dealers throughout the country), their poor level of knowledge and skills seriously hinders the adoption and breakthrough of proper fertilization.
- Costs of distribution and logistics.
- Lack of financing.

TTFA is addressing mainly the first challenge by maintaining a clear focus on specific regions and specific crops. This allows the company to arrive at a more profound knowledge and problem-solving capacity. For financial interventions in the market, TTFA is dependent on external government and donor stakeholders. They only wish a new intervention will be smarter and more effective than the current subsidy schemes, as these do not function due to bad implementation.

Source: Nathaniel Otieno, Agribusiness Development Manager, Toyota Tsusho Fertilizer Africa Ltd.

5.2 Good Agronomic Practices

Farmers are aware of the importance of using fertilizers. However, fertilizer use levels for both maize and potatoes are low, causing low crop yields at 1.5-2.0 t ha^{-1} for maize and 6-7 t ha^{-1} for potatoes. DAP, CAN and urea are the main fertilizers used by farmers. About 40% of the amount of these fertilizers in the market are subsidized. The subsidy fertilizer program is highly complex, often leading to delays (lateness) in supply and quality concerns. Fertilizer blends that give good crop response can compete with the subsidized fertilizers if they are good quality and offered on credit in a timely manner. In the high rainfall areas of North Rift, 90-95% of maize farmers use hybrid/improved maize varieties. Over 80% of the improved maize seed used in Kenya is bred and produced locally through several local companies, such as Kenya Seed Company, Western Seed Company, Olerai, KALRO Seed Unit, and SEDCO. A small percentage of the seed is imported by multinational companies, such as Pioneer, Monsanto, AgriSeed, and Pannar. The low farm yields suggest that the genetic potential of these varieties do not come to expression.

Only 1% of potato farmers use improved seed potato in major growing areas. Seed potato imports in recent years have faced phytosanitary and sanitary issues. Mechanization using farmers' own or hired tractors for land preparation is common in North Rift and, to a lesser extent, in potato growing areas. For instance, mechanized two-wheel soil preparation will outcompete oxen ploughing due to implicit costs, such as food to be provided to the laborer. Notwithstanding, deep ploughing and ridging are needed for potatoes. The need for improved water management or irrigation was not explicitly mentioned by the actors, yet the impact of (rain) water limitation is unclear. However, farmers fear that using contaminated surface run-off/river water could lead to the spread of bacterial wilt in potatoes.

Box 12. The Potato Farmer – ICL On-Farm Testing

A farmer who purchased fertilizer (Agromaster) from ICL for the first time praised the field performance of potatoes where the fertilizer was applied. In addition, he was happy with the extension services offered by the ICL agent. With a 1.8 ha farm, the farmer practices crop rotation using vegetables, maize as fodder for silage making, and potatoes. Currently, he has 0.4 ha under potatoes. On half of the area under potatoes (0.2 ha), he used DAP fertilizer and farmer saved seed. He expects to harvest 1.8-2.3 t. On the other half, the farmer used ICL fertilizer and improved certified seed (Shangi variety) and expects to harvest 2.7-3.2 t. At an investment variable cost of U.S. $1,000, the farmer anticipates earning $3,000 from the 0.4 ha of land under potatoes. This shows that potato production is a worthwhile investment. Returns increase with smart fertilization, use of certified seed, and good agricultural practices. Nonetheless, potato price volatility is high, ranging from $150 at harvesting to $600/t at planting.

Agribusiness Opportunities

- With partners, supply region- and potato-specific blended fertilizer.
- With partners, develop and run affordable credit scheme for blended fertilizer users.
- With partners, develop and run affordable village or sub-county cold storage potato facilities for farmers.

Source: Elijah Kamau, farmer, and Mr. Daniel Wambua, ICL representative

Box 13. Agrico Seed Potato Producer and Seller

Dutch seed potato producer Agrico began operating in Kenya in 2012, aiming to solve the problem of insufficient supply of certified seed potato by developing and introducing high-yield certified Kenya-specific varieties. The target market is subsistence and semi-professional farmers (several thousand, mainly female). This target group typically suffers from insufficient supply of certified seed potato. They rely almost entirely on informal seed sources like farm-saved seed and seed from local sources like markets and neighboring farmers. Only about 1% of seed potato supply is certified seed. Combined with insufficient fertilization (in terms of quantity, quality, and timing) and poor farming practices, this results in extremely low yields that have further decreased over the years. Currently, the average yield is 5-7 t y^{-1}. Sales prices are low due to the lack of storage facilities.

Agrico cooperates with other stakeholders like Yara to arrive at a complete pallet of supplies and technical assistance to improve farming practices. They have 20 demonstration fields managed by selected lead farmers. Each demo field provides training and technical assistance to 200-300 farmers. Yara requires a soil analysis as a condition for participation. Results are substantial. As of now, 13 varieties have passed the certification process of the Kenya Plant Health Inspectorate Service (KEPHIS). In the KEPHIS national performance trials, the new varieties outperformed the local ones by a landslide. Farmers participating in the program saw their yields grow by 500 to 900%. Current capacity is 3.5 t per season. After the multiplication and final acceptance are completed successfully, Agrico can serve 1% of the market. Depending on the success, a new production center will be established in Eldoret. With all extensions realized, Agrico might be able to serve 10% of the market.

Constraints:

- Bureaucracy: The registration process takes a long time (2-2.5 years per variety) and is not transparent. Also, the capacity of KEPHIS is insufficient. To some extent, one might even doubt the level of integrity in this process. The National Potato Council of Kenya (NPCK) is not free from suspicion of protecting vested interests and keeping newcomers out.
- Pest pressure: Some diseases simply cannot be avoided, especially in a country with such a history of fragmentation and inbreeding. Also in this respect, there is a bureaucracy issue; Kenya applies even stricter standards than the Netherlands.
- Availability of fertilizer in the right quantities, right formulations, and at the right time.
- Lack of financing for farmers: Some can invest by their own means, but the majority needs external financing.
- Inappropriate farming practices: Insufficient tillage, crop damage, absence of smart crop rotation, incorrect use of pesticides, etc.
- Absence of large-scale growers.
- Good opportunities exist, but there are no new entries so far.

Source: Willem Dolleman, Jr., Managing Director, Agrico East Africa.

5.3 Fertilizer Supply Side Concerns

As raw market data show, the supply capacity of the Kenya fertilizer market is sufficient. Most of the blending stations do not use their full production capacity, and the number of outlets is impressive (among others, a network 4,000 agro-dealers). Still, the supply side does not seem able to import, produce, and distribute the right products that can close the Kenyan yield gap. To a certain extent, this is due to a mismatch in quality, caused by lack of proper data processing and lack of exchange and mobilization of knowledge and skills. Another hampering factor is the lack of proper distribution and last-mile logistics. Thirdly there’s a financing issue. Closing the yield gap is eventually beneficial yet requires pre-financing to be able to do the investment in soil sampling and analysis, fertilizer recommendation and purchase of improved (and more expensive) tailored fertilizer.

Box 14. Export Trading Group (ETG)

ETG is a pan-African commodity trader with operations in 26 African countries. ETG's regional head office is in Kenya. ETG buys agro-commodities from farmers (mainly maize and pulses) and sells agrochemicals, seeds, and fertilizers (350,000 mt y^{-1}, making them the largest in Africa). ETG mainly works through mutually beneficial "package deals" with farmers, offtake in return for the right to supply inputs. ETG predominantly works with cooperatives like the East African Farmers Association. ETG operates five large warehouses (with a two-way function: both supplies and commodities).

ETG works independent from government initiatives like NCPB. In practice ETG does not really notice NCPB operations in the market. Due to lack of funds, NCPB was only able to buy less than 5% of maize production last year. They sell and distribute through a network of around 150 agro-dealers that are all connected through a mobile app. ETG sells two fertilizer brands:

- Falcon, their standard fertilizer sold to smallholders, often through government programs.
- Kynoch, specialty fertilizer with improved properties, sold to professional, larger farmers.

ETG soon opens its own blending station with a capacity of 150 mt d^{-1}, extendable to 300 mt d^{-1}. The station is able to produce soil-specific formulations with micronutrients added. Expectations are high. The company's customers suffer from depleted soils and demand proper formulations. The necessary soil samples are done in collaboration with CropNuts. To a lesser extent, ETG has collaborated with partners to pilot credit schemes, e.g., with M-Kopa. Risks are high. Perhaps in the future, the company may wish to deploy its own ETG foundation in this matter.

ETG notices the following issues in the market:

- Counterfeit and other types of fraud.
- Access to farmers and access to farmer data.
- Lack of credit for farmers.
- Distribution logistics.
- Brokers that have a harmful impact on the market.

Source: Silas Kimathi Muguna, Head Agronomist, ETG, and Giles Lewis, trader.

The knowledge aspect cannot be emphasized enough. Technically, there's sufficient capacity to import and blend most formulations. However, there is still a lack of knowledge on what formulation to apply for what area or crop, and a lack of holistic approach, in which other parameters (irrigation, agronomic practices, etc.) are considered in an integrated way. It is obvious that all stakeholders in the market have much to gain, yet they are incapable of getting the chain activities organized and pre-financed. Another challenge is the last step in the supply chain: the distributors. These are undercapitalized, lack knowledge, and lack the logistic capacity to facilitate the transition from a commodity approach to a tailored approach.

Box 15. Amiran Kenya Ltd.

Amiran is one of Kenya's leading agro-input suppliers. Amiran is member of the Balton CP group of companies. With 400 employees, Amiran is Balton's main subsidiary. Amiran's portfolio comprises inputs and equipment, project implementation, and business development. Profound knowledge transfer is a key element in Amiran's supply, project implementation, and business development activities. The company employs 60 agronomists.

With regard to fertilizer, 90% of Amiran fertilizer products are water-soluble, due to the company's emphasis on irrigation. Their main market is the floriculture sector, but they cover all segments in Kenyan agriculture. Amiran sources its fertilizer from multiple manufacturers from different continents and countries (China, Israel, EU, U.S.).

According to Amiran's experience, only 10% of agriculture operations in Kenya realize more than 60-70% of their potential. Key elements that determine success or failure are:

- Mindset and skills (especially for smallholders).
- Infrastructure (cost of transporting water).
- Financing (especially for smallholders).
- Ability to apply the right technical solutions (due to lack of R&D, people only work by trial and error).

Other factors that hinder success are market distortion through government and NGO interference and lack of an integrated approach. Fertilization is only part of the job.

Source: Ran Kadosh, Head of Agro Division, Amiran Kenya Ltd.

5.4 Credit Facilities

In Kenya, there are several financial institutions that offer credit to farmers. They include the Agricultural Finance Corporation (AFC), a wholly owned government development finance institution (DFI) that was established in 1963 under the Agricultural Corporation Act, Cap 323 of the Laws of Kenya to offer credit to farmers, commercial banks and microfinance institutions, savings and consumer cooperative societies, and commodity-based organizations such as the Kenya Tea Development Authority. In addition, farmers obtain credit facilities from agro-dealers and informally through "merry-go-rounds" and table banking. Recent AFC lending to the agriculture sector is presented in Table 10.

Table 10. AFC Lending to the Agricultural Sector

Financial Year	Amount Disbursed (million U.S. $)	Number of Beneficiaries	Amount per Beneficiary (U.S. $)
2009/10	15.33	6,256	2,450
2010/11	21.46	7,742	2,772
2011/12	16.71	8,499	1,966
2012/13	33.18	17,414	1,905
2013/14	22.29	16,887	1,320

With less than 5% of households receiving lending from AFC, it is clear that agricultural credit from the public sector is inadequate. Most commercial banks advancing credit facilities to small-scale farmers also find the business risky and costly given the unpredictable weather patterns and dispersed nature of many farmers who demand low credit volumes, respectively. Hence, despite the available credit facilities, the majority of farmers do not access credit partly due to lack of collateral, high interest rates (often above 20% per annum), lengthy loan processing procedures, and farmers' fear of repayment.

Realizing the importance of credit and the fears of the banks, the Government of Kenya initiated a public-private partnership (PPP) framework in 2008 in partnership with Equity Bank (a commercial bank) to facilitate smallholder farmers' access to affordable financial services. The aim was to spur commercialization of farming in a sector plagued by low production, poor marketing, low financial literacy, and misconception. Since 2008, the government has been implementing the Agricultural Credit Guarantee Scheme (ACGS) through the National Accelerated Agricultural Inputs Access Program (NAAIP). Through the agreement signed by the government and participating financial institutions (PFIs) in the implementation of ACGS, four PFIs, namely Kenya Women Finance Trust, Cooperative Bank of Kenya, Family Bank, and Equity Bank, cumulatively disbursed U.S. $34 million to 25,071 beneficiaries by December 2014; beneficiaries included small-scale farmers, agro-dealers, and other value chain players.

In 2011, the government partnered with Equity Bank, Alliance for a Green Revolution in Africa (AGRA), and International Fund for Agricultural Development (IFAD) in the first phase of the ACGS. The first phase sought to scale up and magnify lessons learned throughout the previous years of implementation under the *Kilimo Biashara*. Building on the successes of the initiative, Kenya's Ministry of Agriculture, Livestock and Fisheries signed a U.S. $2.89 million package with Equity Bank to support farmers under the second phase of the ACGS in August 2017. The partnership is a risk-sharing arrangement in which the government provides a guarantee fund to cushion the PFIs for any proven credit loss of the outstanding credit amount in default. In addition to credit, PFIs offer farmers other services, such as capacity building, savings/deposits, and linkages to crop insurance and markets. Besides the partnership with Equity Bank, other commercial banks have tailor-made products for farmers.

Box 16. Financial Services Available to Farmers

Vuna Kilimo Biashara: This product enables individual farmers and associations/groups/cooperatives in cereal production and horticulture to access farm inputs equipment and set up greenhouses and irrigation systems and enables agro-dealers to access working capital.

Tegemeo Loan: This loan covers the short-term financial needs of farmers supplying accredited buyers and aggregators through advances based on their deliveries.

Nafaka Small-Scale Loan: The loan is offered to small-scale farmers to enable them to access farm inputs for production of cereals, which include maize, wheat, barley, sorghum, rice, and millet, among others.

Nafaka Large-Scale Loan: The loan is offered to large-scale farmers to enable them access to farm inputs, working capital, farm equipment, and social needs, e.g., school fees, medical bills, furniture, etc.

Nafaka Agro-Processors/Dealers Loan: The loan is offered to agro-dealers, grain traders, and processors for working capital requirements (capital investments, stocking their businesses, and day-to-day operations).

Source: Cooperative Bank of Kenya.

The farmers visited during the team's feasibility study showed an appetite for obtaining low-cost interest loans to better their farm operations. It was reported that G4AW offered farmers in-kind interest-free credit in the form of seed and fertilizer. However, the organization charges the farmers a paltry margin of U.S. $5-8 per hectare worth of inputs supplied. The credit is collected from farmers at regular intervals (weekly or monthly) by a G4AW agent or through *M-Pesa* (mobile money transfer system used in Kenya) and a register of all participating farmers is kept by G4AW.

Box 16. Discount Coupons

In previous work in Western Kenya applying behavioral economics (the study of how people make economic choices), the project's investigators found that a major reason that farmers fail to invest in fertilizer is the difficulty in saving their income from the harvest until they need to buy fertilizer for the next season. Using field experiments, they also found that farmers have only limited information on the costs and benefits of fertilizer and that learning about fertilizer through social networks is limited. A new scheme offering farmers small, time-limited discounts (15%) on fertilizer that are available in a short window right after harvest should overcome these barriers to fertilizer adoption. A randomly selected group of farmers are reminded by text messaging to redeem their discount coupons in a timely fashion. Preliminary results found the take-up of the coupons to be reasonably high, and they could potentially benefit women as well. Since the subsidy is only 15% the cost of the fertilizer, and the returns to fertilizer average 50-80%, the increase in yields from the fertilizer greatly exceeds the cost of the subsidy. The program entails minimal cost and simple logistics.

Source: https://www.usaid.gov/div/portfolio/increasing-fertilizer-adoption.

Box 17. Agri-Wallet Saving

The Agri-Wallet is an innovative mobile financial savings scheme that will be piloted in Kenya by IFDC. The Agri-Wallet will enhance savings for farm inputs to increase agricultural productivity and income through automatic savings and restricted spending. It solves a number of problems farmers may face including: lack of saving, mixing personal and business funds, slow payment from buyers, inconvenient nature of bank payments, and access to flexible and affordable credits. The system comes with additional benefits, such as incentives to set aside funds, because having savings also helps farmers qualify for loans.

Source: IFDC, Pers. Comm.

6. Value Chain Actors

Farmers are not aware of available fertilizer alternatives, such as the blends. They are, however, willing to use alternative fertilizers. Farmers are more likely to demand fertilizer if: (1) they have access to credit; (2) they are relatively close to good roads and markets; (3) they can produce a fertilizer-responsive crop in a relatively low-risk environment (e.g., under irrigation, in higher rainfall zones, or using soil and water conservation practices); (4) the fertilizer-responsive crop has a relatively stable output demand; and (5) fertilizer is available in appropriately sized packages at the desired time. They are more likely to use fertilizer in a cost-effective manner if: (1) they have access to demonstration packs for testing and demonstration plots; (2) plots are conducted jointly by extension services, input suppliers, and possibly NGOs; (3) they use practices that increase fertilizer use efficiency (soil water conservation, natural resource management, and conservation farming, for example); (4) they are provided with training in analyzing the financial returns to fertilizer use; and (5) market information (input/output prices and quantities) is available.

The government operates a fertilizer subsidy program through the NCPB that is poorly implemented and offers inappropriate fertilizers (e.g., DAP, which is soil acidifying) for some regions. The program often is available some weeks after the onset of rains, leading to late application and eventually low yields. The subsidy program, to some extent, competes with non-subsidized fertilizers sold through the private sector.

Box 18. Confidence in Fertilizer Recommendations

It is noteworthy that changing government recommendations makes it hard for farmers to adopt new fertilizers. This especially is true for small-scale farmers who do not have sufficient means nor alternatives other than to use the subsidized fertilizers available, while medium- and large-scale farmers will adopt other fertilizer products more quickly if they are proven effective. After some country-wide soil analyses conducted in 2014, the government has been trying to discourage farmers from using DAP because its overuse has acidified soils in most parts of Kenya. However, the alternative given, mainly NPK 23:23:0, has not performed as well as DAP, which creates much confusion.

Source: Several actors, Pers. Comm.

All fertilizers for blending are imported into Kenya. There is inadequate knowledge on what to blend for what region or crop. Some blenders have their own models for blending while others rely on CropNuts to provide the model. This is proprietary. The blenders called for other stakeholders to support developing a market for blended fertilizers. The private sector is more likely to import and develop retail distribution networks if: (1) government or donor distribution programs to stimulate fertilizer use are designed collaboratively with the private sector and in a manner that does not crowd out existing commercial demand; (2) the risks of providing credit to retailers are shared (e.g., credit guarantees); and (3) costs of estimating retail demand and dealing with carry-over stocks at remote locations are shared (e.g., farmers organize for bulk orders).

Local retailers are more likely to stimulate demand if: (1) they are well-trained in business management and have good technical knowledge about inputs they carry; (2) they have access to credit to maintain adequate stocks; (3) they sponsor demonstration plots or field days to promote products; and (4) they are able to satisfy local demand (correct timing of availability, package sizes).

Banks are more likely to finance the agriculture sector if: (1) donors or government share the risk during the early years (credit guarantees); (2) loan officers are provided with training in agricultural risk management; and (3) donor funding is available for the development of new loan instruments.

There are several potato processors with a limited range of appropriate potato varieties suitable for processing. Part of maize is also acquired by processors to produce flour. (See Annexes III and IV for details.)

Available research and development activities currently implemented on fertilizer use involve conducting trials that are confounding in nature, such as fertilizer and improved seed trials using a control that is not clear for objective comparisons. There is a need to perform on-station response trials that compare fertilizer products. There is also a need to conduct on-farm trials to compare the performance (demonstrate) of various fertilizer products. In addition, farmers, blenders, suppliers, and processors should be trained on aspects of fertilizers. Institutions and companies that collect and use soil data, including KALRO, ISRIC, SoilCares, CropNuts, IFDC, AfSIS, IPNI, and others, could collaborate to arrive at fertilizer recommendations at the highest spatial accuracy possible, complemented by information about water (eLEAF), seeds (KARLO), and other practices.

Governance: During the feasibility study, the idea of developing a National Fertilizer Platform that will offer a level playing field for all actors was welcome. It will require participation of key actors in the fertilizer industry.

Box 19. National Cereals and Produce Board, Eldoret Branch, Uasin Gishu County

NCPB is a parastatal within the Ministry of Agriculture, Livestock and Fisheries with a network of depots across the country. It is the agency through which:

- Government intervenes in the input market by distributing subsidized fertilizers at a predetermined price. Only a few commonly used NPK fertilizers (DAP, CAN, and urea) are subsidized. It is estimated that about 40% of the fertilizers used in Kenya (about 300,000 t) are subsidized, targeting mainly maize production.
- Government intervenes in the output market as a buyer of maize, as a last resort, through a predetermined price just before harvest. In 2016, the NCPB price for a 90-kg bag of maize was set at U.S. $30. The price is used as a political tool and never an incentive for farmers to make informed decisions on their planned future production cycle. NCPB handles about 80% of the marketed produce, which it later sells to millers and retains part of the grain as the Grain Strategic Reserve. Ideally, the government intervenes in the output market when faced with deficits in the Strategic Grain Reserve as millers can purchase grain directly from farmers.
- NCPB is the custodian of the Grain Strategic Reserve, currently targeting 8 million 90-kg bags.
- NCPB is mandated to import maize grain when the country has a deficit and faces starvation. For instance, the NCPB has been importing maize since June this year.

It was revealed that SMART fertilization in Uasin Gishu County was not practiced by both large and smallholder farmers, partly because of:

- Narrow range of fertilizer types in the market (mainly the NPK products that were subsidized).
- High level of fertilizer brand loyalty, especially with DAP (continuous DAP use over time has worsened the soil acidity problem).
- General lack of information on SMART fertilization.

Way Forward

In order to improve the food security situation and household income in the county, NCPB is ready to partner with other stakeholders, such as the Uasin Gishu County Government and the Kenya-Netherlands Green Deal team, to set up an agriculture-based platform that will be used to build farmer capacity on the use of SMART fertilization and good agricultural practices to boost food security. The platform could also be used to lobby government to solve problems facing the maize industry. In addition, such a platform could be used to conduct on-farm demonstrations on SMART fertilization and good agricultural practices, further unlocking farming information bottlenecks.

Source: Mr. Kodonyo, Regional Manager, NCPB, and Mr. Korir, Silo Manager, NCPB.

7. Proposed Business Cases in Demonstration/Implementation Program

7.1 Rationale

Given that current approaches to soil sampling and fertilizer testing are inadequate for up- or out-scaling, the team proposes to integrate soil sample data in existing soil maps and overlay that with rainfall data to arrive at 100 m x 100 m resolution with adequate accuracy to identify most functional blends. Spatial-temporal analyses should assist in fine-tuning good agricultural practices, such as the need to practice water conservation practices. On-station and on-farm trials should be done that are strategically allocated in space to: (1) maximally capture soil and rainfall variability; (2) serve as a demonstration to farmers; and (3) allow product comparison between fertilizer providers. In addition, successful enhancement of agribusiness requires a multifaceted (holistic or systems) approach with various actors playing their roles.

For instance:

- The government's role regarding agribusiness is to facilitate services (e.g., information, extension/advisory) and to provide an enabling environment (institutional, legal, infrastructure, etc.) to enhance the competitiveness of the Kenyan agribusiness sector.
- Private sector organizations – producers, processors, and traders – are the drivers of a thriving agribusiness sector. They are motivated fundamentally by business interests. With effective business models, values, and external conditions providing secure investment conditions, the private sector will play a very active role in making the system work in a self-sustaining way. Most functions can be carried out by the private sector if business approaches with good business models are used.
- Farmer organizations are central in the development of agribusiness. As stated in this strategy, without an economy of scale in input and output markets, efficiency gains are difficult to achieve. The mobilization of farmers for collective action in marketing, training, innovation, and implementing quality standards is a classic function of farmers' organizations, either groups, cooperatives, or businesses.
- Commodity associations made up of actors in agribusiness value chains have a role in enhancing investment in and increasing the competitiveness of their respective value chains. They also play a part in distributing information and ensuring their members are contributing to putting the agribusiness strategy into practice. Through regulations and other activities, they can crucially influence their members to implement the strategy.
- Banks and financial institutions – This includes insurance companies, savings and credit co-operative organizations (SACCO), and microfinance institutes. They need to develop and provide innovative products and services that meet the needs and requirements of small producers and actors in the value chain. Due to the specific arrangements within the agriculture sector, especially for small entrepreneurs, services must be tailor-made to be functional. These services are urgently needed by those value chain actors to access markets and increase their competitiveness.
- NGOs involved in agribusiness are important stakeholders and actors in this strategy. Depending on their specific area of work, their roles might vary. They often have a comparative advantage and capacity over the public or private sectors in, for example, helping partnerships work and supporting small producers to get access to markets, both nationally as internationally (see Box 2 on 2SCALE).
- Research institutes play a fundamental role in providing innovations and technologies that enhance competitiveness for both large and small producers and all other actors throughout the various value chains. It is especially important to ensure that innovations are actually reaching practitioners to transform research results into practical interventions.
- Regulators must provide a regulatory environment that supports quality assurance and product safety with the goal of increasing competitiveness.
- Farmers must be supported in their aim of reaching standards, as the procedures and costs regarding compliance with standards are often hard for a small entrepreneur to bear. Through supportive regulations, regulators can make access to markets easier. They also can help producers unable to meet regulations get back to the market.

- Media and information and communication technology (ICT) will also play a crucial role by spreading information and helping to create a modern image of agriculture and agribusiness in Kenya. This will help make the sector attractive to people seeking employment and to the younger generation. Providing communication technology to farmers and other actors throughout the value chain is fundamental to enabling the use of new technology services for information exchange and business handling. This includes all types of mobile services. With the TV network soon to go digital, there is the chance to reach a broad number of stakeholders and interest groups through special programs and shows on agriculture and agribusiness.

Key stakeholders in the fertilizer value chain need to work in harmony, with incentives needed by all stakeholders:

- Farmers: Need incentives to enhance the demand and use of agricultural inputs and the supply of farm produce to the market.
- Fertilizer Importers: Need incentives to procure appropriate fertilizers in a timely and cost-effective matter.
- Blenders: Need to import or manufacture crop- and region-specific fertilizers at affordable prices.
- Input traders/suppliers: Need to procure, store, and distribute retail farm inputs in a timely and cost-effective matter.
- Output traders: Need to offer attractive and competitive prices for farmers' produce in order to motivate production.
- Policy: Government should provide a conducive environment (policy, infrastructure, information, and security) for all other stakeholders to function properly.

Fertilizer providers request support from the public (NGO) sector because raising farm awareness for improved fertilizers and creation of an enabling environment that is conducive for adoption are well beyond their reach.

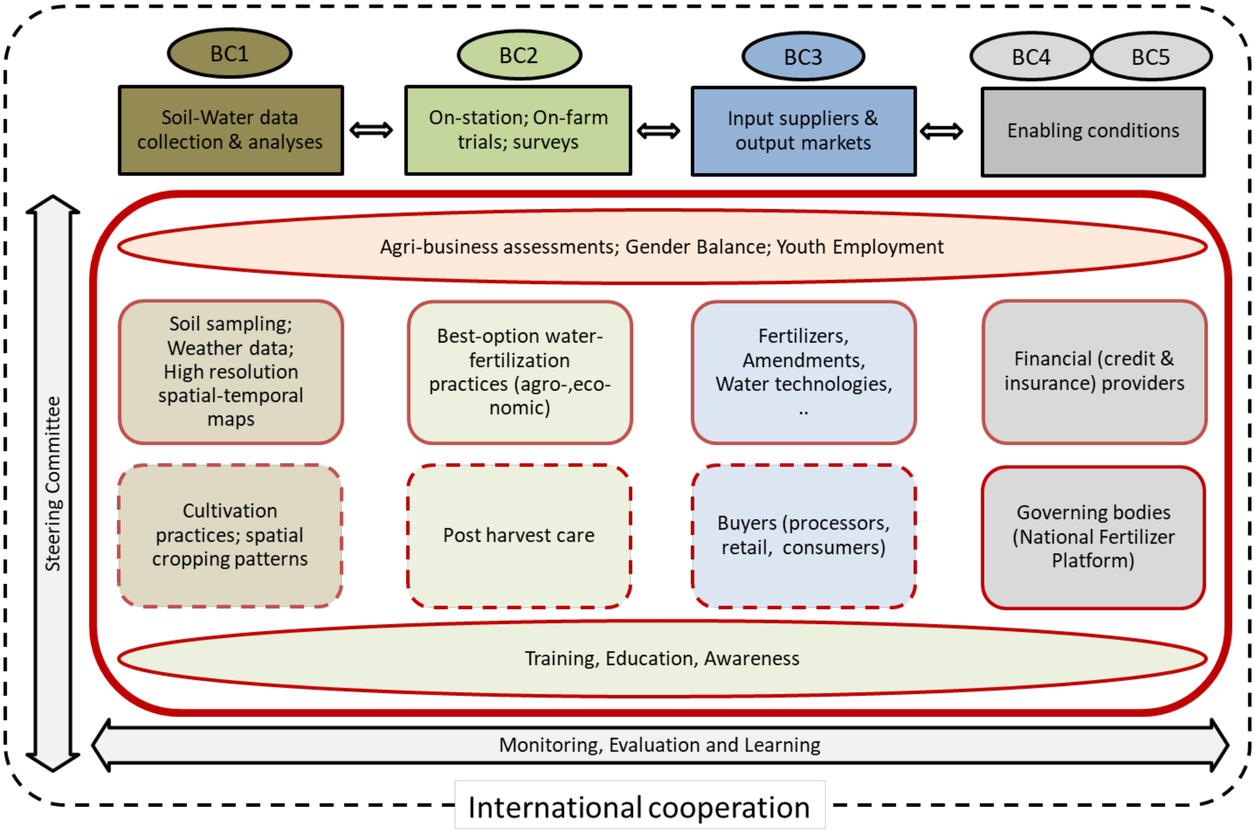
All actors in the fertilizer supply chain and the NCPB favored the development of a National Fertilizer Platform and are willing to participate. Such a platform would create a level playing field for all actors, help build farmers' capacity on the use of SMART fertilization and good agricultural practices, help lobby governments to solve problems facing the maize industry, and lead to on-farm demonstrations on SMART fertilization and good agricultural practices, further unlocking farming information bottlenecks. It is proposed to detail these contours through a stakeholder meeting with selected actors (Annexes V and VI).

7.2 Overview of Business Cases and Cross-Cutting Themes

The limitations of the current market situation mentioned previously provide a basis for six business cases that would address the key bottlenecks. These cases are elaborated below with a focus on their ability to solve the challenges limiting sustainable and scalable intensification and productivity enhancement of the maize and potato value chains. The design of business cases will consider gender aspects and youth employment as a cross-cutting theme throughout the program, as well as training, education, and awareness raising.

➢ Business Case 1. Identify, develop, and promote location-specific water and fertilizer management

- Business Case 2. Conduct on-farm and on-station integrated soil fertility management (ISFM) and integrated crop management (ICM) demonstrations
- Business Case 3. Establish networks of input suppliers and output markets
- Business Case 4. Mobilize financing actors in potato and maize value chains
- Business Case 5. Establish National Fertilizer Platform
- Business Case 6. International cooperation



This initial outline of the demonstration phase serves only as a starting point for a workshop to be held in Kenya with potential actors in designing a demonstration/implementation phase and outlining the details of the required activities, identifying the most relevant actors, and creating their support and commitment to engage.

Cross-cutting with the five business cases in this program are:

I. The integral consideration of gender aspects and youth employment creation within the maize and potato value chains:
   a. Women who form the bulk of the farming community will need to be involved in all stages of the respective value chains. Consideration should also be given to the timing of activities given women's other roles in society. Technologies used should be gender-sensitive, and opportunities for women's access to resources and services should be built into all activities.
   b. Youth involvement will be secure on the R&D side given that new IT methods and technologies will be used in this program and in input and output markets.

c. Initially, the number of agro-dealers might need to increase in the supply chain, which could generate opportunities for young entrepreneurs to join in.

II. The training and education of staff in both Kenya and the Netherlands and the creation of awareness among all the actors for location-specific management and value chain activities.

a. Train staff to strengthen the institutional capacity in order to advance the achievements from this demonstration phase.

b. Boost agricultural productivity and income along the value chain by raising awareness about the potential benefits of this approach.

The team envisions a steering committee with members representing actors identified in Section 7.1. to (1) oversee implementation of activities/achievement of objectives, (2) comment on workplans, and (3) provide policy and other guidance to implementation teams/partners.

A Monitoring, Evaluation and Learning Framework will be applied to systematically review the program's activities. Monitoring is foreseen through the identification of key performance measures of success (indicators for impact, outcomes, outputs, and inputs), and by checking on the implementation of activities as per the approved workplan. These will be evaluated for progress in achieving milestones and overall deliverables of the activity. The lessons learned from monitoring and evaluation will be shared and discussed among stakeholders and for fine-tuning activities throughout the program period if needed.

7.3 Proposed Business Cases

Business Case 1. Identify, develop, and promote location-specific water and fertilizer management

Fertilizer is a key input in the production of maize and potatoes. Therefore, farmer access of fertilizer in terms of timely availability and affordability is critical for performance. In addition, the right composition of nutrients (including micronutrients) in fertilizers for the crop and location must be used in adequate amounts to influence the performance of the crop. However, most of the estimated annual consumption of about 600,000 t of fertilizer in Kenya are compound N- and NP-based, with a few isolated cases of blended fertilizers. Currently, only five companies initiated blending of fertilizers in Kenya: Toyota Tsusho, MEA Ltd, Athi River Mining, YARA, and ETG. The most commonly used NP fertilizer (DAP) in maize and potato production has been reported to contribute to further acidifying soils, particularly in the maize grain basket/North Rift areas, leading to poor crop performance. To reverse this trend and to ensure Kenya's focus on food security is maintained through enhancing maize and potato productivity, the use of blended fertilizers will be key.

Therefore, a business case can be designed with existing fertilizer importing and blending companies and other key stakeholders to manufacture region- and crop-specific fertilizer blends, use existing or other distribution networks, and promote their use in Kenya. This could be achieved through:

- With existing stakeholders, such as KALRO, CropNuts, IFDC, ISRIC, eLEAF, and SoilCares, identify specific crop- and region-specific blended fertilizer nutrient needs through appropriate

soil maps and crop responses based on on-farm and on-station verification response trials (BC1 and BC2).
- Estimate potential requirements for each fertilizer product blend to guide in production of these building blocks at cost-effective volume. By limiting the number of building blocks, a maximal number of grades can be made as output of the blender.
- Existing fertilizer blending companies should be contracted or encouraged to produce or directly import the required fertilizer building blocks in the right amounts and timely fashion.
- Sensitization on use of the blended fertilizers through field campaigns including field demonstrations will be conducted with support of KALRO, Ministry of Agriculture county offices, fertilizer companies, and other key stakeholders. During the demonstrations, other good agricultural practices will be shown.
- In order to enhance farmer access to the blended fertilizer, the government (national or county) will be lobbied to include these fertilizers in their subsidy program. Alternatively, farmers will obtain credit through the mechanism proposed below.

For successful implementation of this proposed business case, farmers will be linked to competitive output markets.

Business Case 2. Conduct on-farm and on-station ISFM, ICM demonstrations

Maize and potato production in Kenya is carried out mainly by smallholder farmers, producing maize on less than 10 ha and, for potatoes, on an average of 0.5 ha of land. However, most of these farmers achieve low levels of crop productivity, partly due to inadequate knowledge of good agricultural practices. In an effort to enhance productivity, timely and adequate extension services are required. However, following the promulgation of the new Constitution of Kenya in 2010, agriculture is a devolved function, handled and coordinated by the various county governments. These governments do not have adequate resources allocated to agricultural extension and, following the national government, have frozen employment for over one decade; the number of extension workers has dwindled over time as a result of retirements and natural attrition. Therefore, demonstrations on the use of fertilizer and seed in addition to other good agricultural practices are effective for reaching large numbers of farmers. This could be achieved through the following steps:
- Identify the theme for the demonstrations, e.g., “Enhance maize and potato yields through appropriate fertilizer and seed use.”
- Identify key partners/stakeholders to host and conduct the demonstration in collaboration with the KNGD team.
- Determine the number of demonstrations to be implemented and the locations for each of them capturing most of the spatial variation, including the time they take place.
- Mobilize resources needed for implementation of the demonstrations and share roles for each key stakeholder.
- Implement the demonstration activities.
- Monitor and evaluate the demonstrations.

In addition to demonstrations on the use of inputs, the occasion will be used to:
- Organize farm visits to demonstration fields.
- Provide farmers with information on organized production supporting services, e.g., soil testing.

- Enable a critical mass of farmers to access input suppliers and creditors, which in turn will lead them access inputs at competitive prices.
- Link farmers to a network of potential buyers through provision of information.

Business Case 3. Establish networks of input suppliers and output markets

Actors along the input and output value chain should be engaged in an orchestrated set of activities on the input side of fertilizer supply and other inputs, while farmers should be actively engaging with buyers of their increased production. The project team will act as brokers to build the necessary relations between the various actors, identify activities together with the actors, and provide support for them to work out their business cases. This will be implemented through the following:

- Create an initial overview of the relevant actors along the value chains of maize and potato.
- Engage these actors in deliberating about the options and obstacles in optimizing the supply side of farm inputs and output side of farm produce.
- Determine sets of activities for each actor, including the program team to address the issues raised.
- Support agro-dealers in developing their business cases in financial and operational terms.
- Specifically address optimization of logistics as a target to cut costs and deal with increased output.
- Build relations between farmers and farmer organizations with potential buyers to the farm produce.
- Ensure sufficient information and competition, leading to fair and transparent market functioning.

Business Case 4. Mobilize financing actors in potato and maize value chains

The findings of the study show that both potato and maize small-scale farmers use inadequate amounts of fertilizers, and no or low amounts of improved seeds in the case of potatoes. This is partly attributed to lack of affordability or access to financial resources. Although microfinance institutions exist, they often charge high interest rates (>20% per annum) and demand for other requirements such as collateral. Commercial banks rarely provide credit to smallholders. The Agricultural Finance Corporation, a parastatal that provides lending to farmers, is discriminatory and only offers credit to farmers with land holdings of at least 2 ha. In addition to farmers, other value chain actors, such as brokers (often assemblers) and input suppliers, are often constrained by their ability to obtain adequate resources to efficiently carry out their businesses by exploiting the available economies of scale; instead, they trade in small quantities, often leading to erratic supply. To this end, it is proposed that a business case involving a leading lending mechanism be put in place and implemented. Such a model will be implemented through the following:

- This initiative will not be built from the ground up but engage with existing systems that may need to be adjusted to the specific needs for this endeavor.
- Look for or work with a strategic partner who will be willing to offer low-cost affordable credit to maize and potato smallholders and other value chain actors.
- Carry out sensitization campaigns on the model to existing farmer groups and key value chain actors.
- Register all willing value chain actors (farmers, input suppliers, transporters, and produce assemblers) to the scheme.

- Let each value chain actor develop a business plan after sensitization and registration.
- Appraise the business plans and let each actor raise up to 50% of the required loan as counterpart funds (to show commitment) to a kit over time.
- For successful applicants, provide the loan with a clear repayment schedule and terms of repayment. For farmers, the loan should be in-kind, whereby they obtain an e-wallet voucher that they take to the input supplier to obtain the required inputs.
- To minimize farmer transaction costs to accessing inputs, contracted or scheme input suppliers transport the inputs (fertilizer, seed, and chemicals) to a network of centers in close proximity to the farmers, where farmers can access inputs upon submission of the e-wallet voucher.
- Link produce assemblers to markets.
- Organize for the regular repayment of loans, undertake the loan repayments, and prepare for the next year's or season's lending/farming cycle.

Business Case 5. Establish National Fertilizer Platform

The findings of this survey indicate that the majority of the maize and potato stakeholders interviewed desired a National Fertilizer Platform in which issues related to enhancing fertilizer use with an ultimate aim of increasing food security, environmental conservation, employment, household income, and contribution to GDP could be articulated. Such a platform or forum will be able to do the following:

- (Re-)unite actors that may aim to develop a dialogue about fertilizer use in Kenya.
- Provide importers with information on types and volumes of fertilizers required (to be imported).
- Share spatial-temporal information about farmers' fertilizer needs.
- Share information on cost-effective methods of distributing fertilizers to retail outlets.
- Educate retailers on cost-effective methods of handling fertilizers, including storage.
- Educate potential fertilizer consumers (farmers) on the various fertilizer products that exist in the market and how to apply them to their crops.
- Harness farmers' fertilizer preferences in terms of type, package size, pricing, and availability (timeliness).
- Lobby government with respect to fertilizer prices (including subsidies) and taxation and also influence maize and potato output prices.

Business Case 6. International cooperation

The business cases will be conducted through international cooperation that aims to combine expertise at all possible scales. The use of advances analytical methodologies will be combined with on-farm trials to arrive at tailored recommendations. Sharing of knowledge about logistical operations, the use and recycling of locally available raw materials (wastes) as alternative nutrients, and trading of farm inputs like fertilizer building blocks and seeds, take on an international dimension that will be explicitly considered by inclusion of international actors.

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9. References

AfDB, 2016. “Increasing African Agricultural Productivity through Promotion of Efficient Input Use,” Paper presented at the “Validation Workshop of the Study on Evaluation of Fertilizer and Seed Delivery System. Alliance for a Green Revolution in Africa (AGRA), 2 Dec. 2016, Nairobi, Kenya.

Allan, A.Y., 1971. “Fertilizer Use on Maize in Kenya,” In: *Improving Soil Fertility in Africa*, pp. 10-25, FAO Soils Bulletin 14. Rome, Italy.

Ariga, J., and T.S. Jayne. 2009. *Fertilizer in Kenya: Factors Driving the Increase in Usage by Smallholder Farmers*. Tegemeo Institute, Egerton University. Nairobi

Bindraban, P.S., C. Dimkpa, L. Nagarajan, A. Roy, and R. Rabbinge. 2015. “Revisiting Fertilisers and Fertilisation Strategies for Improved Nutrient Uptake by Plants,” *Biology and Fertility of Soils*, 51(8):897-911.

Bindraban, P.S., C. Dimkpa, J. Angle, and R. Rabbinge. 2018. “Unlocking the Multiple Public Good Services from Balanced Fertilizers,” *Food Security* (https://doi.org/10.1007/s12571-018-0769-4).

Bindraban, P.S., J.J. Stoorvogel, D.M. Jansen, J. Vlaming, and J.J.R. Groot. 2000. “Land Quality Indicators for Sustainable Land Management: Proposed Method for Yield Gap and Soil Nutrient Balance,” *Agriculture, Ecosystems and the Environment*, 81:103-112.

Bindraban, P.S., Verhagen, A.J., Uithol, P.W.J., Henstra, P., 1999. *A Land Quality Indicator for Sustainable Land Management: The Yield Gap*, Report No. 106. Research Institute for Agrobiology and Soil Fertility (AB-DLO).

Ciampitti, I.A., T.J. Vyn. 2014. “Understanding Global and Historical Nutrient Use Efficiencies for Closing Maize Yield Gaps,” *Agronomy Journal*, 106(6):2107-2117.

Chianu J.N., J.N. Chianu, and F. Mairura. 2012. “Mineral Fertilizers in the Farming Systems of Sub-Saharan Africa. A Review,” *Agron. Sustain. Dev.*, 32:545-566. DOI 10.1007/s13593-011-0050-0.

Coastweek. 2018. http://www.coastweek.com/4104-Kenya-to-enhance-fertilizer-subsidy-program-to-boost-food-security.htm.

Debnath, P., S.K. Pattanaaik, D. Sah, and A.K. Pandey. 2015. “Assessment of Critical Limit of Boron for Cowpea in Piedmont Soils of Arunachal Pradesh,” *Archives of Agronomy and Soil Science*, 61(11):1649-1658.

Debnath, P., and S.K. Ghosh. 2014. “Assessment of Critical Limit of Available Boron for Pea in Acidic Alfisols of East Sikkim, India,” *Legume Research*, 37(5):508-514.

De Haas, H. 2010. “Migration Transitions: A Theoretical and Empirical Inquiry into the Developmental Drivers of International Migration,” DEMIG project paper no. 1. Working papers 24, International Migration Institute. Univ. of Oxford.

Department of Kenya Soil Survey. 2014. “Soil Suitability Evaluation for Maize Production in Kenya,” A Report by National Accelerated Agricultural Inputs Access Programme (NAAIAP) in collaboration with Kenya Agricultural Research Institute (KARI). Ministry of Agriculture, Livestock and Fisheries, State Department of Agriculture, Kenya.

Dimkpa, C., P. Bindraban, J.E. McLean, L. Gatere, U. Singh, and D. Hellums. 2017. “Methods for Rapid Testing of Plant and Soil Nutrients,” *Sustainable Agriculture Reviews*, 25:1-44.

Dimkpa, C., and P.S. Bindraban. 2016. “Micronutrients Fortification for Efficient Agronomic Production,” *Agronomy for Sustainable Development*, 36:1-26.

Driessen, P.M., and N.T. Konijn. 1992. Land-Use Systems Analysis. Wageningen: Wageningen Agricultural University, Department of Soil Science & Geology: Malang: INRES.

Durr, G., and G. Lorenzl. 1980. "Potato Production and Utilization in Kenya," http://pdf.usaid.gov/pdf_docs/PNAAJ221.pdf (accessed on 20/10/2017).

Economic Review of Agriculture. 2010. Ministry of Agriculture, Nairobi.

Economic Review of Agriculture. 2013. State Department of Agriculture, Nairobi.

Economic Review of Agriculture. 2015. State Department of Agriculture, Nairobi.

FAO. 2017. WaPOR database. http://www.fao.org/in-action/remote-sensing-for-water-productivity/en/

FAO. 2018a. http://www.fao.org/economic/ess/investment/expenditure/en/

FAO. 2018b. http://www.fao.org/giews/food-prices/international-prices/detail/en/c/885270/

FEWS NET. 2017. http://www.fews.net/east-africa/kenya/food-security-outlook-update/april-2017 (downloaded December 2017).

FGI. 2017. Fertile Grounds Initiative. Progress Report 2016. Wageningen UR.

Freeman, H.A., and W. Kaguongo. 2003. "Fertilizer Market Liberalization and Private Retail Trade in Kenya," *Food Policy*, 28:505-518.

Freeman, H.A., and J.M. Omiti. 2003. "Fertilizer Use in Semi-Arid Areas of Kenya: Analysis of Smallholder Farmers' Adoption Behavior under Liberalized Markets," *Nutrient Cycling in Agroecosystems*, 66:23-32.

Gildemacher, P.R., W. Kaguongo, O. Ortiz, A. Tesfaye, G. Woldegiorgis, W.W. Wagoire, R. Kakuhenzire, P.M. Kinyae, M. Nyongesa, P.C. Struik, and C. Leeuwis, 2009. "Improving Potato Production in Kenya, Uganda and Ethiopia: A System Diagnosis," *Potato Research*, 52:173-205.

GoK. 2007. Government of the Republic of Kenya. 2007 www.vision2030.go.ke.

GoK. 2010. Government of the Republic of Kenya. 2010. The Agric Sector Development Strategy. Nairobi

GoK. 2012. Government of the Republic of Kenya. National Agribusiness Strategy, 2012. Nairobi.

Government of the Netherlands. 2011. Shift from Aid to Trade and Investment in Africa. https://www.government.nl/latest/news/2011/09/19/shift-from-aid-to-trade-and-investment-in-africa.

Gray, C., and E. Wise. 2016. "Country-Specific Effects of Climate Variability on Human Migration," *Climatic Change*, 135(3-4):555-568.

Guilpart, N., P. Grassini, J. van Wart, H. Yang, M.K. van Ittersum, L.G.J. van Bussel, J. Wolf, L. Claessens, J.G.B. Leenaars, and K.G. Cassman. 2017. "Rooting for Food Security in Sub-Saharan Africa," *Environmental Research Letters* 12, IOP publishing, 114036.

Hall, N. 2017. "What is Adaptation to Climate Change? Epistemic Ambiguity in the Climate Finance System," *International Environmental Agreements-Politics Law and Economics*, 17(1):SI:37-53.

Harris, F., and M.A. Yusuf. 2001. "Manure Management by Smallholder Farmers in the Kano Close-Settled Zone, Nigeria," *Experimental Agriculture*, 37(3):319-332.

Hengl, T., J.G.B. Leenaars, K.D. Shepherd, M.G. Walsh, G.B.M. Heuvelink, T. Mamo, H. Tilahun, E. Berkhout, M. Cooper, E. Fegraus, I. Wheeler, and N.A. Kwabena. 2017b. "Soil Nutrient Maps of Sub-Saharan Africa: Assessment of Soil Nutrient Content at 250 m Spatial Resolution using Machine Learning," *Nutrient Cycling in Agroecosystems*, 109:77-102. doi:/10.1007/s10705-017-9870-x.

Hengl, T., J. Mendes de Jesus, G.B.M. Heuvelink, M. Ruiperez Gonzalez, M. Kilibarda, A. Blagotić, W. Shangguan, M.N. Wright, X. Geng, B. Bauer-Marschallinger, M.A. Guevara, R. Vargas, R.A. MacMillan, N.H. Batjes, J.G.B. Leenaars, E. Ribeiro, I. Wheeler, S. Mantel, and B. Kempen. 2017a. SoilGrids250m: Global gridded soil information based on machine learning. PLoS ONE 12(2): e0169748. doi:/10.1371/journal.pone.0169748.

Hengl, T., G.B.M. Heuvelink, B. Kempen, J.G.B. Leenaars, M.G. Walsh, K. Shepherd, A. Sila, R.A. MacMillan, J. Mendes de Jesus, L. Tamene, and J.E. Tondoh. 2015. "Mapping Soil Properties of Africa at 250 m Resolution: Random Forests Significantly Improve Current Predictions," PLoS One 10(6). doi:10.1371/journal.pone.0125814.

Horton, D.E. 1987. *Potatoes: Production, Marketing and Programmes for Developing Countries*, International Potato Centre.

Guyton, B., F. Sogo, J. Mogire, and R. Njuguna. 1994. *Kenya's Irish Potato Sub-Sector. Characteristics, Performance and Participants' Information Needs*, Ministry of Agriculture Kenya.

International Organization for Migration (IOM). 2016. "Statistical Report Overview. Niger Flow Monitoring Points," http:/www.globaldtm.info/dtm-niger-flow-monitoring-statistical-reportnovember-2016/.

Janssens, S.R.M., S.G. Wiersema, H. Goos, and W. Wiersma. 2013. "The Value Chain for Seed and Ware Potatoes in Kenya: Opportunities for Development," LEI Memorandum 13-080.

Jayne, T.S., J. Govereh, M. Wanzala, and M. Demeke. 2003. "Fertilizer Market Development: A Comparative Analysis of Ethiopia, Kenya, and Zambia," *Food Policy*, 28:293-316.

Jayne, T.S., J. Nyoro, and T. Yamano. 2004. "Interlinked Credit and Farm Intensification: Evidence from Kenya," *Agricultural Economics*, 31(2):209-218.

Iizumi, T., and N. Ramankutty. 2016. "Changes in Yield Variability of Major Crops for 1981-2010 Explained by Climate Change," *Environmental Research Letters* 11(3): Article Number 034003.

InterAcademy Council. 2004. "Realizing the Promise and Potential of African Agriculture. Science and technology Strategies for Improving Agricultural Productivity in Africa," InterAcademy Council (IAC) report.

IOM, 2015. Migration in Kenya, A Country Profile 2015. International Organization for Migration, Nairobi.

Kabubo-Mariara, J., and M. Kabara. 2015. Climate Change and Food Security in Kenya. Environment for Development. Discussion Paper Series. EfD DP 15-05. (not peer reviewed)

Kaizzi, K.C., M.B. Mohammed, and M. Nouri. 2017. Fertilizer Use Optimization: Principles and Approach. In: Fertilizer Use Optimization in sub-Saharan Africa. Charles S. Wortmann and Keith Sones (eds). CAB International, Nairobi, Kenya, pp. 9-19.

Kamau, M., M. Smale, and M. Mutua. 2014. "Farmer Demand for Soil Fertility Management Practices in Kenya's Grain Basket," *Food Sec.*, 6:793-806. doi:10.1007/s12571-014-0398-5.

Keino, L., F. Baijukya, W. Ng'etich, et al. 2015. "Nutrients Limiting Soybean (glycine max l) Growth in Acrisols and Ferralsols of Western Kenya," Plos One 10(12):e0145202.

Kibunja, C.N., K.W. Ndungu-Magiroi, D.K. Wamae, T.J. Mwangi, L. Nafuma, M.N. Koech, J. Ademba, and E.M. Kitonyo. 2017. "Optimizing Fertilizer Use within the Context of Integrated Soil Fertility Management in Kenya," In: *Fertilizer Use Optimization in Sub-Saharan Africa*, pp. 82-99, C.S. Wortmann and K. Sones (Eds.), CAB International, Nairobi, Kenya.

Kihara, J., G. Nziguheba, S. Zingore, et al. 2016. "Understanding Variability in Crop Response to Fertilizer and Amendments in Sub-Saharan Africa," *Agriculture, Ecosystems & Environment*, 229:1-12.

Leenaars, J.G.B., T. Hengl, M. Ruiperez Gonzalez, J. Mendes de Jesus, G.M.B. Heuvelink, J. Wolf, L. van Bussel, L. Claessens, H. Yang, and K.G. Cassman. 2015. *Root Zone Plant-Available Water Holding Capacity of the Sub-Saharan Africa Soil*, version 1.0. Gridded functional soil information (dataset RZ-PAWHC SSA v. 1.0). ISRIC report 2015/02. Collaboration project of Africa Soil Information Service (AfSIS) and Global Yield Gap and Water Productivity Atlas (GYGA). ISRIC – World Soil Information, Wageningen (www.isric.org/projects/afsis-gyga-functional-soil-information-sub-saharan-africa-rz-pawhc-ssa).

Lekasi, J.K., J.C. Tanner, S.K. Kimani, and P.J.C. Harris. 2003. "Cattle Manure Quality in Maragua District, Central Kenya: Effect of Management Practices and Development of Simple Methods of Assessment," *Agriculture, Ecosystems & Environment*, 94(3):289-298.

Lupwayi, N.Z., M. Girma, and I. Haque. 2000. "Plant Nutrient Contents of Cattle Manures from Small-Scale Farms and Experimental Stations in the Ethiopian Highlands," *Agric. Ecosyst. Environ.*, 78:57-63.

Mahendran, P.P., R. Velmurugan, and P. Balasubramaniam. 2016. "Identifying Critical Limit in Soil and Plant for Determining Response of Groundnut (Arachis hypogea) to Boron Application in Madurai Soils of Tamil Nadu, India," *Journal of Plant Nutrition*, 39(2):163-171.

Mallarino, A.P., J.E. Sawyer, and S.K. Barnhart, 2013. *A General Guide for Crop Nutrient and Limestone Recommendations in Iowa*, Iowa State University.

Mati, B.M. 2000. "The Influence of Climate Change on Maize Production in the Semi-Humid-Semi-Arid Areas of Kenya," *Journal of Arid Environments*, 46(4):333-344.

McArthur, J.W., and G.C. McCord. 2014. *Fertilising Growth: Agricultural Inputs and Their Effects in Economic Development*, Global Economy and Development Working Paper No. 77, Brookings Institute, Washington, D.C.

MacKerron, D.K.L., and A.J. Haverkort. 2004. *Decision Support Systems in Potato Production - Bringing Models to Practice*, Wageningen Academic Publishers, Wageningen.

Mbithi, L.M. 2000. "Agricultural Policy and Maize Production in Kenya," Univ. Gent, PhD. Thesis.

Ministry of Agriculture, Livestock and Fisheries. 2015 (revised). *Strategic Plan 2013-2017. Kenya Vison 2030. Towards an Innovative, Commercially Oriented and Modern Agriculture*, Republic of Kenya.

Ministry of Foreign Affairs. 2013. *Zero Hunger, Zero Malnutrition. New Inroads Towards Food and Nutrition Security*.

Minten, B., B. Korub, and D. Stifel. 2013. "The Last Mile(s) in Modern Input Distribution: Pricing, Profitability, and Adoption," *Agricultural Economics*, 44:629-646.

Miriti, J.M., G. Kironchi, A.O. Esilaba, et al. 2012. "Yield and Water Use Efficiencies of Maize and Cowpea as Affected by Tillage and Cropping Systems in Semi-Arid Eastern Kenya," *Agricultural Water Management*, 115:148-155.

Montalvo, D., F. Degryse, R.C. da Silva, R. Baird, and M.J. McLaughlin. 2016. "Agronomic Effectiveness of Zinc Sources as Micronutrient Fertilizer," *Advances in Agronomy*, 139:215-267.

Mulwa, R., K.P.C. Rao, S. Gummadi, et al. 2016. "Impacts of Climate Change on Agricultural Household Welfare in Kenya," *Climate Research*, 67(2):87-97.

Munshaw, G., and E. Ritchey. 2014. *Liming Kentucky Lawns*, Department of Plant and Soil Science. College of Agriculture, Food and Environment. University of Kentucky. AGR-214

Muthoni, J., M. Mbiyu and J.N. Kabira, 2011. Up-scaling production of certified potato seed tubers in Kenya: Potential of aeroponics technology. J. Horticulture and Forestry 3(8): 238-243.

Muriuki, A.W., and S.M. Kanyanjua. 1995. "Fertilizer Use Recommendation Project (FURP)," Proceedings of the Training Workshop at the National Agricultural Research Laboratories, Kabete, Febr. 8-9.

Ng'ang'a, S.K., E.H. Bulte, K.E. Giller, J.M. McIntire, and M.C. Rufino. 2016. "Migration and Self-Protection Against Climate Change: A Case Study of Samburu County, Kenya," *World Development*, 84:55-68.

Ngome, A.F., M. Becker, M.K. Mtei, and F. Mussgnug. 2013. "Maize Productivity and Nutrient Use Efficiency in Western Kenya as Affected by Soil Type and Crop Management," *International Journal of Plant Production*, 7(3):1735-6814.

Njoroge, S., A.G.T. Schut, K.E. Giller, and S. Zingore. 2017. "Strong Spatial-Temporal Patterns in Maize Yield Response to Nutrient Additions in African Smallholder Farms," *Field Crops Research*, 214:321-330.

OECD-DAC. 2015. *Aid to Agriculture and Rural Development*. https://www.oecd.org/dac/stats/documentupload/Aid%20to%20agriculture%20and%20rural%20development%20data.pdf.

Oiko Credit. 2010. *Financial Services in Agriculture Value Chain Report: A Study of Five Kenyan Sub-Sectors Namely Potato, Dairy, Coffee, Extensive Livestock and Domestic Horticulture*.

Okalo, A.J., and K. Zechernitz. 1971. "The FAO Fertilizer Program in Kenya," In: *Improving Soil Fertility in Africa*, FAO Soils Bulletin 14, Rome, Italy.

Omamo, S.W., and L.O. Mose. 2001. "Fertilizer Trade Under Market Liberalization: Preliminary Evidence from Kenya," *Food Policy*, 26:1-10.

Padwick, G.W. 1983. "50 Years of Experimental-Agriculture. 2. The Maintenance of Soil Fertility in Tropical Africa – A Review," *Experimental Agriculture*, 19(4):293-310.

Rasnake, M., and L. Murdock, 1987. "Liming Acid Soils," Leaflet AGR-19, Department of Agronomy, University of Kentucky.

Recke, H., H.F. Schnier, S. Nabwile, et al. 1997. "Responses of Irish potatoes (Solanum tuberosum L) to Mineral and Organic Fertilizer in Various Agro-Ecological Environments in Kenya," *Experimental Agriculture*, 33(1): 91-102.

Rietra, R.P.J.J., M. Heinen, C.O. Dimkpa, and P.S. Bindraban. 2017. "Effects of Nutrient Antagonism and Synergism on Yield and Fertilizer Use Efficiency," *Communications in Soil Science and Plant Analysis*, 48:16, 1895-1920.

Roy, A. 2007. "Fertilizer and Agricultural Intensification: IFDC Experience," Fertilizer Association of India Annual Seminar, New Delhi. India.

Sanchez P.A., C.A. Palm, S.W. Buol, 2003. Soil fertility capability classification: a tool to help assess soil quality in the tropics. Geoderma 114: 157-185

Santos, G.A., G.H. Korndorfer, and H.S. Pereira. 2016. "Methods of Adding Micronutrients to a NPK Formulation and Maize Development," *Journal of Plant Nutrition*, 39(9):1266-1282.

Sheahan, M., J. Ariga, and T. S. Jayne, 2016. "Modeling the Effects of Input Market Reforms on Fertiliser Demand and Maize Production: A Case Study from Kenya," *Journal of Agricultural Economics*, 67(2):420-447, doi:10.1111/1477-9552.12150.

Shukla, A.K., P.S. Babu, P.K. Tiwari, C. Prakash, A.K. Patra, and M.C. Patnaik. 2015. "Mapping and Frequency Distribution of Current Micronutrient Deficiencies in Soils in Telangana for Their Precise Management," *Indian Journal of Fertilisers*, 11:33-43.

State Department of Agriculture. Economic Review of Agriculture (ERA). 2015. Nairobi.

Tamene, L., P. Mponela, G. Ndengu, and J. Kihara. 2016. Assessment of Maize Yield Gap and Major Determinant Factors Between Smallholder Farmers in the Dedza District of Malawi," *Nutrient Cycling in Agroecosystems*, 105(3-SI):291-308.

van Ittersum, M.K., L.G.J. van Bussel, J. Wolf, et al. 2016. Can Sub-Saharan Africa Feed Itself? *PNAS*, 113(52):14964-14969.

Vanlauwe, B., J. Kihara, P. Chivenge, P. Pypers, R. Coe, and J. Six. 2011. "Agronomic Use Efficiency of N Fertilizer in Maize-Based Systems in Sub-Saharan Africa Within the Context of Integrated Soil Fertility Management," *Plant and Soil*, 339(1-2):35-50.

van Ittersum, M.K., and R. Rabbinge. 1997. "Concepts in Production Ecology for Analysis, Quantification of Agricultural Input-Output Combinations," *Field Crops Res.*, 5:197-208.

Vlek, P.L.G. 1990. "The Role of Fertilizers in Sustaining Agriculture in Sub-Saharan Africa," *Fertilizer Research*, 26(1-3):327-339.

Voortman, R., and P.S. Bindraban. 2015. "Beyond N and P: Toward a Land Resource Ecology Perspective and Impactful Fertilizer Interventions in sub-Saharan Africa," VFRC Report 2015/1, Virtual Fertilizer Research Center, Washington, D.C.

Waiyaki, N. 2006. "Determinants of Seed Maize Pricing in Kenya. Production Risk and Farm Technology Adoption in Rain-Fed Maize Production," Kenya Econ. Report. Publications Catalogue. KIPPRA.

Wakeyo, M.B., and C. Gardebroek. 2013. "Does Water Harvesting Induce Fertilizer Use Among Smallholders? Evidence from Ethiopia," *Agricultural Systems*, 114:54-63.

Wani, S.P., G. Chander, K.L. Sahrawat, and G. Pardhasaradhi. 2015. "Soil-Test-Based Balanced Nutrient Management for Sustainable Intensification and Food Security: Case from Indian Semi-Arid Tropics," *Communications in Soil Science and Plant Analysis*, 46(S1):20-33.

Wanzala, M. 2001. "Fertilizer Markets and Agricultural Production Incentives: Insights from Kenya," Background document for the Tegemeo Institute Agricultural Monitoring and Policy Analysis Conference on Poverty, Technology and Competitiveness, September 6, Nairobi, Kenya.

Wasaya, A., M.S. Shabir, M. Hussain, M. Ansar, A. Aziz, W. Hassan, and I. Ahmad. 2017. "Foliar Application of Zinc and Boron Improved the Productivity and Net Returns of Maize Grown Under Rainfed Conditions of Pothwar Plateau," *Journal of Soil Science and Plant Nutrition*, 17(1):33-45.

Webber, F. 2017. "Europe's Unknown War," *Race & Class*, 59(1):36-53.

Wineman, A., N.M. Mason, J. Ochieng, and L. Kirimi. 2017. "Weather Extremes and Household Welfare in Rural Kenya," *Food Security*, 9(2):281-300.

World Economic Forum, World Bank, and African Development Bank. 2017. The Africa Competitiveness Report 2017. http://www3.weforum.org/docs/WEF_ACR_2017.pdf.

World Bank. 2017. World Development Indicators, FAO, https://data.worldbank.org/indicator/AG.LND.CROP.ZS?locations=ZG.

Wuenscher, R., H. Unterfrauner, R. Peticzka, and F. Zehetner, 2015. "A Comparison of 14 Soil Phosphorus Extraction Methods Applied to 50 Agricultural Soils from Central Europe," *Plant Soil Environ.*, 61(2):86-96.

Yamano, T., and A. Arai. 2010. "Fertilizer Policies, Price and Application in East Africa," National Graduate Institute for Policy Studies. Discussion Paper: 10-24.

Appendix I. Fertilizer Import, Export, and Consumption Kenya (tons)

Year	Import	Export	Consumption	Import	Export	Consumption
	Urea			Other nitrogen & phosphates compounds		
2010	62,964	10,704	75,257	840	228	612
2011	18,103	1,032	117,707	4,399	163	4,236
2012	85,961	4,081	47,577	100	56	44
2013	118,739			75	1,034	0
2014	51,658			260	166	94
	Ammonium nitrate			Other nitrogen & phosphorus compounds		
2010	4,442	1,187	3,255	1,127	81	1,046
2011	8,881	684	8,197	33,094	396	32,698
2012	5,614	475	5,139	10,139	141	9,998
2013	4,786	18	4,768	26,077	8	26,069
2014	5,775	492	5,283	62	219	0
	Ammonium sulfate			PK compounds		
2010	7,513	71	7,442	0	0	0
2011	7,545	212	7,333	727	367	360
2012	9,986	38	9,948	831	86	745
2013	10,334	26	10,308	647	0	647
2014	19,474	109	19,365	705	278	427
	Calcium ammonium nitrate (CAN)			Potassium chloride (Muriate of potash)		
2010	5,559	74	5,485	562	309	253
2011	143,777	0	143,777	598	318	280
2012	68,693	0	68,693	3,405	191	3,214
2013	13,410	1	13,409	975	2	973
2014	71,567	472	71,095	6,017	393	5,624
	Diammonium phosphate (DAP)			Potassium nitrate		
2010	135,413	1,897	133,516	6,025	262	5,763
2011	147,602	899	146,703	5,201	381	4,820
2012	156,966	396	156,570	5,488	100	5,388
2013	219,715	434	219,281	2,886	0	2,886
2014	16,154	27	16,127	5,115	27	5,088
	Monoammonium phosphate (MAP)			Potassium sulfate		
2010	823	867	0	1,917	42	1,875
2011	420	57	363	1,229	15	1,214
2012	659	106	553	1,900	9	1,891
2013	53,406	7	53,399	369	37	332
2014	3,298	16	3,282	73	28	45
	NPK complex <=10kg			Superphosphate		
2010	0	178	0	1,550	7075	0
2011	11,169	30	11,139	2,754	885	1,869
2012	1,439	3	1,436	2,476	90	2,386
2013	132	12,116	0	0	0	0
2014	603	34	569	0	0	0
	NPK complex >10kg					
2010	122,660	11,910	110,750			
2011	195,810	7,165	188,645			
2012	180,071	4,927	175,144			
2013	141,699	7,847	133,852			
2014	23,451	13,174	10,277			

Source: FAOSTAT, January 2018.

Appendix II. SoilGrids for Kenya Available to Green Deal, Metadata

Series: references:

- Africa SoilGrids: Hengl T., Leenaars J.G.B., et al., 2017.
- AfSIS-GYGA (RZ-PAWHC-SSA): Leenaars J.G.B., Hengl T., et al., 2015.
- SoilGrids (PTF based on AfSIS-GYGA): Hengl T., Mendes de Jesus J.S., et al., 2017. Based on: Leenaars J.G.B., Hengl T., et al., 2015.
- SoilGrids: Hengl T., Mendes de Jesus J.S., et al., 2017.

List of maps available

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Series	Description	Format	Resolution	Extent	Projection
Africa SoilGrids	Extractable Al for 0-30 cm depth in ppm	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
Africa SoilGrids	Extractable B for 0-30 cm depth in ppm (*)	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
Africa SoilGrids	Extractable Ca for 0-30 cm depth in ppm	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
Africa SoilGrids	Extractable Cu for 0-30 cm depth in ppm (*)	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
Africa SoilGrids	Extractable Fe for 0-30 cm depth in ppm	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
Africa SoilGrids	Extractable K for 0-30 cm depth in ppm	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
Africa SoilGrids	Extractable Mg for 0-30 cm depth in ppm	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
Africa SoilGrids	Extractable Mn for 0-30 cm depth in ppm	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
Africa SoilGrids	Extractable N for 0-30 cm depth in ppm	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
Africa SoilGrids	Extractable Na for 0-30 cm depth in ppm	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
Africa SoilGrids	Extractable P for 0-30 cm depth in ppm (*)	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
Africa SoilGrids	Extractable Zn for 0-30 cm depth in ppm (*)	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
Africa SoilGrids	Total P for 0-30 cm depth in ppm	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
AfSIS-GYGA (RZ-PAWHC-SSA)	ERZD: Rootable depth in cm for Maize	GeoTiff	1 km	Kenya; 2 target regions in Kenya	UTM 37 N

Series	Description	Format	Resolution	Extent	Projection
SoilGrids	BLDFIE_M_agg30cm: Bulk density in kg / cubic-meter of fine earth aggregated 0-30 cm	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
SoilGrids	CECSOL_M__agg30cm: Cation exchange capacity of fine earth in cmolc/kg aggregated 0-30 cm	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
SoilGrids	CLYPPT_M__agg30cm: Clay content (0-2 micro meter) as mass fraction (%) of fine earth aggregated 0-30 cm	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
SoilGrids	CRFVOL_M__agg30cm: Coarse fragments content as volumetric fraction (%) of whole earth aggregated 0-30 cm	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
SoilGrids	PHIHOX_M__agg30cm: Soil pH x 10 in H2O aggregated 0-30 cm	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
SoilGrids	PHIKCL_M__agg30cm: Soil pH x 10 in KCl aggregated 0-30 cm	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
SoilGrids	SLTPPT_M__agg30cm: Silt content (2-50 micro meter) as mass fraction (%) of fine earth aggregated 0-30 cm	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
SoilGrids	SNDPPT_M__agg30cm: Sand content (50-2000 micro meter) as mass fraction (%) of fine earth aggregated 0-30 cm	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
SoilGrids	TEXMHT_M_sl1: Texture class (USDA system) at depth 0.00 m	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
SoilGrids	TEXMHT_M_sl2: Texture class (USDA system) at depth 0.05 m	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
SoilGrids	TEXMHT_M_sl3: Texture class (USDA system) at depth 0.15 m	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
SoilGrids	TEXMHT_M_sl4: Texture class (USDA system) at depth 0.30 m	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
SoilGrids	TEXMHT_M_sl5: Texture class (USDA system) at depth 0.60 m	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
SoilGrids	TEXMHT_M_sl6: Texture class (USDA system) at depth 1.00 m	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
SoilGrids	TEXMHT_M_sl7: Texture class (USDA system) at depth 2.00 m	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
SoilGrids (PTF based on AfSIS-GYGA)	AWCh2_M_agg30cm: Derived available water holding capacity as volumetric fraction (%) of fine earth, with FC = pF 2.3, aggregated 0-30 cm	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
SoilGrids (PTF based on AfSIS-GYGA)	AWCtS_M_agg30cm: Water content at saturation (pF 0.0) as volumetric fraction (%) of fine earth aggregated 0-30 cm	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
SoilGrids (PTF based on AfSIS-GYGA)	PWP_M_agg30cm: Water content at permanent wilting point (pF 4.2) as volumetric fraction (%) of fine earth aggregated 0-30 cm	GeoTiff	250 m	Kenya; 2 target regions in Kenya	UTM 37 N
Sotwis Database	SOTER-based soil property estimates for Kenya	Shapefile + database	---	Kenya; several thematic layers	WGS84

* These maps were produced with values in pp100m (mg/100 kg) and divided by 100 to convert to values in ppm (mg/kg).

Appendix III. Maize Value Chain

Maize is the main staple in the diet of over 85% of the population in Kenya. It is grown by over 80% of the farming households in Kenya. The country produces about 26 million bags annually against a consumption of 36 million bags. Maize, therefore, is associated with food security in Kenya to the extent that when there is a shortfall in maize production, the country is food insecure. Maize production, marketing, and processing have undergone several reforms since the 1980s. The government policy in the maize subsector has been to provide incentives for increased production to ensure food self-sufficiency and security while providing appropriate support to local farmers to get good returns so that they can remain in maize production. Despite these reforms, food insecurity has remained a challenge. Maize yields achieved by Kenyan farmers across the major agro-ecological zones are much lower than the yield potential (Pingali and Pandey, 2000; Waiyaki et.al., 2006).

1. Main Areas of Production

The largest producing counties of maize are located in the North Rift, Central Rift, and South Rift Regions of Kenya, where both large- and small-scale production takes place. Small-scale production accounts for about 70% of the overall production. The remaining 30% of the output is from large-scale commercial producers (Export Processing Zone Authority, 2005). Small-scale producers mainly grow the crop for subsistence, retaining up to about 58% of their total output for household consumption (Mbithi, 2000) with the balance available for sale.

2. Maize Production Characteristics

Maize production is dominated by smallholder farming system, characterized by intercropping and, to some extent, relay cropping. Approximately 3.5 million small-scale farmers (the majority) are involved in maize production, accounting for 75% of the total maize crop while 1,000 large-scale farmers produce the remaining 25% of the production. Maize productivity is low under smallholder systems as a result of land fragmentation, a situation that is inimical to profitable farming. The system is characterized by low mechanization, with most farming activities conducted manually, adding drudgery.

Typical smallholder maize farm

Currently, land under maize production in Kenya is defined in three classes of land sizes: smallholder production, <5 ha; medium-scale farm holders, 5-20 ha; and large-scale farm holders, above 20 ha. Maize is grown across a wide range of environments from the coastal lowlands (10-1,000 meters above sea level) to the highlands (1,800-2,800 meters above sea level). Maize is optimally produced in the medium to highland agro-ecological zones. In semi-arid areas, where drought is cyclic, occurring after every 5-7 years, productivity is limited by moisture and/or heat stress. The hardest hit areas are usually the agriculturally marginal zones; these latter areas rely on the short rain season as their major food crop growing period. This period provides up to 70% of the annual output. Table 1 shows recent trends in maize production.

Table 1. Maize Production Trends

	Variable	2010	2011	2012	2013	2014
Kenya	Area (kha)	2,008	2,132	2,159	2,123	2,116
	Production (ktons)	3,465	3,377	3,750	3,593	3,513
	Yield (t/ha)	1.7	1.6	1.7	1.7	1.7
Trans Nzoia	Area (kha)			104.4	105.3	106.8
	Production (ktons)			432.3	425.3	451.3
	Yield (t/ha)			4.1	4.0	4.2
Uasin Gishu	Area (kha)			91.3	88.8	96.7
	Production (ktons)			257.6	363.6	380.3
	Yield (t/ha)			2.8	4.1	3.9
Nandi	Area (kha)			73.6	70.5	74.0
	Production (ktons)			217.4	170.0	167.2
	Yield (t/ha)			3.0	2.4	2.3

Source: Economic Review of Agriculture, 2012; 2015.

As shown in Annex VII, farmers obtain a positive gross margin by growing maize at current technological levels and prevailing marketing conditions.

3. Maize Marketing Characteristics

Marketing and trade of maize in Kenya are limited only to the domestic channel since the country is a net importer of maize. Most of the imports originate from Tanzania and Uganda. Internal trade utilizes the National Cereal and Produce Board (NCPB), which assists the farmers in the collation of the produce and quality control, serves as one of the maize markets, and warehouses the national strategic grain reserve. The maize market in Kenya includes the following market segments: maize flour, grain maize, green maize, seed maize, corn (maize) oil, and livestock feed.

The main marketing channels include:

- Small-scale farmers selling maize grain to local households, posho millers (hammer millers), and small and medium local traders.
- Small traders including local shopkeepers selling maize grain to consumers.
- Posho millers selling flour to local household consumers.
- Small and medium local traders selling maize grain to posho millers and regional traders.
- Medium-to-large farmers and regional traders selling maize to flour millers, NCPB, and animal feed manufacturers.
- Maize importers selling maize flour to millers and NCPB.
- NCPB selling maize to millers, large private and public-sector institutions.
- Maize exporters (private companies and NCPB) as well as maize millers selling maize grain to regional maize dealers (during periods of surplus – albeit limited in recent years).

- Maize millers selling flour to wholesalers and retailers including supermarkets.
- Retailers, including supermarkets, selling maize flour to household consumers, hotels, and restaurants.

The bulk of the maize is traded as dry-shelled grain. The main players in dry maize marketing include the NCPB, large and small-scale millers, and commodity traders. The NCPB purchases on behalf of government.

Due to the frequent shortages of maize grain and high costs of maize meal, the government often intervenes in the maize industry by providing incentives to farmers while ensuring consumers get maize meal at affordable prices. The most important market segments for maize are grain, maize flour, and seed maize.

The determination of maize grain and flour prices has been an issue of intense policy debate. Some of the questions posed are: What should be the appropriate/fair maize producer price? What should this price be based on? How does it compare with the import price of maize? On the other hand, what would be an affordable price of maize meal to consumers? What should be the government's role in the maize market? These are some of the questions which show the importance of the maize products value chain.

Challenges

Most maize marketing regions in Kenya are constrained by fragmented and small land holdings, infrastructural, production and marketing inadequacies, and extremely low private sector investment. Due to continuous production of maize on the same piece of land, soil degradation has been inevitable. Fertilizer application rates are often below the recommended rates with di-ammonium phosphate (DAP) as the most commonly used fertilizer, now perceived to be contributing to soil acidity and low or no crop response to added fertilizers.

4. Maize Consumption

National maize production ranges between 3.4 and 3.8 million tons per annum (Economic Review of Agriculture, 2015). However, this level of production has not kept pace with consumption levels over the years. Maize consumption in Kenya is estimated at 98 kilograms per person per year (FAO, 2008; MoA, 2010; Jayne *et.al.*, 2005). Currently (2016), the National Strategic Grain Reserves are pegged at 8 million 90-kg bags.

5. Availability and Access to Inputs and Credit, Inputs, Improved Technologies, and Services

Availability of and Access to Inputs

After market liberalization, the maize seed sector is thriving, and seed prices have remained stable. The effect of the liberalization on the fertilizer industry, on the other hand, increased the distribution and availability of this essential input (Roy, 2007; Omamo and Mose, 2001; Wanzala, 2001). The government is still active through the National Cereal and Produce Board (NCPB), which imports fertilizer for the direct sale to farmers at subsidized prices.

Availability of and Access to Research Services

Research services are organized and provided by public, private, and international organizations. They are inadequate and tend to be donor-driven. The National Agricultural Research System (NARS) is the umbrella body that coordinates agricultural research in Kenya. The Kenya Agricultural and Livestock Research Organization (KALRO) is the premier research organization in the country. To-date, KALRO has developed over 64 maize varieties. More than half of the varieties have been licensed to seed companies for commercialization. Additionally, many agronomic technological packages have been developed to tap the genetic potential of these improved varieties.

Availability of and Access to Extension and Training

The government has adopted an all-inclusive extension policy that includes both public and private extension providers. Under the 2010 Constitution of Kenya, extension services are devolved. Therefore, the main extension service providers are the county governments, non-governmental organizations, seed companies, farm input suppliers, and farmer-based organizations. However, the services remain inadequate with few extension agents accessible to farmers, using traditional extension approaches/methods. Efforts toward use of modern information communication technology (ICT) have emerged to share information on technologies, input and output markets, among others.

6. Public-Private Partnership (PPP) Actors in Maize Subsector Development

Private sector players are largely credited with the subsector's growth, with government playing an advisory role. The private sector firms include large-scale farmers and smallholder farmers (majority), farmers' organizations (KENAFF), Seed Trade Association of Kenya (STAK), seed companies, Cereal Growers Association (CGA), Cereal Millers Association (CMA), local and international NGOs (TechnoServe), FBOs, finance providers (AFC, Equity, Family Bank), farm input providers (KFA, agro-chemical companies, Athi River Mining), NCPB, KACE, EABL, policy institutes (Tegemeo, KIPPRA, IPAR), business development service providers, processors and industrial firms. The public sector players include relevant Government Ministries (Agriculture, Livestock and Fisheries; National Treasury), the local universities, KIPI, KALRO and KEPHIS. In the process, many documents have been prepared to guide the implementation of various initiatives; these include Irrigation Policy, Seed Industry Policy, Seed Regulations, and various value chain strategic plans.

7. Maize Value Chain Analysis

Introduction

The importance of maize product value chain analysis is to identify major constraints limiting productivity, commercialization, and competitiveness in order to plan interventions involving private-public partnerships.

Maize Value Chain Mapping

The value chain map identifies the functions, segments, activities, key stakeholders or actors, and product flow and shows the linkages and governance structure identifying who controls the value chain and where investment would result in a change in the value chain.

Quantification and Description of Maize Product Value Chain

Functions: The functions include input provision, production, processing, wholesale, retail, and consumption.

Market Segments: The maize value chain has six main segments: (1) Segment One: Maize Seed: Registered seed merchants produce maize seed and it is inspected by regulatory bodies, processed and packaged, and sold to distributors and to wholesalers and retailers who sell to consumers; (2) Segment Two: Maize Grain: Production of maize by farmers is sold as maize grain to NCPB/ distributors for later utilization in different ways; (3) Segment Three: Green Maize: Farmers produce green maize and sell to the wholesalers and retailers who move the green maize to the markets and finally to consumers; (4) Segment Four: Maize Flour: Farmers produce maize grain with the support of researchers who generate the production technologies, the extension agents who provide advice on the best farming practices, the agro-vet shop-keepers who retail farm inputs, seed companies that supply seeds, the importers who supply farm equipment and machinery, and the distributors and retailers who move the final maize produce (grain) to the markets. The maize is sold, in some cases, directly to the consumers and, sometimes through middlemen, to the NCPB. Traders (small-, medium- and large-scale) sell maize to NCPB. The NCPB sells mainly to millers and also directly to the consumers (NGOs and institutions). Millers then produce flour for sale directly to wholesalers and retailers and sometimes consumers; (6) Segment Five: Maize oil: At processing, millers after produce flour. The maize germ is separated, then used to produce oil, which is then sold, for sale, directly to wholesalers and retailers and sometimes consumers; (6) Segment Six: Livestock Forage: The stover remaining in the fields and bran from processing are sold to livestock farmers.

Key Stakeholders – Actors and Supporters: The key stakeholders (actors, supporters, and enablers) in the maize agriculture product value chain include input suppliers, research and extension institutions, the media, output marketing institutions, such as National Cereals and Produce Board, millers, and regulating institutions such as KEPHIS and KEBS.

Linkages and Governance: Generally, maize linkages are well-structured such that every player has a defined role, resulting in strong linkages. However, seed merchants influence grain and seed production, while KEPHIS controls the quality of seed, PCPB controls the quality of pesticides, and NCPB controls the quantity and quality of the grain in the market. As it is, all the bodies play critical roles, but NCPB is the chain leader being the significant purchaser of grains from farmers.

SWOT Analysis of Maize Value Chain

A Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis of the maize value chain shows several strengths and opportunities in spite of the prevailing weaknesses and threats.

Strengths:

- Technologies and innovations, from a robust KALRO research system, is available.
- A large number of varieties from local and foreign, public and private companies.
- A wide array of farm input (fertilizers/other agro-chemicals) providers available.
- Regulatory measures on farm inputs: seed and fertilizers (KEPHIS) and agro-chemicals (PCPB) available.
- Regulatory measures on farm produce in terms of grain moisture (NCPB), mycotoxins (KEBS) available.

Weaknesses:

- Infrastructure (rural road network) is poor, contributing to high transaction costs.
- The cost of fertilizer is high, leading to high cost of production.
- Fertilizer application rates are based on "blanket" recommendations; not crop- or region-specific.
- Price of maize grain is largest contributor to the cost of producing maize meal.

Opportunities:

- Fertilizer blends now available; region- and crop-specific fertilizer application can be done.
- Encourage formation of marketing groups/associations by small traders to reduce operating costs through exploitation of economies of scale.
- Avoid setting of producer price that does not reflect costs of production and marketing situation.
- Enforcement of inspectorate issues of different agricultural acts relevant to private sector development.
- While the NCPB will be expected to continue with its primary objective of storing strategic reserves that are meant to stabilize the supply, demand, and incomes from the grain, this should be done alongside the promotion of warehousing receipts already promoted in the North Rift by the Kenya Maize Development Program; this system allows farmers to store and market their own produce as need arises. At the same time, secure input loans when need arises: this system, if promoted well, may mature to contracting arrangements between millers and producers without the government having to intervene on supply and demand shifts.
- Foster Insurance Scheme Development for agriculture.

Threats:

- Erosion of genetic diversity (narrowed gene-base) due to various reasons, which limits the scope of plant breeding.
- Adulteration of seed maize (compromising quality) by unscrupulous middlemen.
- Yield losses from ravages of biotic (pests and diseases) and abiotic stresses (drought, acid, and sodic soils).
- Distortion of the maize market by unscrupulous middlemen.
- International trade rules set by the World Trade Organization, to which Kenya is signatory, may pose limitations to Kenya's competitive trading edge.
- Maize meal prices rising faster than maize grain prices (uncertainty to millers). The price of 2.5 kg maize grain needed to produce 2.0 kg of maize meal accounts for 42% of the total price of the maize meal.

- Hoarding maize produce in anticipation of higher prices, leading to grain spoilage by aflatoxin and other mycotoxins.

8. Conclusions and Recommendations

At 2.0-4.0 tons per hectare (t/ha), on-farm maize productivity is still very low. This has led to a deficit in maize to the tune of almost 1,000,000 t. This deficit must be covered through importation, making the Exchequer to 'part' with a colossal amount of foreign exchange, equivalent to about 330 US million dollars. However, newly developed and release maize varieties, yielding 8.0-10.0 t/ha, are commercially available. The current annual maize production gap of approximately 1 million t may be bridged by getting farmers to adopt new genetically superior varieties and to grow them under good agronomic practices.

Therefore, there is a need to implement the following remedial measures to increase maize productivity and make maize farming a lucrative commercial venture, through active engagement with strategic partners, as follows:

1. Create incentives for input dealers to move to the farmers' proximity or mobilize farmers under "special programs/projects" to come together and provide brokerage services for their members, or to purchase fertilizers in bulk.
2. Carry out a detailed study on the fertilizer trade to disaggregate the cost build-up along the fertilizer chain in order to identify the areas of policy interventions with a view to reducing the fertilizer costs to the farmer.
3. Conduct a more detailed study on the farm enterprise mixes and the strategies maize farmers are adopting to cope with the raising costs of maize production.
4. Conduct a consumer study to assess the changes in food consumption patterns, including diversification to other foods, and the household expenditure budgets going to food given the high food prices.

When maize production reaches its optimal level vis-à-vis consumption, then the laws of supply and demand will establish price levels for producers, millers, and marketers to provide a 'win-win' situation in the maize value chain continuum.

Appendix IV. Potato Value Chain

1. Introduction

Potato (*Solanum tuberosum L.*) is one of the most efficient crops in converting natural resources, labor, and capital into a high-quality food with wide consumer acceptance (Horton, 1987). Potentially, more food value (calories and proteins) can be produced per unit of time, per unit of land and per unit of water with the potato than with any other major food crop. The potato was introduced to Kenya from Europe in the late nineteenth century (Durr and Lorenzl, 1980) and was first grown by African farmers after World War I in the Rift Valley Province in 1920. Production was later expanded to Kiambu, Nyeri and Muranga in Central Province from 1930. Currently, potato production is confined primarily to the highland areas, 2,100 m above sea level. The most important growing areas are Molo/Mau Narok in Nakuru County, western Aberdares and Ol Kalau, Kinangop in Nyandarua County, the eastern Aberdares in Kiambu, Muran'ga, Nyeri and Meru Counties. Potato is also grown in areas such as Nandi Escarpment and Cherangani Hills, Kericho and Kisii Counties, and around Taita Hills under small acreages. Potato is grown by approximately 800,000 small-scale farmers on 150,000 hectares with an average yield of 15-20 t ha^{-1}. The majority of these small-scale famers (approx. 90%) are said to have less than 1 ha.

2. Importance of Potatoes

Potato is a strategic food security crop second only to maize due to its high nutritional value and its adaptation to a wide variety of agro-ecological climates. It is also an important cash crop for many rural and urban Kenyan families and, being labor-intensive, it provides employment in the production to consumption continuum (market agents, transporters, processors and vendors) to approximately 2.5 million people with an annual value of production of approximately U.S. $70 million (Kenya Government, 2015). Annual potato production is about 2.9 million t (Government of Kenya, 2015). Kenya is over 99% self-sufficient in potatoes as imports are minimal at less than 6,000 t annually between 2005 and 2013.

Due to the bulky and perishable nature of potato tubers, post-harvest losses are thought to be a significant problem as potato tubers tend to have a poor shelf life. A recent study estimates losses at 19% along the value chain with 95% of the estimated loss occurring at the production level as a result of inappropriate harvesting tools and an insufficiently trained workforce (GIZ, 2014). Interventions made to reduce post-harvest losses have been in the form of improved stores and training of farmers on appropriate pre- and post-harvest activities.

Potato Production Systems

In Kenya, farming units of all sizes produce potatoes, although the smallest tend to produce primarily for home consumption. Most potato farmers follow a diversification strategy, which may include cultivation of potatoes with a variety of crops, such as maize, beans, peas, carrots and an assortment of farm animals, which may include chicken, goats, sheep and cattle. Smallholder potato farmers rarely own machinery. There is little mechanization in potato production except for land preparation.

Production inputs, particularly fungicides and fertilizers, are utilized at rates that are well below the economic optimum. The main crops competing for resources are pyrethrum, onions, tomatoes, barley, tea, coffee, maize, beans and wheat. Most farmers grow the crop without rotation resulting in build-up of pests and diseases.

Crop husbandry in general is poor and yields are low. Among the more than 60 varieties grown in the country, only a few are widely distributed. Ware potatoes are mainly sold at harvest with storage for future sale seldom practiced. Farmers who produce more potatoes than they can consume or sell at harvest time would benefit from storage. Lack of proper storage is a problem not only among small-scale farmers but also among traders and processors. Storage of ware potatoes is needed during the period between harvest and the time of use of the crop for their own consumption or sale.

Over 90% of potato production is undertaken by women. Most of the potato farmers are aging farmers with hardly any youth involved in potato production. Production standards (e.g., agronomy, pest control, pesticide levels) are not well kept by farmers. Production is mainly under rain-fed conditions. The two main planting seasons are April-June (long rains) and October-December (short rains). However, areas such as Meru receive their highest rainfall during the October/December rains whereas Kericho and Kisii receive rains as early as January, and a second crop can be planted in July. Currently, only small volumes of potatoes are produced under irrigation. Table 2 shows the production trends in recent years for key selected counties and for the entire country.

Table 2. Potato Production Trends

	Variable	2010	2011	2012	2013	2014
Kenya	Area (kha)	121.5	135.9	99.5	104.6	115.6
	Production (ktons)	2,725.9	1,846.6	1,436.7	1,667.7	1,626.0
	Yield (tonnes/ha)	22.4	13.6	14.4	15.9	14.1
Nyandarua	Area (kha)	28.7	27.3	27.5	19.9	22.3
	Production (ktons)	869.2	398. 9	835.0	272.5	293.4
	Yield (tonnes/ha)	30.3	14.6	30.3	13.7	13.2
Nakuru	Area (kha)	16.1	23.6	22.6	27.8	34.7
	Production (ktons)	162.5	326.4	512.2	313.7	361.0
	Yield (tonnes/ha)	10.1	13.8	22.7	11.3	10.4
Elgeyo Marakwet	Area (kha)	8.3	17.9	21.0	15.2	11.6
	Production (ktons)	165.3	285.2	324.3	212.6	196.3
	Yield (tonnes/ha)	19.9	15.9	15.4	14.0	16.9

Source: Economic Review of Agriculture (2013, 2015).

On-farm storage under the current market structure is seldom done. Storage of potatoes in factories and restaurants and hotels is for short periods in concrete buildings prior to processing. Often the storage conditions are not ideal. On-farm seed storage is generally done in rustic storage systems employing natural ventilation. Seed is mainly stored in heaps in the house or outside in pits to enhance sprouting. Some farmers store potatoes in bags in their houses or in multipurpose stores, but only a few use improved potato stores. Seed tubers, unlike ware potatoes, require some diffused light to enhance quality sprouting. Seed storage in cold stores exists in KALRO-Tigoni and ADC Molo.

Most marketed potatoes are sold shortly after harvest. The current practice is to package potatoes in extended bags where the extension is done by sewing and netting. The weight of the extended bag normally ranges from 130 to 280 kg. Washing off soils from potato, sorting potato according to size and removing damaged ones are some of cleaning and grading practices done by farmers. In marketing, potato traders sort out and grade potato, classify it into three main grades and differentiate prices accordingly. Retailers mix different sizes when selling.

The standards for packaging exist and require that potatoes should only be packaged in sisal or jute bags with a standard weight of 110 kg. Despite the standards, the use of extended bags is a means of effectively lowering prices for farmers. Furthermore, road and market levies are reduced for the county councils as charges are made on a per bag basis, irrespective of the size of the bag.

Potato packaging in modern business context is hardly done. However, people use sacks, plastic materials, and baskets to transport potato. In some cases, leaves are used to cover the sack to reduce evaporation. Net bags are sometimes used to package small quantities of potatoes. Potatoes are normally transported in lorry trucks of 3.5- to 7-ton capacities and sometimes 12-ton trucks. Lorry owners try to have a full load both ways and try to secure orders for taking goods for business stores prior to transporting the potatoes. The potato industry does not receive adequate attention in terms of extension services. There is no significant private sector or civil society involvement in extension service delivery for potato. The problem is made worse by lack of adequate transport and other facilities for the extension staff. Lack of close links between research and extension is another issue of concern.

As shown in Annex VIII, farmers obtain a positive gross margin by growing maize at current technological levels and prevailing marketing conditions.

3. Availability of Inputs, Improved Technologies and Services

The input/service market includes physical products such as seed, irrigation, fertilizers, agro-chemicals as well as market service such as information, loans/financial support, training storage and transportation. The major inputs and services used by actors in the potato value chain are briefly discussed below:

Seed: There are two seed systems in Kenya: formal and informal. The formal seed production system was established in 1979, in which certified seed production was the sole responsibility of the Agricultural Development Corporation (ADC). KALRO-Tigoni distributed pre-basic seeds to the ADC for further multiplication in its high-altitude farms. The Kenya Plant Health Inspectorate Service (KEPHIS) was involved in all the stages of production by inspecting and certifying the seed. The formal system is focused mainly towards serving large-scale potato growers and does not adequately support small-scale producers. For instance, given that commercial seed has to meet many requirements stipulated by KEPHIS, the certification process is expensive and ultimately culminates in high seed costs that are unaffordable by most small-scale farmers.

KALRO developed a viable informal seed production system for the small-scale farmers in 1994. The informal seed sector includes unlicensed growers and suppliers of seed, mainly in their immediate localities. In the informal sector, the seed potato may or may not be inspected by KEPHIS; therefore the seed is not certified but is of higher quality than what farmers obtain from the markets and neighbors. The farmers obtain pre-basic seed from KALRO. The informal seed system, including farmer-to-farmer distribution, supplies 99% of the estimated 300,000 t required annually. The informal seed production systems encompass the following: (a) seed production with involvement of NGOs and CBOs; (b) seed production by freelance growers; and (c) seed production by private growers.

Mini-tubers: A recent development in the potato industry in Kenya is the trade in mini-tubers for further production of seed potatoes (Muthoni et al., 2011). The use of mini tubers potentially has significant advantages in terms of pest control and logistics. A step further in terms of innovation would be the development and introduction of potato seeds. The advantages this Dutch breakthrough innovation would offer are purely unprecedented. However, it will take years before these innovations will be playing a substantial role in the Kenyan potato value chain.

Credit: Farmers generally have difficulties in accessing affordable credit. Although the government and other stakeholders have rolled out several initiatives to improve farmers' accessibility to credit, most players still complain of difficulties in accessing affordable credit, due to lack of awareness on available credit products, fear of repayments, lack of collateral, high interest rates, lengthy procedures and the like.

Research and extension services: Many high-yield varieties with disease-tolerant traits and good post-harvest traits have been developed by KALRO. Most of these are adapted to medium and highland potato areas. There is ongoing work to identify varieties that are drought-tolerant and adapted to lowland production areas. Agronomic and crop protection packages also exist. These include effective crop husbandry and effective products and techniques for controlling pests and diseases. The public extension staff provide most extension services in the potato industry, but its actual delivery suffers from inadequate staff and limited financing. There is no significant private sector or civil society involvement in extension service delivery for potato. Efforts have been made to provide training to farmers, but many farmers still need to be reached. However, time-bound potato projects provide some technical assistance to farmers within their projects. Embedded extension services provided by input service providers are gaining prominence. Universities, agricultural training centers and other facilities can be used to offer training to actors in the potato value chain. Such trainings have been in the past been organized by the MoA, KALRO, special projects such as PSDA, USAID, and NGOs.

Many farmers are not aware of the importance of soil testing, leading to improper use of fertilizers. Such practices negatively affect potato productivity. Soil testing facilities are available at Kenya Agricultural and Livestock Organization, KALRO-NARL, Kabete, etc. Some private laboratories such as Crop Nutrition Laboratory Services (CNLS) also provide soil testing services. Tractors are hardly used by small-scale growers. There is generally adequate labor in most of the production regions. The road network, especially the feeder roads in production, are poor and generally impassable during the wet season.

4. Marketing

Since the crop is grown under rain-fed conditions, farmers tend to harvest immature tubers early in the season to capture the higher price before supply increases and prices drop. Pre- and post-harvest care tends to be suboptimal. The domestic market for potato and potato products includes: certified seed potatoes, certified mini-tuber tubers, organic potatoes, frozen fries, processed products, (chips, crisps, *Bhajias*), fresh potato (ware of table potatoes), pre-packaged potatoes and baby potatoes. The Kenya organic food market is small but growing. Potato exports are currently insignificant but there is a lot of cross-border trade with neighboring countries, particularly Uganda and Tanzania. Opportunities exist for export of ware potato, certified seeds, certified mini-tubers, frozen fries and processed products such as crisps.

Currently, potatoes are marketed through a fragmented chain, characterized by many handlers, hardly any cooperation, no integration, and faced with market failure, all of which result in high supply risks, high transaction costs, price inefficiencies and quality losses. Challenges on logistics of marketing, physical infrastructure, and market information are enormous for smallholder potato producers.

Potato marketing is poorly structured, and farmers generally get low returns. Potato supply at the local level normally follows the rainfall pattern of the area and is not a direct determinant of the selling or buying prices for potato in the area. Potato growers lack the ability to influence selling prices for their potatoes for reasons that include, high perishability of potatoes, lack of adequate storage facilities and activities of brokers and cartels that bring negative effects into the market.

Several marketing channels for potatoes to the consumers exist. Consumers include the producers, rural and urban consumers and institutional consumers such as hotels and restaurants, schools, hospitals, processors, and export firms. A significant feature is the presence of brokers as agents in the marketing chain, at both producer and consumer levels. The major markets for potatoes are in the large urban areas such as Nairobi, Mombasa, Nakuru and Kisumu. Because potatoes are bulky and have high moisture content, transport costs are high, and therefore, farmers closer to the major markets benefit more than those in remote locations. A detailed description of the marketing chain is as follows (Figure 1; from Guyton et al., 1994):

Farm-gate level: Farmers commonly sell potatoes through rural brokers who assemble bags for the first handler or may sell directly to the handler. A small quantity of potatoes is marketed directly by producers to consumers on contracts. Farmers normally sell in small quantities of 10- to 20-kg tins or less to neighbors or people on transit as they are not organized to sell in retail or wholesale markets. Farmers and transporters complain that they cannot enter the big markets because market cartels block them.

Village-level brokers: These are given orders by traders to assemble the crop at an agreed price. The agents look for farmers and may even pay a deposit to secure their commitment to supply a certain number of bags. The broker leaves the farmer with the required number of bags and is responsible to the trader for ensuring the bags are properly filled and the quality is acceptable.

Traders/transporters/wholesalers: Traders use their own trucks or hire transportation to ship produce to wholesale outlets. They commonly rely on market brokers to locate buyers for them in transshipment and terminal markets such as Nakuru, Nairobi and Mombasa. Others deliver directly to processors, wholesale storeowners, or to institutions. The most common channel is through market brokers. At the wholesale level, the traders may sell to second wholesalers, institutions, and different types of retailers or directly to consumers. Some wholesalers perform multiple functions, retailing potatoes to consumers and wholesaling to other retailers at the same time. Second wholesalers frequently purchase from first wholesalers and repack potatoes into smaller bags.

Market-level brokers: Brokers approach the lorry operators and agree to sell potatoes at an agreed price for a certain commission. Brokers seem to be well-organized and in close business relations with their clients, an indication of cartels, price fixing and little competition leading to market failure.

Retailer level (local/retail markets): Retailers can be either ambulant or of fixed location. Ambulant retailers often pool their financial resources to purchase a bag of potatoes, divide it among themselves and retail whenever they can find space, along streets or within wholesale markets. They usually sell in heaps and tins, although in some markets, potatoes are sold in kilograms. Ambulant retailers are taxed per person to operate in most markets. Fixed-location retailers, on the other hand, operate in retail markets and have established stores. Some purchase directly from farmers but more commonly they buy from wholesalers.

Most of the potatoes are sold in markets rather than supermarkets or established shops. Most local markets operate two to three days a week. The traders in the markets buy directly from the farmers in the growing areas and transport produce by pick-ups, small lorry trucks or donkey/bullock carts. Much of the produce is sold to trucks coming from smaller towns in the district. The markets exist in all the suburban areas and vary in terms of their physical state and volume of trade. Appropriate storage facilities are lacking in the local markets. The county councils collect levies and cess per bag of potatoes entering such markets without regard to the size of bag. Subsequently, the traders find it more profitable to trade with the extended bag rather than the flat bag. Storage space is minimal, and traders are charged additional cess and guard fees for produce that remains at the end of the day.

Consumer-level brokers/wholesale markets: These are intermediaries buying for the restaurant trade, institutions and possibly for the processors. They arrange contracts or buying arrangements and usually the produce is delivered on a weekly basis and paid at an agreed price each month. The main wholesale markets are Wakulima in Nairobi and Kongowea in Mombasa. Wakulima market is too small and much of the trading in potatoes takes place in the streets surrounding it. Markets are overcrowded and have limited access into and out of the facility. Retailing is done on the lanes inside the markets, and trucks have a problem going through.

Porters: These are found at the transshipment point where they load and unload the potatoes at an established place. They carry heavy loads of extended bags, risking their health.

Consumers: They buy potato and potato products such as crisps and chips from farmers, retailers, institutions, and sometimes wholesalers.

Hand cart operators: These transport 1-4 bags of potato from markets such as Wakulima to chips-making outlets, restaurants, kiosks and groceries within and in the suburb areas in Nairobi.

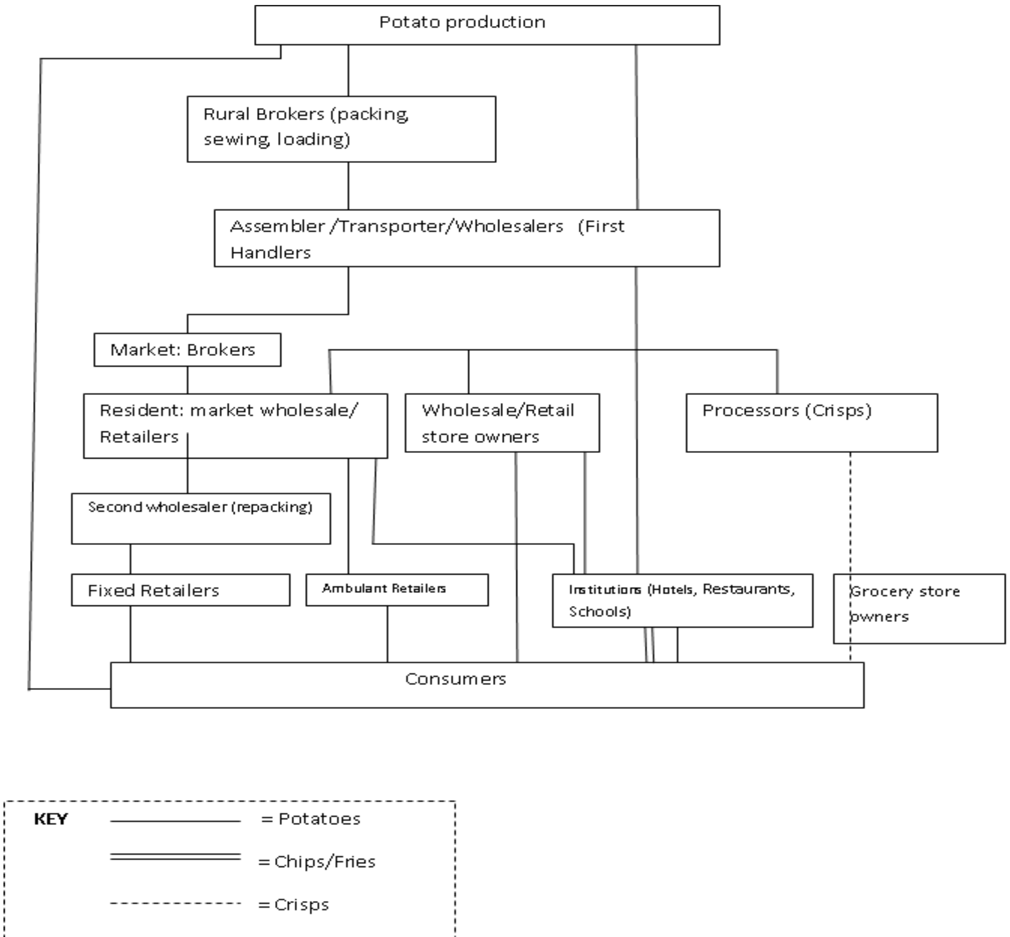


Figure 1. Schematic Representation of Potato Marketing

5. Consumption and Utilization Characteristics

Potato is an important crop consisting of about 80% water and 20% solids. In addition to calories and protein, potato is a vital source of vitamins, potassium and fiber. Potato is a nutritious pro-poor crop as it is rich in protein, calcium, potassium, and vitamin C with a good amino acid balance while having a low fuel requirement and a short cooking time. About one-third of the recommended daily allowance of vitamin C could be obtained from the potato. It is a major ingredient for weaning foods.

The per capita potato consumption is around 28 kg per year, relatively low compared with Europe (87.8 kg) but higher-than-average for Africa of 13.9 kg (FAO, 2008). Consumption of potatoes has been increasing with the increasing urbanization and the growth of the fast-food industry. It is approximated that over 60% of the fresh produce grown and traded by urban traders in Kenya is absorbed by fast-food outlets such as restaurants and street market stalls. For the past several years, production of potatoes has staggered around 2.3-2.9 million t.

Potatoes are mainly consumed when boiled, fried or mashed. Urban inhabitants are the major potato consumers, stimulating demand for ware potatoes and processed products such as chips and crisps. Fresh consumption is common in the rural areas and in urban homes and institutions but changing food habits have brought about increasing demand for processed potato products. Consumption is growing in urban areas and in both traditional and non-traditional zones of production. Potato is also used together with milk as a weaning food for babies and can also be converted into a number of food products like pre-fried or deep-frozen chips, crisps and dehydrated products such as potato flakes. Processing is currently restricted to the production of snack foods such as crisps and chevra. Several large companies are also processing frozen potato chips for sale in leading supermarkets for product diversification.

6. Potato Value Chain Mapping and Actors

The value chain map identifies the functions, segments, activities, key stakeholders or actors, demonstrates the product flow and shows the linkages and governance structure, identifying who controls the value chain and where investment would result in a change in the value chain. Figure 2 is a diagrammatic representation of the potato value chain map.

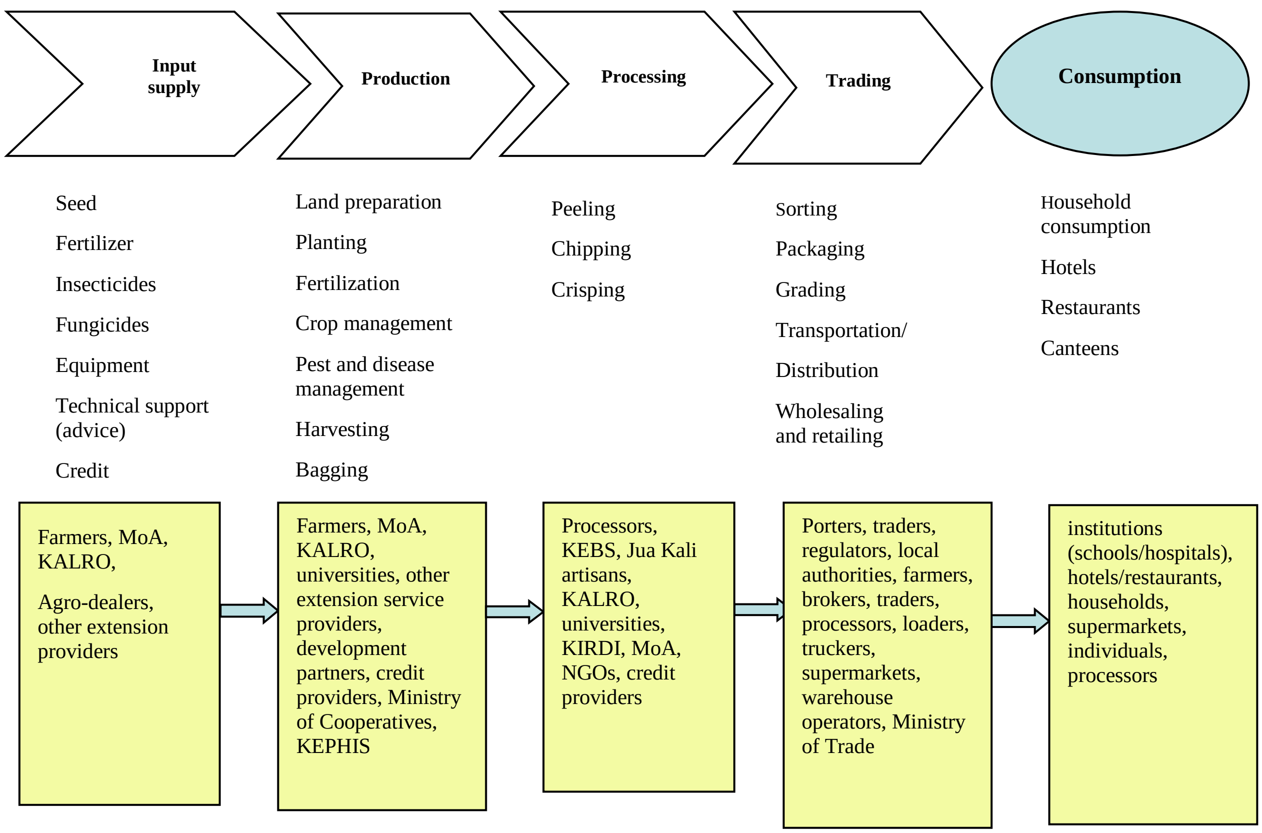
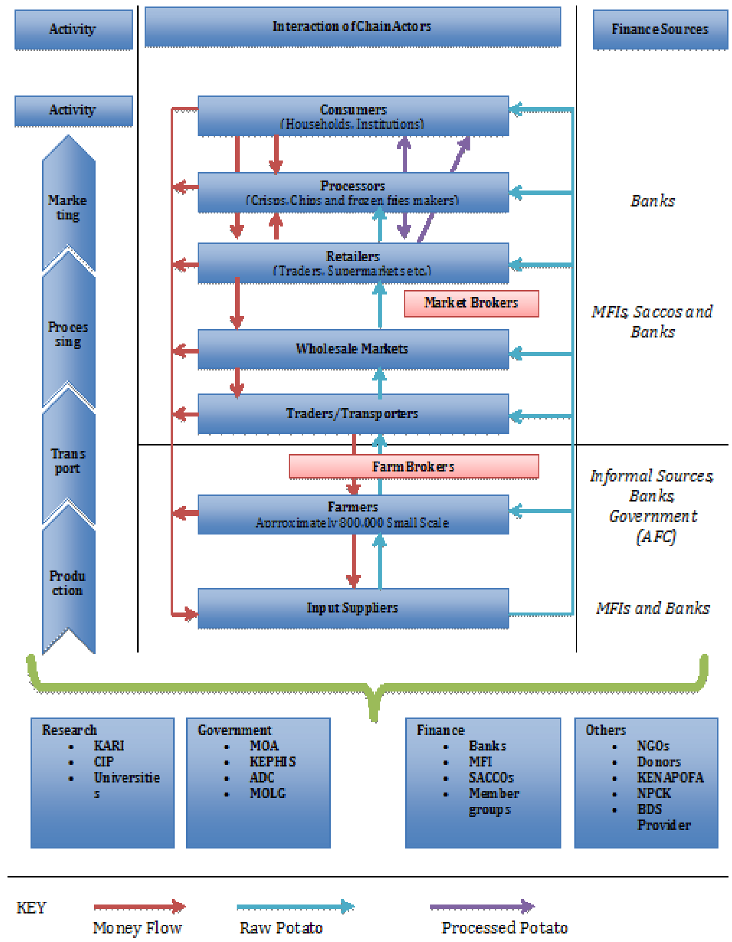


Figure 2. Potato Product Value Chain Map

The functions include input provision, production, processing, wholesale, retail and consumption. The potato value chain has six main segments, namely ware (consumption) potato, seed potato, crisps, fresh chips, and frozen chips. The potato value chain is very short as most of the functions are performed by potato growers themselves. The involvement of private entrepreneurs (seed and fertilizer agencies), registered transport companies and agro-trade houses is nearly absent, or it is at a subtle level. The main actors in the potato value chain in Kenya comprise producers, traders, processors, distributers, wholesalers and retailers and marketing chains (e.g., Uchumi and Nakumatt).

Figure 3 below shows the main potato value chain actors and supporters.



Source: Oiko Credit, 2010.

Figure 3. Value Chain Actors

The potato value chain has several sub-value chains. The most important are: (i) seed potato value chain, (ii) fresh/ ware potato value chain, and (iii) the processed potato value chain.

The brokers govern the potato value chain. Due to the informal marketing of potatoes, brokers control the value chain by determining prices and quantities and by controlling market information. The main actors in the potato value chain in Kenya comprise certified seed potato producers, including ADC, Midlands, Kisima farm and KALRO seed unit, producers, traders, processors, distributers, wholesalers and retailers and marketing chains (Uchumi, Nakumatt, etc.). Most of the potato is harvested immature. Although standards are in place, almost any quality of produce is sold. Produce is brought into the markets in poor containers with no regulated weight. Mechanical damage, contamination and microbial infestation are common. Ware potatoes are packaged in extended bags where the extension is made by sewing or netting. These bags are over-packed and rupture easily when loading, in transport or when offloading in the market place. Loading and offloading is cumbersome and damage to potatoes is common; in addition, the health of the workers is put in jeopardy. Most processors complain that the quality of potato they receive for processing is of poor quality.

Seasonality of production results in unstable market prices because of oversupply during harvesting and shortages during the planting time. Prices differ from one area to another. The variations are also found from market to market. The market information flow is controlled by brokers (cartels) in urban markets and production areas, thus manipulating prices to the disadvantage of the grower Over 80% of commercially marketed potatoes go through brokers at both ends of the marketing channel.

7. Production and Marketing Challenges

Most potato marketing regions in Kenya are constrained by fragmented and small land holdings, infrastructural, production and marketing inadequacies, and extremely low private sector investment. According to Janssens et al. (2013), production of potatoes in Kenya is characterized by a couple of constraints. First, production is bi-modal, only produced twice a year following the rainfall pattern of Kenya. Around July to August, potatoes are usually in high volumes and fetch low prices, while in December, April and May, they are usually in low supply, fetching higher prices for farmers involved. Due to continuous production of potatoes in the same piece of land, soil degradation has been inevitable. Fertilizer application rates are often below the recommended rates with diammonium phosphate (DAP) as the most commonly used fertilizer.

Another major constraint lies in poor use of certified seeds. About 1% of the planted area is under certified seeds. The other farmers use seeds raised locally through retention from previous harvests, which farmers obtain from their stores or buy from local markets, friends and relatives. Yield reduces with each successive generation. Other constraints that have affected productivity of potatoes in Kenya include diseases such as brown rot and late blight, lack of crop rotation where farmers cultivate potatoes in the same piece of land over and over again, poor storage facilities and lack of enough capital for capital-intensive production, which can see their overall production increase as result of employing motorized machinery.

8. Potato Value Chain Platforms

The National Potato Council of Kenya (NPCK) is a public private partnership (PPP) and comprises multiple stakeholders; the Council bears the responsibility of planning, organizing and coordinating activities of the value chains in the potato subsector and developing it into a robust, self-regulating and competitive industry. Its organizational structure enables it to draw synergies from a wide membership representing all stakeholders and actors in the industry. Membership to the organization is by stakeholders. Currently, the NPCK has 18 members as follows: research (KALRO-Tigoni), seed/mini-tuber producers, Ministry of Agriculture, International Potato Centre (CIP), universities (Mount Kenya University), Kenya Plant Health Inspectorate Service (KEPHIS), Agricultural Development Corporation (ADC), processors, seed producers (farmers), ware producer (farmers), traders, financial institutions (Equity Bank), seed traders associations (STAK), farmers associations (KENAFF), Ministry of Devolution and Planning, Kenya National Potato Growers (KENAPOFA), and development partners (GTZ, USDA, ASCU, KAPAP).The vision of NPCK is that the potato industry emerges as a leading contributor to stable incomes, food security and improved welfare in Kenya. Its mission is to coordinate and regulate potato subsector stakeholders toward development of potato industry profitability and livelihood improvement.

Kenya National Potato Farmers Association (KENAPOFA) is a registered farmer association that covers 23 potato growing counties. The association has representation at the divisional, county and national levels. The association plays the role of advocacy in policy and regulatory frameworks for the potato industry and aims at providing its members with affordable farm inputs, market information and potato value addition services. The association aims to empower farmers to take ownership of their potatoes during production and marketing. The association will give farmers a bargaining power on price setting and allow producers to take advantage of the economies of scale. The association will also facilitate in assisting farmers in scouting for local and external markets.

9. Conclusions

In spite of the existing production and marketing, there is need to exploit opportunities and strategies in potato production through increased farmers' access to novel potato varieties, application of GAPs and expanding the production area through irrigation. The value chain is increasingly seen as an important development framework, with contract farming being viewed as an instrument for improving value chain performance by reducing transaction costs and risks and by building trust in vertical cooperation. The jointly developed picture of the potato chain revealed the following: (i) low productivity due to absence of inputs and improved seeds; (ii) high transaction costs due to prevailing mistrust between farmers and traders, resulting in low number of repeated transactions; (iii) inefficient marketing due to the presence of cartels, lack of market information, and high transaction costs; (iv) policy failure reflected, for example, by uncoordinated collection of cess or levies on roads and product markets (which is additionally prone to bribery and corruption), resulting in over-taxation; and (v) lack of legal and regulatory framework as well as grades and standards.

With the development of the potato processing industry in Kenya, new potato cultivars with specific uses are needed. There is tremendous room for improvement of seed potato quality, including more strict regulations and their enforcement by the relevant authorities. There is a need to improve technologies for mechanical cultivation, field management, and the integrated control of pests. Additional weaknesses in potato processing, storage, and transportation technologies must be addressed, as they are the major constraints for the healthy development of the potato industry.

Appendix V. Key Institutions Involved in the Potato Value Chain

Farmer Groups and Associations: Potato growers as individuals, groups and associations form a key category of the stakeholders in the potato production and marketing process. The Kenyan agro-based private sector includes profit-making and not-for-profit organizations. Profit-making agencies include farm input suppliers, agribusiness entrepreneurs, financial and other service providers and agro-insurance organizations, among others. On the other hand, not-for-profit organizations form the bulk of core actors in the potato value chain. These include the farmers themselves (over 800,000), farmers' groups or organizations at various levels and the networks/federations. The Kenya National Potato Farmers Association (KENAPOFA), being a member of KENFAP, represents the potato farmers at various levels. Other private players include GTIL, Midlands, and Kisima Farm.

Ministry of Agriculture, Livestock and Fisheries (MoALF): The Ministry of Agriculture, Livestock and Fisheries coordinates the implementation of agricultural policies. It is also a major extension service provider.

Research Institutions (KALRO, KIRDI, and Universities): The Kenya Agricultural Research and Livestock Research Organization (KALRO), in collaboration with local and international universities through its center in Tigoni, carries out potato research. However, other stations and sub-stations are highly involved, including the International Potato Centre (CIP). In addition, the Kenya Industrial Research and Development Institute (KIRDI) is mandated to undertake research and development in industrial and allied technologies, specifically in development and transfer of technologies in processing of horticultural produce.

Kenya Plant Health Inspectorate Services (KEPHIS): KEPHIS is mandated to coordinate all matters related to pests and disease control; monitor the quality and levels of toxic residue in plants, soils and products; administer plant breeders' rights; undertake inspection, testing, certification, quarantine control, variety testing and description of seeds and planting materials; establish the machinery for educating the public on safe use of agro-chemicals; approve import application for seeds, plants and appropriate phytosanitary requirements and importation of such materials; and inspection of produce for export and import.

Agricultural Development Corporation (ADC): The ADC is a strategic public corporation in charge of germplasm for crop seed and livestock. It is an important stakeholder in the potato industry given its historical role in seed production and the infrastructure it possesses, such as a large cold seed potato store.

Fresh Produce Exporters Association of Kenya (FPEAK): The functions of FPEAK include representation and liaison with the relevant public and private sectors, local and international organizations; trade associations' formation and management; promoting export through overseas exhibitions and trade missions and buyers' missions to Kenya; providing market information on export products and their destinations; training members and their outgrowers on production, post-harvest handling, packaging and export marketing techniques; ensuring high-quality and environmentally safe products through adherence to an established Code of Practice.

Pest Control Products Board (PCPB): The function of the PCPB is to regulate the importation, exportation, manufacture, distribution and use of products for the control of pests and of the organic functions of plants and animals for connected purposes.

Kenya Bureau of Standards (KEBS): KEBS' primary function is to promote standardization in the commerce and industry through development of standards, quality control, certification and metrology. It has the mandate of establishing and enforcing quality standards of all products on the Kenyan market, whether locally produced and imported.

Export Promotion Council (EPC): This organization is responsible for the country's export development and all export promotional activities. Its major mandate is to identify and remove constraints facing exporters and producers of export goods and services, formulate market strategy and identify export opportunities and promote public awareness to the need of export development.

Ministry of Public Health (MOH): The MOH liaises with stakeholders in the horticultural industry to ensure hygiene in market and public places. It also protects Kenyan consumers from health risks of contaminated food. The Ministry ensures regular inspection of food premises to ensure they conform to health requirements and inspects food imports at ports of entry in order to detect foreign diseases. It participates in promotion of food hygiene curricula in schools.

County Governments: County governments are involved in the development of markets and market infrastructure for produce in their areas of jurisdiction. They are also responsible for collection and disposal of garbage, provision of sanitary facilities and land allocation for marketing facilities. They collect fees and charges from agricultural produce and they are expected to use some of these revenues in the maintenance of rural access roads and in the maintenance and development of new markets.

Agro-Chemical Association of Kenya (AAK): The AAK facilitates the regulation of agrochemical registration and the provision of technical advice to its members and other stakeholders. The association trains the agro-stockists countrywide on the hazards of chemicals and safe storage. It also disseminates information on safe use of existing and new products. Training of farmers and other users of their products is undertaken frequently to ensure safe use, food safety, minimum or no environmental hazards and good welfare of the workers.

Non-Governmental Organizations: International Agricultural Research Centers: These include the International Potato Centre. It has an international agenda on potato research.

Rural Financial Institutions (RFIs): The potato industry requires rural financial institutions to provide financial services for various aspects of the production-to-consumption value chain. Organizing farmers in associations will facilitate their easier access to financial services suited to their needs.

Media Houses (MHs): The mass media can play an important role in the dissemination of information on potato production, processing, marketing and consumption. Part of the dissemination involves advertising of new potato technologies and products.

Appendix VI. Key Stakeholders in the Maize Value Chain

Key Institutions	Role / Entry Point
Agriculture, Water, Cooperatives, Livestock	Collaboration in program development and implementation, coordination and provision of extension services, policy guidelines, market information and access, provide necessary infrastructure, facilitate access to inputs and credit
Trade, Industry, Local Government Finance, Planning	Provide international market information, maintain quality standards, provide information on tariffs, taxes, levies (cess)
Roads, Transport, Public Works, Energy, Local Government, Agriculture	Provision and development of power, roads, storage facilities, telecommunication
KARI, KIRDI, NCS&T and Universities	Provision of expertise, capacity building, provision of science technology and innovation, collaboration and coordination of partnerships in research programs
STAK: (Seed Companies)	Multiplication and production of seeds
Parliament, States Law Office	Legislate and approve budgets policies and bills. Technical input into preparation of bills and policies
KEPHIS, PCPB, KEBS	Provision of quality advisory services. Setting of standards and regulatory services
CGA, EAGC, KEBS, KSPSA, CMA, KAM, Chamber of Commerce & Industry	Provide partnership in research, extension, resource mobilization, entrepreneurship development
AFC, Private Banks, Microfinance Institutions	Provision of financial facilities, saving and credit, investment in capacity building
Bilateral and Multilaterals Partners	Provision of technical support, financial assistance, capacity development and consultancy
CIMMYT, IITA, ASARECA, ACIAR, Regional/International Universities, Bioversity International (GCDT).	Cooperation in areas of agriculture, implementation of international treaties, resource mobilization, technical support
BAYER EA, MEA Ltd, AGRO, UNGA Ltd., PREMIER Mills, etc.	Provision of quality agricultural inputs, credit facilities, capacity building, dissemination of technologies

Source: Maize Value Chain Report, 2014.

Appendix VII. Gross Margin Analysis of Maize

	Unit	Quantity	Unit Price (Ksh)	Total Ksh/ha	U.S. Dollars
Gross Revenue (yield*unit price)	***90-kg bag***	***45***	***3,000***	***135,000***	***1,350***
Variable Costs					
Intermediate Inputs					
Plowing	hectare	1	2,000	2,000	**20**
Ridging	hectare	1	1,000	1,000	**10**
Seeds	kg	25	150	3,750	**37.5**
Fertilizer DAP	50-kg bag	2.5	3,000	7,500	**75**
Fertilizer CAN	50-kg bag	2.5	2,600	6,500	**65**
Fungicides	kg/liter	2.5	1,200	3,000	**30**
Insecticides	kg/liter	2.5	1,200	3,000	**30**
Labor Costs					
Planting	mds	15	300	4,500	**45**
Weeding 1st	mds	25	300	7,500	**75**
Weeding 2nd	mds	13	300	3,900	**39**
Topdressing	mds	5	300	1,500	**15**
Pesticide application	mds	2	300	600	**6**
Stocking	mds	10	300	3000	**30**
Harvesting	mds	25	300	7,500	**75**
Other Costs					
Transport from farm to store	bag	45	30	1350	**13.5**
Shelling	bag	45	60	2700	**27.5**
Bags	Number	45	50	2,250	**22.5**
Transport to the market	Number of bags	45	50	2,250	**22.5**
Market levies	Number of bags	45	20	900	**9**
Total Variable Cost				***64,750***	***647.5***
Gross Margin				**79,450**	**702.5**

Appendix VIII. Gross Margin Analysis of Ware Potato

	Unit	Quantity	Unit Price (Ksh)	Total (Ksh/ha)	Total (U.S. Dollars/ha)
Gross Revenue (yield*unit price)	90-kg bag	113	1,500	169,500	**1,695**
Variable Costs					
Intermediate inputs					
Plowing	hectare	1	5,000	5,000	**50**
Ridging	hectare	1	2,500	2,500	**25**
Seeds	50-kg bag	7.5	3,000	22,500	**22.5**
Fertilizer DAP	50-kg bag	2.5	3,000	7,500	**75**
Insecticides	liters	5	1,200	6,000	**60**
Fungicides Ridomil	liters	2.5	1,350	3,375	**33.75**
Labor Costs					
Planting	Manday	15	300	4,500	**45**
Weeding 1st	Manday	13	300	3,900	**39**
Weeding 2nd	Manday	13	300	3,900	**39**
Spraying	Manday	15	300	4,500	**45**
Harvesting	Manday	20	300	6,000	**60**
Sorting	Manday	10	300	3,000	**30**
Other Costs					
Bags	bags	113	50	5,650	**56.5**
Transport to the store	bags	113	100	11,300	**113**
Total Variable Costs				***89,625***	***896.25***
Gross Margin				**79,875**	**798.75**

Additional information: https://ifdc.org/vfrc-reports/
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