Food and Agriculture Organization of the United Nations

KENYA'S TEA SECTOR UNDER CLIMATE CHANGE

An impact assessment and formulation of a climate-smart strategy

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Preface

Changing weather patterns in Kenya are increasingly being experienced within agricultural systems, including by farmers. In Kenya, there is particular concern with regard to the effects of climate change on tea – an extremely important sector for the economy. Tea producers already are facing reduced and erratic rainfall, a higher rate of hail or frost and rising temperatures that heavily affect yields and productivity levels. Over 500 000 smallholder tea producers are facing increased uncertainty about their livelihoods in the future. The challenge of climate change is raising concern at the policy level over the long-term viability of the tea value chain.

At a special session on climate change that took place at the Inter-Governmental Group on Tea, held in New Delhi in 2010, concern was raised by major tea producing countries about the potential negative impact of climate change on the future of the tea sector. The Food and Agriculture Organization of the United Nations (FAO) was requested to provide technical support by way of a climate change impact assessment of tea in Kenya. FAO initiated a two-year technical assistance project in Kenya, the Climate-Change Impact Assessment and Tea Policy Response. The project was funded through FAO's Multidonor Mechanism with financial support from the Swedish International Development Cooperation Agency. The project aims were to (i) develop evidence of climate change impact on Kenya's tea production through a series of biophysical and socio-economic analyses; and (ii) provide policy support to the Government of Kenya that is specific to climate change and tea, which can be used as a template for a broader climate-smart agriculture development strategy.

To undertake this work, FAO mobilized a team of Kenyan national researchers, FAO and international experts to carry out assessment and generate decision tools under the technical coordination of Aziz Elbehri, Project Manager. An innovative multistage framework was applied combining a multi-disciplinary climate impact assessment (evidence generation) with an inclusive multi-stakeholder process to develop a new climate-compatible strategy for tea (strategy formulation). The conceptual framework was built on elements of climate-smart agriculture concept and focused on the enabling environment for adaptation mainstreaming at the sector level. This framework applied to tea sector in Kenya was also guided by core principals, namely: (i) ***demand-focused***, based on priority needs and aligned with current programs and initiatives relating to climate change; (ii) ***evidence-based***, combining both biophysical and socio-economic assessments of climate change impacts; and (iii) ***participatory***, relying on active engagement by relevant stakeholders in priority setting and strategy development.

This document is the synthesis report from the project. Chapter 1 describes the overall conceptual framework that guided the project. Chapters 2 through 7, report on the climate impact studies and chapter 8 provide a succinct description of the new climate-compatible strategy for tea in Kenya.

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Acronyms

AEZ	agro-ecological zones
ASDS	Agriculture Sector Development Strategy
°C	centigrade
CO_2	carbon dioxide
CTC	cut-tear-curl method
Defra	Department of Environment, Food and Rural Affairs
eq.	equivalent
ETo	evapotranspiration
FAO	Food and Agriculture Organization
FAOSTAT	Statistics Division of the FAO
FGD	focus group discussion
g	gram
GDD	growing degree days
GDP	gross domestic product
GHG	greenhouse gas
GIS	geographic information system
GMP	Green Morocco Plan
GWP	global warming potential
ha	hectare
HDPE	high-density polyethylene
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
KARI	Kenya Agricultural Research Institute
KES	Kenyan shilling
Kg	kilogram, kilo
Km	kilometre
KTDA	Kenya Tea Development Agency Ltd.
KTGA	Kenya Tea Growers Association
kWh	kilowat
LCA	life cycle assessment
m	metre
mg	miligram
MALF	Ministry of Agriculture, Livestock and Fisheries
mm	millimetre
MtCO2e	million metric tonnes of carbon dioxide equivalent
MUAC	mid-upper arm circumference
N2O	nitrous oxide
NCCRS	National Climate Change Response Strategy
PE	polyethylene
pH	measure of acidity
PP	polypropylene
SWD	soil water deficit

TBK	The Tea Board of Kenya
TRFK	Tea Research Foundation of Kenya
UK	United Kingdom
WHO	World Health Organization

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CHAPTER ONE

INTEGRATING CLIMATE ADAPTATION INTO AGRICULTURAL SECTORS: A METHODOLOGICAL FRAMEWORK AND COUNTRY CASE STUDIES

Aziz Elbehri

1. Introduction

Climate change is expected to exacerbate the sustainability of most agricultural systems and threaten long-term agricultural productivity, food supply, and future food security. Tackling the impacts of climate change and ensuring that agriculture is aligned with climate-compatible practices is of the utmost urgency. Concerted efforts at the farm, community and national levels are necessary to deploy a variety of solutions, interventions and instruments to address the impacts of climate change on agriculture. Climate challenge to agriculture requires adaptation solutions that could extend beyond the scope of current agricultural techniques and farmers systems. Mainstreaming adaptation to agriculture is a dynamic process that goes beyond introducing new agricultural techniques that must also cover institutional reform, policy and regulatory mechanisms as well as harness market-based instruments.

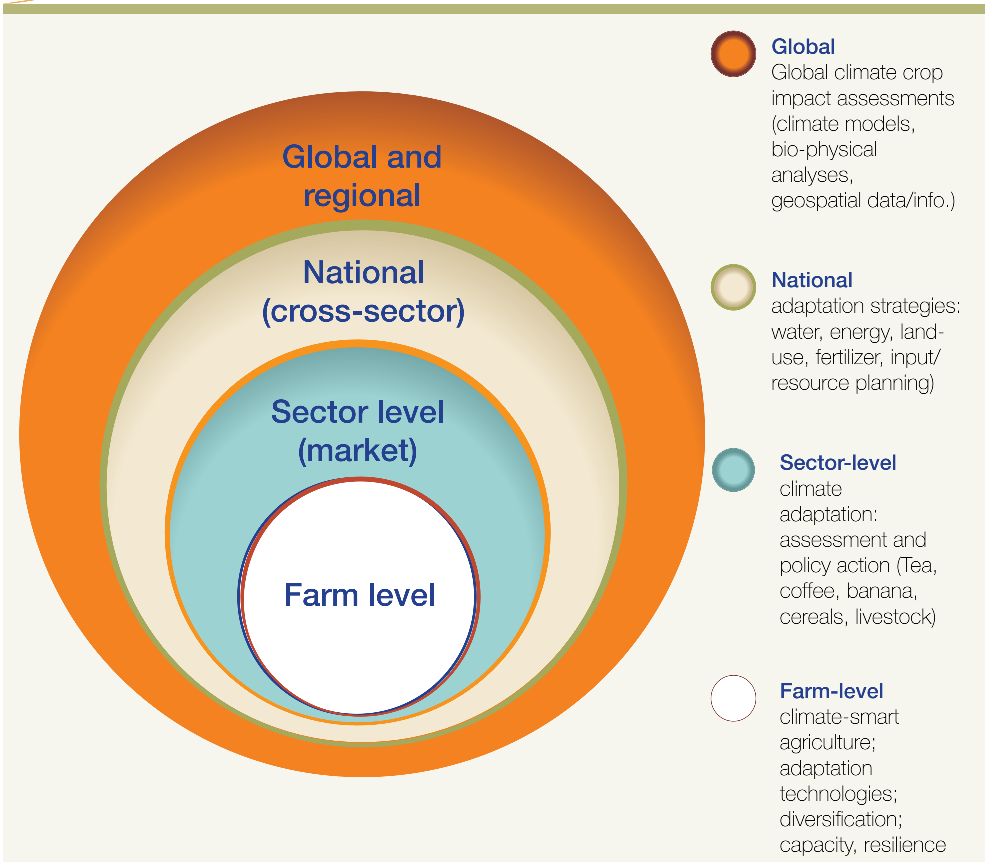
A systems approach that can link climate change to sustainable agricultural development is essential for an effective transition to climate-smart agriculture, where adaptation and mitigation are integrated into sustainable agricultural intensification. An effective climate action must derive from evidence-based assessments to inform policy-making and to propose concrete and context-relevant options and interventions. Impact assessments and identification of appropriate adaptation responses, including policy formulation and implementation, will vary depending on the scale under consideration which range from the farm, sector, national and global. Climate-compatible agriculture policy formulation also requires a greater degree of coordination by stakeholders and policy-makers alike.

2. Climate impact analysis for agriculture: The question of scale

Given the context-specific nature of agricultural systems, the selection of scale for climate impact analysis is a critical first step. The choice of appropriate scale derives from the objective of the impact assessment and the nature of the climate actions required. The scale also determines the appropriate methodological tools required for the climate impact assessment and follow up responses. Figure 1 shows a simplified with the four major scales often considered in climate impact assessment and policy action.

At the ***global*** level, the focus of climate action is to evaluate the broad trends in agricultural productivity impacts, resource availability and future land use, as well as the likely impacts of climate change and their relative magnitude. Assessments at this scale rely on global aggregate climate, crop and economic models that use data on climate, biophysical and socioeconomic trends. The aim is to derive the relative magnitude of changes across regions and agricultural systems. Global models – such as the Global Agro-Ecological Zones (GAEZ) (developed by FAO and the International Institute for Applies Systems Analysis) and the Agricultural Model Inter-Comparison and Improvement Project (AgMIP) model suite – have been applied to estimate the magnitude of climate change

Figure 1 Four scales of climate impact analysis and action



impact on future productivity trends for major crops, animal systems, forestry and fisheries. These global assessments provide the evidence used within the global governance framework of the United Nations Framework Convention on Climate Change (UNFCCC), which seeks to reach common agreement across countries for joint action, the mobilization of resources and the development of the global governance that is essential to implement adaptation and mitigation actions.

At the ***regional*** level – and within homogenous and contiguous regions – the aim is to evaluate regional climate vulnerability assessments and how they relate to population, agriculture, ecosystem, natural resources (e.g. soils, water). Analyses may combine both regionally and locally specific models to generate the evidence required for joint policy action. Follow up action at regional level may involve setting a common strategy; sharing best practices with regard to policy and interventions; and seeking economic integration, including through the enhancement of regional trade. In addition, it is essential to establish regional institutions to monitor manage and share information to improve the efficiency in the use of resources (e.g., water) and to implement national adaptation plans. Examples of climate-compatible interventions at this scale may also include efficient management of critical common resources, such as water, or combating other climate-induced threads to agriculture (such as pests and diseases).

At the ***national*** level, climate adaptation for agriculture begins with macro-policies, regulations and institutional reform. Emphasis is placed on adaptation strategies that can be cross-sectoral in scope involving agriculture, health, energy, water, infrastructure, (i.e. irrigation) and rural financial services (banking). The design and implementation of national adaptation plans also will necessitate a heightened degree of coordination across sectors, institutional reforms and improved governance structures in order for multilayered adaptation decisions to take place, aimed at transitioning towards climate-smart agriculture.

Given the context-specific nature of agriculture, concrete planning, assessments and proposals for action, are best carried out at the sub-sector level (e.g. crops, livestock, agro-forestry), agro-ecologically homogenous or territory. Designing a climate-compatible, sector-level strategy requires a systems approach that must include the economics of the sector, the biophysical implications of climate impacts, and the socio-institutional implications including governance, gender, and other relevant social indicators. A biophysical climate impact analysis of the sector will identify the sector's vulnerable areas vis-a-vis climate change in terms of yields, disease and resource availability and future production suitability. The economics of the sector would cover the policy and regulatory environment, market structure, drivers of demand and supply (including trade) and sector competitiveness, as well as the level of efficiency of resource use and the likely evolution under climate change. A socio-institutional analysis will generate an understanding of the scope to improve stakeholder participation in the decision-making (governance) process and the scope to leverage the economic and regulatory incentives by decision-makers. A sector/territorial level assessment is the appropriate scale to develop a precise action plan that will be supported by an investment programme; institutional reforms; agricultural research and extension; market-level regulations; trade and other economic incentives to induce farmers, forestry folks and fisherman to adopt climate-compatible technologies and practices. The sector/territorial level analysis of climate smart-agriculture is a necessary bridge between national cross-sectoral policy interventions and farm-level adaptation decisions.

At the ***farm*** level, adaptation decisions are made on the basis of internal endowments and constraints, as well as external incentives. Farms and households have internal resources to cope with a changing climate and to adapt accordingly. These include changing crop patterns, adopting new production techniques, or reallocating labour to other uses, such as outside agriculture. Farms may also exhibit limits to adaptation, owing to a lack of or dwindling resources (water), information, credit or a combination of the three. Smallholder farmers often face more constraints to adapt than do the larger farms. Farms also respond to external signals or incentives to change practices to improve productivity and resilience. Analysing the internal and external factors that influence the decision of farmers to adapt is an important step. It is, however, insufficient. It will need to be complemented with a sector- or territory-wide analysis to identify and to propose the macro- or sector-wide incentives and measures to induce farmers to transition towards a more climate-compatible agriculture.

Selecting the appropriate scale is essential to ensure focus both for assessment for action. Moreover, regardless of the scale of analysis chosen, a certain degree of an integration and systematic approach is still required. Such integration is both spatial (farm, community, national) or disciplinary (biophysical, socio-economic, and institutional). An analysis at the farm-level requires a parallel sector/market assessment to generate the critical macro-economic incentives (e.g. prices, supply and demand factors, trade, sector-wide regulations) to understand how best to prompt a transition to climate-smart practices within the sector or territory. Similarly, a sector assessment should be complemented with a national and cross-sectoral analysis to align the sector-specific process with relevant national policies, institutions and resource management and investment decisions. Solutions at the sectoral level will identify the links between evidence and policy-making which, in turn, can guide the formulation of interventions or strategies at the national or cross-sectoral level. For example, national policies for food security and climate adaptation and mitigation also can be facilitated under a regional strategic framework to tackle the common challenges and objectives.

3. A sector-specific framework for climate adaptation

This section describes a methodological framework designed to organize our approach to climate impact assessment needed to generate the evidence required for policy action at the level of an agricultural industry or agro-ecological territory. This framework has been applied in three country case studies, namely Kenya's tea sector, Ecuador's banana sector and Morocco's fruit tree sector. In all cases, the application of the framework consisted of undertaking an inter-disciplinary climate impact assessment (economic, biophysical and socio-institutional) followed with a stakeholder-led process to facilitate a transition towards a climate-compatible best practices within the section facilitated either by a new strategy, new policy or improving an existing polity. The country case studies have confirmed the suitability of the demand-centered approach that focuses on a strategic sector to generate context-specific outcomes. In Kenya, a new climate-compatible strategy for tea was developed and a new policy reform for tea initiated using this framework. In Ecuador, the unique analysis of climate impact on banana has guided the Government of Ecuador to pursue environmentally safer disease controls, steer further productivity-enhanced initiatives using more climate-adapted techniques, and raised greater awareness of the future challenges to banana viability by preparing for better pest controls outbreaks under climate change. In Morocco, the biophysical decision tools and the socio-institutional diagnostic approaches developed with the application of the methodological framework have improved the capacity to mainstream innovative climate adaptation beyond production techniques and helped strengthen the national capacity of better integrate climate adaptation within a national investment program for agricultural intensification and value addition.

3.1. Framework overview

Mainstreaming climate adaptation within agriculture, at sector-level requires an appropriate framework that can effectively combine the economic, social and environmental dimensions in a coherent, complementary and interlinked manner. The economic analysis of the sector should be made to clearly separate the characteristics that drive efficiency from those characteristics that contribute to the lack of sustainability. The analysis should include the key aspects of the market, institutions and governance.

A biophysical assessment of the agricultural system is needed to understand the agronomic, agro-ecological and geospatial (or territory) impacts of climate change and measure the technical scope for adaptation. The economic and biophysical assessments should help identify the existing sources of unsustainability and the economic incentives and/or disincentives that drive them. Such an assessment will establish the technical options available in terms of adaptation, as well as the economic incentives that are necessary. To transition to a more sustainable agricultural system, however, a socio-institutional analysis will be required in order to address the critical issue of social structures, organizations, power relations and governance. Such socio-institutional analysis is also required for their uptake to ensure social acceptance and inclusive policy decisions.

Figure 2 Problem statement: from unsustainable to a climate-compatible sector

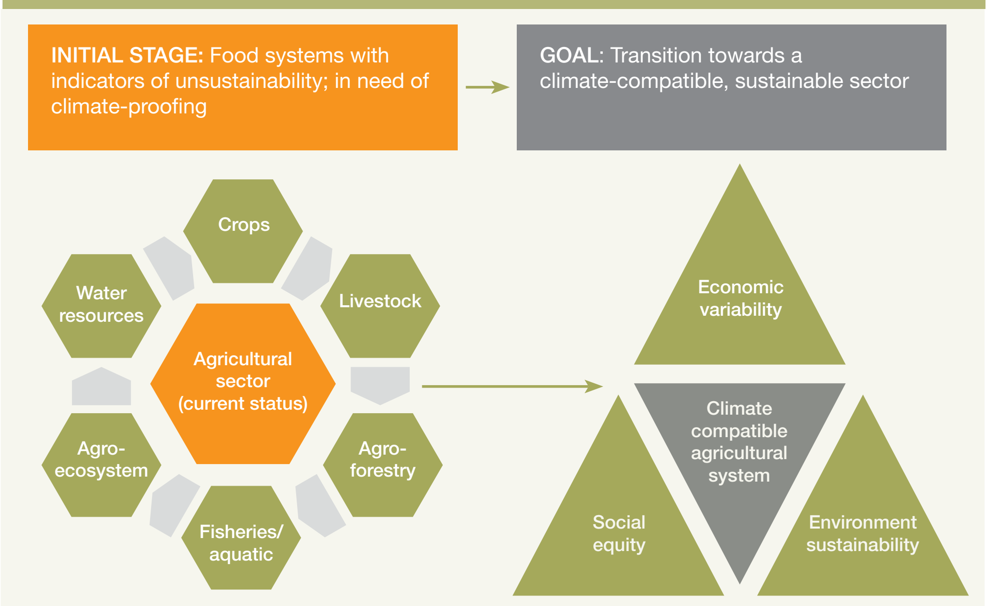


Figure 3 Three-stage approach to sector-level climate adaptation

3.2. Description of proposed framework

The proposed methodological framework is designed to examine includes specific agriculture sub-sector (e.g. crop-based, livestock, mixed, agroforestry) or a geospacial ecosystem that share a common set of biophysical and socio-institutional factors. The framework focuses on the sustainability implications of the system and the exacerbating impacts of climate change. The aim of the analysis under the framework is to identify the scope of climate adaptation and enhance resilience, while ensuring continuous economic viability and social equity (Figure 2).

To enable a transition to a climate-compatible or climate-smart agriculture, the framework is implemented in three stages. Figure 3 illustrates this.

■ Stage 1: Tri-dimensional analytical

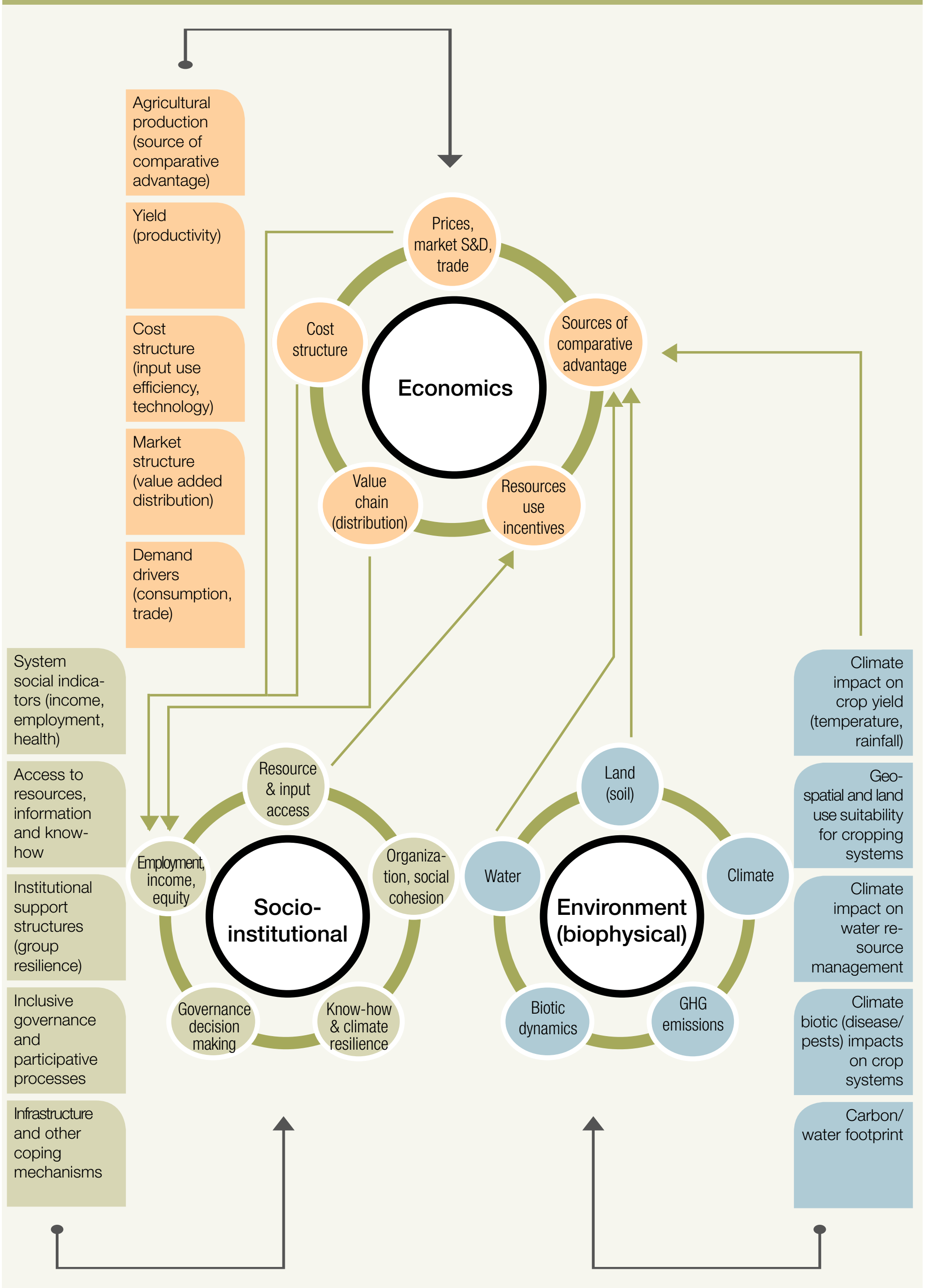
This stage includes the gathering of evidence and consists of three assessments dimensions: biophysical, economic, and socio-institutional. The framework is schematically described in Figure 3 above.

A. Biophysical analysis

The biophysical analysis of the targeted agriculture sector(s) should cover the climate impact assessment of the specific crop and should draw from existing analyses at various levels (national and local). Ideally, such an analysis would use locally available changing climate parameters that apply, as much as possible, to the crop that is analyzed. The focus of this climate impact assessment will be dictated as much by the regional location of the agricultural system as by the agronomy and the agro-ecology of the crop. The biophysical analysis may also stress specific issues that are critical to the production system, such as water hydrology (in terms of future water demand and supply) and/or land classification. When relevant, the analysis also may emphasize the biotic dynamics of climate change on the crop, especially in those situations where pests and disease are important features of the cropping system or where the changing climate is thought to introduce new biotic dynamics in the future, which will alter the management and the productivity of the system.

Finally, the biophysical analysis of the agricultural system also covers an environmental assessment that includes the carbon cycles and footprint of

Figure 4 Tri-dimensional conceptual framework for sector-level climate adaptation analysis



Source: Author

the current production system and the implications for greenhouse gas (GHG) emissions for mitigation. Measuring water footprints is also critical in some cases. It is important to recognize that the specific focus of the biophysical analysis should be dictated by the local climate, the crop agronomy and the associated management system, as well as by the location agro-ecology, including the biotic and abiotic aspects. Existing cropping systems and management (the latter of which is tied to economics) are as much factors as are those of pure environmental and ecological considerations.

B. Economic analysis

The economic analysis of the targeted sector(s) should include an appraisal of the costs and efficiency of production and post-production production, the level and scope for productivity and intensification (input use). Agronomy and agro-ecology are determining factors as are the economic drivers (incentives and disincentives). Negative externalities, should also be reviewed, especially in relation to the presence of incentives in overuse input resources that lead to the sub-optimal use of resources or economic disincentives to resource preservation and their expected changes in light of the aggravating impacts of climate change (e.g. water). Finally, the economic analysis should provide the basis for determining the scope to adjust the economic levers necessary to tackle the current unsustainability constraints and future challenges arising from changing climate.

C. Socio-institutional analysis

Adaptation options can be technically possible and economically viable; however, they still need to be socially feasible and acceptable. The socio-institutional analysis is the critical third dimension that assures the link to policy processes. It is, however, highly context-specific. The economic analysis of the agricultural system already will offer pointers to the critical dimensions for focus. Cost analysis and value distribution will suggest the social implications of the economic systems with regard to the return to labour, employment and incomes. Management systems also will highlight the social issues relating to input access, the role of gender and the significance of youth in the production system. Land and water considerations, which are inputs into the economic analysis, will have social implications in terms of access, management and investments. In examining the scope for adaptation and building resilience, a review of social coherence, modes of decision-making and organization structures is important to factor in.

Lastly, an analysis of the enabling environment should be made in terms of infrastructure, investments and capacity. This will require an evaluation of governance systems, participatory processes and the extent of inclusive decision-making in order to facilitate the adaptation of improved techniques to enhance productivity, as well as climate-adaption and emissions saving when relevant. To the extent that adaptation strategies and policies are introduced or facilitated, adaptation technologies will require greater adherence by men and women farmers – the ultimate decision-makers. This will require a thorough socio-institutional analysis of the agricultural system within the local physical, economic and institutional environments.

D. Interlinkage of the three dimensions

While each of the three main analyses (economic, biophysical and socio-institutional) have a core set of issues to be examined in relation to the sector under examination, there are important linkages that cut across the three dimensions and serve as feeding loops (see Figure 3). For example, a biophysical analysis of the impact of climate change on water, temperature and soil conditions (biophysical) directly feeds into resource use, affecting economic input use efficiency which, in turn, will affect the cost structure (economic) and which, ultimately, will affect the return to labour and incomes (social). Likewise, when climate change is expected to reduce water availability, this will in turn change the economics of the agricultural system (through productivity, water efficiency and related cost), which may require policy decisions for water resource management and reallocation across uses (social).

Another example is when climate change (through temperature and rainfall changes) alters the dynamics of pests (biophysical), thus altering the productivity of the system. This, in turn will change the input use intensity and, hence, the cost-benefit structure (economic) with social implications in terms of income and health (chemical and pesticide use). It will also implicate policy and governance (socio-institutional). Clearly, the identification of the linkage between the three dimensions is critical for a coherent and interconnected assessment. It is necessary to provide the evidence upon which an adaptation strategy can be built upon.

There are two key prerequisites for the successful implementation of this analytical framework. First, it is necessary to have as much local expertise as possible at all levels and at all times. Second, it is critical to make use of available local data, information and knowledge. These not only will ensure more relevant outcomes but they will facilitate local ownership of the process – essential to ultimately enact and achieve transformation. This may not always proceed smoothly in the context of developing countries, however, where data is often not available or is not easily accessible or usable. Moreover, national research data may often be lacking, which will necessitate capacity building from external sources. The two mentioned prerequisites, however, are important and should be followed whenever possible.

■ Stage 2: Policy formulation

The above description of the proposed analytical framework provides the evidence that is necessary to initiate the second stage (policy action facilitation). This, by definition, is a process that should be led by multi-stakeholders to focus on the issues and frame them by using the insights and evidence obtained from the initial analyses. Attention should be placed on identifying and introducing a climate-compatible strategy or new policy or improve existing policy or program that is tailored to the agricultural sector under evaluation, but which is in line with a broader national policy and cross-sectoral climate change strategy. Improving the enabling environment through policy action and governance reform for climate adaptation also requires synergies that are horizontal (across ministries and government agencies) and vertical (between public and private sectors, especially between government and vulnerable stakeholders, including small-scale farmers, women and young groups).

■ Stage 3: Implementation

This stage involves a range of possible actions and interventions depending on the outcome of the first two stages. The exact nature of implementation steps to take are context specific and depend on the nature of the findings, the existing policy processes, the extent of national awareness and ownership and the state of national capacity. Implementation could involve further developments to strategy formulation including setting up investment options and mechanisms for adopting priority adaptation measures; scaling up demonstrated best practices; or supporting capacity development required for enhancing national ownership in the planning and design and execution of adaptation measures. Required interventions may also require putting in place market-based mechanisms or policy driven economic incentives to encourage the uptake of adaptation best practices. Implementation may also require policy dialogue resulting in institutional reforms and new governance structures that are necessary to achieve climate adaptation and sustainability.

4. Application to three agricultural systems: Kenya, Morocco, and Ecuador

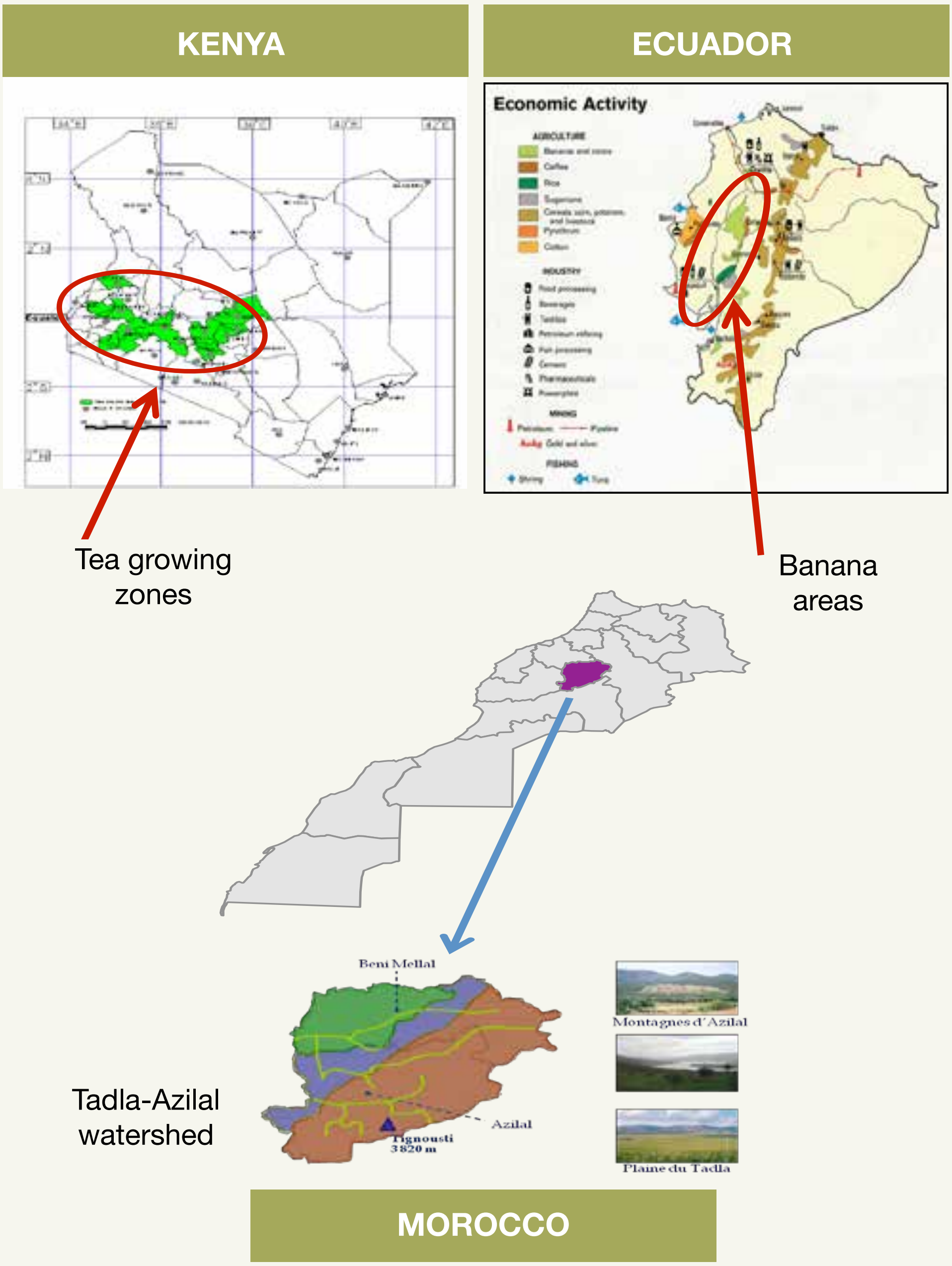
The methodological framework described above was applied in three countries under three FAO pilot projects relating to the (a) banana value chain in Ecuador; (ii) tea sector in Kenya; and (iii) fruit tree crops in Morocco (Figure 4). Each pilot project included a full-scale climate adaptation assessment, followed by a participatory policy process that involved sectoral and national government stakeholders.

4.1. Ecuador's banana sector: improving climate resiliency and sustainability

Banana industry is Ecuador's top agricultural sector with nearly 10% of the total population living directly or indirectly from this crop. In terms of climate change impacts, a key concern for banana production is the likely implications of climate-induced increased incidences of pests and diseases and their consequences for future banana yields and future viability.

In 2013, a study was carried out in Ecuador to examine the sustainability of the banana sector in the context of climate change using the methodological framework described above. In generating the evidence, both the biophysical and socio-economic analyses were carried out simultaneously. The economic analysis focused on cost (driven by labour and pesticide inputs) and market structures, as well as the uneven distribution along the value chain, which is creating significant social inequality. The biophysical analysis (i) emphasized the

Figure 5 Application of the multidisciplinary framework for climate adaptation in Ecuador, Kenya and Morocco



climate change impact on banana suitability in Ecuador; (ii) the implications of the changing climate parameters on the dynamics of pests and disease; and (iii) the likely changes that will need attention immediately and in the future to ensure the continued economic viability of a system that is vital to Ecuador's agricultural economy.

This biophysical analysis also examined the carbon footprint and GHG emissions associated with banana production, including the stages from transportation through to consumption. From a socio-institutional perspective, a study was made of the national social policies to ensure a fairer distribution of returns to stakeholders across the banana value chain, especially with regard to smallholder farmers and banana plantations workers, who play an important role as constituents within Ecuador's main agricultural industry. The socio-institutional analysis included the issue of governance relating to the banana value chain, not only within Ecuador (labourers, producers, exporters), but also beyond its borders (retailers, consumers).

The impact of climate change on Ecuador's future banana production suitability has been found to be robust, unlike in other key banana-producing countries. The results of climate change impact on the dynamics of pests and disease in Ecuador, however, were less robust, pointing to potential negative impacts based on preliminary global analysis of diseases dynamics under changing climate. However, further research and more detailed analyses are still required to reduce the scope of uncertainty in current knowledge.

The findings from the biophysical and socio-economic analyses were shared with national stakeholders through a national workshop and follow p policy dialogue for greater national partner's engagement. The aim was to facilitate and guide the implementation of recently enacted banana law in light of the study findings, especially in relation to responsible environmental management of pesticides.

4.2. Kenya's tea sector: Developing an evidence-based climate-smart strategy

Tea is Kenya's principal agricultural industry, employing over 2 million people. And the continued viability of the sector is critical to Kenya's rural economy and the livelihood of 500 000 farm families. The Kenya case study included a climate impact assessment of the tea sector followed by a formulation of a climate-smart strategy. The methodological framework started with a series of impact assessments that included a biophysical study of the link between climate and tea yields, a life-cycle analysis of tea, and a crop modelling of tea management under various climate scenarios (FAO model Aquacrop). The economic analysis covered the tea value chain, market structure; sources of competitiveness and comparative advantages; the sources of technical progress that ensured Kenya's continued tea productivity improvements that kept the country among the world top producers and exporters of tea.

Socio-economic analyses also included tea farms and household-based surveys that investigated current farmers' perceptions of climate change and evidence of adaptation (through changes in cropping techniques and crop diversification) changes under perceived recent climate variability. The surveys also examined household responses to climate-induced income variability and observed adjustments to household food security and nutrition behavior.

Once the cumulative evidence was obtained from the studies, a multistakeholder process was initiated to develop a climate-compatible strategy for Kenya's tea sector. A national dissemination workshop, attended by representatives of government agencies, tea industry representatives and civil society, was organized where the study findings were shared and discussed. This was followed by working meetings with a Technical Committee to jointly formulate a new climate-adaption tea strategy for Kenya. The Committee included representatives from various ministries and specialized government agencies and representatives of the tea industry and tea farmers.

4.3. Morocco: mainstreaming climate adaptation within the Green Morocco Plan

In the case of Morocco, the methodological framework described above was applied to develop tools necessary to mainstream climate adaptation for small-scale agriculture in the context of the national agricultural investment programme, known as the Green Morocco Plan (GMP). Unlike the cases of Ecuador and Kenya where the focus was on a single-strategic-sector, Morocco's case study was based on a territorial approach where the focus of the analysis is Tadla-Azilal watershed. Within the target area emphasis was placed on water use by agricultural fruit tree crops by small scale producers and targeted for investments by the GMP (pilar 2).

Water scarcity is a crucial concern for Morocco. The biophysical study focused on crop suitability under different climate scenarios, taking into account the local soil types and the demand for water. A hydrological model, especially developed for the Tadla-Azilal zone, examined the demand and supply of water and future crop suitability under changing water supply levels due, in large part, to climate change. The economic analysis included the two key concerns that are linked to climate change impacts on Morocco's agriculture, namely: (i) the impact of climate change on future food supply variability and on food security in light of the investment and value chain priorities of the GMP; and (ii) trade-offs between agricultural intensification under the GMP and water use preservation and sustainability. The economic and biophysical analyses converge on the central issue of optimal use of water, given the changing climate conditions.

The socio-institutional evaluation included diagnostic studies that targeted small-scale farmers to evaluate their degree of participation in nationally supported investment programmes and to assess the scope for integrating climate adaptation into their agricultural systems. A socio-institutional analysis focusing on governance was carried out to examine the governance structure guiding the government agents' relations to small scale farmers in the initiation, design and execution of government funded projects to improve the productivity and value added of the target value chains under the GMP-Pilar 2.

The analysis was designed to develop a participatory diagnostic tool aimed to foster an inclusive implementation of investments projects under GMP and ensure better acceptance by small scale farmers and thus improve the conditions for higher adoption of climate-smart and resilient production practices.

This document presents the findings from the Kenya case study. The Ecuador and Morocco's case studies will be published in separate reports.

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CHAPTER TWO

TEA VALUE CHAIN AND THE POLICY FRAMEWORK IN KENYA: AN OVERVIEW

Aziz Elbehri, Mary Mwale, John Nyengena, John Bore, Beatrice Cheserek and Hernan Gonzalez

1. Introduction

Tea is one of the most important crops within Kenya's agriculture industry. In 2012, the tea industry alone represented 4 percent of national GDP and 17 percent of agricultural GDP, totalling KES 112 billion and, therefore, making it the country's leading export earner. The tea industry also provides a livelihood to approximately one eighth of the Kenyan population.

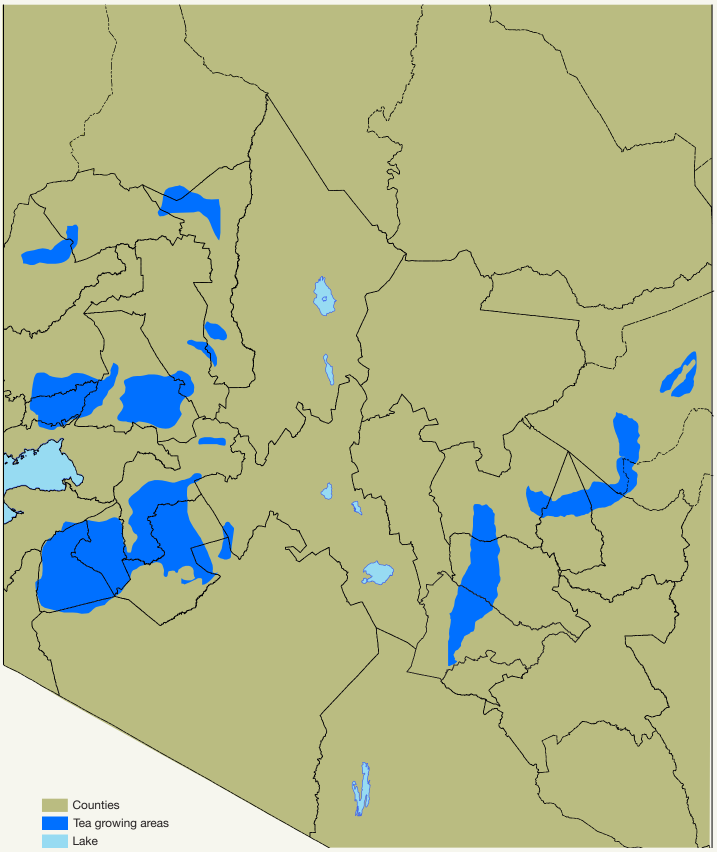
Tea was introduced to Kenya from India by the British settler, G.W.L. Caine, in 1903. Commercialization of the product began in 1924 and it has continuously been growing, making Kenya one of the world's leading producers and exporters of tea. Prior to independence, indigenous Kenyans were barred by law - under British colonial rule - from growing tea. Tea growing was restricted to large-scale foreign farmers and multinationals, ostensibly to maintain quality, although it primarily served to "lock out locals from this lucrative cash crop". Following independence in 1963, however, a series of land reform bills were passed that impacted positively on agriculture and permitted the local farmers to grow tea.

The tea plant is an evergreen shrub from the genus, *Camellia sinensis*, which includes 82 species. Most of the species that are grown derive from the *assamica* strain, originally from Asia, which was developed for Kenyan conditions over the last half a century by the Tea Research Foundation of Kenya and its predecessor, the Tea Research Institute of East Africa. The seed is planted in deep, well-drained, fertile soil with a pH level of between 5.0 and 5.6 and at a minimum depth of two metres (m). The plant grows best in areas where the rainfall ranges between 1 200 to 1 400 millimetres (mm) *per annum* and is evenly distributed, alternating with long sunny days. Kenya, located in the tropic zone, has the ideal climate to grow tea year round with minimal seasonal variation in terms of quality. Tea plucking usually continues throughout the year, with two peak seasons, between March and June and between October and December. TRFK has developed over 50 tea varieties, although farmers have not adopted them fully due to their long gestation period (approximately three to five years). The high cost of planting tea to maturity further hinders the growing of these new varieties.

In 1966, the first suitable areas for tea growing were delineated by what are known as the "Brown" lines. These were based on annual rainfall (1 270-1 397 mm) and distribution, cloud cover and humidity, temperature, soil pH (4.5-5.8), soil depth and indicator plants. The demarcation is found in and around the highland areas on both sides of the Great Rift Valley and astride the Equator within altitudes of between 1 500 and 2 700 m above sea level. Today, the tea growing regions include the areas of Mount Kenya, Aberdare Range, Nyambene Hills, Mau Escarpment, Kericho highlands, the hills of Nandi and Kisii, Mount Elgon and Cherangani Hills. The potential land for tea growing is estimated at over 344 000 hectares (ha). By 2012, approximately 190 717 ha were covered by tea plants, comprising approximately 124 985 ha of smallholder growers and 65 732 ha of large estates.

Kenya's tea is grown free of pesticides, owing to the prudent selection of pest resistant clones. The environment in which it is grown also acts as a natural deterrent to pests and disease. Agrochemical fertilizers (mainly NPK, which is

Figure 6 Tea growing areas in Kenya, 2013



Source: TRFK, 2013

a rating that is based on the content of nitrogen, phosphorus and potassium - commonly used in fertilizers) are the only type used to replenish soil nutrients. Over 50 varieties of clone-planting materials, developed through scientific innovation by TRFK, have made vegetative propagation possible, resulting in the high yield of well-adapted plants. The tropical climate and rich volcanic soil in Kenya's tea growing areas has afforded its tea a distinct bright colour and aromatic flavour. Typically, tea is produced from the upper two leaves and a bud, picked using the cut-tear-curl (CTC) method to ensure maximum cuppage per unit weight. It is this part of the bush that is processed into the tea leaves for brewing. Although Kenya mainly produces black CTC tea, it also produces other varieties, such as green, yellow and white teas.

The tea industry in Kenya is comprised of two distinct players: smallholders who are small-scale growers and the large-scale plantations or estates, the majority of which are owned by multinational corporations. Smallholders include more than half a million growers who sell their produce through tea processing factories, managed by KTDA. There are over 560,000 farmers who distribute the green leaves to 67 KTDA-managed factories for processing.

Among the main issues facing smallholder green leaf output are:

Fertilizer use: Although fertilizer is easily accessible, there are significant intra- and inter-regional disparities on the quantity applied per ha. This implies an underuse of fertilizer that not only influences yield and income, but can also result in decreasing biomass production.

Labour: Tea growing and harvesting are labour-intensive activities, and many farmers allocate only a portion of their time to tea production, which often is inadequate to achieve optimal production.

Low technology adoption: Smallholder farmers lag behind large estates in terms of the adoption of technology and appropriate management practices. Given the large number of registered farmers, it is difficult to incentivize them to use appropriate technologies.

Adoption of high-yielding clones: The adoption of high-yielding tea clones among smallholders has been slow, due to their aversion to risk. The long gestation period (three to four years) of tea significantly deters farmers from adopting new clones, particularly in the absence of an alternative source of income.

Pesticide use: The use of pesticide is currently limited; however, with climate change, the emergence of climate-induced pests is likely to take place in tea zones.

2. Production trends

Table 1 provides information on tea production, planted areas, and average yields over the last five decades. The tracts under cultivation increased from 17 756 ha in 1961 to 190 717 ha in 2012, while yields increased from 712 kilos (kg) to 2 690 kg per ha (kg/ha), respectively. The average yield per hectare, however, is higher on the large estates (between 1 500 and 3 300 kg/ha) compared to smallholder farms (between 600 and 2 321 kg/ha), mainly due to the improved use of technology, inputs, and economies of scale. Over the same period, productivity among estate producers rose from 992 kg/ha to 3 058 kg/ha, an increase of 208 percent. Productivity, however, has fluctuated considerably due to climate variability, with major swings especially occurring in the west of the Great Rift Valley, where most estates are located.

The significant increase in yields following 1980 resulted from the adoption of new high-yielding clones and improved management techniques, particularly the use of fertilizer. The highest average production of 3 511 kg/ha was recorded in 1998, when the country experienced the warm oceanic effects of El Niño on its rainfall. Performance in the smallholder tea industry was further boosted by

Table 1 Area under tea: quantity and yields, 1961-2010

Item	1961	1970	1980	1990	2000	2010	2011	2012
Area Planted (ha)	17 756	40 278	76 541	96 981	120 390	171 900	???	190 717
Production (tonnes)	12 641	41 077	89 893	197 000	236 286	399 000	377 000	369 000
Yield (kg/ha)	712	1 020	1 174	2 031	1 963	2 321	???	2 690

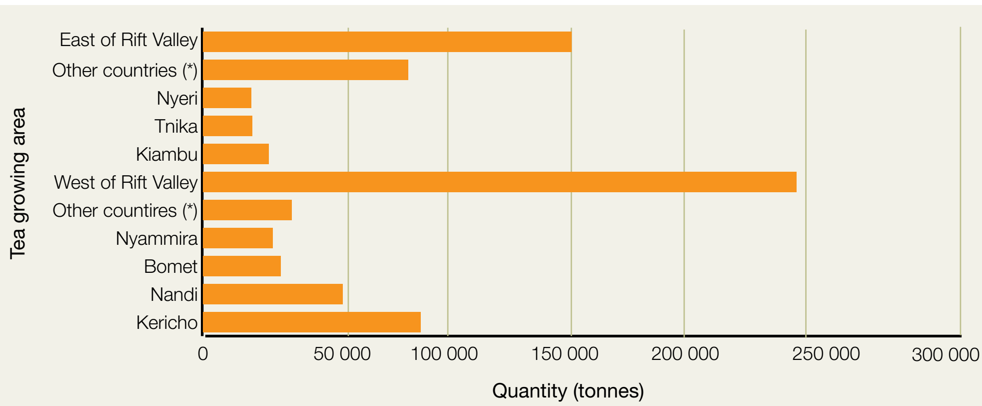
Source: Statistics Department of FAO (FAOSTAT)

an enabling policy environment; adequate organizational structure within the industry; reliable income streams and profitability; and diminished returns from other agricultural enterprises. This led to higher output for a growing number of tea factories. Small-scale output accounts for approximately 67 percent of total production *per annum*.

Approximately 62 percent of Kenya's tea comes from the west of the Great Rift Valley, while the remaining 38 percent is grown on the east side. The distribution in 2010, according to county, is illustrated in Figure 7.

In 2010, Kenya's production level was 399 000 tonnes (2 321 kg/ha), the highest in the world, while China yielded 1 034 kg/ha; India, 1 700 kg/ha; and Sri Lanka, 1 293 kg/ha. These four leading tea producing countries account for over 73 percent of total tea output. As shown in Figure 8, however, Kenya is the world's third largest exporter of tea due to its low domestic consumption. While its world market share has consistently expanded from 6 percent in 1970 to 26 percent in 2010, average domestic consumption has remained constant at approximately 5 percent.

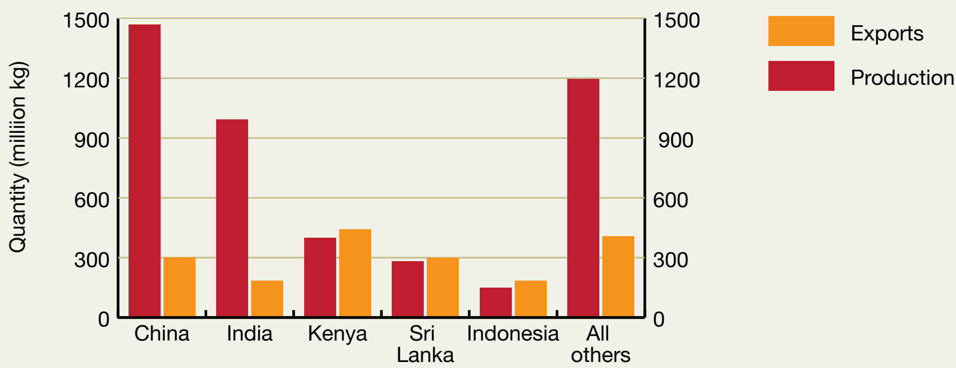
Figure 7 Distribution of tea production by county, 2010



Source: KTDA, 2012

* Only counties producing more than 20 million kg of tea are included

Figure 8 World production and export of tea



Source: FAOSTAT

3. Tea value chain

The tea value chain includes approximately 14 distinct stakeholders. As Figure 9 illustrates, these can be grouped into three basic stages: green leaf production, tea processing, and trade.

3.1. Green leaf production

Tea growing in Kenya is mostly rainfed. Green leaf production begins on a smallholder's farm or on a plantation. Key factors include land, fertilizer use,

Figure 9 Tea value chain

Green leaf production	Smallholder	Plantation
	Green leaf collector	Green leaf collector
	Transporter	Transporter
Tea processing	Tea factory	Tea factory
International trade	Transporter	
	Warehouse operation	
	Traders/Auction brokers	
	Port authority	
	Blenders/Packers	
	Retailers/Consumers	

Source: Azapadgic *et al.* (2013)

moisture and soil conditions, cultivar selection, labour conditions and general tea husbandry. Labour, cultivar type and fertilizer have the greatest impact on tea output and production costs. Subsequent to the three to five years it takes the tea plant to mature and for the bush to be fully established, it will take another 1.5 years to re-establish itself following the selected type of rim-lung pruning. Harvesting takes place at 7- to 14-day intervals, and is done either by hand or machine (the latter is limited to estate growers), whereby the upper two leaves and a bud are plucked. The picked tea is usually collected and delivered to the processing factory on the same day. That from small-scale producers is delivered in KTDA trucks from various buying centres.

The main players at the green leaf output stage are the farmers, labourers, leaf collection clerks, transporters and factory workers. The entities involved include the TBK , KTDA, and KTGA.

3.2. Tea processing

While black tea is the main type grown in Kenya, also grown are small quantities of green, white, and orthodox (carefully handpicked, hand-rolled, and dried without the bud - as opposed to CTC) tea. The leaves are harvested and transported to the factory, where they are withered to remove excess water and allowed to oxidize. At this stage, the leaves lose more than a quarter of their weight. The withering is necessary to break down the leaf proteins into free amino acids and to free the inherent caffeine, both of which are critical to the taste variation of tea.

Once the leaves have reached 68-76 percent of their original water content, they are softened or torn to promote and speed up the oxidation process. The leaves are then pushed through a machine with two steel rollers, where they are cut into small particles. The tea leaves are finally left to ferment for between 60 and 100 minutes, depending on the leaf quality and prevailing climatic conditions. Since low humidity can retard fermentation, cool humid conditions are essential to extend the fermentation time to produce blacker, grainier and heavier teas. The character of the tea, therefore, is developed significantly during this particular process. In addition, the grade of tea is determined by the grooves in the CTC rollers, which deliver a significantly improved and thicker quality of liquid to yield more cups of tea per kg of leaf compared to orthodox tea.

Following fermentation, the tea is dried to remove excess moisture. This is performed in various ways, including panning, sunning, air drying or baking, the latter of which is the most common. Baking, however, requires greater care to ensure that the leaves are not overcooked. Once the dried tea has become black, it is sifted into various grain sizes before packaging in relation to its properties and the needs of the end user.

3.3. Tea trade

Kenyan tea is sold through private contracts or through the largest tea auctions in the world, which take place in Mombasa. At auction, tea samples are tasted by brokers who set the value according to the market and forward samples to those companies which are entitled to operate in the auction on a weekly basis. The samples are accompanied by catalogues with the details of the tea farms, the quality grade of the tea, and other information. Participating tea companies will taste the samples, evaluate them and, ultimately, place their bids.

Two groups represent the downstream tea supply chain. The first is the East Africa Tea Trade Association, which brings together the producers, brokers, buyers and packers and various warehouse operators, whose day-to-day operations are managed by a secretariat located at Tea Trade Centre in Mombasa. The second group comprises the Kenya Tea Packers Association, a private entity involved in the packaging and domestic marketing of the product. It is owned by various tea factories within KTDA. Each factory sends processed tea to the Kenya Tea Packers Association for repackaging for the local market. Packaging for the international market is undertaken primarily by multinational organizations.

The certification - including carbon offset labelling - of products includes emerging international economic standards under the International Organization for Standardization (ISO), used to differentiate products and generate additional revenue. They are based on the special characteristics of the commodity. Certification is a form of disclosure between the seller and the buyer, while the label is applied to inform the consumer. As the need for sustainably grown products increases, companies and brands are seeking ways in which to demonstrate their commitment to sustainable development. These have a direct impact on the tea trade and, therefore, can influence the volume of tea exports.

The incorporation of carbon credits to reduce emissions and sustainability in agriculture in terms of international development has resulted in many trade barriers. Kenyan tea, for example, is unable to access certain international markets without ISO certification, thus impacting the tea industry. The branding, packaging and export of Kenyan tea are linked to tariff barriers, while research, development and sustainability are equally important for the industry. Meeting the requirements of the various standards, however, is a big challenge for the smallholder farmer, given that the source of the tea is often unknown when the product is repackaged and rebranded for sale in some import countries. In the case of Kenya, this reduces the value of the tea, despite Kenya having made great efforts to brand its own tea. Industry players, therefore, should ensure that they are aware of the specifications that tie the tea trade to climate change and carbon trade requirements. To address these issues, Kenya is in the process of developing a new policy.

4. Policy, legal and institutional framework

4.1. Policy

Kenya vision 2030

Kenya Vision 2030 is an overarching, long-term development programme, with the objective to transform Kenya into a "newly industrializing, middle-income country providing a high quality of life to all its citizens by 2030 in a clean and secure environment". Its three economic pillars (economic, social and political) aim to achieve an average economic growth rate of 10 percent *per annum*, and the agricultural industry is recognized among the key contributors to assist in the delivery of objectives. Kenya Vision 2030, in terms of the agricultural industry, intends to reach the status of “a food-secure and prosperous nation”, through “an innovative, commercially oriented and competitive agriculture”. The ambitions of this blueprint, however, may increase GHG emissions.

The transformations that are required to take place under the economic pillar of Kenya Vision 2030 are as follows:

- restructure the key institutions relating to agriculture, livestock, forestry and wildlife, in order to promote agricultural growth;
- increase the productivity of crops, livestock and tree cover;
- introduce land-use policies to improve output;
- develop more irrigated areas in arid and semi-arid lands for crops and livestock;
- improve market access for smallholders through improved supply chain management; and
- provide added value to farm crops, livestock and forestry products to enable their access to local, regional and international markets.

Despite the central role of tea in the Kenyan economy, the threat of climate change and the factors necessary to adopt relevant measures have not been adequately highlighted in the key strategies of the economic pillar. There is, however, a commitment to improve research and development, strengthen the human and financial capacities of research institutions and strengthen collaboration between research, policy and public-private partnerships.

Agriculture sector development strategy

The Agriculture Sector Development Strategy (ASDS) is the overarching policy framework for agriculture development in Kenya. Its goal is “to achieve a progressive reduction in unemployment and poverty, the two major challenges of poverty and food security that Kenya continues to face”. It is aligned to Kenya Vision 2030 and guides the sector’s medium-term plans. ASDS places the principles of the Comprehensive Africa Agriculture Development Program on a national platform, under the New Partnership for Africa’s Development. Through this strategy, it is anticipated that the tea industry will grow at an annual rate of 7 percent for the period 2010-2020. The programme takes into account the impact of climate change and the associated risks to Kenya’s climate-sensitive agriculture sector - especially in terms of its leading industrial crop - in relation to its foreign exchange revenue and GDP. In addition, the strategy outlines the policies and institutional adjustments that are necessary to create a vibrant and productive industry, recognizing at the same time the importance of public-private partnerships within the industry.

ASDS proposes a consolidation of numerous agriculture sector reforms to streamline the legislative framework that governs the agriculture sector in Kenya. It aims to foster agricultural and land-use best practices and align the sector to the new Constitution of Kenya (2010). Some of the reforms and pilot projects being implemented in the sector that could benefit the tea industry are the following:

Consolidated Agricultural Policy Reform Legislation: The Agriculture, Livestock, Fisheries and Food Authority Act 2012; Kenya Agricultural and Livestock Research Act 2012; Pyrethrum Act 2012; and Crop Act 2012.

The Fertilizer Cost-Reduction Initiative: To make fertilizer more affordable and easily accessible to farmers in order to increase agricultural production. In this regard, the Kenyan Government has been procuring and distributing fertilizer at a subsidized rate to farmers across the country in order to stabilize its price. In addition, the Government has carried out a feasibility study for locally manufactured fertilizer.

Improvement of weather and climate forecasts: To improve the issuance of timely and accurate weather and climate forecasts and provide early warning system information by:

- ensuring the continued operation of rainfall stations, especially those in the tea growing areas;
- strengthening existing networks of agro-meteorological stations to cover the tea growing areas; and
- incentivizing relevant institutions (e.g. TRFK, TBK and the Kenya Meteorological Society) to jointly research extreme weather events that may affect the tea sector.

Although the ASDS does not explicitly identify the challenges specific to the tea industry, it does recognize the potential of value addition to increase its competitiveness in the global market. It should be noted that despite the importance of tea in the country's economy, it so far has been operating without a policy framework.

National climate change response strategy, 2010

The National Climate Change Response Strategy (NCCRS) was developed by the previous Ministry of Environment and Mineral Resources in response to the United Nations Framework Convention on Climate Change. The NCCRS is founded on the principle of mainstreaming climate proofing and climate change adaptation in the planning process of the agriculture sector. The strategy recognizes the impact of climate change and the risk of crop failure on rainfed agriculture, as well as the differences between the production and market share of small- and large-scale farming. Furthermore, it calls for an increased capacity for research in the industry to enhance productivity; adaptability and mitigation; product quality and safety; and the competitiveness of agricultural products in domestic and global markets.

A key outcome of the NCCRS is the National Climate Change Action Plan, which calls for measures to enable Kenya to transition into a low-carbon, climate-resilient position to improve people's livelihoods, while taking into account its Vision 2030 goals. The plan acknowledges that Kenya's growing population and urbanization have the potential to increase GHG emissions and, therefore, intensify climate-change risk and vulnerability.

The NCCRS comprises eight components to guide the country towards a low-carbon, climate-resilient course, thus acknowledging the sensitivity of the agricultural industry in relation to climate change. It recommends adaptation by agricultural systems and outlines the priorities to expand climate resilience. It also advocates the mainstreaming of such considerations in all sector programmes.

The NCCRS indicates that the agriculture industry is a growing source of GHG emissions, responsible for approximately 30 percent of Kenya's GHG emissions in 2010. The strategy includes a warning that industry emissions could increase from 20 million metric tonnes of carbon dioxide equivalent ($MtCO_2e$) in 2010 to 27 $MtCO_2e$ by 2030. In response, the Ministry of Agriculture, Livestock and Fisheries (MALF) has established a climate change unit that coordinates the implementation of climate-related programmes and projects in the industry. It has outlined priority adaptation actions to increase climate resilience of the industry.

4.2. Legal and regulatory framework

The tea industry is well developed and is controlled by law under the Tea Act (Chapter 343 of the Laws of Kenya). The Tea Act established TBK, which falls under MALF as the body responsible for regulating the industry with regard to the growing, research, manufacture, trade and promotion of tea. TBK disseminates information relating to tea and advises the Government on policy issues. The Tea Act governs the registration of growers, manufacture, and export relating to tea, as well as the Board's financial provisions, which include tax on tea, allocation of TBK cash flows, investment and borrowing. Since 2013, the legal framework within the tea sector has changed. The tea industry is now controlled by law under the Crops Act, 2013 (which replaces the Tea Act). The Tea Board of Kenya was abolished and was turned into the Tea Directorate under the Agriculture, Food and Fisheries Authority (AFFA). The Kenya Agricultural and Livestock Research Act, 2013 established the Kenya Agricultural and Livestock Research Organization (KALRO) while the Tea Research Foundation of Kenya (TRFK) has become the Tea Research Institute (TRI) which is part of KALRO.

Establishment of new tea farms

In order to establish a new tea plantation, a farmer must meet certain requirements, such as (i) the land must be within the demarcation of the Brown lines and (ii) TRFK is to provide technical support. There are two reasons for this. The first relates to preventing the planting of tea in unsuitable regions, as well as controlling the soil types, which could reduce the quality of Kenyan tea. The second reason is to safeguard the supply of agricultural goods (mainly food crops) in tea producing areas.

Licensing of new factories

TBK regulates and controls the cultivation of tea, registers the tea growers and overseas management agents. It also licenses the manufacturing factories and regulates and controls manufacturing methods, ensuring that there are adequate tea leaves to meet processing capacity and avoiding over-capacity in any given area. Licensed factories are required to maintain, on behalf of TBK, a register of the growers that distribute to them. Prior to issuing a licence to new investors, TBK decides the distribution of growers between existing and new factories.

Licences are issued to factories or firms that have at least 250 ha of planted tea bushes. They may also be applied for by a group of persons or business on the condition that there are at least 250 ha of tea bushes and that the land parcels are within a 50-kilometre (km) radius. In the case of high-value or specialty teas, TBK may grant the licence based on the economic viability, technology used or range of products. TBK may modify, cancel or suspend a licence that is issued to a company if the terms and conditions of the licence are violated.

Tea ad valorem levy, 2011

MALF has enacted a value added levy under the Tea Act, payable at the rate of 1 percent of the customs value for manufactured tea exports and imports, excluding bulk tea imports into Kenya for blending and re-export. Of this, 50 percent is passed on to TBK, 40 percent to TRFK and 10 percent flows into infrastructure. Manufactured tea that is packed in Kenya, in accordance with Kenya Standard 1927:2005 (tea packets and containers), however, is exempt from value added tax.

4.3. Institutional setup

The Tea Research Foundations of Kenya

Institutionally, MALF provides direction, while TBK regulates the industry and TRFK. TRFK's objectives are "to promote research and investigate problems related to tea and such other crops and systems of husbandry as are associated with tea throughout Kenya including the productivity (yield), quality and suitability of land in relation to tea planting; and matters ancillary thereto".

Kenya Tea Development Agency Ltd.

The Kenya Tea Development Agency (KTDA) represents smallholder tea farmers (owning less than 2.5 ha) and acts as the management agent for the 67 smallholder factories that are technically owned by the small-scale producers through shareholding. The management of a factory is undertaken by a Board of Directors, elected by the farmers, and technical personnel who are recruited by the Board.

Kenya Tea Growers Association

The Kenya Tea Growers Association (KTGA) is the entity that represents Kenya's industrial estates. Its role is to promote the common interests of its members in the cultivation and manufacture of tea and to promote good industrial relations and sound wage policies for workers. Currently, the tea industry owns 39 factories, each of which operate as an independent entity, including tea management activities such as farm management and green leaf assembling, processing and transportation to markets. In most cases, factories also sell tea using other avenues outside the Mombasa auction market.

Nyayo Tea Zones Development Corporation Ltd.

The Nyayo Tea Zones Development Corporation Ltd. promotes forest conservation by guarding against human encroachment into forestland. This is done by growing tea and assorted tree buffer belts to surround the forests. The tea zones protect the forests while, at the same time, contribute towards the rehabilitation of fragile ecological areas. The corporation operates in 17 zones across the country with 2 factories.

East Africa Tea Trade Association

The role of the East Africa Tea Trade Association includes facilitating the Mombasa tea auctions; facilitating the settlement of tea trade disputes; promoting the best interests of Africa's tea trade; compiling and circulating statistical information; and promoting close relations within the tea industry.

CHAPTER THREE

AN IMPACT ASSESSMENT OF CLIMATE CHANGE ON KENYA'S TEA PRODUCTION

Beatrice Cheserek[1]

[1] The author acknowledges John Bore of the Tea Research Institute (Kenya) whose collaboration on previous climate change analyses was a valuable input to this research.

1. Introduction

Tea (*Camellia sinensis* O. Kuntze) is Kenya's leading foreign exchange earner. It is grown on approximately 157 720 ha: 64 percent on smallholder land units and 36 percent on large estates (TBK Annual Report, 2009/2010). Most of the product is processed for black tea. Annual production in 2010 was 398 500 000 kg - a record - and valued at slightly over USD 1.4 million, contributing to Kenya's foreign exchange revenue.

Climate change is the greatest global challenge facing mankind this century, and since Africa is one of the most vulnerable regions, it is most likely to suffer from its effects. Climate change is a transformation of average weather conditions or the spread of climatic events beyond the average (e.g. less or more prevalent extreme weather events), primarily as a result of global warming. Gas emissions contribute to the GHG effect on the earth's surface, with the largest source emanating from the burning of fossil fuels (oil, gas, petrol, kerosene, etc.), leading to the emission of carbon dioxide. Not only has carbon dioxide into the environment increased dramatically over the past 50 years, it has also raised weather temperatures.

Tea growth depends heavily on stable weather conditions, and the effects of climate change are alarming to tea industry stakeholders. Stephens *et al.* (1992) list some of the major environmental variables that affect the growth of tea shoots. These are temperature, vapour pressure saturation, plant and soil water deficits (SWD) and rainfall and evaporation.

One of the major impacts of climate change is the occurrence of severe weather conditions, such as hail, frost and drought, all of which significantly influence the growth of tea shrubs. The crop requires a well-distributed annual rainfall above 1 200 mm, a temperature range of 18-30°C and well-drained soil. Most of the tea growing areas in Kenya experience a regular three-month drought period between December and March, when tea yields can drop by an estimated 14-20 percent, climbing to 30 percent during severe droughts. This is, however, prone to variation, according to the time span and intensity of the climate change effect. Although previously a rare phenomenon, frost bite has become a threat to tea plants, with up to a 30 percent loss over three consecutive months when it occurs, as it did in January 2012. In Kericho, Sotik and Nandi Hills, the net loss of green leaves due to hail is estimated at 2.7 million kg *per annum*, based on reports.

Using global models to predict climate change for areas that grow tea, one study has discovered that the change in suitable conditions for tea growing is site-specific (CIAT, 2011). The study also noted that some areas will gradually become unsuitable for tea (Nandi, Kericho, Gucha), while others will remain stable (Bomet, Kisii, Nyamira). In contrast, however, there will be areas where conditions could raise the possibility of tea growing (Meru, Embu, Kirinyaga, Nyeri, Murangá, Kiambu) with yet other areas that are not apt today becoming more so in the future (especially in the higher altitudes around Mount Kenya).

The climate change challenge is further complicated by the limited research that is available. The dynamics of climate change, thus, are still poorly understood. Given this, the Kenya Tea and Climate Change project aims to identify the most vulnerable tea producers in Kenya and to build capacity within the country's tea sector in relation to the impacts it has experienced as a result of climate change. This will assist in future policy-making relating to climate change mitigation to ensure that vulnerable producers can secure their future livelihoods and make them more environmentally and economically sustainable.

2. Recent climate change trends in Kenya

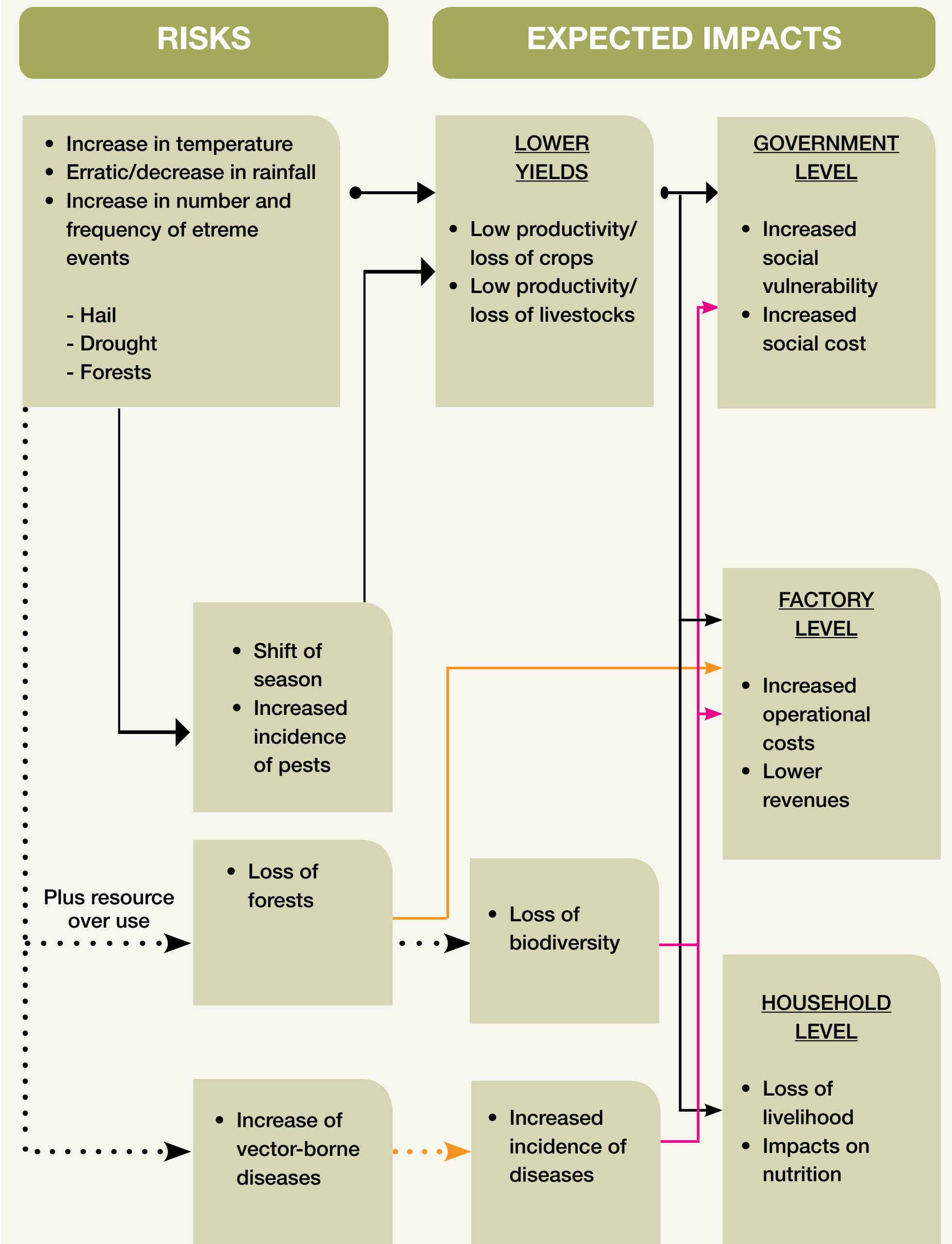
Climate change continues to raise the intensity and spread of temperature and rainfall variability (causing droughts, floods, frosts, etc.). Extreme weather patterns due to global warming have the potential to accentuate current pressures and pose serious threats to the socio-economic development of many countries. Although the future of climate change remains very uncertain, the model scenarios demonstrate an increase in mean annual temperature - a rise of almost 1°C by 2030 and approximately 1.5°C by 2050 in terms of a mid-range emission scenario. In sum, however, all models project a rise from 1°C to 3.5°C by 2050. Changes in precipitation are even more uncertain, with average annual rainfall forecast to increase and shift in terms of the seasons. Some models exhibit a reduction in rainfall during some seasons. Overall, there is less of a consensus on rainfall pattern changes as there is with temperature.

The information on extreme events, such as floods and droughts, is much more unpredictable, given the wide variables in projections. Many models indicate an intensification of heavy rainfall during the wet seasons, particularly in some regions, with greater possibility of flood risk. Droughts will likely continue, but these projections are more varied, with some models alluding to a worsening in some regions and others indicating a lessening of severity. Millions of people, globally, will face water scarcity and food insecurity if climate change adaptation and efforts to stop global warming continue to be ignored.

Overall, rising temperatures, erratic precipitation, and increasingly more extreme weather events are expected to affect the tea production in Kenya, leading to reduced crop yields. In recent years, drought, frost and hail have affected production and earnings in a number of tea growing areas. Most parts of Kenya, for example, experienced frost damage in January 2011, especially in the areas of Kirinyaga, Trans-Nzoia, Nandi and Nyeri, which prompted a decline of more than 32 percent in the production of green leaves over a three-month period; however, there was no frost occurrence during 2012. The Bureti region has actually experienced a growth in production of more than 11 percent (Kenya Meteorological Society). Figure 10 shows a schematic diagram of the risks and expected impacts of climate change on the tea sector. Among the impacts are the lower productivity of crops and livestock, altered quality of tea, emergence of new diseases and higher incidence of pests and disease.

The aggregate models indicate that the cost of climate change on the Kenyan economy may amount to a loss of almost 3 percent of GDP *per annum* by 2030. Future weather impacts could lead to uncertain and potentially very significant economic costs, although some areas may experience more favourable agro-

Figure 10 Risk and expected impacts of climate change on tea



Source: FAO, 2013

climatic conditions, particularly in the highlands. Although the economic costs to Kenya could be large, adaptation to climate change could provide an opportunity not only to protect Kenyan livelihoods to a significant extent, but also to help reduce some of those costs.

The potential of climate change to significantly affect agriculture-based livelihoods depends on the climatic factors that challenge the sustainability of their arable, pastoral and fishing practices. Potential impacts include:

- higher temperatures, which are likely to directly reduce the yield of crops in the long term, as well as the number of crop-growing days;
- changes in precipitation patterns, which are expected to increase the chance of crop failure in the short term, as well as decrease the average yield of rainfed agriculture in the long term;
- extreme weather events (drought, hail, and frost) that are expected to intensify with significantly negative impact on industry, especially with regard to livestock; and
- a number of indirect impacts, such as an increased rate of runoff and soil erosion and crop loss due to wildlife migration, insects, disease and weeds, which could lead to significantly severe production loss.

Extreme events, especially in relation to drought, have been highlighted as major hazards to the livelihood of the smallholder farmer. The droughts that occurred in 1991-1992, 1995-1996, 1998-2000, 2004-2005, and 2008-2011 caused severe crop losses, which led to famine and population displacement in Kenya. In particular, the prolonged drought of 2008-2011 was estimated to have cost more than KES 120 billion (USD 1.4 billion) in terms of food and cash crops. In 1997, 2000 and 2006, weather conditions in most tea growing areas of the country resulted in some factories having to shut down or operate at far below capacity due to the inadequate supply of tea leaves and revenue.

Kenya's GHG emissions continue to be low, but new economic plans could lock Kenya into a higher carbon energy course relative to 2005. Consistent with its pursuance of its Vision 2030 goals, the potential effects of socio-economic change and development in Kenya portrays very different socio-economic characteristics that will affect economic conditions, resource management, population vulnerability and GHG emission profiles, assuming a continuing high growth in its population, urbanization and economy. Studies relating to Kenya's future emissions outlook are consistent with planned development and indicate that GHG emissions could double between 2005 and 2030, giving an expedient call for a climate-resilient and low-carbon development pathway. Model results, however, highlight the considerable uncertainty in predicting future impacts and, thus, there is a need to consider a robust approach towards the decision-making process relating to adaptation, especially in relation to an uncertain future. There is justification for the consequential need to prepare for future climate scenarios, instead of remaining inactive, simply because of uncertainty.

Recent analyses in tea producing areas indicate that temperature has increased by an average of 0.02°C *per annum* since 1960. By 2090, readings in

East Africa are expected to increase by a median value of 3.2°C. Precipitation is projected to increase annually - on average by 0.2 to 0.4 percent. The regional variations are significant, with coastal regions likely to become drier and the highlands and northern region of Kenya to become wetter. The severe rainfall events that occur in Kenya every ten years are expected to increase in number during the short and long rainy seasons, while the dry extremes are likely to be less severe, particularly in the northern region. Within the tea growing areas, TRFK reports that there has been a growing occurrence of hail, drought, and frost, based on the average annual number of events since 1960.

A study of current and future climate data from 20 models relating to 2020 and 2050 has concluded that monthly and yearly rainfall and minimum and maximum temperatures in Kenya are expected to rise moderately by 2020, but will progressively intensify by 2050. The overall climate is predicted to become less seasonal in terms of variation throughout the year.

3. Shifts in the suitability of tea production areas (brown lines)

In Kenya, the yearly and monthly rainfall and mean air temperatures are expected to increase moderately by 2025 and will so continue progressively to 2075. The country's overall climate condition is predicted to become less seasonal throughout the year in terms of variation. Mean air temperature in East Africa reflects a rise of about 2.5°C by 2025 and 3.4°C by 2075, while rainfall could increase by about 2 percent by 2012 and 11 percent by 2075. The distribution of rainfall and the rise in mean temperature beyond the threshold of 23.5°C will shift the current demarcation of the Brown lines, changing the distribution of suitable areas for growing tea in Kenya. The above scenario will decrease the distribution of suitable tea growing areas by 2050, but migration to upper altitudinal gradients will generally occur and will compensate for the predicted increase in temperature.

Tea in Kenya is currently grown in the districts of Bomet, Embu, Kakamega, Kericho, Kiambu, Kirinyaga, Kisii, Meru, Murang'a, Nakuru, Nandi, Nithi, Nyamira, Nyeri, Trans-Nzoia and Vihiga. The analysis shows that tea grows only in specific areas, much of which will deteriorate and prevent growth - a decrease of 22.5 percent by 2075 - while, on the other hand, some land conditions will improve, increasing tea growth by 8 percent by 2025. Where the land becomes unsuitable to grow tea (Nandi, Kericho, Gucha), farmers will need to adapt by identifying alternative crops to take the place of tea, compared to those areas that are expected to have improved conditions for tea growing (Meru, Embu, Kirinyaga, Nyeri, Murangá, Kiambu). Finally, there are those areas where, today, no tea is able to be cultivated, but which - in the future - will become suitable (especially in the higher altitude around Mount Kenya). Many of these areas, however, are currently protected and cannot be cleared for planting.

There are various multidisciplinary climate change impact assessments that have been undertaken with regard to the tea industry which have integrated economic and social dimensions, as well as those that are biophysical and socio-institutional. The vulnerability of the industry is associated to the (i) high dependency by a large number of farmers on the crop for their livelihoods; (ii) low genetic diversity on the farm; (iii) observed decrease in quality; (iv) decrease in yield; and (v) tea processing capacity.

4. Tea production and weather parametres

Tea production depends heavily on the stability of weather parametres. The tea crop requires a well-distributed annual rainfall above 1 200 mm, mean air temperature of 14-24°C and well-drained soil. It grows well in warm temperatures, where the soil moisture is not counterproductive. Annual mean temperatures below 13°C or above 23.5°C and rainfall of less than 1 200 mm are not conducive to tea growing.

Most tea growing regions experience a regular three-month dry period between December and March, when the yield decreases by approximately 14-20 percent, rising to 30 percent during worse spells. Given climate change predictions, however, this could change and intensify over time. Over the past two decades, the tea industry has witnessed major shifts in key climatic parametres. Most of the cultivated land has recorded a high variability in temperature, radiation and rainfall, as well as SWD. An analysis of the links between the main climate variables and tea yields demonstrates a positive correlation with the progressive upward trend of average temperatures, with the exception of rainfall patterns. Projected climatic patterns, including weather extremes in many of the tea growing areas, are expected to adversely affect the performance of tea in Kenya.

4.1. Temperature variability

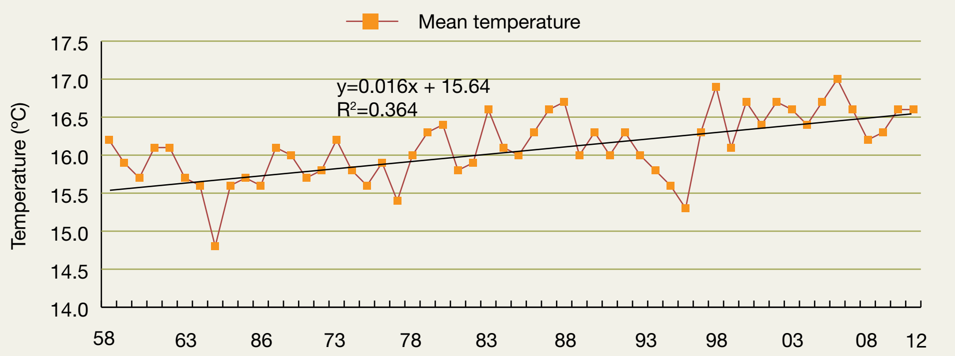
Studies carried out at Timbilil Tea Estate in Kericho, Magura Tea Estate in Sotik and Kangaita farm in Kirinyaga - using data from TRFK's agro-meteorological stations - indicate that the estates have experienced increasing temperature trends. At Timbilil Tea Estate, for instance, the mean temperature increased by 0.02°C annually between 1958 and 2011 (Figure 11). Assuming a constant annual 0.02°C rise in temperature over the next 20 years, the temperature will increase by between 0.4°C and 1°C by 2050.

Similarly, mean annual temperature increased by 0.22°C in the Sotik area and by 0.01°C in that of Kirinyaga. Monthly mean air temperature varied significantly over the 30 year period (1982-2011) under study, with a mean of 17.0°C. The coldest month was July (15.3°C) and the warmest was March (17.3°C).

Radiation

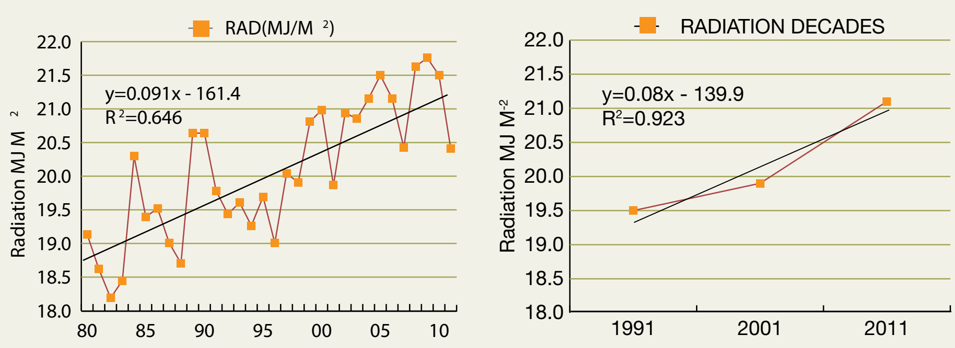
The mean annual radiation at Timbilil Tea Estate in Kericho shows an increase of 0.091MJm-2y-1 (r2=0.646) from 1980 to 2011(Figure 12(a)). The lowest annual radiation was recorded in 1983 (18.1MJm-2d-1), while highest annual radiation of 21.7MJm-2d-1 was recorded in 2009 (Figure 12(a)).The ten-year radiation average showed a positive linear relationship with time (r2=0.9230) (Figure 12(b)).

Figure 11 Trends on mean temperature at Timbilil Tea Estate



Source: Author's calculations

Figure 12a and 12b Mean annual radiation and annual radiation in decades, respectively



Source: Author's calculations

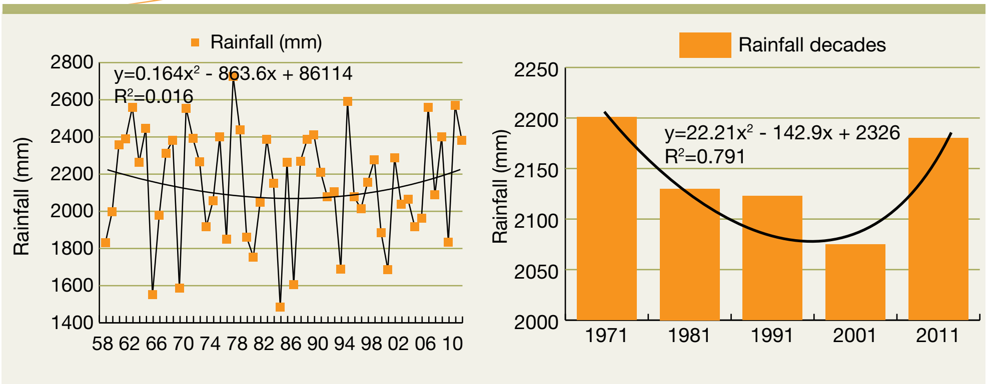
Rainfall variability

Rainfall distribution and patterns have also changed in all the three stations, making it unpredictable. Although the annual variation of rainfall does not relate to time, the ten-year rainfall average depicts a quadratic relationship with time at Timbilil Tea Estate. Figures 13 (a) and (b) illustrate annual and mean annual rainfall variability, respectively, in Timbilil for 1958-2011.

Soil water deficit

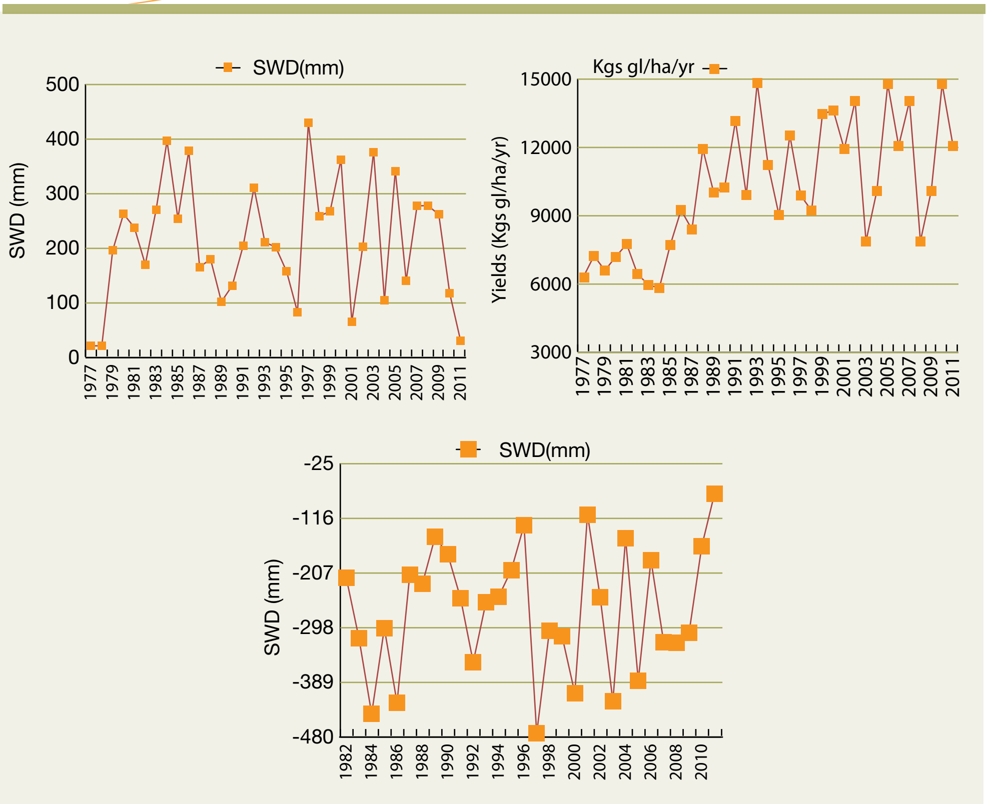
Data on the annual variation of SWD from 1980 to 2011 suggest a decrease (Figure 14(a)), with the least (-429.0 mm) in 1997. The fluctuations varied during the period and there is no relationship (r2=0.003) between SWD and time (years) due to SWD being dependent on the amount of rainfall, which has been erratic.

Figure 13a and 13b Rainfall variability in Timbilil, 1958-2011



Source: Author's calculations

Figure 14a and 14b Soil water deficits and SWD/tea yields, respectively



Source: Author's calculations

It is important to note that the loss in water yield relates negatively to SWD (Figure 14(b)), although not significantly ($P \leq 0.05$). Kericho is in a critical position in terms of SWD, which is approximately 30 mm above, showing a linear decrease in yield of approximately 1.1 kg ha-1 week-1 (mm SWD)-1 of water (Ng'etich, 1995). SWD also affects dry matter production in plants, while other factors affect the productivity of the plant during SWD stress, one of which is the rate of application of nitrogen fertilizer. High fertilizer rates catalyse the effects of SWD on tea plants.

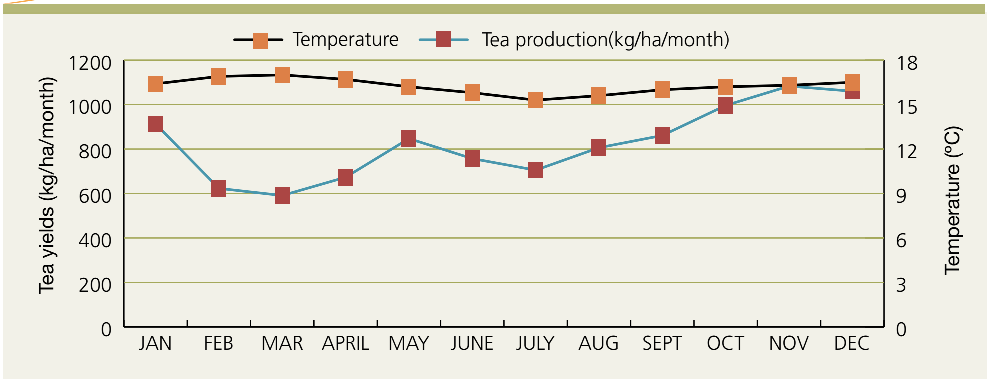
5. Climate change impacts on tea

Tea output data for Timbilil Tea Estate in Kericho has been used specifically to demonstrate how weather parametres can affect tea yields in Kenya. This model was used to demonstrate that the monthly trend in tea production of this estate is similar to the national output in Kenya, which is generally lower on a monthly basis (Kg Made Tea Ha-1). While this lower national trend is a possible consequence of the different farm management practices used between smallholder farmers and the large-scale growers, the effect of climate variability on tea production at Timbilil Tea Estate, nevertheless, represents a further impact of climate change on the national tea output.

5.1. Impact of temperature variability

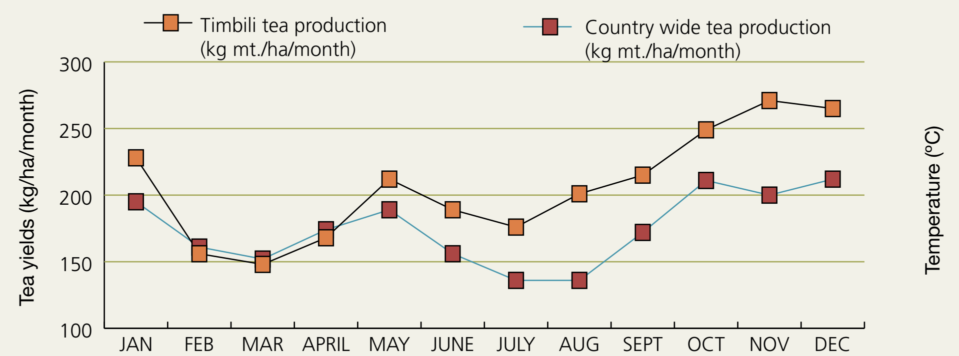
Temperature variability has the greatest impact on tea yields. A negative correlation between temperature and tea yields has been observed during dry spells. Output at Timbilil Tea Estate was compared to the national average (Figure 16) and it showed a lower monthly average than the national level. Despite the fact that national tea output includes yields from smallholder farms and large plantations with different farm management practices that can affect output (Figure 14), evidence points to the fact that temperature and radiation are key factors that can affect production, including when soil moisture is not limiting.

Figure 15 Relationship between output and mean temperature



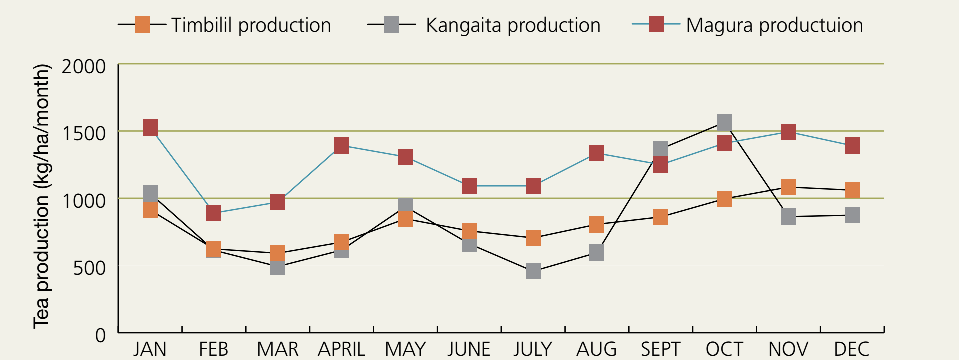
Source: Author's calculations

Figure 16 Comparison of output between Timbili Tea Estate and the national average



Source: Author's calculations

Figure 17 Mean monthly tea output at Magura, Kangaita and Timbilil tea estates

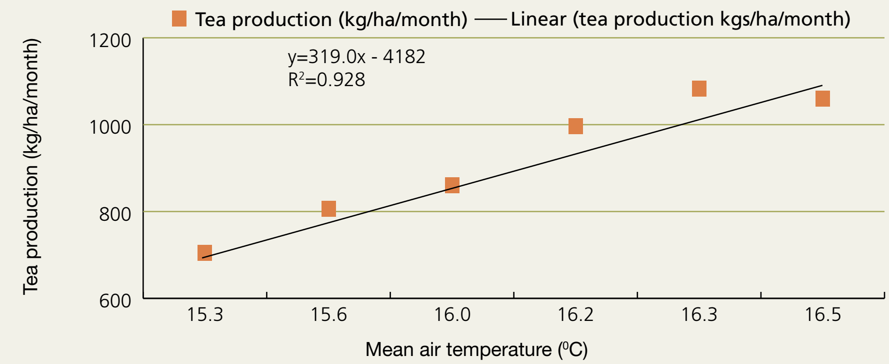


Source: Author's calculations

As demonstrated, temperature plays a vital role in tea production. Analysis shows that the warmer areas (e.g. Magura Tea Estate) have recorded the highest monthly output consistently over the years, with an annual mean of 295 kg Made Tea ha, followed by Timbilil Tea Estate with 213 kg Made Tea ha and, finally, Kangaita Tea Estate (located in a cooler area) which has recorded 176 kg Made Tea ha. The highest output during the last two quarters of the year - when mean temperatures are higher and the soil moisture is not limiting - has been at Magura Tea Estate (295 kg Made Tea ha), followed by Timbilil Tea Estate (213 kg Made Tea ha) and Kangaita Tea Estate (176 kg Made Tea ha).

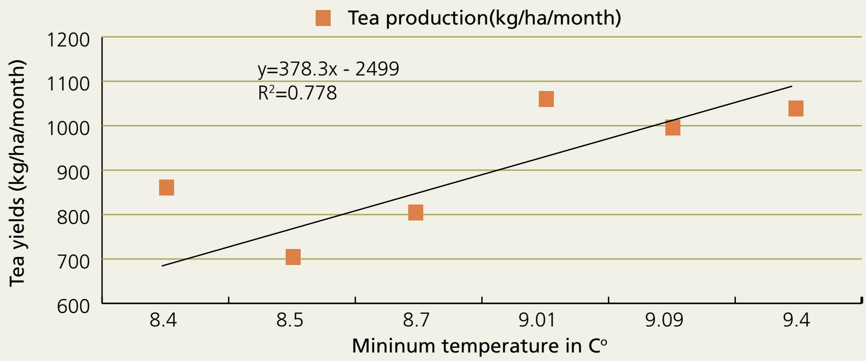
There is a significant positive relationship between mean air temperature and tea yields (319 kg ha-1m-1 °C-1) when soil moisture is not limiting (Figure 18).

Figure 18 Tea output and mean air temperature, when soil moisture is not limiting at Timbilil Tea Estate (July-December)



Source: Author's calculations

Figure 19 Relationship of tea output and minimum temperature when soil moisture is not limiting at Timbilil Tea Estate (July-December)



Source: Author's calculations

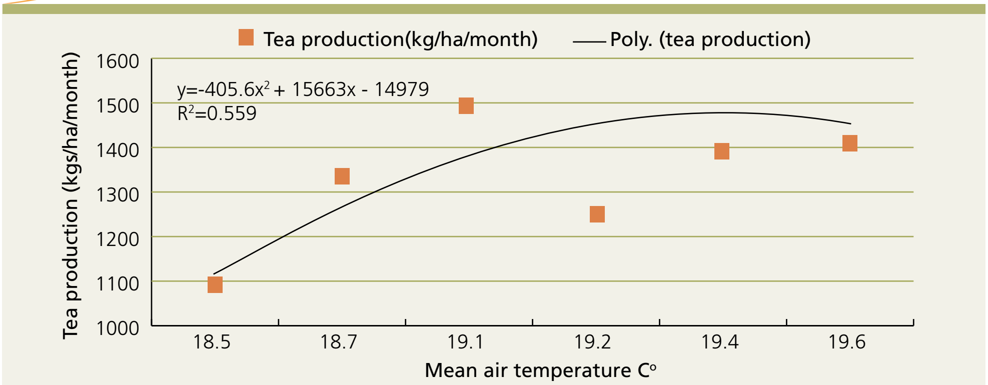
The simulation of attainable yields under different edapho-climatic and management techniques, including irrigation, indicates that climate change patterns will have a positive impact on production over the medium term (within two decades), but that there will be a possible fall in production with fewer apt areas for tea growing thereafter.

Furthermore, Timbilil Tea Estate (which has adequate soil moisture (Figure 19)) in Kericho illustrates a significant ($P \leq 0.05$, n=270, r2=0.778) positive relationship between minimum temperature and yields (378 kg ha-1m-1°C-1). This has taken place for the last two quarters of the year.

Temperature at Magura Tea Estate in Sotik

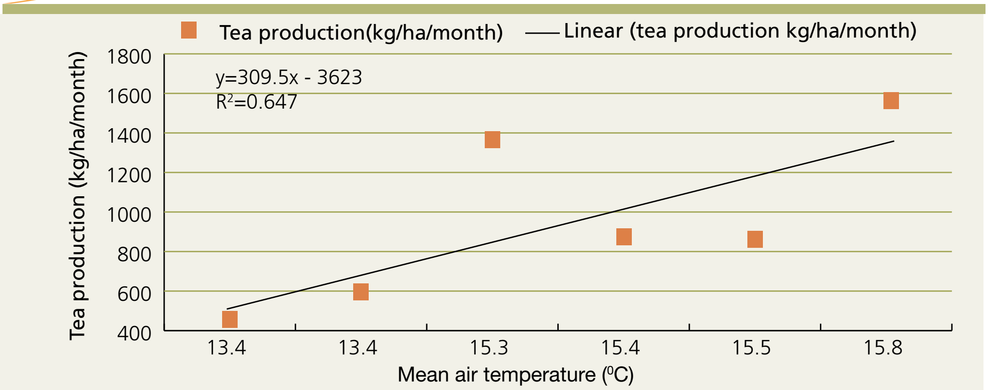
The case of Magura Tea Estate illustrates a significant ($P \leq 0.05$, n=117, r2=0.559) polynomial relationship between mean air temperature and yields (220.0

Figure 20 Relationship of tea output and mean air temperature, when soil moisture is not limiting at Magura Tea Estate (July-December)



Source: Author's calculations

Figure 21 Relationship of tea output and mean air temperature, when soil moisture is not limiting at Kangaita Tea Estate (July-December)



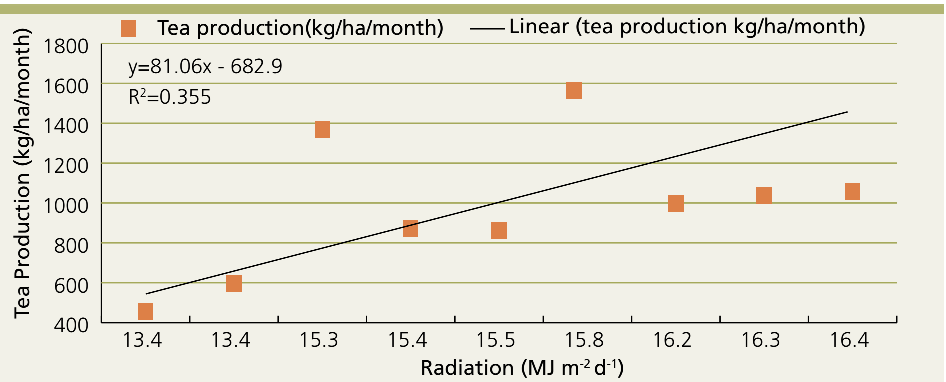
Source: Author's calculations

kg ha-1m-1°C-1) for the last two quarters of the year, when there usually is adequate soil moisture (Figure 20). This indicates that the response of output to temperature increases with the rise in temperature to an optimum of about 19.2°C, but then decreases when there is temperature stress. Magura Tea Estate is in the warmest area of the three tea growing regions under study, with a mean of 19.2°C.

Temperature at Kangaita Tea Estate in Kirinyaga

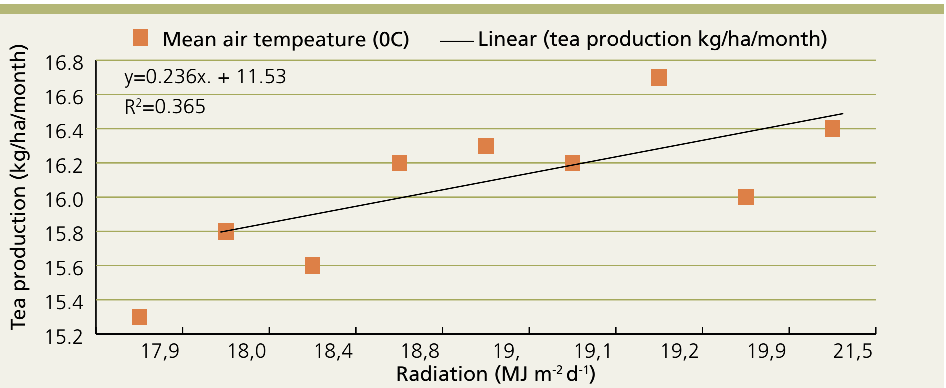
At Kangaita Tea Estate in Kirinyaga, the results illustrate a significant ($P \leq 0.05$, n=96, r2=0.647) positive relationship between mean air temperature and yields (309.5 kg ha-1m-1°C-1) for the last two quarters of the year, when there is usually adequate soil moisture (Figure 21). The response of tea production to temperature increases in cold areas, therefore, is higher compared to that in the

Figure 22 Monthly radiation and tea output at Timbilil Tea Estate (April-December)



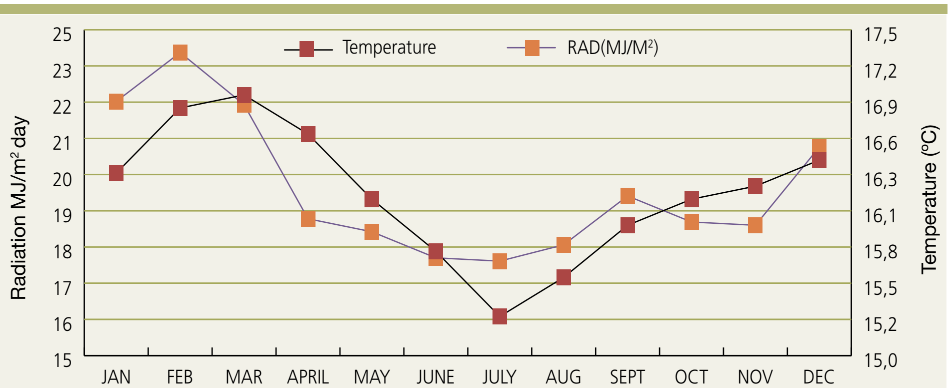
Source: Author's calculations

Figure 23 Monthly radiation and mean air temperature at Timbilil Tea Estate (April-December)



Source: Author's calculations

Figure 24 Monthly radiation and mean air temperatures at Timbilil Tea Estate



Source: Author's calculations

warm areas. Kirinyaga is the coldest area of the three tea growing areas in this study, with a mean of 15.3°C.

Radiation at Timbilil Tea Estate in Kericho

Mean monthly radiation of 19.09 MJm-2 d-1 was recorded at Timbilil Tea Estate for two seasons during the study period (April-December), when the soil moisture was not limiting. The peak was in December, a usually very productive month (Figure 22). The monthly radiation varied significantly over the study period ($P \leq 0.05$, n=270), with a tea yield increase of 81.06 kg ha-1MJ-1m2 d (r2=0.355). Radiation is also positively related with temperature 0.236°C MJ-1m2 d (r2=0.365) (Figure 23). In general, the months with high radiation also recorded higher mean air temperatures (Figure 24).

5.2. Impact of rainfall variability

There is a weak negative relationship between tea yields and rainfall (1.4 kg ha-1 mm-1) (Figure 25) at Timbilil Tea Estate. This is due to the low temperatures that accompany the rainy season and depress crop yields. A warm wet season, therefore, is ideal for production.

The situation is, however, different at Magura Tea Estate where there is a weak positive relationship between yields and rainfall (5.5 kg ha-1 mm-1) (Figure 26). This relationship is due to the warm temperatures in the region.

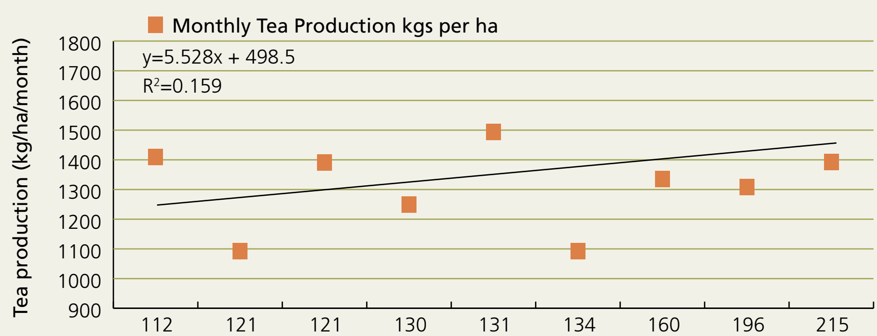
Frost bite has a significant potential to reduce tea yields by up to 30 percent for three consecutive months. In areas such as Kericho, Sotik and Nandi Hills, the net loss of green tea leaves due to hail is estimated at 2.7 million kg *per annum*.

5.3. Correlation analysis

Timbilil Tea Estate

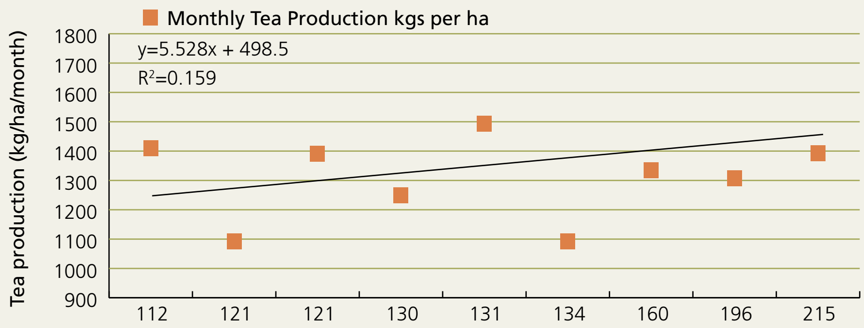
A correlation analysis was undertaken on a quarterly average and monthly average basis. As demonstrated in Table 2, the increase in temperature

Figure 25 Monthly rainfall and tea output at Timbilil Tea Estate over 30 years



Source: Author's calculations

Figure 26 Monthly rainfall and tea output at Magura Tea Estate



Source: Author's calculations

Table 2 Correlation matrix for quarterly weather parametres and tea output at Timbilil Tea Estate*

	Quarters	Temperature	Radiation	Rainfall	SWD	Tea Production
Quarters	1.0000					
Temperature	-0.440	1.0000				
Radiation	-0.492	0.651	1.0000			
Rainfall	0.061	-0.346	-0.627	1.0000		
SWD	-0.292	0.560	0.683	-0.720	1.0000	
Tea Production	0.378	-0.015	-0.004	-0.079	-0.152	1.0000

Source: Author's calculations
*(n=120)

correlated positively with radiation (r=0.651, n=120), which is important for plant photosynthesis. It also correlates positively with SWD (r=0.560, n=120), stressing the tea crop and countering the benefit of increased radiation. A similar relationship exists between radiation and SWD, with both strongly correlating negatively with rainfall at (r=-0.627, n=120) and (r=-0.720, n=120), respectively.

Table 3 indicates that radiation and temperature had a weak positive relationship with tea production: (r=0.190, n=270) and (r=0.324, n=270), respectively; radiation, however, appeared to increase production more than mean air temperature.

Table 4 further shows that radiation and temperature in Kericho increased tea output when the soil moisture was not limiting: (r=0.445, n=60) and (r=0.422, n=60), respectively; radiation, however, appeared to increase production more than it did mean air temperature.

Table 3 Correlation matrix for two seasons (April-December), monthly weather parametres and tea output at Timbilil Tea Estate*

	Months	Temperature	Radiation	Rainfall	Tea Production
Months	1.0000				
Temperature	0.034	1.0000			
Radiation	0.280	0.368	1.0000		
Rainfall	-0.470	-0.050	-0.467	1.0000	
Tea Production	0.360	0.190	0.324	-0.279	1.0000

Source: Author's calculations
*(n=270)

Table 4 Correlation matrix for two quarters (July-December), monthly weather parametres and tea output at Timbilil Tea Estate*

	Months	Temperature	Radiation	Rainfall	Tea Production
Months	1.0000				
Temperature	0.618	1.0000			
Radiation	0.401	0.531	1.0000		
Rainfall	-0.479	-0.358	-0.462	1.0000	
Tea Production	0.465	0.422	0.445	-0.319	1.0000

Source: Author's calculations
*(n=60)

Table 5 Correlation matrix for quarterly weather parametres and tea output at Magura Tea Estate*

	Quarters	Temperature	Rainfall	Tea Production
Quarters	1.0000			
Temperature	-0.100	1.0000		
Rainfall	-0.071	-0.109	1.0000	
Tea Production	0.282	-0.007	0.256	1.0000

Source: Author's calculations
*(n=52)

Magura Tea Estate

Table 5 depicts a weak positive relationship between rainfall and tea production at Magura Tea Estate (r=0.256, n=52), unlike Timbilil Tea Estate which showed a negative relationship between rainfall and production. This is due to the warmer temperatures in Sotik.

Table 6 demonstrates that there was barely any relationship between rainfall, temperature and production at Magura Tea Estate (n=117) from April to December.

Table 7 further emphasizes the positive relationship between rainfall and output at Magura Tea Estate (r=0.425, n=26) for the last two quarters of the year. It illustrates that rainfall was an important factor, considering the existing warm conditions in the area.

Kangaita Tea Estate

Table 8 indicates a weak positive relationship between rainfall and tea production at Kangaita Tea Estate in Kiringaya (r=0.238, n=64). There was hardly any relationship between average temperature and production for each quarter.

Table 9 shows a positive relationship between rainfall and temperature (r=0.472, n=144) at Kangaita Tea Estate, which was the opposite of what was found at Timbilil Tea Estate. It is also evident that both temperature and rainfall hardly related to production.

Table 9 further emphasizes that there was a positive, but weak, relationship between rainfall and temperature at Kangaita Tea Estate (r=0.600, n=32) for the last two quarters of the year. It also demonstrates that temperature affected production more so (r=0.330, n=32) than did rainfall (r=0.295, n=32).

6. Conclusion

Climate change is all about global warming, with the latter worsening due to the persistent increase in temperature over a long period of time. It can

Table 6 Correlation matrix for two seasons (April-December), monthly weather parametres and tea output at Magura Tea Estate*

	Months	Temperature	Rainfall	Tea Production
Months	1.0000			
Temperature	0.110	1.0000		
Rainfall	-0.337	-0.044	1.0000	
Tea Production	0.144	0.043	0.031	1.0000

Source: Author's calculations
*(n=117)

Table 7 Correlation matrix for two quarters (July-December), monthly weather parametres and tea output at Magura Tea Estate*

	Months	Temperature	Rainfall	Tea Production
Months	1.0000			
Temperature	0.263	1.0000		
Rainfall	-0.218	0.016	1.0000	
Tea Production	0.360	-0.090	0.425	1.0000

Source: Author's calculations
*(n=26)

Table 8 Correlation matrix for quarterly weather parametres and tea output at Kangaita Tea Estate*

	Quarters	Temperature	Rainfall	Tea Production
Quarters	1.0000			
Temperature	-0.438	1.0000		
Rainfall	0.251	0.213	1.0000	
Tea Production	0.260	0.088	0.238	1.0000

Source: Author's calculations
*(n=64)

Table 9 Correlation matrix for two seasons (April to December) monthly weather parametres and tea production at Kangaita Tea Estate*

	Months	Temperature	Rainfall	Tea Production
Months	1.0000			
Temperature	-0.013	1.0000		
Rainfall	-0.223	0.472	1.0000	
Tea Production	0.150	0.172	0.076	1.0000

Source: Author's calculations
*(n=144)

Table 10 Correlation matrix for two quarters (July-December) monthly weather parametres and tea output at Kangaita Tea Estate

	Quarters	Temperature	Rainfall	Tea Production
Quarters	1.0000			
Temperature	0.854	1.0000		
Rainfall	0.675	0.600	1.0000	
Tea Production	0.214	0.330	0.295	1.0000

Source: Author's calculations

either increase or decrease the amount of rainfall in an area. The variability in temperature was evident from the study and it can have a significant impact on tea yields. Results from the analysis indicate a negative correlation between air temperature and yields, since high temperatures occur during dry spells. It is evident that temperature, together with radiation, is a key weather parametre that can affect output, particularly when soil moisture is not limiting. The correlation analysis also confirms that rainfall may not be the only important factor in promoting better yields; mean air temperature also plays a role.

The findings of this review are useful in predicting future climate change scenarios and the economic impacts of climate change on tea production in Kenya.

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CHAPTER FOUR

A GIS ANALYSIS OF SUITABLE AREAS FOR GROWING TEA IN KENYA UNDER VARIOUS CLIMATE CHANGE SCENARIOS

Beatrice Cheserek

1. Introduction

FAO and TRFK aim to increase the resilience of Kenyan tea producers in the face of climate change and to secure their future livelihoods in an environmentally and economically sustainable way. To achieve this, the two organizations, in partnership, have carried out an extensive Geographic Information System (GIS) analysis of the possible changes that could affect the tea growing areas of Kenya.

In Kenya, the monthly and yearly rainfall and mean air temperature are expected to increase moderately by 2025 and they will continue to increase progressively by 2075. The overall climate will become less seasonal in terms of variation throughout the year. Mean air temperature in East Africa is predicted to rise by about 2.5ºC by 2025 and 3.4ºC by 2075, while rainfall is forecast to increase by about 2 percent and 11 percent by 2025 and 2075, respectively. This implies that the distribution of suitable land for tea growing in Kenya will drop, not because of the amount of rainfall but because of its distribution and the rise in mean air temperature beyond the threshold of 23.5ºC.

The tea growing areas that are currently under cultivation in Kenya are found in the districts of Bomet, Embu, Kakamega, Kericho, Kiambu, Kirinyaga, Kisii, Meru, Murang'a, Nakuru, Nandi, Nithi, Nyamira, Nyeri, Trans-Nzoia and Vihiga. This chapter presents an overview of the activities undertaken during a GIS analysis to establish the tea growing areas in Kenya that are suitably cultivated. The objective of the study is to predict the impact of progressive climate change on the tea cultivation in Kenya to the year 2075, based on experience from 2000.

2. Conditions for growing tea in Kenya

Tea production in Kenya and elsewhere in Africa and Asia is dependent on weather stability. Yields are influenced by air and soil temperature, air saturation deficits (kPa), plant and SWD (mm), radiation (MJ m-2 d-1), rainfall (mm) and evaporation (mm d-1) (Carr, 1972; Squire and Callander, 1981; Stephens and Carr, 1991; and Stephens et al, 1992). Among the above weather factors, rainfall and temperature are the most important.

Tea production varies with the type of soil which, in turn, differs depending on the altitude (agro-ecological zones) (Ng'etich, 1995). Tea is grown in a wide range of soil types found in tropical, sub-tropical and temperate conditions. Although any soil texture will do for the growing of the tea plant - especially in Kericho, where the soil is the best and has a high clay content - the ideal soil for tea is that which is deep, well drained and is found at a minimum depth of 2 m from the topsoil. Tea is, however, very sensitive to soil acidity and only does well where the acidic pH balance is less than 5.8, generally between 4.0 and 6.0 pH. The most appropriate pH balance ranges between 5.0 and 5.6. Any pH level below 5.0 results in a deficiency of base nutrients, such as potassium, magnesium and calcium.

The GIS integration of spatial analytical capabilities and the constraint optimization power of mathematical programming facilitate the generation of composite data sets for extensive geographic regions. A coordinated and holistic approach to policy development may be necessary if one is to appreciate and analyse various physical, environmental, economic and socio-economic attributes within a coherent framework. Intuitively, the analytical frameworks or models used must conform to the naturally occurring interactions among these attributes, across space and through time (Mallawaarachchi, *et al.*, 1996).

In a previous examination to predict climate change for tea growing areas using global models, it was found that the change in tea growing suitability as climate change occurs is site-specific (CIAT, 2011). It was also noted that some areas will become unsuitable for tea (Nandi, Kericho, Gucha), while others will remain conducive to growing it (Bomet, Kisii, Nyamira). Using data from 2000, the principal objective of this study is to predict the impact of progressive climate change on tea in Kenya to the year 2075, using regional climate prediction data from the Intergovernmental Panel on Climate Change (IPCC) of 2010.

3. Data collection

The initial step was to gather the required data and digitize it, using GIS software to create a GIS database. The data collected was as follows:

- factories;
- major town centres;
- road networks;
- forests;
- main tea growing areas;
- district boundaries;
- annual average temperature data;
- annual average rainfall data;
- agro-ecological zones data;
- soil data (derived from FAO's Harmonized World Soil Database, 2012); and
- rainfall and temperature change projections from 2000 to 2075 (Herrero *et al.*, 2010).

The maps were scanned and geo-referenced in Esri's ArcGIS software platform. The projection used was Arc 1960/UTM zone 37S to reference the datasets. Additional location information for the project was obtained through the use of a Mobile Mapper 6 GPS receiver.

3.1. GIS database development

Data was captured and stored in GCS_WGS_1984 format through the use of ArcGIS Version 10.1. Each data layer was displayed separately and uniquely, using the ArcGIS ArcMap against the outline of the map of Kenya. The sections below (Figures 26 to 34) outline various datasets that were used for this research.

Figure 30 illustrates the locations of the tea growing regions in Kenya.

Figure 31 displays agro-climatic zones, based on research undertaken by the Kenya Agricultural Research Institute (KARI). The zones are classified depending on agricultural suitability. Zones 1, 2 and 3 illustrate the areas that are highly

Figure 27 Tea growing areas in Kenya: Eastern Tea Zone 1

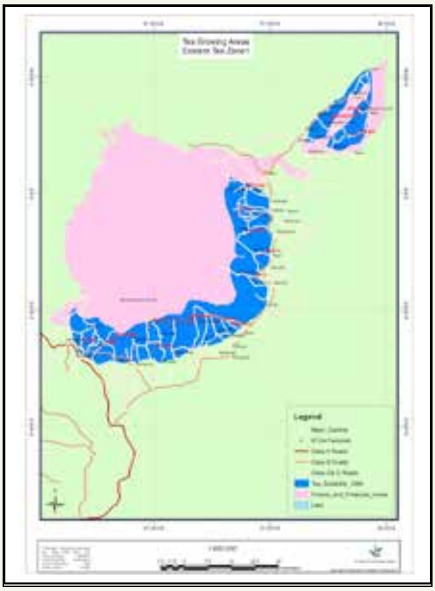


Figure 28 Tea growing areas in Kenya: Eastern Tea Zone 2

Source: TBK, 2012

Figure 29 Tea growing areas in Kenya: Western Tea Zone 1

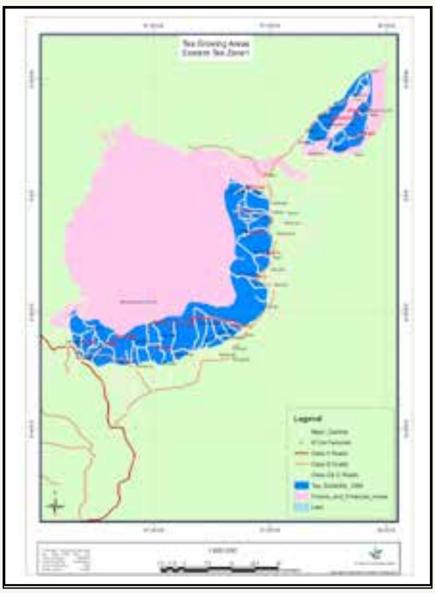


Figure 30 Tea growing areas in Kenya: Western Tea Zone 2

Source: TBK, 2012

Figure 31 Current tea growing areas in Kenya

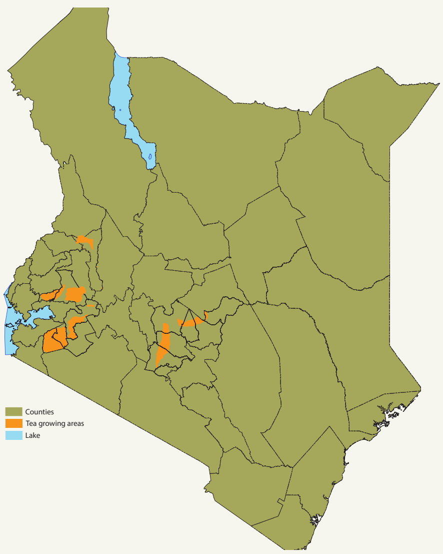
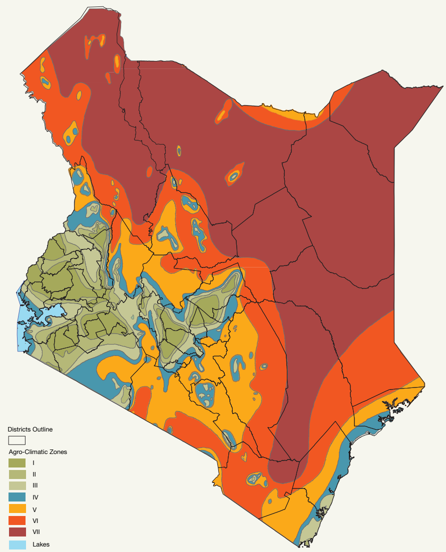


Figure 32 Agro-climatic zones in Kenya



Source: TBK, 2012

suitable for agriculture, while Zones 4 and 5 are only fairly appropriate and Zones 6 and 7 are unsuitable.

3.2. Data analysis

GIS data analysis was carried out as a step-by-step process. This is summarized in the schematic diagram below (Figure 32).

3.3. Suitability prediction

The summary output of 21 Global Circulation Models, used by IPCC in their latest report to predict the annual changes in temperature and rainfall that will occur by the end of the 21st Century, is presented in Table 11 (Herrero *et al.*, 2010).

Maximum and minimum predictions of change are provided, together with the 25th, 50th and 75th quartile values from the 21 Global Circulation Models (Cooper *et al.*, 2008). While all models agree that it will become warmer, the degree is quite variable.

3.4. Map conversion to raster files

This study was undertaken using four datasets (i.e. temperature, rainfall, agro-ecological zones (AEZ) and soils). The Raster Conversion Tool in ArcGIS was used to convert the four datasets into raster files so that classification could be done according to the defined suitable parametres. The datasets were displayed in ArcGIS 10.1, subsequent to classification, using an appropriate symbology.

Figure 33 GIS analysis schematic diagram

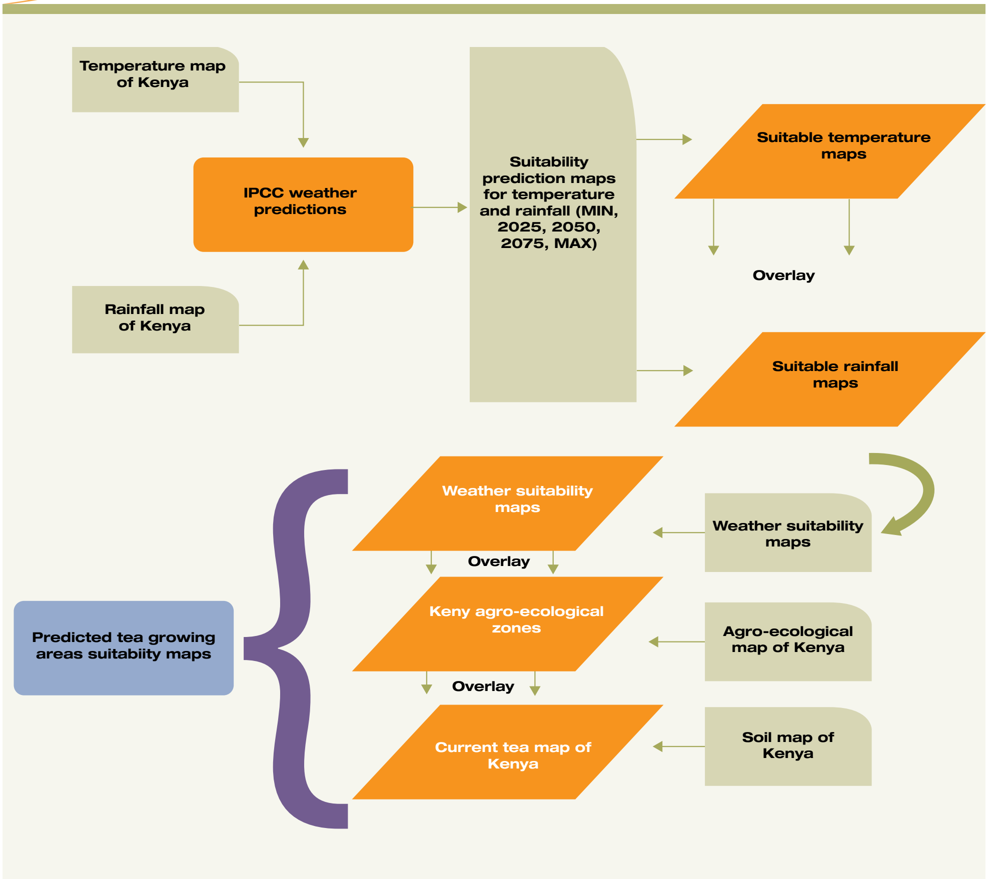


Table 11 East Africa predictions for climate change in Africa by the end of the 21st century

Season	Temperature response (°C)					Precipitation response (%)				
	Min	25	50	75	Max	Min	25	50	75	Max
DJF	2.0	2.6	3.1	3.4	4.2	–3	6	13	16	33
MAM	1.7	2.7	3.2	3.5	4.5	–9	2	6	9	20
JJA	1.6	2.7	3.4	3.6	4.7	–18	–2	4	7	16
SON	1.9	2.6	3.1	3.6	4.3	–10	3	7	13	38
Annual	1.8	2.5	3.2	3.4	4.3	–3	2	7	11	25

Source: Statistics Department of FAO (FAOSTAT)

3.5. Reclassification of the datasets

Since the study relates to tea farming, various indicators were used to define suitable and non-suitable conditions for tea growth, based on temperature, rainfall, AEZ and soil data. For rainfall, the zones with an annual average precipitation of over 1 100 mm were considered appropriate for tea growth, while those below were considered unsuitable. Temperature values between 13°C and 23.5°C were good, compared with those below or above these values (i.e. less than 13°C and above 23.5°C). Zones 1 and 2 were conducive to tea for the AEZ dataset, while the areas above these values were not. The soil data were clearly classified and those FAO soil classes that were considered conducive to tea growing were *Nitisols*, *Andosols*, *Cambisols* and *Acrisols*.

3.6. Climate suitability maps

Subsequent to the reclassification study in Section 3.3, the new dataset were extracted for each feature class and maps were generated. The temperature and rainfall maps were created, based on values for suitability for various time periods. These time periods (scenarios), according to Herrero *et al.*, 2010, are based on expected temperature changes and relate to the (i) minimum expected climate change, (ii) expected climate changes for 2025, 2050 and 2075 and (ii) expected maximum climate change.

3.7. Suitable agro-ecological zones map

Figure 33 demonstrates AEZs that favour tea growth, highlighted in blue (i.e. Zones 1 and 2). These data were obtained the Kenya Agriculture Research Institute (KARI, 2008).

3.8. Soil suitability map

Figure 34 illustrates soils that are favourable to tea growth (highlighted in green), taken from the soil data obtained from the Harmonized World Soil Database by FAO. The soil types, based on FAO classifications, are *Nitisols*, *Andosols*, *Cambisols* and *Acrisols*.

3.9. Extraction of final raster files

The Raster Calculator Tool, available in Esri's ArcGIS software, was applied to obtain the regions shared by the four layers (temperature, rainfall, soils and AEZ) over various periods (i.e. current scenario, expected minimum and maximum changes in rainfall and temperature and suitability by 2025, 2050 and 2075). The maps below outline these findings.

4. Findings

4.1. Suitable tea growing areas, based on current climate conditions

The zones that are highlighted in red on the map below (Figure 35) are those considered to be appropriate for tea growing, based on current climatic conditions (temperature and rainfall). The suitability extends from the already established tea farms to Nakuru, Koibatek and Narok regions in the west of

Figure 34 Agro-ecological zones suitable for tea growth

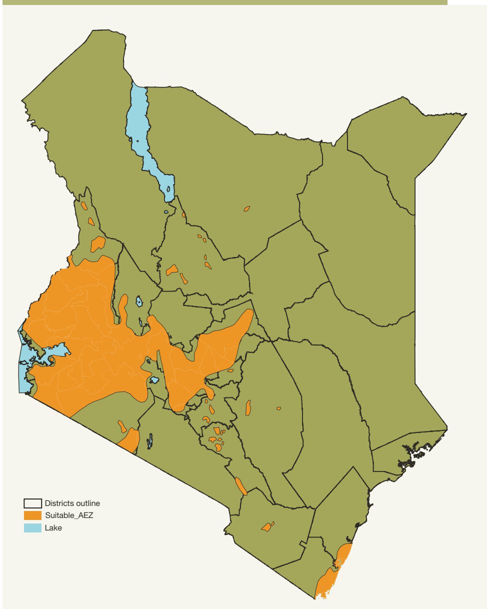
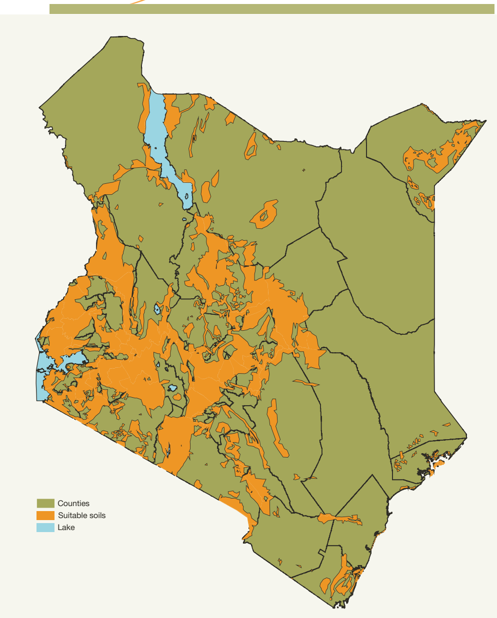


Figure 35 Areas with soil types suitable for growing



Source: TBK, 2012

Figure 36 Suitable tea growing areas, based on current climatic conditions

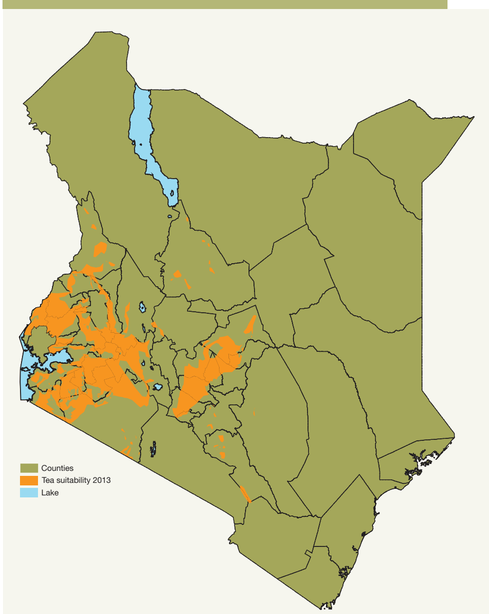
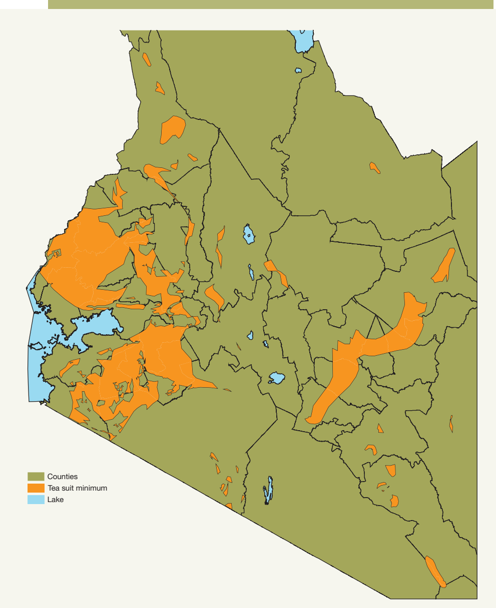
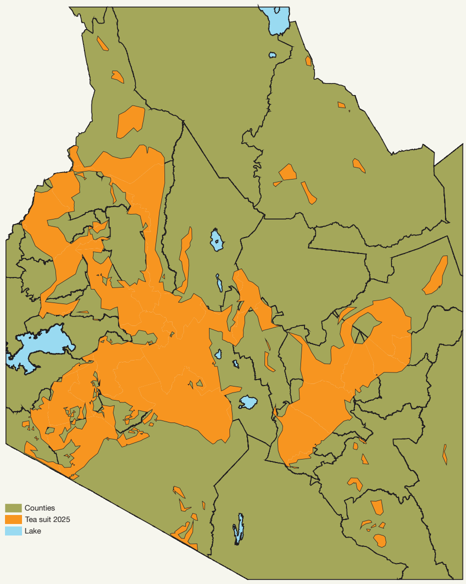


Figure 37 Suitable tea growing areas with minimum expected climate change



Source: TBK, 2012

Figure 38 Suitable tea growing areas in 2025



Source: B. Cheserek, *et al.*, 2013

Figure 39 Suitable tea growing areas in 2050

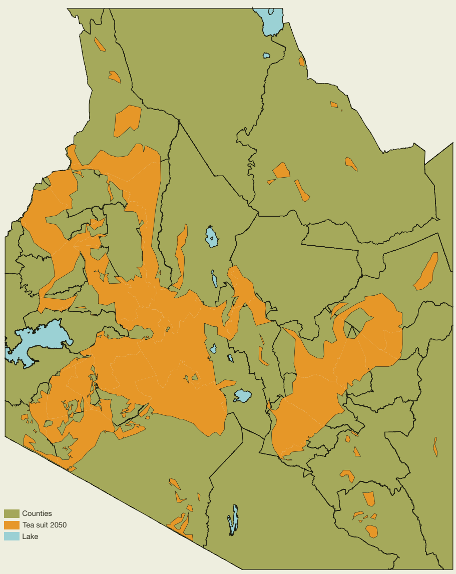
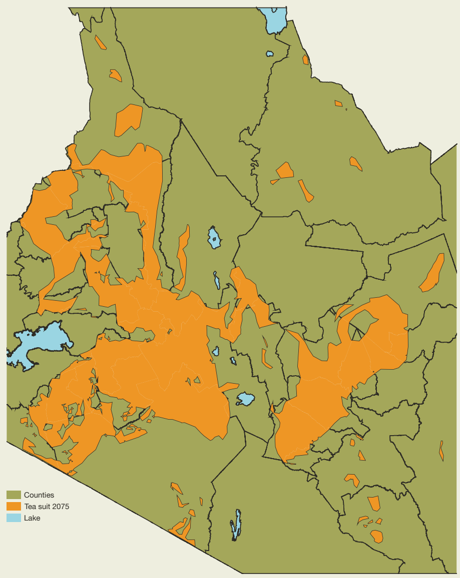
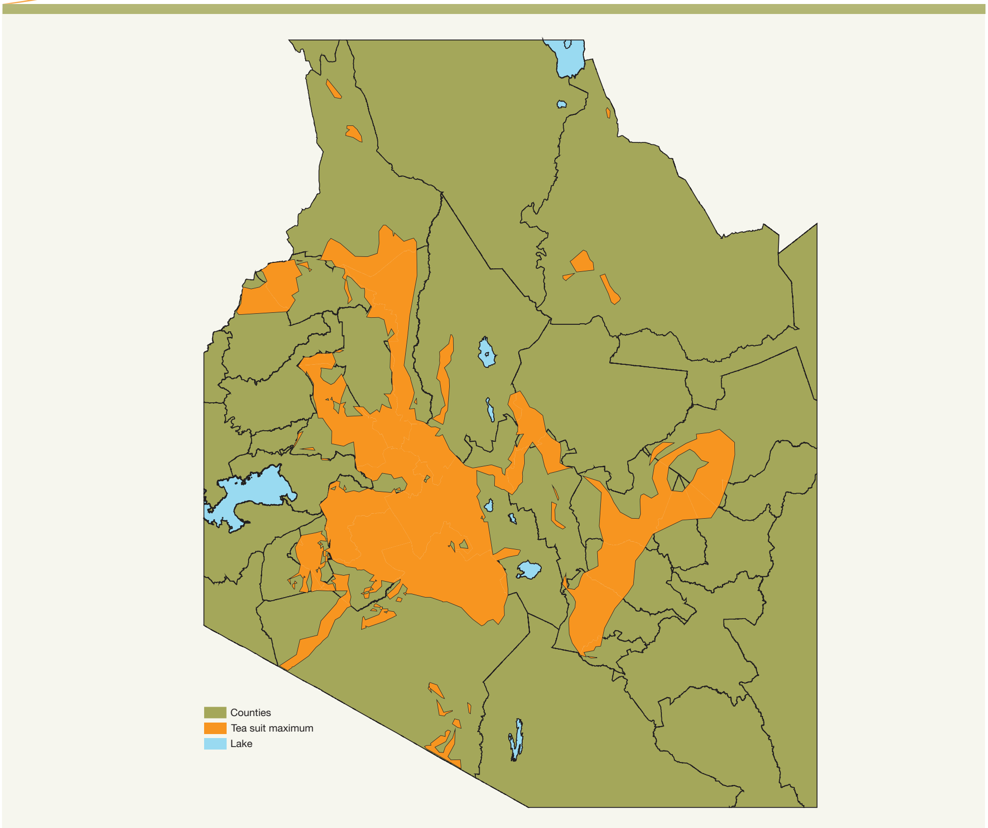


Figure 40 Suitable tea growing areas in 2075



Source: B. Cheserek, *et al.*, 2013

Figure 41 Suitable tea growing areas, based on maximum expected climate change



Source: B. Cheserek, *et al.*, 2013

the Great Rift Valley, while in the east of the valley, tea growing areas extend to include Nyeri, Kirinyaga, Embu and Meru towards Mount Kenya.

4.2. Areas suitable for tea cultivation relating to minimum expected changes

Based on expected minimum changes in climate conditions, the areas highlighted in red in Figure 36 illustrate those regions that will be suitable for cultivation. From this, it is clear that a number of areas located in the west of the Great Valley Rift (Narok, Nakuru, Kericho, Koibatek, Keiyo and Kakamega) will become drastically unsuitable, while a few locations east of the valley (Meru, Kiambu, Thika, Muranga and Nyeri) will have shrunk in size, with a minimum increase in temperature of 1.8^{O}C - possibly attributable to the expected decrease in rainfall by 3 percent.

4.3. Projected suitable areas for tea cultivation in 2025

The areas highlighted in red in Figure 37, below, reflect the regions that will become suitable for tea growing, based on projected climatic conditions for 2025. These will stretch east and west of the Great Valley Rift to include the districts of Narok, Nakuru, Kericho, Marakwet, Keiyo, West Pokot, Koibatek, Keiyo and Transmara. The locations east of the Great Valley Rift are expected to extend to the higher altitudes around Mount Kenya, 3 000 m above sea level, although these are officially government mapped areas for conservation. The expansion by 2025 will be largely due to the rise in temperature by 2.5 ^{O}C, where temperature and rainfall are predicted to increase by 2 percent.

4.4. Projected suitable areas for tea cultivation in 2050

Figure 38 includes those areas in red that are anticipated to be appropriate for tea cultivation, in relation to climatic conditions projected for 2050. It is obvious that the 3.2^{O}C increase in temperature by 2050 will not have affected the extent of suitable zones for growing tea. The change expected by that year will be based largely on temperature, since rainfall is expected to increase by 7 percent.

4.5. Projected suitable areas for tea cultivation in 2075

Based on projected climatic conditions in 2075, Figure 39 shows those areas that will be suitable to cultivate tea. The temperature increase of 3.4^{o}C by 2075 should not affect those regions that will be appropriate for growing by 2025 and 2050. The change expected by 2075 is based on the rise in temperature, since rainfall is expected to increase by 11 percent, although its distribution is critical.

4.6. Expected maximum changes to tea cultivation in 2075

Figure 40 highlights in red the regions that are suitable for tea growing, based on the expected maximum changes in climatic conditions. The maximum expected changes would be a temperature increase of 4.3^{o}C and rainfall climbing to 25 percent. From the map, it is noted that the areas east and west of the Great Valley Rift have shrunk. The zones west that significantly will be affected are the districts of Kisii, Nandi, Kakamega, Tranzoia and Bomet, while the Meru, Kiambu, Thika, Muranga, Kirinyaga, Maragua, Tharaka and Embu tea cultivation areas in the east will be the most affected. In both regions, low-altitude areas will be considerably influenced.

4.7 Graph relating to the suitability of tea cultivation

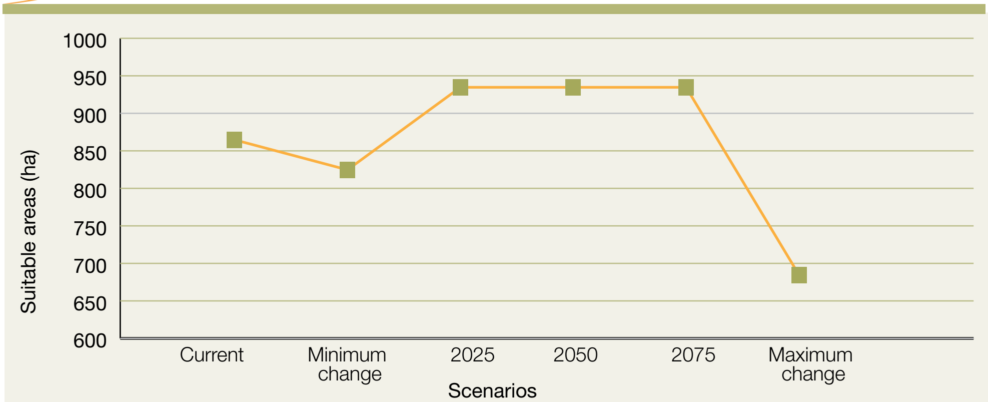
Table 12 includes data that indicate that rainfall and mean air temperatures are expected to progressively rise by 3.4^{o}C, while annual rainfall will climb to 11 percent by 2075. The tea growing areas will drop by up to 22 percent if expected maximum climate change is realized, but they also are expected to increase by 8 percent by 2025 (Figure 41). The increase in the zone with minimum change is due to the warming of high altitude areas, which currently experience lower mean air temperatures than the range required by tea. They will not be accessible for cultivation, given that they are officially mapped by the Government as conservation areas.

Table 12 A summary of GIS analysis findings

Scenarios	Expected Change	Suitable Areas (Ha)	
	Temperature (°C)	Rainfall (mm)	
Current suitable areas	0	0	876 710.8
Minimum change	1.8	-3	828 065.8
2025	2.5	2	943 860.8
2050	3.2	7	943 860.8
2075	3.4	11	943 860.8
Maximum change	4.3	25	688 563.3

Source: B. Cheserek *et al.*, 2013

Figure 42 Changes in trends of predicted suitable tea growing areas



Source: B. Cheserek *et al.*, 2013

5. Conclusions

Kenya's monthly and yearly rainfall and mean air temperature will increase progressively to a maximum of 25 percent and 4.3°C respectively, implying that the distribution of current suitable cultivating areas for tea, in general, will decrease drastically by 2075. The optimum tea-producing zone in Kenya today is at an altitude between 1 000 and 2 100 m above sea level. By 2075, this will have increased to between 2 100 and 3 000 m above sea level, where conservation areas are delineated by the Government of Kenya. If climate conditions continue to change - with a mean air temperature increase of more than 4°C - the tea growing areas are likely to shrink further, despite a rise in the amount of rainfall.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CHAPTER FIVE

LIFE CYCLE ASSESSMENT OF KENYAN TEA

Adisa Azapagic, John Bore, Beatrice Cheserek, Samson Kamunya and Aziz Elbehri

1. Introduction

This chapter presents the environmental impacts of Kenyan tea, estimated using life cycle assessment (LCA). The LCA study has been carried out by Professor Adisa Azapagic of the University of Manchester, in collaboration with TRFK.

The focus of the study is on the global warming potential (GWP) of tea, but other LCA impacts are also considered. The study follows the ISO 14040/44 methodology, detailed in Section 3. The results are presented in Section 4 and conclusions in Section 5. Prior to that, an overview of tea cultivation in Kenya is given in the next section.

2. Tea cultivation in Kenya

Tea was first introduced in Kenya in 1903 when it was planted on a two-acre farm (TBK, 2013). Today, Kenya has approximately 190 000 ha of land under tea cultivation, of which 65 percent is managed by small-scale producers and 35 percent by large-scale farms (TRFK, 2013). The latter is owned by 39 large tea companies, while the smallholder sector is operated by half a million farmers who sell their produce to approximately 58 factories (TBK, 2013). The small-scale sector is managed by KTDA and the large-scale producers are grouped around KTGA.

Tea is grown on the volcanic soil that is found in the highland zones on both sides of the Great Rift Valley, at 1 500-2 700 m above sea level. The main tea growing regions include those around Mt. Kenya; the Aberdares and the Nyambene Hills in central Kenya; and Mau Escarpment, highlands of Kericho, Nandi and Kisii Highlands and Cherangani Hills (TBK, 2013). Large-scale producers are primarily based west of the Great Rift Valley, while the smaller are spread throughout the tea growing region.

In terms of volume, Kenya is ranked third behind China and India. It produces 377 000 tonnes of tea per year (t/yr), equivalent to 9 percent of world tea production (FAOSTAT, 2013; TBK, 2013). The majority of this (343 000 t/yr) is exported, representing approximately 20 percent of world exports. This makes tea a top foreign exchange earner in Kenya, contributing 20 percent to total export revenue (Kenya National Bureau of Statistics, 2012).

As the tea industry in Kenya is an important economic activity, it is important to understand the environmental impacts of its production. This study, therefore, aims to estimate the potential life cycle impacts of tea produced in Kenya. The focus is on the GWP - or the carbon footprint - of tea, while taking into consideration other environmental impacts. LCA has been applied as a tool for this purpose.

3. Life cycle assessment: Methodology

The LCA methodology applied in this study follows the ISO 14040/44 guidelines of the ISO (ISO, 2006a&b). According to these standards, LCA is conducted by:

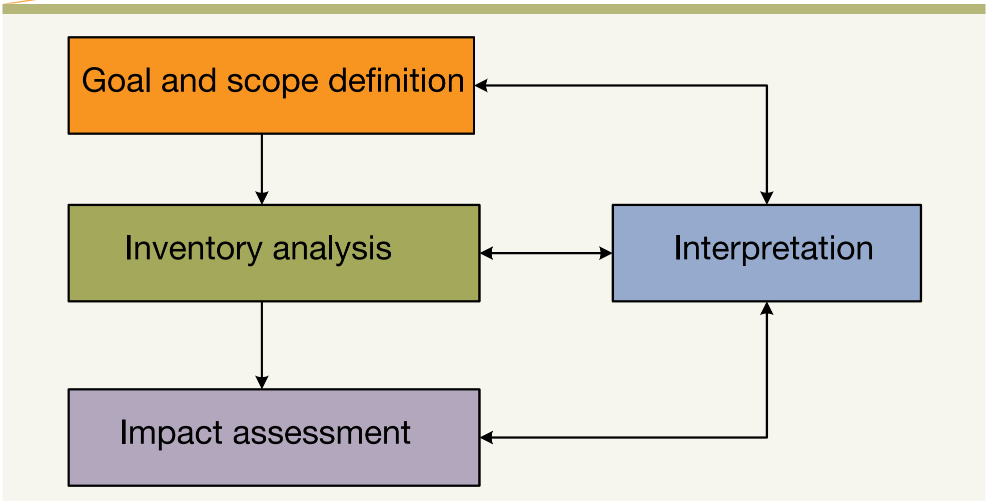
- compiling an inventory of relevant inputs and outputs in the life cycle of the system under study; these include materials and energy used in the system and emissions to the environment;
- evaluating the potential environmental impacts associated with those inputs and outputs (e.g. carbon footprint, acidification, etc.); and
- interpreting the results with regard to the goal and scope of the study.

As shown in Figure 43, this process comprises four steps (ISO, 2006 a&b), as follows:

- goal and scope definition, in which the intended purpose of the study, the functional unit (unit of analysis) and the system boundaries are defined;
- inventory analysis, which involves collection of data related to the inputs of materials and energy and outputs of emissions to the environment in each life cycle stage considered in the study;
- impact assessment, in which the inputs and outputs are aggregated into a smaller number of environmental impacts (e.g. carbon footprint, acidification, etc.); and
- interpretation, in which the LCA results are analysed and opportunities for improvements are identified.

The following section outlines the goal and scope of the study. This is followed by the summary of inventory data in Section 3.2 and by the impact assessment in Section 3.3.

Figure 43 The LCA methodology, according to LCA standards ISO 14040/44 (ISO, 2006a and b)



3.1. Goal and scope of the study

The main goal of this study is to estimate the global warming potential or the carbon footprint of tea produced in Kenya. In addition, the following potential environmental impacts are calculated: acidification, eutrophication, ozone layer depletion, photochemical smog and human toxicity. The analysis is based on the functional unit defined as 'production and consumption of 1 kg of dry tea'. Tea consumption is assumed in the United Kingdom (UK), one of the largest export markets for the Kenyan tea. The results of this study are relevant to the tea producers in Kenya and other stakeholders in the tea supply chain, including consumers.

The life cycle of tea is shown in Figure 44, which illustrates the system boundary of the study from cradle to grave, comprising the following life cycle stages:

Cultivation and harvesting: production of fertilizers and their transport to Kenya; direct and indirect emissions of GHG from the application of fertilizers during cultivation and in the nursery; water and materials used in the nursery; land-use change for cultivation and in the nursery; pruning and harvesting of tea; collection of picked tea and transport to processing.

Processing and packing: water, electricity and heat used for processing the harvested tea leaves, involving withering, maceration, oxidation, drying and sorting; packing of the processed tea leaves into large bags.

Storage: transport of packed tea to storage in Mombasa, where some of the tea is re-packaged into smaller bags; electricity used during repacking and storage of tea.

Consumption: shipping of tea for consumption in the UK; repacking of the tea into smaller consumer packaging; water and electricity used for tea preparation.

Packaging: all primary, secondary and tertiary packaging associated with the life cycle of tea.

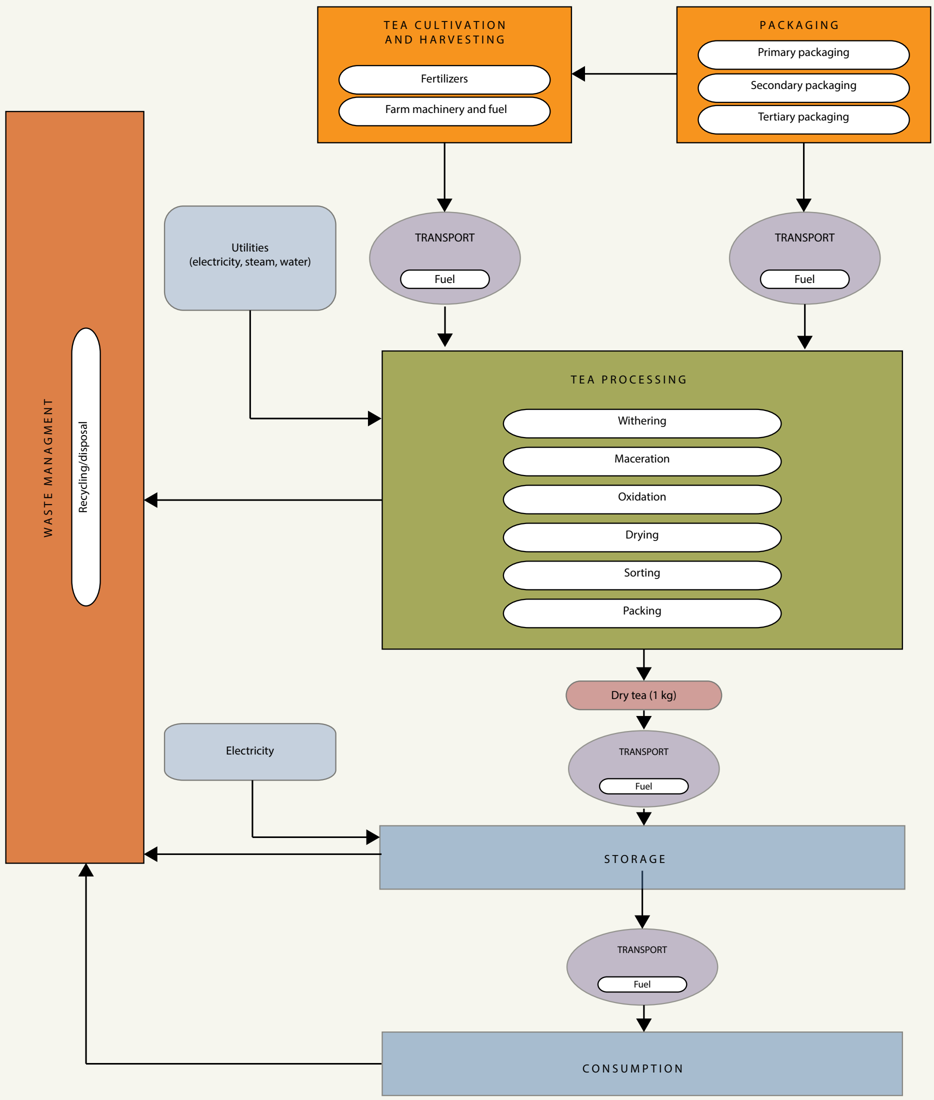
Waste management: all waste arising in the life cycle of tea and related waste management options.

Transport: all transportation steps throughout the life cycle of tea, except for the consumer transport to purchase the product (in line with common practice).

Excluded from the system boundary are:

- woven baskets used during harvesting, as they last for a very long time;
- transport of consumer tea packaging to the packing facility (owing to a lack of data); and
- consumer transport to purchase the tea as mentioned above.

Figure 44 The life cycle of tea considered in the study



The following section describes the tea life cycle stages in more detail, together with the assumptions and data.

3.2. Inventory data and assumptions

Primary data have been obtained from tea producers and TRFK, including data on fertilizers, energy and water usage for tea processing, packaging materials, as well as transport modes and distances. The data have been collected from 11 small-scale and 3 large-scale tea producers in Kenya, located in the eastern and western growing regions of the Great Rift Valley. This represents 19 percent of smallholders and 8 percent of large producers - or around 15 percent of the total number of tea producers. (The 15 percent represents 14 out of 38 large and 59 small producers.) This sample was selected as representative of tea production in Kenya, in relation to geographic spread, covering both sides of the Great Rift Valley; the different farming techniques used; processing practices; and age of the production facilities.

The collected data cover five years of production in the period 2007-2011. These have been averaged by producer and then averaged across the small- and large-scale producers, respectively, prior to LCA modelling. Tables 13 to 19 provide a summary of the data.

Background LCA data were sourced, primarily from the CCaLC database (CCaLC, 2013), with the gaps filled by data from ecoinvent (2010). The primary and background data are discussed further in the following sections.

Cultivation and harvesting

Owing to a favourable climate with evenly distributed rain throughout the year and long, sunny days, the tea requires no irrigation and is harvested all year round. As a consequence - and because of periodic pruning - the bushes are maintained approximately 1 m high; otherwise, they will grow as tall as 5-6 m. Fertilizer is used to increase the yield; on average, 0.24 kg/kg dry tea of fertilizer is applied by smallholders and 0.13 kg by large producers (Table 13). No pesticides or other chemicals are applied.

The application of fertilizer results in the direct and indirect emissions of nitrous oxide (N_2O), which have been estimated in line with the IPCC methodology (IPCC, 2006). The results are provided in Table 14.

Smallholder farmers harvest tea leaves using manual labour, while the large-scale producers use both manual labour and machinery (the fuel use for the latter is given in Table 13). To ensure the best quality of tea, only the top two leaves and the bud are plucked. The fresh tea leaves are collected in either woven baskets or polypropylene bags, typically carried by tea pickers on their backs. The tea pickers take the harvested tea (on foot) to a local collection point from where it is transported in small trucks to a tea processing plant.

Each year, the tea fields are expanded by planting new tea bushes. During the period covered by this study, the new land that was cultivated by the 11 small producers considered in the study amounted to 136 ha per year and that of the large producers to 37 ha (Table 13). As this constitutes a land-use change from grassland to perennial crop, GHG emissions associated with this activity have

Table 13 Materials and energy used in the life cycle of tea

Inputs	Additional information	Unit	Small-scale production	Large-scale production
Fresh tea	Plucked tea leaves	kg/kg dry tea	4.53	4.51
Fertilizer	N:P:K=26:5:5	kg/kg dry tea	0.24	0.13
Land	New land	ha/yr	136	37
	New land	ha/kg dry tea	$3.8x10^{-5}$	$8.5x10^{-6}$
Fuel	Diesel for cultivation	kWh/kg dry tea	-	0.51
	Petrol for pruning	kWh/kg dry tea	-	0.26
	Petrol (mixed with diesel[a]) for harvesting	kWh/kg dry tea	-	0.07
	Diesel (mixed with petrol[b]) for harvesting	kWh/kg dry tea	-	0.02
Electricity (Kenyan grid)	Tea production	kWh/kg dry tea	0.56	0.441[c]
	Tea packing	kWh/kg dry tea	0.04	-
Electricity (UK grid)	Tea consumption	kWh/kg dry tea	13.75	13.75
Steam (from biomass[d])	Tea production	kWh/kg dry tea	23.13	4.12
Water	Equipment cleaning	l/kg dry tea	4.79	1.20
	Tea preparation	l/kg dry tea	125	125

[a] 1 l of petrol and 0.25 l of diesel; [b] 1 l of diesel and 0.25 l of petrol; [c] Includes electricity for packing;
[d] 50% hardwood and 50% softwood

Table 14 Greenhouse gas emissions from the use of fertilizers and land-use change

Source of emissions	Small-scale production (g CO_2 eq./kg dry tea)	Large-scale production (g CO_2 eq./kg dry tea)
Direct N_2O emissions from fertilizer	0.98	0.53
Indirect N_2O emissions from fertilizer	0.10	0.05
GHG emissions from land-use change	0.40	0.01

been calculated using the IPCC (2006) methodology, with the estimates given in Table 14.

A tea nursery - established and managed by TRFK - supports tea cultivation by breeding and selecting high-yielding cultivars that are highly tolerant to environmental stress. The data for the nursery represent the average nursery

Table 15 Inputs used in the nursery

Inputs	Amount (g/kg of dry tea)[a]
Water	2253.9
Fertilizers (N:P:K=26:5:5)	5.7
Fertilizers (diammonium phosphate)	3.4
Insecticide	0.02
Pesticide	0.03
Polyethylene tubing	1.2
Gauge polyethylene sheetsb	6.5
Polyethylene sleeves[b]	8.6
Eucalyptus/bamboo poles and wood frames	49.5

[a] Data represent an average over seven years for two nurseries.
[b] These are recycled after the use so that 100% recycled polyethylene has been assumed in the input.

operation over seven consecutive years; these are provided in Table 15. As shown, approximately 50 kg of wood, 2.2 litres of water, 16.3 grams (g) of plastic and 9.1 grams of fertilizer are used per kilogram of dry tea in the nursery. In addition, a small amount of pesticides and insecticides is used (0.05 g/kg).

Processing and packing

On arrival to the processing plant, the tea leaves are processed using the CTC method. The leaves are first spread on a series of long, perforated trays and are left to wither, using warm air (25-30°C) fans. This is followed by maceration in a series of cylindrical rollers that crush, tear, and curl the tea, breaking the tea leaves into small particles and releasing the enzymes, leading to their oxidation (fermentation). Laid out on trays in a cool atmosphere, the tea leaves progressively turn darker as they oxidise, which typically takes three to four hours. The leaves are subsequently dried in a drier, using heat from one or more onsite biomass boiler(s). On average, it takes around 4.5 kg of fresh leaves to produce 1 kg of dry tea (Table 13).

The dried tea, now black in colour, is then sorted by particle size and quality, packed into 50- to 70-kg paper bags and loaded onto wood pallets, ready for transport to Mombasa. The data for the energy and water used in the processing stage can be found in Table 13; the packaging data are provided in Table 16.

Storage and shipping

Tea is transported by truck from the processing plants to Mombasa, where it is stored in a warehouse prior to shipping overseas. As mentioned previously, this study assumes that the tea is exported for consumption in the UK.

Consumption

On arrival at its destination in the UK, the tea is transported by road to a repacking (and blending) plant in Manchester, after which it is distributed to the

Table 16 Packaging used in the life cycle of tea

Packaging use	Material	Small-scale production (g/kg dry tea)	Large-scale production (g/kg dry tea)
Fertilizer	Polyethylene (bag)	1.17	-
	Polypropylene (bag)	-	0.57
	Polyethylene (wrap film)	-	0.17
Fresh tea (harvested)	Polypropylene (container)[a]	3.35	7.9
	High density polyethylene (container)[a]	7.55	
Dry tea (at factory)	Paper (bags)	4.9	4.9
	Aluminium (bag lining)	2.1	2.1
	Polyethylene (bag lining)	2.4	3.0
	High density polyethylene (bag lining)	1.2	1.0
	Polyethylene (wrap film)	4	-
	Wood (pallets)[a]	38	4
	Compacted carton (slip sheet)	2.1	-
Dry tea (at consumer)[b]	Paper (tea bag and tag)	440	440
	Corrugated cardboard (tea box)	280	280
	Bleached cardboard (tea box)	260	260
	Polyethylene (tea box overwrap)	42	42

[a] Reused 20 times; [b] 20 bags of 50 g of tea.
Source: Data for the type and quantity of packaging from Jefferies *et al*. (2012)

retailers by road. For the purpose of this study, it is assumed that the Kenyan tea is not blended and that consumers drink it pure. It is assumed that for each 2-g tea bag the consumer will boil the exact amount of water required to consume the beverage (125 l/kg dry tea or 250 ml/cup; see Table 13). The effect on the results of various amounts of water (and the associated energy to boil the water) is examined within the sensitivity analysis in Section 3.4.1.1.

Packaging

Table 16 provides a summary of the types and the amounts of packaging. In the absence of further information, packaging is assumed to be produced from virgin materials. As indicated in the Table 16, fertilizer is packaged either in polyethylene (PE) or polypropylene (PP) 50-kg bags. The PE shrink film to wrap bag stacks during transport is also considered. PP and high-density polyethylene (HDPE) containers, used during the harvest, are assumed to be reused 20 times. At factory, the tea is packed into 50-70 kg paper bags that are lined with aluminium and either PE or HDPE film. The bags are stacked and loaded onto wood pallets and then wrapped in PE shrink film. Slip sheets, made of compacted carton, are sometimes inserted between the bags. The wood pallets are assumed to be reused 20 times.

Table 17 Waste arising in the life cycle of tea and waste management options

Source	Type	Small-scale production (g/kg dry tea)	Large-scale production (g/kg dry tea)	Waste management option
Fertilizer	Waste bags & wrap film	1.17	0.74	Landfilled
Process waste	Waste tea	4	11	Landfilled
	Boiler ash	60	11	Landfilled
Post-factory packing waste	Waste tea	88	88	Landfilled
Consumer waste	Waste tea	1000	1000	Landfilled
Packaging waste	Various materials	As in Table 16	As in Table 16	All landfilled except for paper which is 80% recycled

Table 18 Transport modes and distances in the life cycle of tea

	Small-scale production (km)	Large-scale production (km)	Transport type
Fertilizer	11 200	11 200	Shipping
Fertilizer	720	720	Truck (40 t)
Picked tea	15	5	Truck (7.5 t)
Large tea bags	200	300	Truck (7.5 t)
Wood pallets	50	50	Truck (7.5 t)
Slip sheets	85	-	Truck (7.5 t)
Tea (post-factory)	720	720	Truck (22 t)
Tea (to UK)	11 200	11 200	Shipping
Tea (for repacking in the UK)	400	400	Truck (40 t)
Tea (to retailer)	300	300	Truck (22 t)

Table 19 Electricity mix in Kenya

	2008 (GWh)	2009 (GWh)	2010 (GWh)	2011 (GWh)	Average (GWh)	Contribution (%)
Hydro	3 267	2 160	3 224	3 217	2 967	43.52
Oil	2 145	2 997	2 201	2 800	2 536	37.20
Geothermal	1 039	1 293	1 442	1 444	1 304	19.13
Wind	0.2	7.2	16.8	17.6	10.45	0.15
Total	6 452	6 457	6 884	7 479	6 817	100

Source: Kenya National Bureau of Statistics, 2012

Consumer packaging in this analysis assumes a box made of cardboard, with a capacity for 50 tea bags, each containing 2 g of tea. The tea bags are made from Kraft paper as is the tea bag tag; the tea bag string is not considered owing to a lack of data. The box is wrapped in PE film. Overall, 1.1 kg of packaging is used per kilogram of dry tea.

Waste management

As indicated in Table 17, all relevant waste streams have been considered, including in-process, storage and post-consumer waste. Process waste includes waste tea, broken packaging and boiler ash, all of which are disposed in landfill sites. During storage, a small number of tea bags are broken and the relevant waste tea and packaging are also landfilled. Finally, at the consumer level, the waste tea and packaging are transported to disposal sites, except for the tea box which is recycled at the rate of 80 percent, with the rest landfilled. This waste management is in accordance with current UK waste management practice (Defra, 2009). The system has been credited for the impacts avoided from the recycling of waste paper.

Transport

The transport modes and distances during the various stages of the tea life cycle are listed in Table 18. Fertilizer is shipped to Kenya from the UK (11 200 km) and then transported by trucks (720 km). The tea travels the same journey, but in the opposite direction. In addition, once at its destination in the UK, the tea is transported from the south of England to Manchester (400 km) for repacking and then to the retailer. For the purposes of this study, an average distance of 300 km has been assumed for transport to the retailer. Freshly harvested tea travels between 5 and 15 km to the processing facilities, while the large paper tea bags are transported to the tea factories at a distance of 200-300 km (Table 18).

Electricity

Since LCA data for the electricity generated in Kenya were not available, they had to be collected as a part of this study. An average electricity mix over the past four years (2007-2011) has been assumed (Table 19), comprising hydro (44 percent), oil (37 percent) and geothermal electricity (19 percent). LCA data for these sources of electricity have been sourced from ecoinvent (2010). It should be noted, however, that the data relating to Kenya were not available; instead, average European data have been used. The effect of this data gap on the overall results is considered within the sensitivity analysis in Section 3.4.1.1.

3.3 Impact assessment and interpretation

The life cycle impact assessment method developed by the Institute of Environmental Sciences in the Netherlands (Guinee *et al.*, 2001) has been applied to estimate the environmental impacts. The LCA modelling has been carried out in CCaLC V3.0 (2013). As previously mentioned, the GWP is the focus of this study so that these results are discussed first, followed by the other environmental impacts. Care should be taken, however, when interpreting the latter, since not all relevant data have been available to allow a full estimation of the impacts so that they may be underestimated.

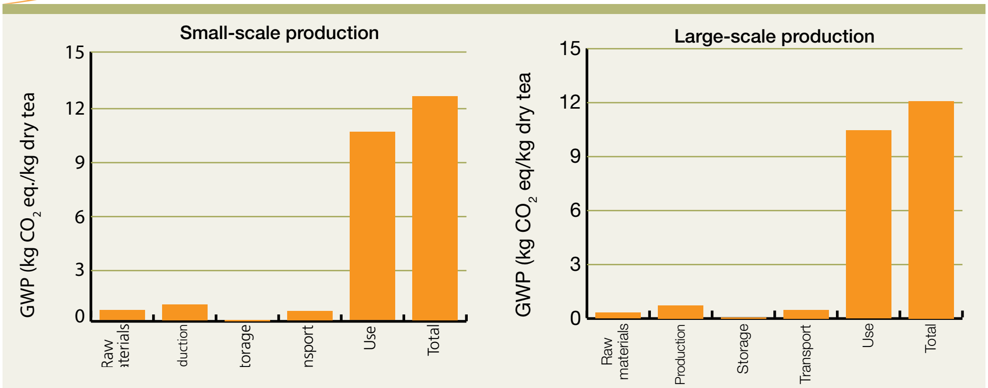
Global warming potential

The GWP has been estimated by applying the IPCC 100-year GWP factors (IPCC, 2007). Following the Publicly Available Specification PAS:2050 standard for estimating the GWP of food-related products (BSI, 2011), neither biogenic carbon dioxide (CO_2) nor credits for its sequestration from the atmosphere by the tea plants have been considered. This is because the sequestered carbon is only stored on a very short-term basis in food products (including tea) and will be released back again into the atmosphere when tea is consumed and digested. This also avoids the need to include the CO_2 emissions caused by the consumption and digestion of food. Further information on the topic can be found by consulting the PAS:2050 standard (BSI, 2011).

As shown in Figure 45, the GWP of tea from cradle to grave is estimated at 12.45 kg CO_2 eq./kg dry tea for smallholders and 12.08 kg CO_2 eq./kg dry tea for large farms, suggesting that there is little difference in the impact between them. This is largely because a large proportion (over 85 percent) of the GWP is generated in the consumption stage, obscuring any differences in the tea production process, which itself contributes only 10 percent to total GWP.

The differences in the GWP between the two scales of production can be seen more clearly in Figures 46 and 47, which give a breakdown of the contribution of the raw materials and the tea production process, respectively. The results suggest that at 1.07 kg CO_2 eq./kg dry tea, large-scale production has a lower GWP from cradle to gate compared to 1.42 kg CO_2 eq./kg dry tea for the small-scale production. This is mainly due to a lower amount of fertilizer used in the large-production systems and lower direct and indirect emissions of N_2O. Further differences are observed in the emissions from land-use change: 0.038 kg CO_2 eq./kg dry tea for small-scale versus 0.009 kg CO_2 eq. for large-scale (Table 14).

Figure 45 Global warming potential of 1 kg dry tea for the small- and large-scale production systems



The latter also has a more energy-efficient production process. The large-scale producers, however, use machinery (and fuel) for pruning and harvesting, which increases GWP - but only very slightly - by 0.08 kg CO_2 eq./kg dry tea. A similarly small contribution (0.06 kg CO_2 eq.) is observed for the nursery (Figures 46 and 47).

As mentioned above, tea consumption is responsible for the vast majority of the GWP, largely owing to the GWP of electricity required to boil the water in a kettle, estimated at 9.2 kg CO_2 eq./kg dry tea (Figure 48).

The remaining impact from this stage is a result of consumer tea packaging, adding 1.39 kg CO_2 eq. or 11 percent to the GWP of the entire tea system (Figure 49). As also indicated in this table, more than half of the impact (0.75 kg CO_2 eq./kg dry tea) from consumer packaging is from the paper used for tea bags and tags, followed by 40 percent (0.54 kg CO_2 eq.) from the cardboard for the tea box. The GWP from factory packaging is small (0.026 kg CO_2 eq./kg dry tea).

Figure 46 Global warming potential associated with the material inputs for the small- and large-scale production systems

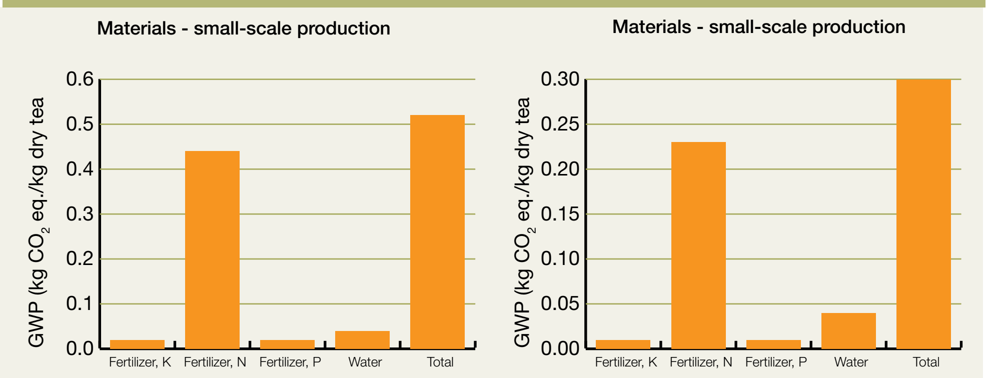


Figure 47 Global warming potential associated with the production process in small- and large-scale tea production

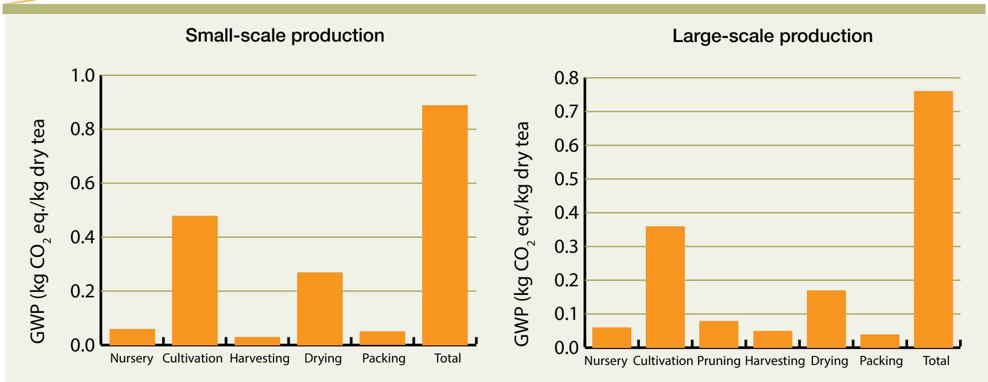


Figure 48 Global warming potential associated with tea storage in Mombasa and tea consumption in the UK

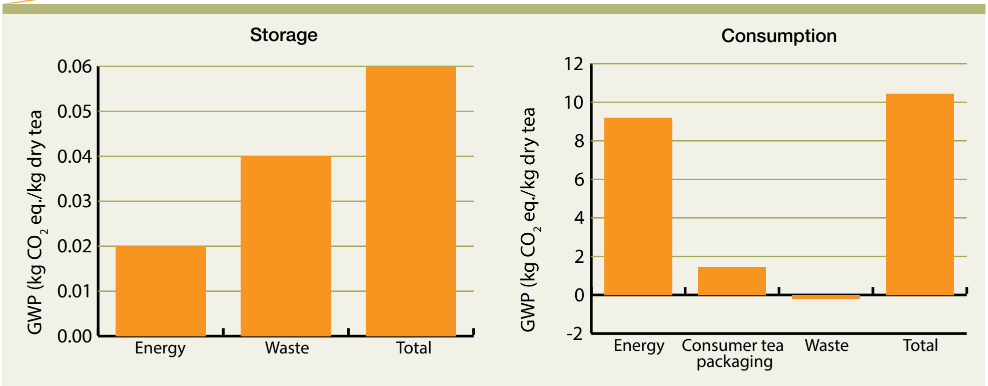
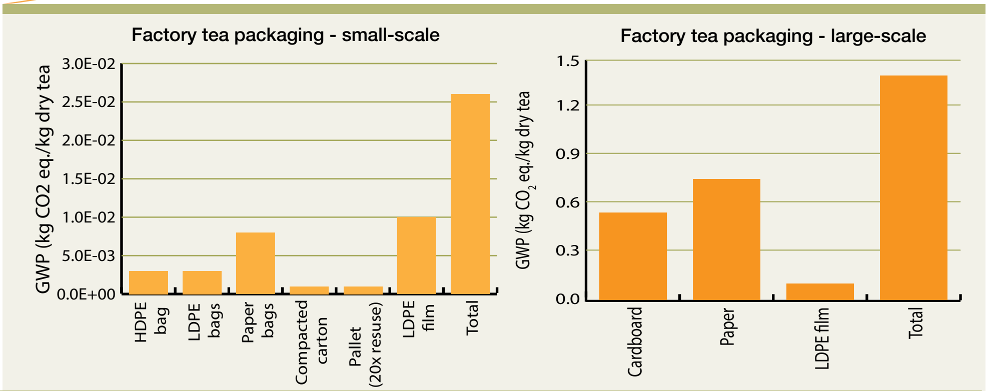


Figure 49 Global warming potential associated with tea packaging at (small-scale) factory and at the consumer level



The contribution from transport is also relatively small (4 percent) and the impact from storage is negligible (<0.01 percent). As shown in Figure 50, shipping the tea to the UK is the major contributor (72-74 percent) to the GWP from transport, followed by the transport of fertilizers (17 percent) and tea packaging to the processing plant (7 percent).

The impact from waste management throughout the life cycle of tea is summarized in Figure 51. As can be observed, the overall GWP from waste management is negative (-0.08 kg CO_2 eq.), indicating a saving in GHG emissions. This is due to the credit for post-consumer tea box recycling. Even without the credits, the contribution of waste to total GWP would be small.

■ *Sensitivity analysis*

This section explores the influence of some of the less certain data on the GWP results, including the following parametres: Kenyan electricity, land use change

Figure 50 Global warming potential associated with transport in the life cycle of tea for small- and large-scale production

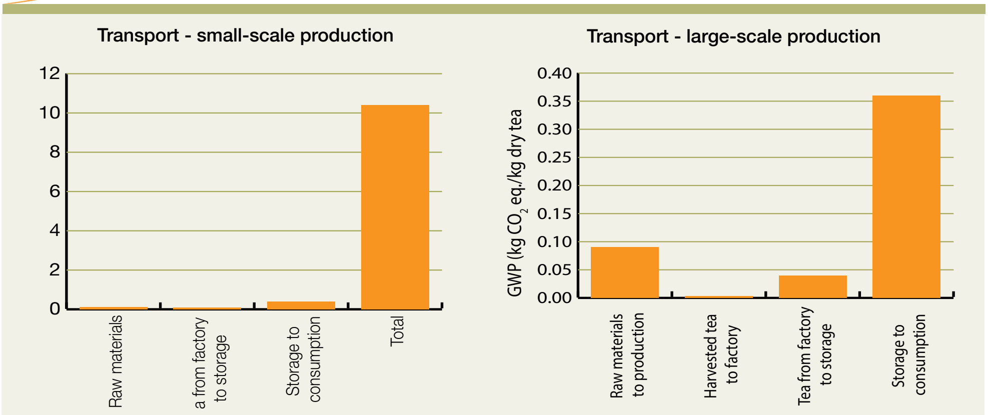
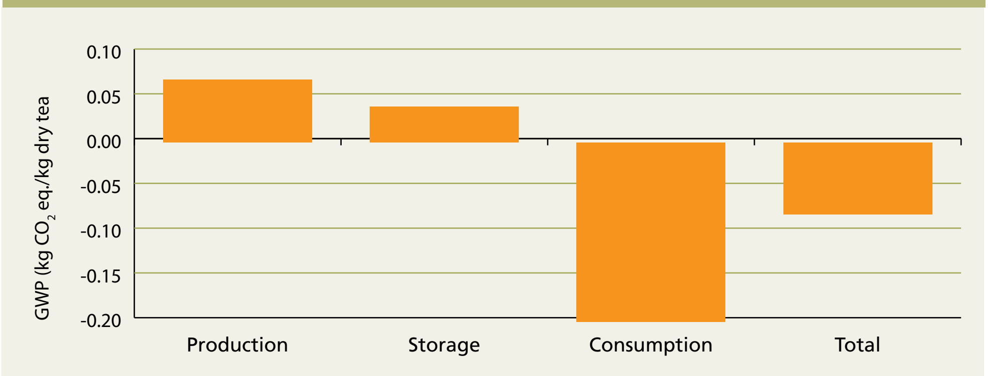


Figure 51 Global warming potential associated with waste management in the life cycle of tea



and tea consumption. Since the total GWP for the small- and large-scale production is very similar, the discussion below refers only to the small-scale production.

A. Kenyan electricity

The GWP of Kenyan electricity has been estimated in this study at 0.365 kg CO_2 eq./kWh. As mentioned previously, however, the data are based on LCA data for different electricity technologies in Europe, so that there is some uncertainty associated with this estimate, owing to the lack of data. For the sensitivity analysis, it is assumed that current GWP is underestimated by (an extreme value of) 50 percent, raising the GWP to 0.73 kg CO_2 eq./kWh. If that were the case, the total GWP of tea from the small-scale system would increase from 12.45 to 12.61 kg CO_2 eq./kg of dry tea or by 1.3 percent. This insignificant change in the result suggests that the GWP of Kenyan electricity is not a critical parameter in the estimation of the GWP of tea. The same is true for the large-scale production. Therefore, the results are robust with respect to the assumptions for the GWP of Kenyan electricity.

B. Land-use change

To examine the influence of land-use change on the GWP of tea, the sensitivity analysis assumes that its impact is 50 percent higher than originally estimated, doubling its GWP value from 4 to 8 t CO_2 eq./ha yr. In that case, the GWP of small-scale production would change from 12.45 to 12.62 kg CO_2 eq./kg of dry tea or by 1.3 percent. Thus - similar to electricity discussed above - the GWP of land-use change does not influence the results.

C. Tea consumption

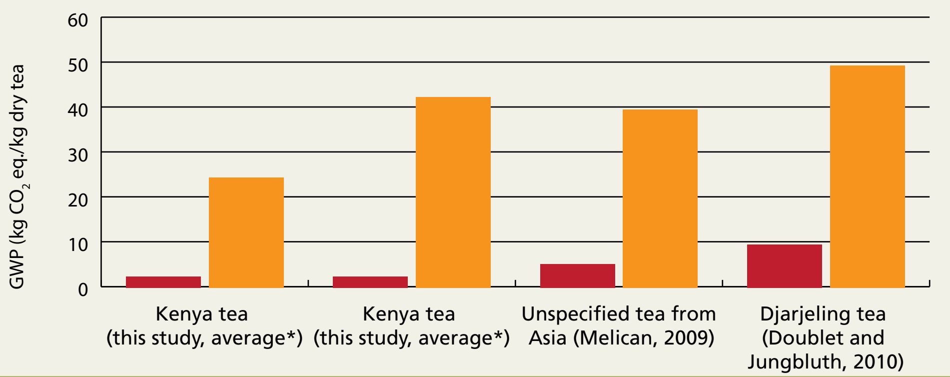
This study assumes that the consumer boils exactly the amount of water needed to make a cup of tea (250 ml). It is well known, however, that consumer behaviour differs and that people often boil more water than is necessary. For this reason, as part of the sensitivity analysis, it is considered that the consumer uses twice the amount of water (500 ml per cup). This almost doubles the GWP, from 12.45 to 21.3 kg CO_2 eq./kg of dry tea. The results are, therefore, very sensitive to consumer behaviour and indicate the single most important area for reducing the environmental impacts from tea. This is not surprising, given that tea consumption represents 85 percent of the total GWP of tea.

■ *Comparison of GWP results with literature*

At the time of writing, only two other LCA studies of tea were found in literature: one by Doublet and Jungbluth (2010) relating to Darjeeling tea grown in India and another by Melican (2009) on an unspecified tea produced in Asia. Both studies focused on the GWP and these results are compared to those obtained in this study (Figure 52). For this purpose, the functional unit is defined as one cup of tea, following the functional unit definition in the other two studies. Therefore, the GWP for the functional unit of 1 kg of dry tea considered in this study has been converted to the GWP of one cup of tea (assuming, as previously, 2 g of tea per bag and 250 ml of water). Since the difference between the small- and large-scale production systems is small, the GWP results were first averaged between the two and then converted to the functional unit of one cup of tea.

As indicated in Figure 52, at 2.5 g CO_2 eq. per cup of tea, the GWP from cradle to gate is the lowest for the tea produced in Kenya: it is about two times lower than for the (unspecified) tea grown in Asia, estimated by Melican (2009), and almost four times lower than for Darjeeling tea, reported by Doublet and Jungbluth (2010). While there could be many reasons for these differences, including varying assumptions and the LCA databases used, one is due to different impacts from cultivation. For example, tea yield is almost twice as high in Kenya as it is in India (FAOSTAT, 2013), requiring less fertilizer. Furthermore, no pesticides or other chemicals are used to grow tea in Kenya and the vast majority of energy used for tea processing is from biomass.

Figure 52 Comparison of GWP results with literature

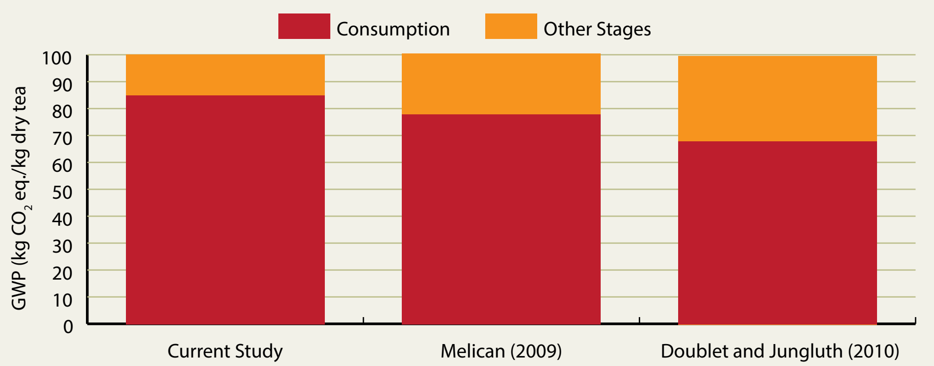


*Assuming the consumer boils exactly the amount of water required for a cup (250 ml).
**Assuming the consumer boils twice the amount of water required for a cup (500 ml).
Results average between small- and large-scale production. Darjeeling tea is grown in India.
No information is available about the country of origin of the tea in the study by Melican (2009).

Figure 52 also reveals that the GWP from cradle to grave, estimated in this study, is 24.5 g CO_2 eq./cup, assuming that the consumer boils exactly the amount of water required for a cup of tea (250 ml). This compares to 39.7 and 49.5 g CO_2 eq./cup, estimated by Melican (2009) and Doublet and Jungbluth (2010), respectively. Thus, the differences in the results are 1.6 and 2 times, respectively, in favour of tea produced in Kenya. If it is assumed, however, that the consumer boils twice as much water (500 ml), the GWP of tea considered in this study goes up to 42.5 g CO_2 eq./cup, approaching the GWP of Darjeeling tea of 49.5 g CO_2 eq.

Regardless of the differences in total GWP, similar trends are found in all three studies with respect to the contribution of tea consumption to total GWP. This is illustrated in Figure 53, where tea consumption is the main contributor to the

Figure 53 Contribution of tea consumption and the remaining life cycle stages to the GWP of tea in different studies



GWP, ranging from 67 percent in the Doublet and Jungbluth (2010) study to 78 percent in the Melican (2009) study to 85 percent in the current study.

3.4. Other environmental impacts

As mentioned previously, in addition to the GWP, several other environmental impacts have also been estimated: acidification, eutrophication, ozone layer depletion, photochemical smog and human toxicity. These are shown in Figure 54. For example, the acidification potential is estimated at 63 g SO_2 eq./kg dry tea and the eutrophication potential at 5.5 g PO_4 eq./kg dry tea. The ozone depletion potential is equal to 1.3 mg R11 eq./kg and photochemical smog 3.8 g C_2H_4 eq. Finally, the human toxicity potential is around 845 g dichlorobenzene eq./kg. It can be observed is that the trends are the same for all impacts with the consumption of tea being responsible for 70-100 percent of environmental impacts. With regard to the GWP, this is largely due to the life cycle impacts of electricity used to boil water for the tea. As indicated previously, however, these results should be treated as tentative owing to data gaps for some of the impacts. Nevertheless, they are indicative of the general impact trends. It should also be noted that these are only *potential*, rather than actual impacts, as per standard LCA practice.

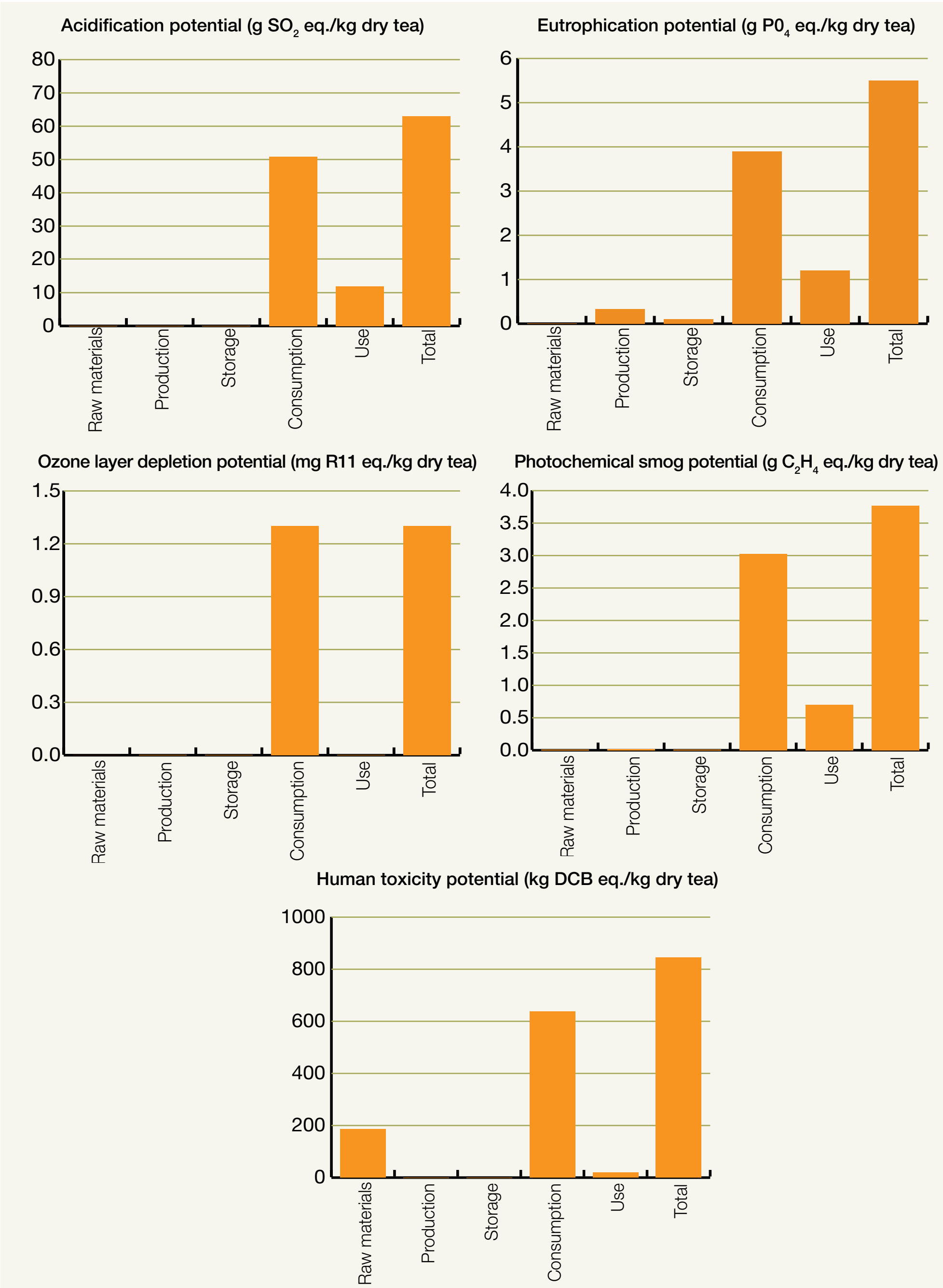
4. Conclusions

This study has examined the life cycle environmental impacts of tea grown in Kenya, considering both small- and large-scale production. The focus has been on the GWP, but the following environmental impacts have also been considered: acidification, eutrophication, ozone layer depletion, photochemical smog and human toxicity. The results suggest that the total GWP of tea from cradle to grave is equal to approximately 12 kg CO_2 eq. per kilogram of dry tea or 25 g CO_2 eq. per 250 ml cup of tea, with little difference between small- and large-scale production.

The main contributor to this impact is tea consumption, responsible for 85 percent of the GWP. This is due to the electricity needed to boil the water for the tea. At 1.07 kg CO_2 eq./kg dry tea for large-scale production and 1.42 kg for small-scale production, tea cultivation and processing contribute approximately 10 percent to total GWP. The contribution of transport is relatively small (4 percent). The GWP from waste management is negative (-0.08 kg CO_2 eq.), which indicates a saving in this impact. This is because of the credits for post-consumer recycling (tea box). A similar trend with respect to the contribution of different life cycle stages is noticed for the other environmental impacts assessed in this study.

GWP results are most sensitive to consumer behaviour, with the GWP almost doubling with twice the amount of water boiled for each cup of tea. The influence of other parametres, such as the GWP of land-use change and Kenyan electricity, is negligible. Comparison of the GWP results with literature reveals a relatively good agreement.

Figure 54 Environmental impacts (other than global warming potential) of tea production of tea



NB: The results shown relate to the small-scale production. The trends are the same for the large-scale production R11: CFC-11; DCB: dichlorobenzene

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CHAPTER SIX

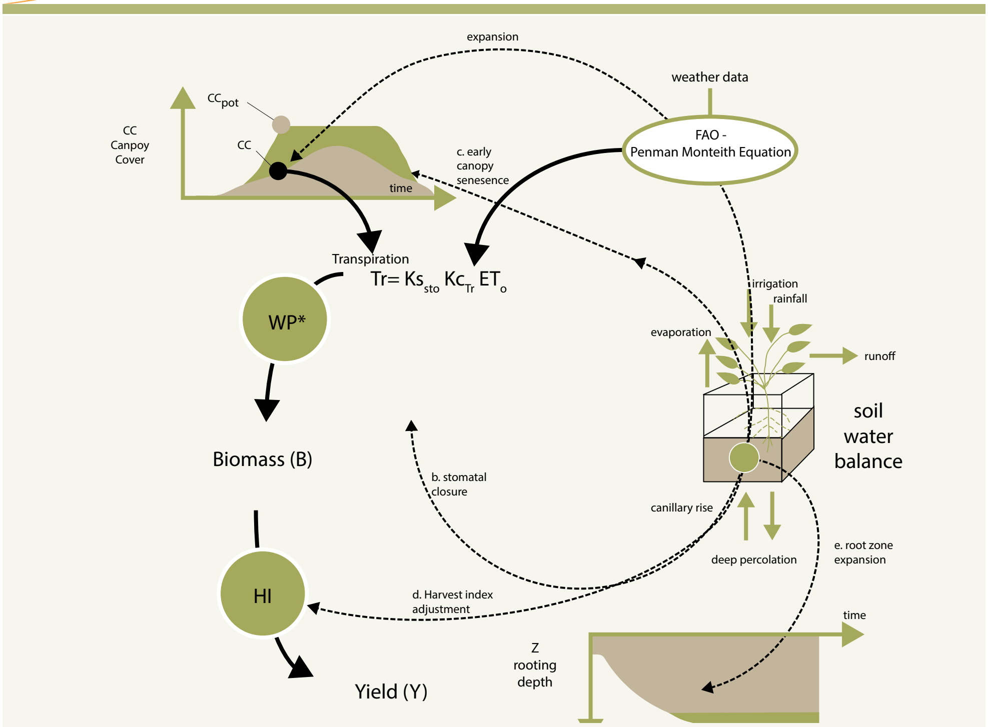
SIMULATION OF TEA YIELDS UNDER MANAGEMENT AND CLIMATE CHANGE SCENARIOS USING AN AQUACROP MODEL

Dirk Raes, Patricia Mejias, Samson Kamunya, John Bore, Beatrice Cheserek and David Kamau

1. Simulation of tea production

Throughout the crop cycle, the amount of water stored in the root zone is simulated by calculating the incoming (rainfall and irrigation) and outgoing (runoff, evapotranspiratfffion (ETo) and deep percolation) water fluxes at its boundaries (Figure 55). The root zone depletion determines the magnitude of the water stress coefficients (Ks) affecting: (a) green canopy (CC) expansion; (b) stomatal conductance and, hence, transpiration per unit CC; (c) canopy senescence and decline; and (d) harvest index (HI). Each of these effects has its own threshold depletion and response curves. Additionally, (e) the root system deepening rate is a function of Ks for stomatal conductance. If water ffstress occurs, the simulated CC will be less than the potential canopy cover (CCpot) for no-stress conditions. The coefficient for transpiration (KcTr) is proportional to CC and, hence, continuously adjusted throughout the simulation. Above-ground biomass (B) is derived from transpiration by means of the normalized water productivity (WP*), a conservative parametre. At the end of the crop cycle, yield is calculated as the product of the simulated B and the adjusted (HI).

Figure 55 Schematic representation of the simulation



NB: For full details, consult the Reference Manual of AquaCrop

Step 1. *Canopy development* (CC): Water stress can hamper canopy expansion (Ks_{exp} < 1) and might trigger canopy senescence (Ks_{sen} < 1);

Step 2. *Crop transpiration (Tr)*: The crop transpiration coefficient (Kc_{Tr}) is proportional to CC (Step 1). Water stress can (partially) close stomata (Ks_{sto} < 1);

Step 3. *Daily biomass production* (b_i) is proportional to the ratio Tr/ETo (proportional factor is WP*) and can be hampered by air temperature stress (Ks_b < 1):

$$b_i = Ks_b \; WP^* \left(\frac{Tr}{ET_o} \right) \qquad \text{(Equation 1)}$$

Step 4. *Daily tea yield* (y_i) is proportional to b_i (proportional factor is HI, which gradually increases after pruning until HI_o is reached), and can be hampered by water stress affecting leaf expansion (Ks_{exp}):

$$y_i = Ks_{\exp} \; HI \; b_i \qquad \text{(Equation 2)}$$

2. Crop characteristics

Table 20 Tea crop characteristics (*TeaCalib.CRO* crop file)

A. Crop phenology			
Symbol	**Description**	**Value**	**Observations**
	Planting density (plants/ha.)	13 448	Given
CC_{ini}	Initial canopy cover after pruning	25%	Lung pruning
CC_x	Maximum canopy cover (%)	95%	As observed
CGC	Canopy growth coefficient	0.7%/day	It takes 1.5 years (550 days) to reach maximum canopy cover after pruning
	Time between pruning	1 460 days (= 4 x 365 days)	Every 4 years, the bush is pruned
Z_x	Maximum effective rooting depth (m)	2 m	It is a tree
Z_n	Minimum effective rooting depth (m)	2 m	At pruning, the effective rooting depth is already at Z_x

Table 21 Tea crop characteristics (*TeaCalib.CRO* crop file)

Symbol	Description	Value	Observations
B. Crop transpiration coefficient			
$Kc_{Tr,x}$	Crop coefficient when canopy is complete but prior to senescence	0.85	As given in literature
	Decline of crop coefficient (%/day) as a result of ageing, nitrogen deficiency, etc.	none	No ageing considered, since tea is picked once a week
C. Biomass production and harvest index			
WP*	Water productivity normalized for evapotranspiration (ETo) and CO_2 (gram/m^2)	14 g/m^2	At the lower end of the range for C3 crops
HIo	Reference harvest index	14%	Range: 10 – 19%
	Time for building up the Harvest Index	30% of the 4 year cycle	The reference HIo is reached after 14.5 months

Table 22 Tea crop characteristics (*TeaCalib.CRO* crop file)

D. Temperature stress			
T_{base}	Base temperature (°C)	8°C	
T_{upper}	Upper temperature (°C)	30°C	
	Minimum growing degrees required for full biomass production (°C - day)	8°C day $= T_{base} - T_{mean}$	With Tbase = 8°C, the biomass production is not hampered by air temperature if Tmean is at or above 16°C. The optimal mean air temperature for tea is 25°C.
E. Water stress			
$p_{exp,lower}$	Soil water depletion threshold for canopy expansion - Upper limit	0.10	Slightly stronger water stress than observed in green house research project
$p_{exp,upper}$	Soil water depletion threshold for canopy expansion - Lower limit	0.40	
	Shape factor for water stress coefficient for canopy expansion	3	(default value)
p_{sto}	Soil water depletion threshold for stomatal control - Upper threshold	0.25	Slightly stronger water stress than observed in green house research project
	Shape factor for water stress coefficient for stomatal control	3	(default value)
p_{sen}	Soil water depletion threshold for canopy senescence - Upper limit	0.60	Derived from green house research project
	Shape factor for water stress coefficient for canopy senescence	3 (default value)	
	Vol% at anaerobiotic point (with reference to saturation)*	5 vol %	(default value)

*: 'Vol%' stands for 'volumetric water content'

Figure 56 Canopy development

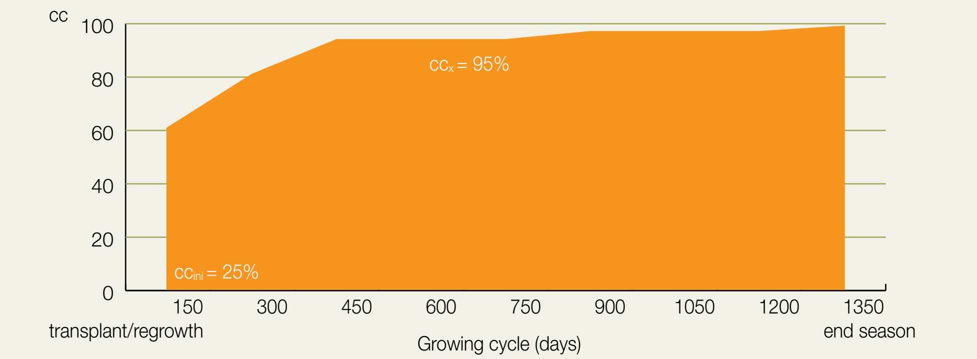
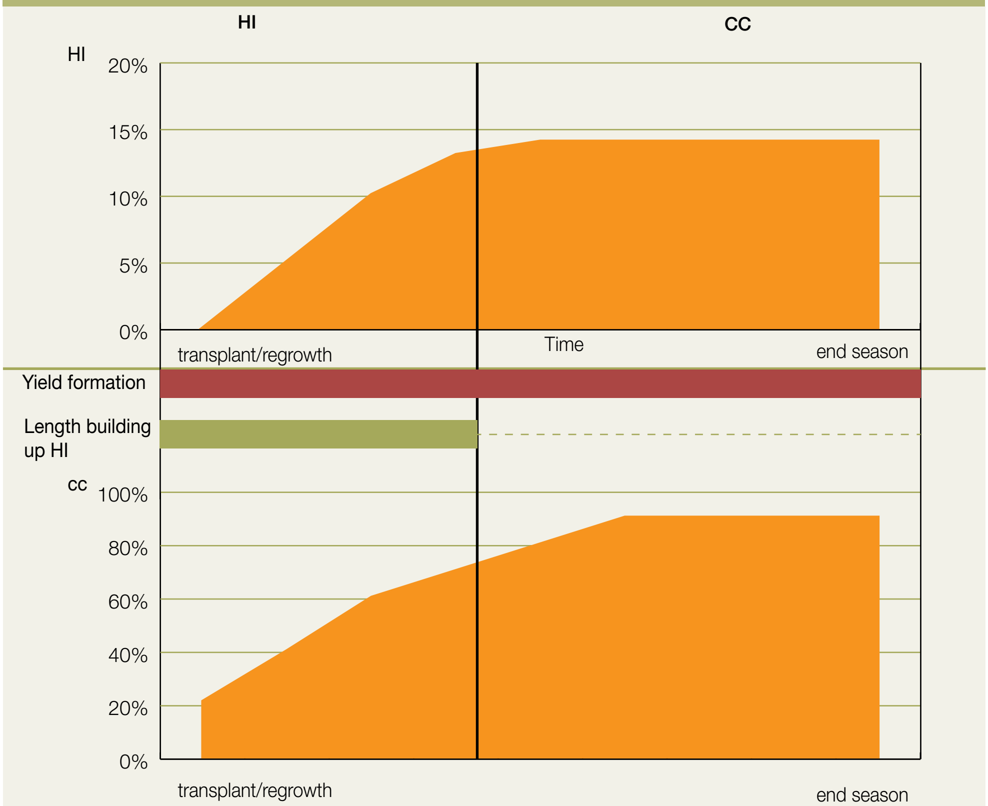


Figure 57 Development of harvest index



3. Running simulations and assessment of results

AquaCrop for tea was calibrated and validated with data collected at the Timbilil Tea Estate (0° 22' S, 35° 21' E, 2 180 m above sea level), located 12 km from Kericho. The total area of tea production is 210 ha. The estate is operated by TRFK.

The first step involved calibrating the crop file for the commercial, high yielding clone TRFK 31/8, which is cultivated in experimental fields of the estate. Subsequently, the crop file was validated by simulating the tea yield in the fields on the estate. Finally, some projections were made of the likely impact of climate change on tea production.

3.1 Description of the environment

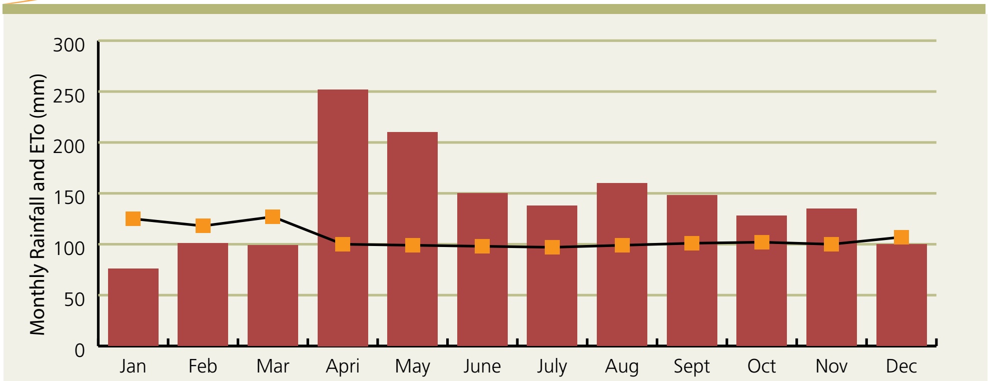
Weather data

Mean monthly rainfall and reference ETo for Kericho is plotted in Figure 58. With the exception for December, January and February, total rainfall exceeded the monthly reference ETo.

Thirty years of climate data were collected from Timbilil Tea Estate (0° 22' S, 35° 21' E, 2 180 m above sea level) (January 1982-December 2011) and stored in the Timbilil 30.CLI climate file. It includes the following:

- daily rainfall (mm/day);
- daily ETo (mm/day), determined by the FAO Penman-Monteith equation, with the help of the ETo Calculator, considering the daily maximum and minimum air temperature, dew point temperature, wind speed and hours of bright sunshine;
- daily maximum and minimum air temperature (°C); and
- annual observed CO_2 levels in Mauna Loa (ppm).

Figure 58 Mean monthly rainfall (bars) and reference evapotranspiration (line) for Kericho*



Source: New LocClom).

* 0° 22' S, 35° 21' E, 2 180 m above sea level

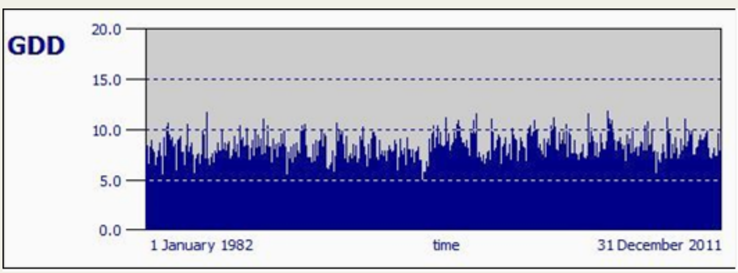
Table 23 Classification of years, based on the probability of exceedance (Pex) of total rainfall and corresponding return period

Type of year	Symbol	Pex	Return period
		%	Year
Very wet	Wet+	0 to 10	10 years or more
Wet	Wet	11 to 30	from 3.3 to 9.1 years
Normal	N	29 to 69	3.2 years or less
Dry	Dry	70 to 89	from 3.3 to 9.1 years
Very dry	Dry+	90 to 100	10 years or more

The average total rainfall is 2 146 mm, but varies strongly from one year to another (Table 22). The years were classified as very dry, dry, normal, wet and very wet by considering the return period (Table 21). The probability of exceedance of the total rainfall (Pex) and corresponding return period were obtained with the help of a frequency analysis (total rainfall to the power 2.5 is normal distribution).

The average reference ETo is 3.7 mm/day, with an average variation of only 2.3 percent *per annum*. By considering a Tbase of 8°C, the average growing degrees received during a year was 3 043°C. Growing Degree Days were plotted for the 30-year period in Figure 59. Given the threshold of 8°C day for Ksb (cold stress coefficient for B), the average cold stress affecting biomass production was 2.1 percent (Table 22).

Figure 59 Growing Degree Days* for Timbilil for a base temperature of 8°C, 1982-2011



* (GDD in °C day)

Table 24 Total and average rainfall, reference evapotranspiration, growing degree days and temperature stress affecting biomass production at Timbilil Tea Estate, 1982-2011*

Year	Rainfall			ETo			Growing degree			T_{stress}
	Tot	Pex	Type	Tot	Avg	Var	Tot	Avg	Var	Tot
	mm	%		mm	mm/d	%	°C	°C d	%	%
1982	2 390	19	Wet	12 309	3.6	-2.3	22 867	7.9	-5.8	3
1983	22 243	39	N	12 302	3.6	-2.8	32 131	8.6	2.9	1
1984	12 502	97	Dry+	12 425	3.9	6.4	22 953	8.1	-3.0	2
1985	22 247	39	N	12 338	3.7	-0.1	22 889	7.9	-5.1	3
1986	12 629	95	Dry+	12 366	3.7	2.0	22 997	8.2	-1.5	2
1987	22 289	32	N	12 367	3.7	2.1	32 144	8.6	3.3	1
1988	22 405	17	Wet	12 299	3.6	-3.0	32 050	8.4	0.2	2
1989	22 474	11	Wet	12 297	3.6	-3.2	22 929	8.0	-3.7	3
1990	22 230	41	N	12 350	3.7	0.8	32 013	8.3	-1.0	2
1991	22 135	55	N	12 305	3.6	-2.6	22 932	8.0	-3.6	3
1992	22 106	59	N	12 316	3.6	-1.7	32 011	8.2	-1.0	2
1993	12 687	94	Dry+	12 344	3.7	0.3	22 951	8.1	-3.0	3
1994	22 582	4	Wet+	12 305	3.6	-2.6	22 843	7.8	-6.6	3
1995	22 121	57	N	12 309	3.6	-2.3	22 760	7.6	-9.3	4
1996	22 011	72	Dry	12 257	3.4	-6.1	22 658	7.3	-12.6	6
1997	22 104	60	N	12 376	3.8	2.7	32 230	8.8	6.2	1
1998	22 287	33	N	12 354	3.7	1.1	32 258	8.9	7.1	1
1999	12 982	75	D	12 361	3.7	1.6	32 008	8.2	-1.1	2
2000	12 700	93	Dry+	12 434	3.9	7.1	32 144	8.6	3.3	1
2001	22 228	42	N	12 289	3.5	-3.8	32 101	8.5	1.9	2
2002	22 076	64	N	12 353	3.7	1.0	32 178	8.7	4.4	1
2003	22 151	53	N	12 391	3.8	3.9	32 222	8.8	5.9	1
2004	12 929	80	Dry	12 345	3.7	0.4	32 069	8.4	0.9	2
2005	12 951	78	Dry	12 404	3.8	4.8	32 200	8.8	5.2	1
2006	22 548	6	Wet+	12 367	3.7	2.1	32 293	9.0	8.2	1
2007	22 099	61	N	12 335	3.7	-0.3	32 119	8.5	2.5	2
2008	22 432	15	Wet	12 347	3.7	0.6	32 020	8.3	-0.7	2
2009	12 808	88	Dry	12 343	3.7	0.3	32 087	8.5	1.5	2
2010	22 581	4	Wet+	12 250	3.4	-6.7	32 161	8.7	3.9	1
2011	22 443	13	Wet	12 343	3.7	0.3	32 065	8.4	0.7	2
Avg	22 146			12 339	3.7	-2.3	32 043	8.3	-5.8	2.1
Stdev	286			43	0.1		149			1.1

Abbreviations: Tot=total; Avg=average rainfall; ETo=reference evapotranspiration; GDD and temperature stress affecting biomass production (T_{stress})
* With indication of the standard variation (Stdev), variation (Var) from one year to another and, for rainfall, the probability of exceedance (Pex) and type of year (Table 21)

Soil physical characteristics

Timbilil soils are deep dusky-red to red friable clays with no obvious horizon beyond 3 m. Since water logging and surface run-off occur only very rarely on the estate, very good drainage characteristics can be assumed. The characteristics of the soil profile are presented in Table 23.

3.2 Observed tea yield at Timbilil Estate

The tea crop at Timbilil Tea Estate is pruned every four years. The pruning activity consists of so-called lung-pruning, which leaves approximately 25 percent of the bush intact. As such, the tea output is guaranteed from the first year of its four-year cycle. The simulated relative tea yield, in terms of tea-crop characteristics (Table 20(a) and Table 21 (b, and c)) and in the absence of water or temperature stress, is plotted in Figure 60 for the years between prunings.

The climatic data analysis (section 3.1.1) indicates that cold stress will hamper tea output. In Table 24, the mean monthly cold stress for biomass (Ksb) is presented for each month. With reference to the biomass production in March, the relative monthly biomass production was calculated and plotted in Figure 61.

Tea output (i) from experimental fields with the commercial high-yielding clone TRFK 31/8, and (ii) from smallholder fields are available for several years (Table 25). When evaluating the simulated tea output data, however, some years were excluded due to weakness or poor quality:

i. By comparing the observed tea yield in the experimental field with the tea yield in the farm fields (the major part of the estate), the following can be concluded:
   - tea yield for 1997 was rather high, although it was a normal year; and
   - tea yield for 2010 was far too low, since it was a very wet year; however, it was the best yield for the 30-year period.

ii. Fertilizers are applied once a year in August/September at 150 kg N/ha. Due to high fertilizer prices and logistics, however, fertilizers were only applied in 2002 at the same rate, although in the three subsequent years (2003, 2004 and 2005), none was applied. The tea plantation survived on residual and

Table 25 Clay loam soil characteristics (*ClLoamKericho.Sol soil profile file*)

Soil physical characteristic	Value
Soil water content at soil saturation (θ_{SAT})	50 vol %
Soil water content at field capacity (θ_{FC})	39 vol %
Soil water content at permanent wilting point (θ_{PWP})	23 vol %
Total Available soil water (TAW)	160 mm/m
Saturated hydraulic conductivity	500 mm/day
tau (τ) drainage coefficient	0.76

Figure 60 Simulated relative tea yield for the years between pruning in the absence of water and temperature stress

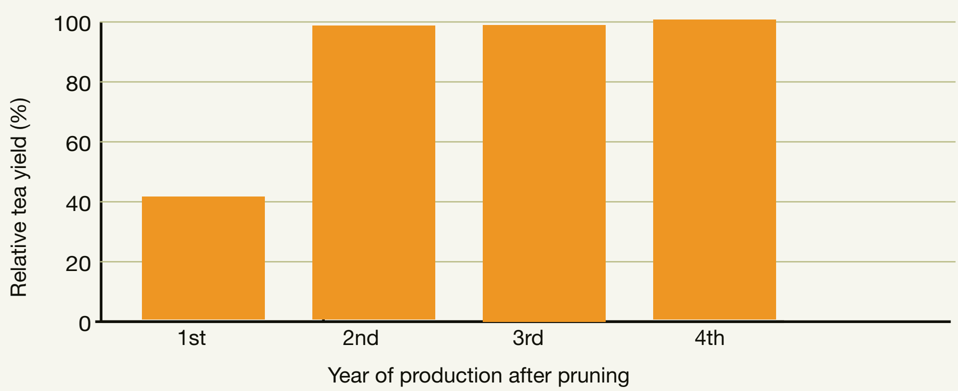


Figure 61 Relative mean monthly biomass production with reference to production in March (reference) in the absence of water stress

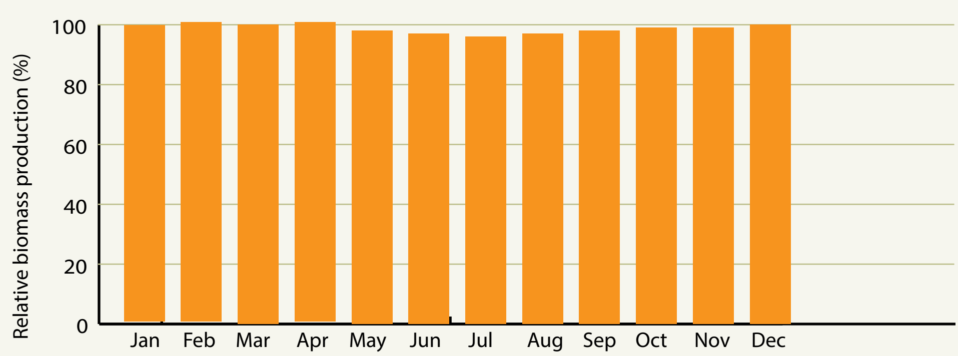


Table 26 Mean monthly cold stress and corresponding relative biomass production in the absence of water (in percent)

Month	1	2	3	4	5	6	7	8	9	10	11	12
Stress	1.5	0.8	0.5	1.2	2.1	3.1	5.6	3.9	2.4	1.7	1.8	1.4
Brel	99.0	99.7	100	99.4	98.4	97.4	94.9	96.6	98.1	98.9	98.7	99.2

NB. Reference point is March

Table 27 Observed tea yield in the experimental and farm fields (farm) for various years

Year	Exp[1]	Pr[2]	Farm	Type of year	Observations
	Kg/ha		kg/ha		
1985			1 620	N	Clonal tea not yet predominant
1986			1 690	Dry+	Clonal tea not yet predominant
1987				N	Clonal tea not yet predominant
1988				Wet	Clonal tea not yet predominant
1989				Wet	Clonal tea not yet predominant
1990				N	Clonal tea not yet predominant
1991				N	Clonal tea not yet predominant
1992	2 101	Yes	1 890	N	
1993	4 793		2 680	Dry+	
1994	4 835		2 270	Wet+	
1995	4 942		2 300	N	
1996	3 575	Yes	2 950	Dry	
1997	5 599		2 230	N	
1998	6 042		3 330	N	
1999	4 627		2 520	D	
2000	2 668	Yes	2 030	Dry+	
2001	4 943		2 810	N	
2002	4 250		2 230	N	Start of shortage of fertilizers
2003	3 095		1 780	N	Shortage of fertilizers
2004	3 301		3 040	Dry	Shortage of fertilizers
2005	4 263		3 060	Dry	Shortage of fertilizers
2006	4 355		2 680	Wet+	End of shorgage of fertilizers
2007	5 773		3 150	N	
2008	2 350	Yes	1 620	Wet	Problem in labour dynamics in farmers fields
2009	2 495		2 270	Dry	
2010	3 965		3 330	Wet+	Too low yield in experimental field
2011	792		2 700	Wet+	
Average	**4 072**		**2 604**		**Average of selected years**

[1] Experimental
[2] Indicates year of pruning (Pr) in experimental fields, type of year and rainfall for year (described in Table 21) and observations on quality of data

native N during this period. Fertilizer application resumed in 2006. The soil fertility stress, therefore, may have affected the tea yield from 2002 to 2006;

iii. Simulations are likely to overestimate tea production since, in the 1980s, a significant amount of seedling tea (with a lower Harvest Index than clonal tea) was still cultivated in Kenya. The period from 1985 to 1991, therefore, was disregarded.

iv. In 2008, labour dynamics proved to be a problem and due to under-plucking, output was low with regard to the farm fields.

3.3 Simulated tea yield in experimental fields (calibration)

Tea production for the commercial high-yielding clone TRFK 31/8 without soil fertility stress (fertilizer rate of 150 kgN/ha) was simulated and compared with observed data for 20 years (January 1992–December 2011). The simulations were made for the five successive cycles of the four-year pruning cycle.

Input data and files for AquaCrop

Climatic file: file Timbilil30.CLI

Crop file: file TeaCalib.CRO. The specified crop characteristics for tea are provided in Table 20.

Planting date: Pruning is done in January. When selecting 1st January as the start of the growing cycle (i.e. regrowth subsequent to pruning), the comparison between the simulated output (when the four-year pruning cycle is aggregated year by year) and real output is straightforward.

No Irrigation file is selected: Rainfed agriculture, excluding irrigation, is assumed.

No Field file is selected: Field conditions are standard and are free of fertility stress, mulch to reduce evaporation, field surface practices to reduce surface runoff, pests and diseases, weed infestation.

Soil Profile file: file ClLoamKericho.SOL. The physical soil characteristics relating to the soil profile are demonstrated in Table 22.

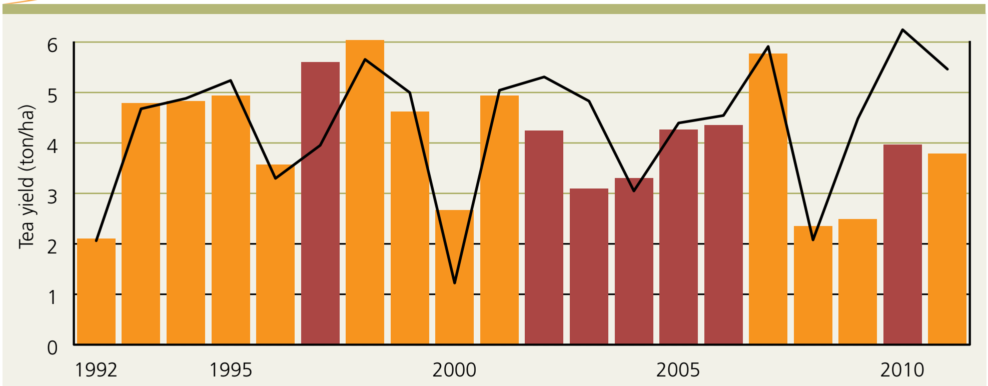
No Groundwater file is selected: The groundwater Table is assumed to be more than 4 m below the root zone.

No Initial conditions file is selected: The soil water content at the start of the simulation is set at Field Capacity (default), since rainfall is likely to exceed the crop ETo after pruning. At the start of each year, the soil water content at the end of the previous year was taken into account as the initial soil water content.

Discussion of the results

Simulated and observed tea yields are plotted in Figure 62.

Figure 62 Simulated (line) versus observed (bars) tea yield for TRFK31/8 at 150 kgN/ha



NB. The light bars are the years that were excluded from the analysis (Table 25).

Table 28 Simulated and observed tea production in the experimental fields

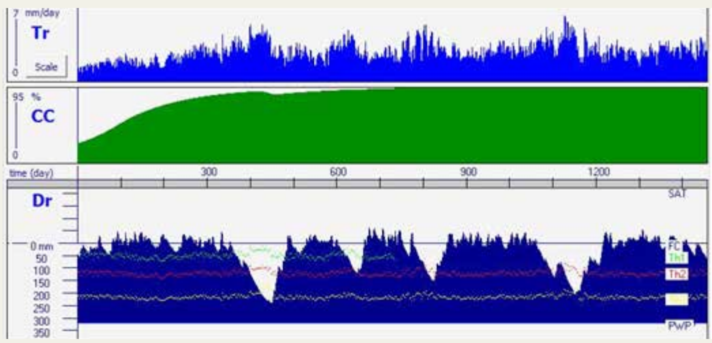
Year	Type year	Observed tea yield kg/ha	Simulated tea yield kg/ha	Difference %
1992	N	2 101	2 401	14.3
1993	Dry+	4 793	5 293	10.4
1994	Wet+	4 835	4 742	-1.9
1995	N	4 942	4 966	0.5
1996	Dry	3 575	2 378	-33.5
1998	N	6 042	5 407	-10.5
1999	Dry	4 627	4 808	3.9
2000	Dry+	2 668	2 311	-13.4
2001	N	4 943	5 680	14.9
2007	N	5 773	5 707	-1.1
2008	Wet	2 350	2 578	9.7
2009	Dry	2 495	4 812	92.9
2011	Wet	3 792	5 344	40.9
Average		**4 072**	**4 341**	**9.8**

Although it is obvious that the observed data contain some errors (Table 25), the dataset, nevertheless, was used to fine-tune the crop parametres. The average simulated tea yield was 4.3 ton/ha, which compared well with that observed for 4.1 ton/ha (Table 26). Seventy-seven percent of this period, representing the difference between simulated and observed yield, is less than 15 percent. For the remaining years, AquaCrop captured the trends, but these either over- or underestimated the tea yield. Given the poor quality of the data, statistics of goodness of fit were not calculated.

The simulations described some of the effects of drought on canopy cover and tea yield:

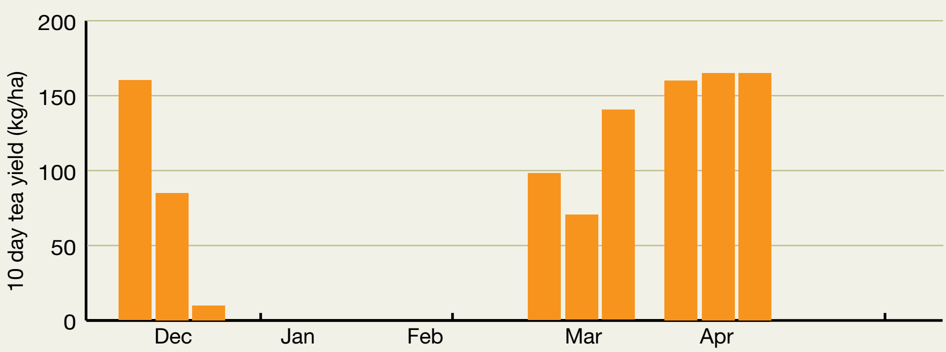
- periods of severe stress result in some decrease in the canopy cover (Figure 63). Severe water stress can cause the leaves to turn brown.
- if the water stress is mild, the size of the leaf reduces and less tea is produced as a result (Equation 2). On the other hand, if the water stress is significant and affects the leaves in the same way, the tea output is further reduced or can be nil over several weeks (Figure 64).

Figure 63 Simulated crop transpiration, canopy cover and root zone depletion*



Abbreviations: Tr=transformation; CC-canopy cover; Dr=root zone depletion
* January 1996 (pruning) to 31 December 1999 (end of fourth year, prior to next pruning

Figure 64 Simulated ten-day tea yield affected by water stress*



* First decade of 2005 (December) to third decade of 2006 (April).

3.4 Simulating tea yield in farmers' fields (validation)

Tea output was simulated for the smallholder fields on Timbilil Tea Estate and was compared with data over a period of 30 years (January 1982–December 2011). The simulations were carried out for a clone with a somewhat lower Harvest Index (12 percent instead of 15 percent) and with the typical four-year pruning cycle. The pruning activity consists of lung-pruning, which leaves approximately 25 percent of the bush intact. The non-perfect uniformity of the tea canopy cover and the corresponding occurrence of weeds were taken into account.

Input data and files for AquaCrop

Climatic file: file Timbilil30.CLI.

Crop file: file TeaTKDA.CRO. Calibrated crop characteristics for tea, presented in Table 20 (TeaCali.CRO). To consider the tea characteristics in farm fields, the following adjustments were made:

- Harvest Index was lowered from 14 to 10 percent (lower yielding varieties).
- CCx was lowered from 95 to 70 percent, since the tea canopy is not very uniform in the fields.

Planting date: Since pruning is carried out in January, the first day of the month was selected as the start of the growing cycle (i.e. regrowth after pruning). Since farmers do not prune all bushes in the same year, four simulations were made for each year. The first assumed that the crop was pruned that particular year (Year 1), and in the three successive simulations, it was assumed that the crop was either in its first (Year 2), second (Year 3) or third year (Year 4) after pruning. The resulting simulated yield for each year is, therefore, the average of the four simulations for each year.

No *Irrigation file* is selected: Rainfed agriculture, excluding irrigation, is assumed.

Field Management file: Field conditions are standard and free of fertility stress; mulch to reduce evaporation; field surface practices to reduce surface runoff; pests and diseases; weed infestation.

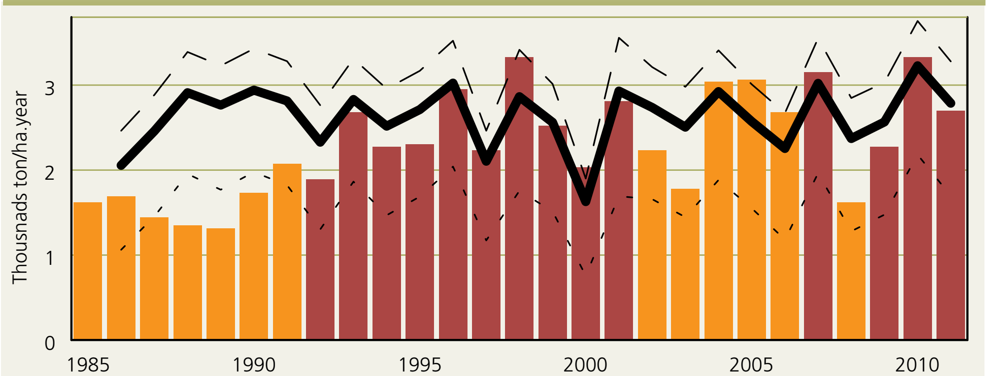
Soil profile file: file ClLoamKericho.SOL. Soil characteristics are listed in Table 22. No *Groundwater file* is selected: Groundwater Table is assumed to be more than 4 m below the root zone.

No *Initial conditions file* is selected: Soil water content at the start of each four-year cycle is assumed to be at Field Capacity.

Results and discussion

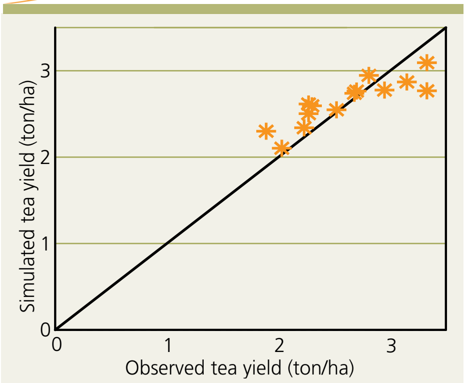
The simulated and observed yields are plotted in Figures 65 and 66 and presented in Table 29. Statistics of goodness of fit are presented in Table 30.

Figure 65 Simulated (lines) versus observed (bars) in terms of tea yield at Timbilil Tea Estate[1,2]



[1] By considering a maximum canopy cover of only 70 percent and a Harvest Index of 10 percent.
[2] The light bars refer to years excluded from the analysis. The dotted lines are the tea yields for the Years 1 and 3 of the four-year crop cycle between prunings.

Figure 66 Simulated versus observed tea yield



* First decade of 2005 (December) to third decade of 2006 (April).

Since the simulated tea output is an average of the four-year crop cycles between prunings, the yearly variation is slightly adjusted. This is mainly due to the effect of the pruning year (Year 1). Given that the canopy cover was recovering from the pruning that particular year, the rainfall was almost sufficient to cover the relative low crop water requirement and, thus, the tea yield was hardly affected by water stress. The yield in Year 1, therefore, was almost constant (averaging 1 500 kg/ha), with a standard deviation of only 68 kg/ha (Figure 65 and Table 29). In Years 2, 3 and 4, the canopy cover was fully grown and the crop water requirements were approximately 60 percent higher than in Year 1. Consequently, output was considerably affected by water stress and the simulated yearly variance more or less paralleled the variances in the observations.

3.5 Expected impact of climate change on tea yield

It is expected that in future years, due to climate change, the following will occur:

- the CO_2 concentration will rise significantly. Depending on the selected scenario, the concentration of 500 parts per million (ppm) will occur

Table 29 Simulated and observed tea production in fields

Year	Type year	Observed tea yield kg/ha	Simulated tea yield kg/ha			Difference between observed and simulated %
			1st yr	3rd yr	Average	
1992	N	1 890	1 491	2 586	2 300	21.7
1993	Dry+	2 680	1 471	3 186	2 739	2.2
1994	Wet+	2 270	1 486	2 859	2 503	10.3
1995	N	2 300	1 473	2 986	2 594	12.8
1996	Dry	2 950	1 475	3 235	2 776	-5.9
1997	N	2 230	1 411	2 683	2 340	4.9
1998	N	3 330	1 505	3 218	2 768	-16.9
1999	Dry	2 520	1 538	2 902	2 548	1.1
2000	Dry+	2 030	1 443	2 347	2 103	3.6
2001	N	2 810	1 561	3 440	2 946	4.8
2007	N	3 150	1 449	3 365	2 870	-8.9
2009	Dry	2 270	1 603	2 970	2 615	15.2
2010	Wet+	3 330	1 641	3 610	3 093	-7.1
2011	Wet	2 700	1 598	3 174	2 765	2.4
Average		**2 604**	**1 510**	**3 040**	**2 640**	**2.9**
Std. Dev		**467**	**68**	**348**	**268**	

in approximately 2042 (A1B and A2 scenario), 2059 (B2 scenario) or 2056 (B1 scenario)[1]. This will result in an increase of the biomass water productivity (WP*) from 13.8 g/m2 (in 2012) to about 16.5 g/m2 (in approximately 2050).

- air temperature will rise, which will reduce the cold stress affecting biomass production (Table 24);
- rainfall will increase. By assuming that rainfall will remain well distributed, water stress on tea output will likely be reduced.

Due to CO_2 fertilization, the increase of WP* will increase biomass output by approximately 20 percent and the output will rise by the same. Given that air temperature and water stress may be milder in future years, tea output at Timbilil Tea Estate could rise to an estimated 25 percent by 2050.

[1] Several carbon cycle models for projecting atmospheric CO_2 concentrations are available and used by IPCC. The various models consider responses of the carbonate chemistry of terrestrial and ocean components. Various simulated atmospheric CO_2 concentrations for various story lines are available. The A2, A1B, B2 and B1 storylines describe the future world, but differ due to dissimilarity in the assumed speed of economic growth; the moment of peak and decline of global population; the introduction of new and more efficient technologies; the changes in economic structures toward a service; and information economy, among others.

Table 30 Statistical indicators of the goodness of fit

Statistical indicator	Value	Observation
R^2	0.76	Values greater than 0.50 are considered acceptable.
RMSE	261 kg/ha	Summary of the mean difference in simulated and observed.
NRMSE	10.0 %	Simulation can be considered excellent if NRMSE is smaller than 10%.
EF	0.66	An EF of 1 indicates a perfect match between the model and the observations; an EF of 0 means that the model predictions are as accurate as the average of the observed data.
d	0.85	0 indicating no agreement and 1 indicating a perfect agreement between the predicted and observed data. This statistical indicator overcomes the insensitivity of R^2 and EF to systematic over- or underestimations by the model.

Abbreviations: R2=Coefficient of determination; RMSE= Root Mean Square Error; NRMSE=Normalized Root Mean Square Error; EF= Nash-Sutcliffe model efficiency; d=Willmott's index of agreement

Coefficient of determination R^2	$r^2 = \left[\frac{\sum(O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum(O_i - \bar{O})^2 \sum(P_i - \bar{P})^2}} \right]^2$
Root mean square error (RMSE)	$RMSE = \sqrt{\frac{\sum(P_i - O_i)^2}{n}}$
Normalized RMSE (NRMSE)	$NRMSE = \frac{1}{\bar{O}} \sqrt{\frac{\sum(P_i - O_i)^2}{n}} \, 100$
Nash-Sutcliffe model efficiency (EF)	$EF = 1 - \frac{\sum(P_i - O_i)^2}{\sum(O_i - \bar{O})^2}$
Willmott's index of agreement (d)	$d = 1 - \frac{\sum(P_i - O_i)^2}{\sum(\lvert P_i - \bar{O} \rvert + \lvert O_i - \bar{O} \rvert)^2}$

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CHAPTER SEVEN

THE SOCIO-ECONOMIC EVALUATION OF CLIMATE CHANGE: IMPACT ON SMALLHOLDER TEA FARMERS

Paul Kiprono

1. Introduction

Kenya's economy relies heavily on agriculture to provide employment and reduce poverty. The agriculture sector represents 26 percent of GDP and 60 percent of Kenya's export revenue, indirectly contributing a further 27 percent to GDP through linkages with the manufacturing-, distribution- and service-related sectors. It accounts for 60 percent of national employment, with women representing 75 percent of the labour force. The majority of people in Kenya are poor (80 percent), live in rural areas and depend on agriculture for their livelihood (Republic of Kenya, 2004). Agriculture is critical to the country's economic development and its efforts to reduce poverty, given that 25 percent of the population is food insecure (Republic of Kenya, 2011).

According to Suri *et al*. (2008), almost 46 percent of Kenya's population lives in poverty. It relies, to a large extent, on climate-sensitive economic activities, including rainfed subsistence or smallholder agriculture. The latter is generally used to describe the rural family producers who farm the land themselves and for whom the farm provides a principal source of income. Smallholder farmers grow most of the country's maize, as well as significant quantities of potato, beans, peas, sorghum, cassava, banana, oilseeds, vegetables, tree fruit, among other foods. These farmers, however, face the challenge of increasing crop production while, at the same time, attempting to preserve natural resources that are vital to the sustainability of livelihoods and the reduction of poverty, especially within these fragile dry-land and semi-arid areas near the Great Rift Valley.

The tea sector in Kenya has an important influence on the socio-economic status of its rural households. The farmers in the country's tea growing areas depend on the income generated from tea production for their livelihoods. Tea is currently the leading cash crop in Kenya and significantly contributes to the economy. In 2012, the country produced 369 000 metric tonnes of processed tea, of which 340 000 metric tonnes were exported, representing KES 112 billion in foreign revenue. This represents approximately 27 percent of total export earnings and approximately 4 percent of GDP (TBK, 2012).

Society will usually seek to make use of existing resources, adapting to the natural environment. Likewise, changes in the environment will influence farmers to adapt accordingly; for example, by clearing forests and other natural vegetation in order to grow food and cash crops for their livelihood. This type of adaptation, however, brings a risk to the population and the economic output of a nation due to its various side effects, such as - floods, land erosion and storm surges. For example, erosion can occur when land has been cleared and replanted with fast-growing trees and crops that are especially adapted for specific soils and hydrological changes in the environment.

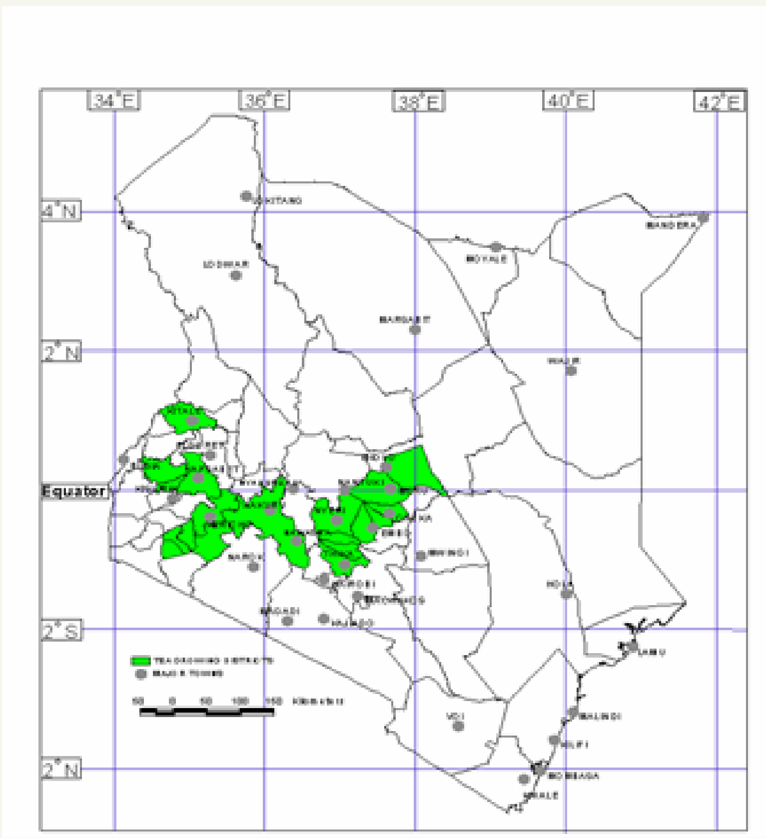
The dynamic interaction between humans and climate is a continuum. In the short term, a significant change in climate can positively or detrimentally impact the use of resources in any given area. Likewise, moving away from a traditional farming economy to a market economy can have an impact on society and the environment. When climate variation and rapid social change coincide, the outcomes can be profound.

2. Tea producers survey: Methodology

This study assesses the socio-economic impact of climate change on the smallholder tea farmers in Kenya. Figure 67 shows the two main tea growing areas in Kenya, in proximity of the Great Rift Valley which geographically divides the country into two regions from east to west.

A total of 700 smallholders were selected from 14 smallholder factory plantations on the eastern and western sides of the Great Rift Valley. Forty-two percent had no formal education and depended on the revenue they earned from the production of tea, mainly for food. In the face of the challenges of climate change, smallholder farmers indicated having applied adaptation strategies by combining tea with other income-generating activities. The study included four main questions for those surveyed:

Figure 67 Map of tea growing areas in Kenya



Source: TRFK, 2013

i. How does climate affect tea farmers and the economy in Kenya?
ii. What societal trends contribute to the vulnerability of Kenyan tea farmers in terms of climate change?
iii. What are the potential future socio-economic impacts of climate change on the Kenyan tea subsector?
iv. What alternatives are there for farming communities in Kenya to adapt to climate change?

The objectives of the study were to:

- assess tea farmers' vulnerability to climate change;
- measure the impact of climate change on the composition of farm businesses in the tea growing areas; and
- identify the most effective coping strategies/mechanisms for tea farmers.

The key parameters and indicators used in the farm survey are summarized in table 31 below.

Table 31 Survey parametres and data

Parametres	• baseline data of sex disaggregation on socio-economics; • patterns of resource use; • choice of crop enterprise and composition; • market opportunities; and • agricultural productivity in project's targeted communities.
Criteria for measuring and monitoring socio-economic status	• characteristics of agricultural production (e.g. farm size, land utilized for tea growing, tea production, number of farm enterprises owned, distribution of important crops, including tea grown) with respective gross margins; and • livelihood diversification indices, such as household involvement in non-farming activities and businesses.
Household characteristics	• distribution of members by gender; • size of household; • distribution of heads of household by age; • distribution of head of household by years of formal education; • distribution of heads of household by type of occupation; • structure of asset ownership; • marital status of heads of household; • type of land tenure; • size of tea farm plots; • type of crops grown; • quantity of crops produced; • crops that are no longer grown, and reasons why; • percent of crops produced that is sold by household; • estimate of gross margins from crops produced; • factors that determine profitable crop farming and the constraints; and • animal stock composition and constraints to profitable livestock farming.
Key variables	• household and interviewee identification; • individual records, including age, sex, occupation, educational achievement and relationship to head of household; • key agricultural enterprises by household; • key livestock activities by household; and • perception of head of households' view relating to climate change impacts.

Source: Study data, 2012

Sampling procedure and data collection

Sampling

The samples included 14 factory catchments from which data were collected, relating to smallholder tea farmers across the eastern and western slopes of the Great Rift Valley. The catchments are managed by KTDA and are grouped into seven regions. The assessment included one factory from each region, namely, Makomboki and Njunu in Murunga County, Ragati and Gathuthi in Nyeri County, Kimunye in Kirinyaga County, Rukuriri in Embu County, Githongo and Kiegoi in Meru County on the eastern side of the Great Rift valley and Kapset, Momul in Kericho County, Tombe in Nyamira County, Eberege in Kisii County, Chebut in Nandi County and Kapsara in Trans Nzoia County on the western side.

In order to provide a geographic spread of sample households and avoid bias in terms of data, the survey was redesigned to collect information from 50 randomly selected farmers within six electoral areas in each factory catchment. A transect walk was made to ensure that all areas within the factory catchment were fairly represented by the farmers. This resulted in a total of 700 smallholder farmers, from whose households the survey participants were drawn with their informed consent. To ensure a gender balance, the survey was designed so that 25 percent of all respondents represented women. The baseline data were obtained from the survey of households and the main instrument used for the data collection was a well-structured questionnaire, presented during face-to-face interviews undertaken by trained enumerators.

Statistical and budgetary analysis

The socio-economic analysis of households included such characteristics as the mean, standard deviation and frequency distribution. The evaluation of farm profitability, however, included a budgetary analysis of crop and livestock production activities by calculating the gross margin and return per Kenyan shilling of outlay. The monetary value of variable inputs and the miscellaneous production costs were then subtracted from the gross revenue, resulting in gross margin estimates for crop and livestock activities.

3. Results and discussions

3.1. Household characteristics

Head of household

Respondents represented 62.7 percent of men and 37.3 percent of women (Table 32), a characteristic of most rural households in Africa where the cash from crops, including coffee and cocoa, is earned by the man who also owns the land. Gender inequality is attributed to women's limited access to and control of resources; limited access to financial services, education and technology; cultural challenges; and other constraints that limit employment opportunities and prevent them from participating in their household's decision-making.

Table 32 Gender of head of household

Gender of head of household		
Gender	**Frequency**	**Percent**
Male	439	62.7
Female	261	37.3
Total	700	100.0
Relationship to Household		
Head	512	73.1
Spouse	144	20.6
Others	44	6.2
Total	**700**	**100.0**

Source: Survey data, 2012

The proportion of women to men in this survey represents the data collected relating to the sex of the head of households. This is illustrated in Figure 68, wherein 73.1 percent are men and 20.6 percent represent their spouse.

Table 33 demonstrates the mean age of household members living under the same roof. The mean age of the head of household was 46.6 years. The mean distribution of household members were: 11 for those below 5 years of age; 2 for 5-18; 2 for 19-35; 2 for 36-50; 1 for 51-64; and 1 for above 65 years of age. Most respondents had household members of pre-school age below 5 years, showing a significant dependency ratio.

Level of education of household

Education can be a significant indicator to determine the level of technology adoption and decision-making by farmers. Figure 69 demonstrates that 44 percent of respondents had completed primary level; 38 percent, secondary level; and 5 percent, college/tertiary level. The remaining 1 percent of respondents was rated as "Others". This implies that the farmers in the area under study were sufficiently literate to easily adopt new technologies. Their level of education significantly correlates with the level of technology adoption.

Occupation of the respondents

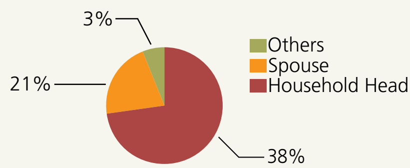
Most respondents were involved in agriculture (93.6 percent). Approximately 2.9 percent were salaried employees; 9.0 percent were in private business; 6.9 percent did casual labour; 2.0 percent were involved in artisan work; and 0.6 percent represented retirees. This indicates that most farmers involved in the study depend primarily on crop and animal husbandry as their principal source of income. The main cash crop is tea, with some farmers in the marginal areas growing coffee in addition to tea.

Table 33 Mean age of household members

	Mean household members			Mean household members - Age range					
Age of head of household	Male	Female	Total	< 5yrs	5-18 year	19-35 years	36-50 years	51-64 years	>65 years
Total: 47	**3**	**3**	**5**	**11**	**2**	**2**	**2**	**1**	**1**

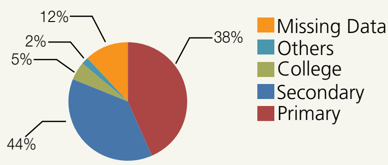
Source: Survey data, 2012

Figure 68 Category of respondents



Source: Survey data, 2012

Figure 69 Respondent's level of education



Source: Survey data, 2012

Livestock ownership

The tea growing areas of Kenya are located in regions that are conducive to high output, with excellent conditions for dairy produce and the rearing of other livestock. Table 34 provides a breakdown of average livestock numbers and the type of livestock owned by the farmers in the eastern and western regions of the Great Rift Valley. Approximately 81.1 percent of households depend on various forms of livestock, including sheep and poultry. On average, farmers on the eastern slopes own two dairy cows, producing an average of seven litres of milk per animal *per diem* and, likewise, two shoats (mainly goat) producing an average of two litres. Poultry is reared for eggs for local consumption. On the western side, the average number of livestock is three dairy cows, producing 8 litres of milk per cow *per diem*. Most families raise chickens for their own consumption, as well as for local sale.

Table 34 Average livestock size and output

Type of livestock	Great Rift Valley - East		Great Rift Valley - West	
	Number of animals	Daily unit of production	Number of animals	Daily unit of production
Dairy cows	2	7 litres of milk	8	8 litres of milk
Goats	2	2 litres of milk	2	1.6 litres of milk
Sheep	2	2 litres of milk	3	1 litres of milk
Poultry – egg layers	9	1 egg	10	1 egg
Poultry - broilers	10	6 sold per month	24	8 sold per month

Source: Survey data, 2012

Despite the western areas of the Great Rift Valley having larger sizes of land compared to the eastern region, there is no significant difference in the numbers of livestock and productivity, which suggests that the farmers in the west of the valley under utilize the land that is available to them. As ownership of livestock is a contributing factor to the vulnerability of households, as discussed previously, this study indicates that the livelihoods of farmers can be protected by owning livestock, especially during times of climate change events, such as frost, drought and hail, which can reduce the output of tea.

Other contributing factors of households

Those who were interviewed live in semi-permanent homesteads (Table 35). Only 28.3 percent of total households in the survey have access to electricity and 8.1 percent own a motor vehicle. Since rural homes in Kenya are not supplied with electricity by the government, households have to apply to Kenya's utility company for approval and connection. This assumes, therefore, that those households with electricity have a higher level of income from tea farming, compared to those that use other sources of power, such as kerosene lamps for lighting.

Households with piped water represented 41.6 percent of total homes. While water is primarily channelled to urban areas, more recently the Government of Kenya has made an attempt to support projects in rural areas, saving women the chore of fetching the water from the rivers and streams which tend to be a great distance from the homestead. The time saved has contributed to the operation of the farm, which mainly constitutes the picking of tea leaves and buds and delivering them to the distribution centres.

Table 35 Assets and commodities of households

Asset/commodity	Percent of ownership	
	Yes	No
	%	%
Land	99.0	1.0
Radio	94.0	6.0
Telephone(mobile)	91.4	8.6
Access to shelter	97.7	2.3
Access to health care	96.6	3.4
Electricity	28.3	71.7
Good road network	95.3	4.7
Piped water	41.6	58.4
Farm inputs	76.9	23.1
Motor vehicle	8.1	91.9

Source: Survey data, 2012

Households with access to farm inputs represented 76.9 percent, with KTDA supplying the farmers with fertilizers, although some inputs are purchased from agrochemical stores. Since farm inputs form a major component of productivity in the agriculture sector, the more there is access to farm inputs, the higher the productivity.

Table 36 illustrates the economic status of households in the study area. The data is based on the ability of a household to meet its expenses by using the available revenue from sources at the farm level. The average percentage represents households that have had to struggle less to meet their subsistence, whereas the above-average figure relates to those that

Table 36 Rating the economic status of household

	Percent
Below average	11.7
Average	81.3
Above average	4.4
No response	2.6
Total	**100.0**

Source: Survey data, 2012

Table 37 Household income level, based on expenses

	Frequency	Percent
Insufficient	127	18.1
Barely sufficient	384	54.9
Saving ability	165	23.6
No response	24	3.4
Total	**700**	**100.0**

Source: Survey data, 2012

have been able to save above subsistence. Most respondents (81.3 percent) rated their households as average; 11.7 percent, below average; and 4.4 percent, above average. No response was provided for the remaining 3.4 percent. The data imply that the monthly income of a majority of households is sufficient and includes food and medical expenses.

A household's ability to meet its subsistence requirements is set out in Table 37, based on available income from farm activities and expenses. Those homes that earn incomes barely sufficient to cover basic expenses total 54.9; those with insufficient income, 18.1 percent; and those able to save some income after expenses, 23.6 percent. This indicates that most households cannot put away any savings and their subsistence is barely covered by what they earn. Any interventions relating to climate change, therefore, need to be given careful consideration. The cost of mitigation can result in a low adoption of such interventions at the household level.

3.2. Land tenure, size, and income

A majority of farmers, who were interviewed, own their land. The average landholding is one ha on the eastern side and four ha on the western side of the Great Rift Valley.

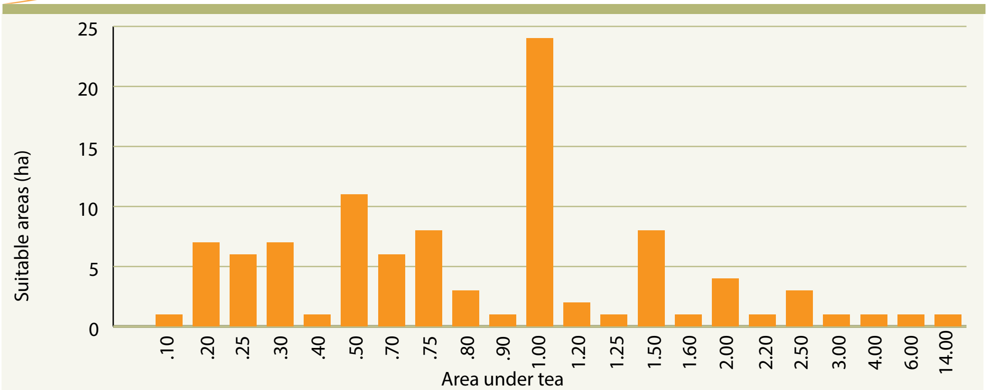
Land under tea plantation

In the east of the valley, tea growing represents 0.5 ha on each farm (50 percent of total landholding), although only 0.2 ha in the western area (8 percent of landholding). This implies that the socio-economic value of tea as a cash crop significantly differs between farmers in either direction of the valley.

Figure 70 shows that the average size of land in the west of the valley varies considerably, ranging from as low as 0.05 ha to 6.4 ha, with a mean of 0.22 ha and a δ of 0.72. On the other hand, the average land under tea in the eastern region (Figure 71) ranges from 0.11 ha to 2.0 ha, with a mean of 0.27 ha and a δ of 0.54.

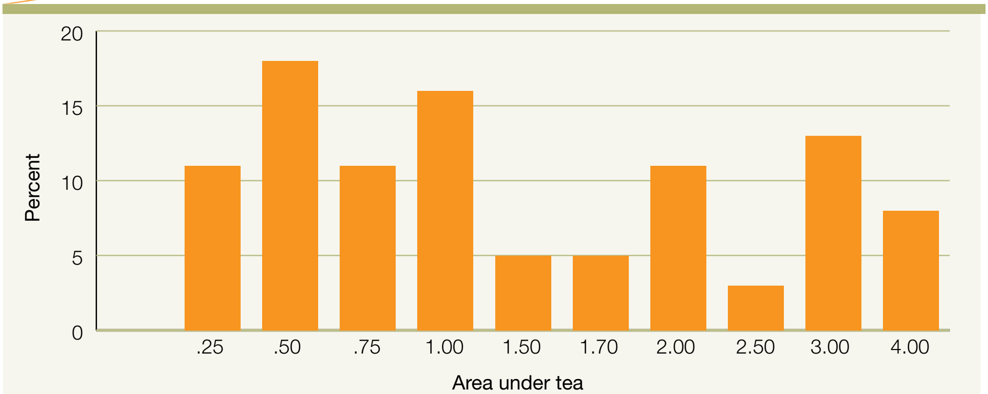
The mean number of years of experience relating to tea farming is 24.6 (Table 38). The number of tea bushes on a tea plantation averages 3 016, with an annual production of 3 402 kg *per annum*. The income from green leaf tea per kg, on average, is KES 34.20. There exists, however, a significant difference between

Figure 70 Percentage of land under tea in the west of the Great Rift Valley (in acres)



Source: Survey data, 2012

Figure 71 Percentage of land under tea in the west of the Great Rift Valley (in acres)



Source: Survey data, 2012

Table 38 Tea production among smallholder tea farmers

Average land size (acres)	11.9
Proportion of land under tea	3.2
Average tea bushes	3 016.3
Annual production (kg)	3 402.6
Average production per bush	1.13
Mean years in tea farming	24.57
Mean of 1st payment KES/kg GL	14.00
Mean of 2nd payment KES/kg GL	34.20
Mean NPK fertilizer applied/acre	7.84
Mean price per bag (50 kg)	2 551.96

Source: Survey data, 2012

the price of green leaf tea either direction of the valley, where it was KES 52.70 in the east and KES 39.80 in the west, indicating that farmers in the former area earn more from tea than do those in the latter.

The amount of fertilizer that is recommended for farms is 150 kg/ha of Nitrogen (N) *per annum* (Kamau *et al*., 2005). Farmers in the areas under study apply a mean of approximately 7.8 (50 kg) bags, an amount that approximates the recommendation. Table 39 shows a

Table 39 Mean estimate of annual income and expenditure of household (in KES)

	Estimated Annual Income	Estimated Annual Expenditure	Estimated Annual Savings
Average of the two regions			
	233,442.00	158 530.80	75 630
East of the Great Rift Valley			
	146,688.00	89 034.00	57 654
West of the Great Rift Valley			
	87,466.80	69 498.00	17 968.80

Source: Survey data, 2012

Table 40 Household income and expenditure for non-tea farmers in the study area (in KES)

Annual estimate of household	East of Great Rift Valley (12 percent)			West of Great Rift Valley (17 percent)		
	Min	**Max**	**Mean**	**Min**	**Max**	**Mean**
Income	4 800	240 000	55 812.70	6 000	360 000	86 742.10
Expenditure	4 800	180 000	59 599.90	120	153 600	39 231.00

Source: Survey data, 2012

mean annual income of KES 233 442 and an annual expenditure of tea farmers of KES 158 530.80.

Farmers involved in the production of tea have relatively higher incomes than those who are not (Table 40). On average, non-tea farmers in the western region have an annual income of KES 86 742 and on the western side, KES 55 812.70. While there is a significant difference between tea and non-tea farmers, those non-tea farmers with more land available to them for other income-generating activities in the west of the valley are able to earn more than those non-tea smallholders on the east side. The main sources of income are crops and livestock, and most of the economically active household members take part in these activities.

As seen from Table 40, there is little difference (KES 6 302.50) between the estimated monthly income (KES 19 453.50) of a household and its estimated monthly expenditure (KES 13 210.90). Farmers, on average, earn KES 19 456.50 per month - KES 2 778.65 per person. In US dollar terms (US$1=KES 85, November 2012), household expenditure is approximately US$155.40 per month. Divided by the average number of members within the household (seven), this becomes US$22.20 per month per person, a daily average of US$0.74 and averaging a monthly savings of US$74.14.

Types of agricultural practices

In addition to tea, farmers in the west of the valley tend to produce maize and banana, while those in the east produce maize, miraa, kale and banana. The gross margin for these marketable crops varies from region to region. Average total annual earning per acre of tea is KES 65 625 on the western side, reaching KES 143 794 in the east. The land size for maize also differs significantly between the two areas. The western side, which grows maize for market, averages approximately 1 ha, while the opposite side - where maize is grown primarily for household consumption - averages 0.2 ha. Nevertheless, the gross return for maize is higher on the eastern side (KES 28 175), compared with that of the other (KES 14 544).

Miraa is only found in the Kiegoi catchment on the eastern side of the valley. It is a major cash crop and, on average, farmers earn an annual income of KES 450 000 per ha, making it a key alternative to tea. Other crops that are grown include vegetables, sweet potato, banana and beans, which are mainly grown for household consumption. As climate conditions shift, the farmers east of the valley have a stronger base on which to plant a diversity of crops compared with those in the western area.

Mean annual income from alternative crop enterprises

Farmers west of the Great Rift Valley have different crop and livestock businesses from those on the eastern side. Table 41 shows the various income levels derived from the main crops in both regions.

The above table shows a comparison of total earnings from the five most lucrative farm enterprises in Kenya's two tea growing regions. East of the valley,

Table 41 Average income from various enterprises in the eastern and western areas of the Great Rift Valley

Enterprise	Area in acres	Total production	Price (in KES/kg)	Earnings (in KES)
East of the Great Rift Valley				
Tea	1.1	3 408.5 kg	52.00	177 242
Maize	0.9	22 bags	2 485/bag	54 670
Beans	0.5	1 bag	3 900/bag	3 900
Miraa	0.3	5 bags	10 000/bag	50 000
Tomato	0.1	12 crates	1 560/crate	18 720
Total				304 532
West of the Great Rift Valley				
Tea	0.8	2 863.6 kg	39/kg	111 680.40
Maize	1.1	7 bags	2 600/bag	18 200
Beans	0.5	4 bags	3 700/bag	14 800
Tomato	0.1	20 crates	1 600/crate	32 000
Cabbage	0.3	10 bags	1 500/bag	15 000
Total				191 680.40

Source: Survey data, 2012

the average gross return on 4.9 ha is KES 304 532, while on the western side, it is KES 191 532 on 4.8 ha.

The above reveals that there was a significant difference in farmer productivity between the two regions. The average annual production per bush, in relation to green leaf tea, is 1.57 kg on the eastern side of the valley and 0.8 kg on the western side. This may be due to the fact that farmers east of the valley have a greater value for tea, since it is the only crop which generates a higher income at the farm level. This may also be the reason why the proportion of tea plantations is greater in the eastern region compared with those on the western side.

3.3 Impact of climate change: vulnerability, awareness, adaptation

Earlier studies have shown that the adverse conditions of climate variability on the production of tea, such as drought and frost, can cause an annual green-leaf loss of up to 30 percent. The level of impact depends on the amount of tea produced. Farmers with less bushes/acreage will be more affected than those farmers with more tea per acre, while those with a higher proportion of land cultivated with tea will experience a higher loss. In this study, 47 percent of farmers in the east of the Great Rift Valley own less than 2 000 tea bushes compared to 56 percent on the western side. Since their average productivity differs, the average annual return for farmers in this category in the two regions is KES 163 208 and KES 62 400, respectively. A climate-induced tea production drop of 30 percent (as occurred in 2011) in the eastern region would result in an income loss of 48 960 kg. This would place 47 percent of households in the region, dependent on tea, below the poverty line (under US$1 per day per person). On the western side, a similar drop would have proportionately greater impact, given the low tea productivity and the higher output from the crop mix. A drop in earnings would place 56 percent of households below the poverty line. Table 42 shows the proportion of farmers west of the valley with different tea plantation acreages.

Tables 43 and 44 demonstrate the income loss (30 percent and 15 percent, respectively) that could occur for the tea farmers west of the valley, who have experienced two drops in output due to climate variability.

Table 42 Proportion of land under tea and expected income west of the Great Rift Valley

Proportion of land under tea	Percent of farmers	Average land size	Average yield (Kg GL/bush)	GL per acre (4 000 bushes)	Average price (KES/Kg GL)	Expected annual income from tea (KES)
0.3	51	9.7	0.8	3 200	39.80	370 617
0.5	36	9.7	0.8	3 200	39.80	619 696
0.9	13	9.7	0.8	3 200	39.80	1 054 541

Source: Survey data, 2012
Note: GL = green leaf

Table 43 Expected income loss resulting from 30 percent loss in output, due to climate variability, west of the Great Rift Valley

Proportion of land under tea	Percent of farmers	Average land size	Average yield (Kg GL/bush)	GL per acre (4 000 bushes)	Average price (KES/Kg GL)	Expected annual income from tea
0.3	51	9.7	0.8	2 240	39.80	259 432.30
0.5	36	9.7	0.8	2 240	39.80	432 387.20
0.9	13	9.7	0.8	2 240	39.80	778 297.00

Source: Survey data, 2012
Note: GL = green leaf

Table 44 Expected income loss resulting from 15 percent loss in output, due to climate variability, west of the Great Rift Valley

Proportion of land under tea	Percent of farmers	Average land size	Average yield (Kg GL/bush)	GL per acre (4 000 bushes)	Average price (KES/Kg GL)	Expected annual income from tea
0.3	51	9.7	0.8	2 730	39.80	316 183.10
0.5	36	9.7	0.8	2 730	39.80	526 971.90
0.9	13	9.7	0.8	2 730	39.80	948 549.40

Source: Survey data, 2012
Note: GL = green leaf

Table 45 Proportion of land under tea and expected return east of the Great Rift Valley

Proportion of land under tea	Percent of farmers	Average land size	Average yield (Kg GL/bush)	GL per acre (4 000 bushes)	Average price (KES/Kg GL)	Expected annual income from tea (KES)
0.3	18	2.3	1.57	6 280	52.70	228 359.60
0.5	38	2.3	1.57	6 280	52.70	380 599.40
0.9	43	2.3	1.57	6 280	52.70	685 078.90

Source: Survey data, 2012
Note: GL = green leaf

The farmers on the western side of the valley, who have 90 percent of their land cultivated with tea, will lose up to 30 percent of their crop as a result of climate variability - an annual loss of KES 276 244. Those with 50 percent of their land under tea will lose only KES 187 307 *per annum* (Table 44). The scenario in Table 45 shows a loss in returns, based on a 15-percent drop in yield on the eastern side of the valley.

East of the valley, 43 percent of farmers have 90 percent of their land under tea plantation; 38 percent of farmers, up to 50 percent; and 18 percent of farmers, 30 percent.

The analysis in Table 46 demonstrates that on the east side of the valley, a loss of up to 30 percent, resulting from adverse climate conditions, would affect 43 percent of farmers and 90 percent of the tea plantations - an annual loss of up to KES 205 523.90. The magnitude of this financial loss due to changes in weather patterns calls for the concerted effort of stakeholders to develop sustainable mitigation strategies.

Should the drop in output be 15 percent on the east side of the valley, due to climate variability, farmers (especially those with 90 percent of their land cultivated with tea) could experience a financial loss amounting to KES 102 761.90 *per annum*.

As shown in earlier studies (chapter 2, this report), the effects of climate change can lead to rising temperatures, which are more conducive to tea growing and can improve productivity by up to 30 percent. Tables 48 and 49 show the expected increase in income in both directions of the valley if this scenario were, in fact, to take place. The average increase in yield per bush, as a result of the rise in temperature, would be 0.471 kg with all other factors remaining constant.

Table 48 shows that if rising temperatures result in an increase in green leaf output of up to 30 percent, the return would be higher, since the gross margin would rise. A farmer with close to 1 ha of tea could expect a return of approximately KES 900 000 *per annum,* compared to his current annual average of KES 685 000.

Table 46 Expected income loss resulting from 30 percent loss in output, due to climate variability, east of the Great Rift Valley

Proportion of land under tea	Percent of farmers	Average land size	Average yield (Kg GL/bush)	GL per acre (4 000 bushes)	Average price (KES/Kg GL)	Expected annual income from tea (KES)
0.3	18	2.3	1.57	4 396	52.70	160 458.40
0.5	38	2.3	1.57	4 396	52.70	266 419.60
0.9	43	2.3	1.57	4 396	52.70	479 555.20

Source: Survey data, 2012
Note: GL = green leaf

Table 47 Expected income loss resulting from 15 percent loss in output, due to climate variability, east of Great Rift Valley

Proportion of land under tea	Percent of farmers	Average land size	Average yield (Kg GL/bush)	GL per acre (4 000 bushes)	Average price (KES/Kg GL)	Expected annual income from tea (KES)
0.3	18	2.3	1.57	5 338	52.70	194 105.70
0.5	38	2.3	1.57	5 338	52.70	323 509.50
0.9	43	2.3	1.57	5 338	52.70	582 317.00

Source: Survey data, 2012
Note: GL = green leaf

Table 48 Expected increase in income resulting from 30 percent increase in productivity, due to climate variability in the east of the Great Rift Valley

Proportion of land under tea	Percent of farmers	Average land size	Average yield (Kg GL/bush)	GL per acre (4 000 bushes)	Average price (KES/Kg GL)	Expected annual income from tea (KES)
0.3	18	2.3	2.041	6 280	52.70	296 867.50
0.5	38	2.3	2.041	6 280	52.70	494 779.20
0.9	43	2.3	2.041	6 280	52.70	890 602.60

Source: Survey data, 2012
Note: GL = green leaf

Table 49 Expected increase in income resulting from 30 percent increase in output, due to climate variability, west of the Great Rift Valley

Proportion of land under tea	Percent of farmers	Average land size	Average yield (Kg GL/bush)	GL per acre (4 000 bushes)	Average price (KES/Kg GL)	Expected annual income from tea (KES)
0.3	51	9.7	1.04	4 160	39.80	481 802.90
0.5	35	9.7	1.04	4 160	39.80	803 004.80
0.9	13	9.7	1.04	4 160	39.80	1 445 408.60

Source: Survey data, 2012
Note: GL = green leaf

The same scenario would apply west of the valley (Table 49) although, given the lower rate of productivity, the yield will not increase as much.

It is estimated that a farmer with 3 ha could experience an increase in output by up to 30 percent due to climate variability, thus resulting in an annual return of KES 1 445 408.60 compared to the current KES 1 054 541 *per annum*, all other factors remaining constant.

Climate change awareness

The awareness of farmers of the climatic change effects that have occurred over the last 50 years and the climate variation over this period are captured in Table 50. The most noticeable change indicated by the respondents has been the change in the rain and dry seasons, resulting in a modified planting season (43.1 percent) and incidents of frost (35.6 percent), followed by drought (34.6 percent). Other changes included hail (19.4 percent), frost (5.6 percent), cooler temperatures (28.1 percent), storms (16.6 percent), higher temperatures (12.0 percent), floods (5.1 percent), increased water surface temperature (13.9 percent) and climate-related land or mud slides (5.7 percent). From these responses, the three most critical changes experienced from climate variability have been drought, frost and a shift in the seasons.

Vulnerability to climate change

Based on the expected poverty framework, vulnerability is defined as the

Table 50 Type of climate hazards

	Experienced	Not experienced	Category
Climate hazards and impacts	%	%	
Storm	16.6	83.4	Low
Change in rainy and dry season, leading to change in planting season	43.1	56.9	High
Drought	34.6	65.4	High
Flood	5.1	94.8	Low
Climate related land or mud slide	5.7	94.2	Low
Increased water surface temperature	13.9	86.1	Low
Frost	35.6	64.4	High
Hotter climate	12.0	88.0	Low
Cooler climate	28.1	71.9	Medium
Hail	19.4	80.6	High

Source: Survey data, 2012

prospect of a person - who is not poor to begin with - becoming poor. It also relates to a continuation of poverty by someone who is poor (Christiansen and Subbarao, 2004). Vulnerability, therefore, is seen as expected poverty and consumption (income) is used as a proxy for well-being. This method is based on an estimate of the probability that a given shock or set of shocks will move consumption by households to below a given minimum level (e.g. consumption poverty line) or force the consumption level to remain below the given minimum requirement, if it is already below that level (Chaudhuri *et al.*, 2002; Tesliuc and Lindert 2002).

Climate change adaptations

Many climate change studies indicate that the adverse impact of climate will alter the outcomes of farming. Nevertheless, the adaptation strategies of farmers are likely to alleviate the potentially damaging effect of global warming. Smit *et al*. (2000) review several adaptation definitions, which imply that adapation refers to any societal or structural adjustment to reduce the adverse effects of climate change. According to IPCC (2001; p.6), “Adaptation has the potential to reduce adverse impacts of climate change and to enhance beneficial impacts, but will incur costs and will not prevent all damages”.

Table 51 lists the vulnerability indicators used to evaluate the impacts of climate change at the household level. Adaptation measures are commonly categorized according to their level of implementation. Farm-level adaptations consist of changes in crop selection and the agronomic practices of farmers. Regional, national and international adaptations involve adjustments to trade and the modification of public policy by government and/or relevant

Table 51 Vulnerability indicators, units of measurement and expected direction with respect to vulnerability

Determinants of vulnerability	Vulnerability Indicators	Description of each indicator selected for analysis	Unit of measurement	Hypothesized functional relationship between indicator and vulnerability
Adaptive capacity	Wealth	livestock ownership ownership of radio quality of residential home non-agricultural income gift and remittance	Percent of total population who own or have access	The higher the percent of total population with asset ownership and access to these income sources, the less their vulnerability
	Infrastructure and institutions	all-weather roads health services telephone services (landline) primary and secondary schools veterinary services food market microfinance	Percent of total population within 1–4 km of these infrastructures and institutions.	The higher the percent of total population of the region within 1–4 km, the less their vulnerability
	Irrigation potential	Irrigation potential	Percent of potential irrigable land (irrigable land divided by total area)	The higher the irrigation potential, the less their vulnerability
	Literacy rate	Literacy rate, age 10 years and older	Percent of total population	The higher the literacy rate, the less their vulnerability.
Exposure	Extreme climate	Frequency of droughts and floods	Number of occurrences (droughts and floods in different parts of the region)	The higher the frequency, the more their vulnerability.

Source: Deressa and Hassen, 2008

institutions. In this particular study, the principal climatic issues were frost and drought, rated high by respondents, although their severity ranged from low to medium.

Farm level adaptation

The capacity for adaptation is synonymous with the ability of a system to adjust to actual or expected climate stress or to cope with the consequence of the stress. According to IPCC (2001), the main features that determine a community or region's adaptive capacity include economic wealth, technology, information and skills, infrastructure, institutions and equity.

The direct impact of climate on sustainable livelihoods compels farmers to adopt new practices and coping strategies to respond to the altered conditions. Farms and rural households adapt in various ways to reduce the impact of climate variation on crop yields, farm profits and household incomes.

In order to adapt to climate change and lessen the impact, farmers do so by modifying the group of crops they plant and their agricultural process. The feedback from this study includes irrigation technology (51 percent), tree planting and cultivation of alternative crop varieties that are tolerant to drought (13.2 percent), frost (8.7 percent) and pest and disease (8.7 percent). On the other hand, 18.4 percent of respondent farmers currently do not have any adaptation measures in place.

Crop selection

Literature indicates that the selection of crops, made by farmers, would not be affected by climate change. The studies that assume that the set of crops under cultivation will remain unchanged in the future - despite reduced yields as a result of climate change - are likely to overestimate the damage or underestimate the benefits. It is widely acknowledged, however, that the impact of climate change can be lessened by adopting more suitable crops. To maximize profit, farmers should select the crops that best suit the climate at the time. They can alter the mix by either selecting better suited varieties of the current ones that they cultivate or by growing other types.

Some farmers in this study had planted mixed clones of tea to address the climate variability; others had planted drought-tolerant crops, such as sorghum and millet. East of the Great Rift Valley, it was evident that smallholders had begun to plant varieties of maize that mature faster in the tea and coffee transition areas, while banana and beans - originally grown in the lowlands of the coffee zones - are being planted in the higher altitudes that had been more suited to tea.

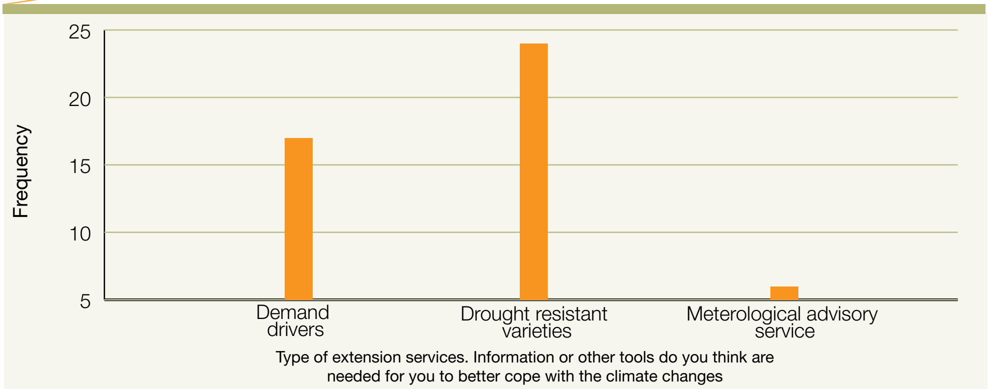
West of the valley, farmers have introduced the H600 series of maize variety in regions that were previously cooler and where maize has been grown. In some areas of the Kisii highlands, farmers now grow pineapple, a crop that used to grow in the warmer fields of Tombe and the lower farmlands of Kericho (e.g. Roret in Bureti District).

Cultivar selection

Different crop hybrids and cultivars can be used to achieve higher yields under changing climate conditions. The characteristics of cultivars that may be suitable to warmer climates include late maturing, heat resistance and pest and disease tolerance. The introduction of high-yield, late-maturing hybrid varieties of crops may be considered when the growing season is expected to be longer. From the survey, it was found that 72.5 percent of farmers on the east side of the valley and 38 percent on the west side diversify their crop in order to mitigate the negative impacts of climate change. Drought-tolerant cultivars are planted by farmers on both sides of the valley (2.7 percent in the east and 8 percent in the west) as a means to mitigate the impacts.

Although occurring only in a few parts of these valley regions, the incidence and intensity of frost is increasing. Farmers (2.7 percent) on the eastern farms

Figure 72 Types of extension services needed to better cope with climate change



Source: Survey data, 2012

plant cultivars that are more tolerant of frost, while 6 percent in the western areas do so.

Coping strategies and resilience

It was found that farmers lack adequate knowledge relating to climate change and the impact it has on their farming activities. This was evident from some of the coping strategies and adaptation measures, which appeared on the basis of trial and error. The early warning of extreme climatic events, such as drought, would alert farmers to sell their livestock and prepare to buy adequate supplies of food and other necessary items. Failing this, farmers would experience a reduction or loss of their livestock which, otherwise, could have been used as protection from adverse weather patterns. The study further revealed that although damage from the incidence of frost and the frequency of hail was rated high (50 percent), their severity was rated as low to medium. The coping strategies of respondents include irrigation technology (16 percent), tree planting (12 percent), shelterbelts and crop diversification (58 percent). Productivity in the area is dependent on the coping strategies implemented.

The absence of clear, long-term adaptation strategies and short-term adjustments to climate change issues suggests that smallholder farmers in the tea regions of Kenya may not be as resilient as expected. Little, if any, coping strategies have been developed or adopted to deal with the environmental changes experienced. For example, the occurrence in 1998 of severe frost compelled some farmers to plant trees as a windbreak to protect their tea farms. This sort of adjustment would assure a good harvest.

The fact that there should be more in-depth research with regard to plants with greater tolerance to drought was reflected by 50 percent of the respondents. TRFK, funded by tea industry stakeholders and the Government of Kenya, continues to provide information to and innovative ideas for the tea industry. The development of clonal types of tea has been a major breakthrough that will improve the quality and quantity of tea output in Kenya. The analysis has revealed that 37.5 percent of tea farmers have demanded that more information be provided to them, while 12.5 percent considered that there was insufficient meteorological information to enable them to increase their output of tea. They felt that there should be a direct link between the tea farmers and the meteorological service. It was evident that most farmers were knowledgeable about climate change, in general, but were unable to understand the implications and resolutions. This lack of information creates significant uncertainty for tea farmers.

4. Findings and conclusions

Kenya, like most developing countries, depends heavily on agriculture. The effects on the agriculture sector from global warming and climate change are likely to threaten the welfare of Kenya's population, as well as Kenya's economic development. This gives ground for the issuance of prudent agricultural policies to enable farmers to adapt successfully to climate change in order to protect their crops and livestock yields from the changes in temperature and precipitation and the frequency and severity of extreme events, such as drought and frost. Kenya, in addition, suffers from socio-economic challenges, a poor institutional framework and inadequate infrastructure. The inadequate support for research with regard to climate change and the lack of timely information limit the capacity of farmers to adapt to climate variations and the consequences. It is too costly for farmers to adjust their crop varieties/clones, introduce irrigation or modify farm management methods, all of which depend on capital investment. In addition, it will also take some time before the benefits of drought-resistant crops are seen. As a result, there will be lower crop and tea outputs.

The projected change in the annual distribution of rainfall may pose a greater threat to the livelihoods of the rural population. Neither climate change nor its impact can be reversed; therefore, the risks that could occur during the hiatus for clear information and data are real. As climate variability evolves beyond its natural bounds, the potential for further 'surprises and unanticipated rapid changes' is considerable. The delay by government and society to address the issues may increase not only the rate and magnitude of damage from the impacts of climate change, but also the cost relating to adaptation and repair. The inability to predict climate events with sufficient skill in a timely manner has resulted in a lack of risk management policies.

The results of this study indicate that the smallholder farmers in the tea areas of the western and eastern areas of the Great Rift Valley have not been excluded from the threat of climate change. In fact, the effects of changing weather patterns are already working against Kenya's tea industry in terms of output. In an effort to assist the farmers in tackling the most challenging consequences, the following recommendation is put forward: farmers should be encouraged to adopt irrigation technologies and plant trees and drought-resistant crops as adaptation strategies.

The socio-economic and environmental factors of each region of the tea growing areas of the Great Rift Valley were included in this study to effectively assess the vulnerability of smallholder tea farmers in the face of climate change. The indicator approach was adopted to combine both factors. This led to the farm-level indicators to measure the impact of climate change on farm operations. It also provided a means to evaluate the response of farmers regarding new technology in terms of their adaptation strategies, taking into account the socio-economic factors, including wealth, literacy rate, and the level of adoption of recommended technologies, institutions and infrastructure. The environmental factors included the potential for irrigation, frequency of climate extremes and future changes in temperature and rainfall.

Investing in irrigation in the regions where there is potential (e.g. on the eastern side of the valley surrounding Mount Kenya) could increase the country's tea production and food supply. By storing food, it can be sold during periods of drought and, therefore, reduce imports. Strengthening existing adaptation methods, such as water harvesting and other natural conservation programmes, at the micro-level, by the Government of Kenya and non-governmental organizations would boost the adaptive capacity of farmers.

Tea clones, which are resistant to drought, have been developed and tested by TRFK. Farmers should be encouraged to plant them in order to increase their output level and reduce the impact of climate change on their tea production. From the study, it is noted that farmers have adopted various measures to lessen the impacts on their farm operations and profitability. Farms that are in high-altitude areas are more likely to select crops that will do well in those areas, such as vegetables (including kale and cabbage) and, as these areas experience rising temperatures, lowland crops such as bananas and beans, are planted. Farmers in dry, lowland zones tend to pick drought-tolerant crop varieties. Crop switching, however, was not as evident, although it could be in the future as higher temperatures develop.

This report mainly focuses on the issue of climate change; however, climate soon may not be the only factor that alters. Other changes will occur that will most likely impact the perception of climate change at the farm level. These are population, technology and institutional frameworks. Future studies will need to include these issues to be able to provide clarity on the measures required to address the environmental impacts.

It is evident from this assessment that farmers have been able to adopt several adaptation strategies, which implies that these should be available to them. Relevant institutions, therefore, should develop farmer-based adaptation measures. As a policy issue, the Kenyan Government and its agencies, as well as relevant stakeholders, should prepare a group of adaptation options for the individual farmer, while simultaneously provide them with much needed knowledge through efficient public extension services. Drought- and frost-tolerant crop varieties should be developed and made available to farmers for use in the affected areas. Finally, stakeholders should lessen the effects of climatic variations on food output and farm incomes by putting mechanisms in place to promote societal adaptation.

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CHAPTER EIGHT

FOOD SECURITY AND NUTRITION IN THE CONTEXT OF CLIMATE CHANGE: A HOUSEHOLD ASSESSMENT OF TEA PRODUCING AREAS

Constance Ambasa

1. Summary

Climate change is real. It has significantly affected all sectors of the Kenyan economy, particularly that of agriculture, for which rainfall farming is depended on by the majority of small-scale farmers. Droughts and frost have become more frequent and intense in the tea producing areas of Kenya, reducing the yield. Since most smallholders plant their food crops in limited quantities, stakeholder livelihoods are well placed at the risk of nutrition implications if the effects of climate change make them vulnerable to food insecurity. Despite the fact that data on the impact of climate change on food security and nutrition in this sector is much needed for public policy intervention, it is very limited.

To this end, a study was undertaken to assess the magnitude of the effect of food security and nutrition on the households of tea farmers and relevant workers. Its scope included an analysis of the links between climate variability, food security, and nutrition status and an examination of (i) whether or not climate change has led to a change in the composition of food and crops; (ii) the status of health and nutrition outcomes in tea producing areas; and (iii) whether or not tea farmers and workers have adopted strategies to cope with and improve food security.

Conclusions from the study indicate that tea farmers, pickers and factory workers are prone to the effects of climate change because of their reliance on the tea sector for their income. From a survey that was undertaken during the study, a little over a half of the respondents (232, representing 57.1 percent) indicated that they were food secure and that there were no cases of severe undernourishment among children. Only 3.9 percent of children were somewhat undernourished, while 4.9 percent of women suffered from undernourishment. Most households (282, representing 69.5 percent) reported that they had a balanced diet, within which the majority consumed more than four food groups. Despite the effects of climate change, the income generated from tea has enabled families to access nutritious food from local markets, indicating that earnings play a significant role in improving household food security and nutrition. The study reveals that it is the woman who generally manages the family income and who freely spends it on food. It also establishes that new crops have appeared in some areas where it has become either cooler or warmer than it has been. Results also show changes in the quantity of food and its composition, sources and preparation practices.

The study further indicates that an increased access by women to land and resources, as well as an involvement in the decision-making process, would significantly improve food security and nutrition. While men were shown to be unwilling to lose their control over land and earnings from tea, respondents to the survey acknowledged, nevertheless, that women were better managers and preferred purchasing food to growing cash crops. Women, therefore, could have an impact on the improvement of food security and household nutrition.

The coping strategies in place are shown to be working well in relation to food insufficiency, but there are challenges which include the fragmentation of land and lack of markets for alternative livelihoods. The strategies can be improved

to ensure continued food security and a positive nutrition outcome in the tea producing areas of the country.

2. Introduction

By exacerbating the ability of people to access food, climate change could worsen food security and the nutrition status of households in Kenya. In this vein, a follow-up farm survey on food and nutrition provided an initial baseline that links the current business choice of crops and the responsibilities of household members with the status of household nutrition and the role of gender. This baseline is used not only to evaluate the likely impact of climate change and crop choice on food security and nutrition within the tea growing areas of Kenya, but it also fills the relevant knowledge gap that currently exists.

3. Study hypotheses

This study is based on the following hypotheses:

i. climate change has led to changes in the composition of food and crops within the households of tea farmers, pickers and factory workers in Kenya.
ii. increased access by women to resources, their use of these resources and an involvement in the decision-making process improves food security, health and nutrition outcomes in tea producing areas.
iii. tea farmers, pickers and factory workers - while challenging - have developed coping strategies, such as those that can alter livelihoods, to improve food security, health and nutrition in the face of climate change.

The following core questions were included in the farm survey to establish the baseline:

- to what extent do households in tea producing areas feed their families on a balanced diet and from what sources is food acquired?
- in households, who makes the decision on where and how to access and utilize resources for food production and consumption?
- what is the nutrition status of children and women in tea producing areas and what are the determining factors explaining nutrition status variability?
- how has climate change or recent climate variability affected household coping strategies in terms of producing, acquiring and consuming food? Have there been recent changes in food consumption and composition as a result?

4. Literature review

This review conceptualizes food security as synonymous with the food sufficiency of households within the tea producing areas found in the eastern and western regions of the Great Rift Valley. The term ‘food insufficiency’ refers to restricted family food stores or too little food intake among adults or children in households

(Bickel *et al.*, 2000). The concept has been operationalized by the question, "Which of the following best describes the amount of food [that] members of your household have to eat? Adequate; Sometimes Inadequate; Inadequate". (Sorsdahl *et al.*, 2011). Previous studies have demonstrated that this single item has been accepted as a valid measure of food insufficiency (Scott, 1998).

Research evidence also shows that there is an association between household food insecurity or sufficiency and climate change and nutrition outcomes (FAO, 2008; Leyma *et al.*, 2007). Climate change can affect four dimensions of food security: food availability, food accessibility, food utilization and food system stability (FAO, 2008). Agriculture-based livelihood systems that are already vulnerable to food insufficiency face a myriad of challenges, such as the risk of crop failure, new patterns of agriculture pests and diseases, lack of appropriate seeds and the loss of livestock (FAO, 2008).

In Kenya, the debate regarding the link between cash crops and food security continues. It has been established from two previous studies that there is a positive relationship between the production of cash crops and food security. While the first study, conducted in Western Kenya in a sugar cane growing zone, found that there was no significant difference between the nutrition status of sugar cane growers and non-growers (Kennedy, 1989), the second evaluation discovered that the farmers did not meet their calorific requirements. Approximately 80 percent of the households interviewed were found to be food-insecure due to monocropping more than growing multiple food crops (Oniang'o & Kennedy1990. The study revealed that the lack of adequate calorific intake can have a negative impact on health.

While Kenya has limited data relating to the links between climate change, food security and nutrition, such data can play a key role in policy-making and the implementation of appropriate interventions for adaptation and mitigation at the micro and macro levels. This study attempts to fill the knowledge gap by assessing climate change impact on the households of smallholder farmers, factory workers and pickers in the regions that produce tea.

5. Analytical approcah

The design of the study was cross-sectional and a survey was conducted of 406 households, covering seven regions in the eastern and western sides of the Great Rift Valley (Tables 52 and 53). Four factory catchment areas were visited on the eastern side, namely, Kiegoi in Meru County, Kimunye in Kirinyaga County, Ragati in Nyeri County and Makomboki in Muranga County. On the western side, data were derived from the following three factory catchment sites: Chebut in Nandi County, Momul in Kericho County and Tombe in Kisii County. Data were collected from a total of 228 and 178 households in the east and west areas of the valley, respectively. Focus group discussions (FGDs) were conducted with farmers in each of the seven regions (Table 54). In addition, two FGDs were conducted with women at Ragati and Tombe in the east and in the west, respectively. At least one in-depth interview was conducted with a farmer in each of the research sites visited in order to cross-check and clarify issues that had not been clear during FGDs.

Table 52 Survey sampling frame

Characteristics	Western Part of the Great Rift Valley - 3 Regions			Eastern Part of the Great Rift Valley - 4 Regions				Total
Number of factories	1	1	1	1	1	1	1	7
Farmers/head of households	40	40	40	40	40	40	40	280
Tea pickers	10	10	10	10	10	10	10	70
Factory workers	10	10	10	10	10	10	10	70
Total	**60**	**60**	**60**	**80**	**80**	**80**		**420**

Table 53 Land use patterns of respondents

Characteristics	N	Minimum	Maximum	Mean	Standard Deviation
Total land owned (acres)	406	0.25	5.70	1.5234	1.26365
Area under tea	406	0.10	3.99	1.1259	0.87544
Area under food crops	406	0.00	5.85	0.4184	0.94470

Table 54 Sampling frame of FGDs

Characteristics	Western side	Eastern side	Total
No. of factories/regions	3 (1 per region)	4 (1 per region)	7
Regions	3	4	7
FDG: Farmers	3	4	
FDG: Women	1	1	
Total	**3**	**4**	**7**

Convenient sampling was used to target 60 households in the seven regions that had been selected. Household selection was based on transect walks in the study areas to identify households with socio-economic characteristics that had been targeted in the initial survey. Anthropometric data of the youngest index child and the mother were taken; specifically, the Mid-Upper Arm Circumference (MUAC). Quantitative data were entered using Epidata 3.1 entry software. The data were analysed using the Statistical Package for Social Sciences (SPSS), Version 17, while qualitative data were transcribed and coded using Nvivo, Version 10. Quantitative and qualitative data, as well as anthropometric data, were collected simultaneously in one region. Dietary data were collected from 351 caregivers, while the MUAC of children was taken in 335 households. Univariate, bivariate and multivariate analyses were performed, using descriptive statistics, chi square, Analysis of Variance and linear regression.

6. Results

The results of the study are presented in three sections. The first section includes the questionnaire response rates and the demographic and socio-economic characteristics of respondents, based on a univariate analysis. The second presents the results, based on a bivariate analysis of the relationship between food security and nutrition and the socio-economic characteristics of respondents. It also includes data, on a multivariate basis, relating to gender dynamics and the determinant factors of food security/nutrition. The strategies that tea farmers, factory workers and tea pickers adopt to cope with climate change are discussed in the third section. The results of qualitative data are integrated with the quantitative results to further explain the emerging trends and links between climate change, food security/sufficiency and nutrition in this particular agricultural area of Kenya.

6.1. Demographic and socio-economic characteristics of respondents

While the following provides a descriptive summary of the demographic and socio-economic characteristics of households that were sampled, it also demonstrates the awareness of respondents in terms of climate change and its effects on tea and food production. The awareness factor serves to simplify the interpretation of the key results of the study.

Household head and composition

Survey results show that most households are headed by men (339, representing 83.5 percent, while 67 (16.5 percent) of women headed the household. An equal number of respondents 86 (21.2 percent) represented the 30-34 age group and the above-50 age group. Only 61 (15 percent) respondents were under 30 years of age. This demonstrates that tea production attracts youth and the elderly in Kenya. Most of those surveyed (106, representing 26.1 percent) had four children, while 83 (20.4 percent) had five. The younger respondents had as few as one child, while the elderly had as many as 15 children. Qualitative results show the same difference between young and elderly farmers.

Occupation of respondents

A majority of the respondents (291) were farmers, representing 54.4 percent of the total, followed by 45 factory workers (8.4 percent) and 61 tea pickers (11.4 percent) (Figure 73). The second largest group included 72 respondents (13.5 percent), comprised of casual labourers, traders and salaried employees. Some farmers (66), representing 12.3 percent, were engaged in the rearing of livestock, which included dairy cattle, sheep, goats and poultry.

Awareness of climate change

Respondents' awareness and knowledge of the term "climate change" are summarized in Figure 74 and 75. Most respondents (360), or 88.7 percent, had witnessed changes in weather patterns over the last ten years, compared to 46 (11.3 percent) (Table 55). Over half of the respondents (282), representing 71.8

Figure 73 Sampling frame of FGDs

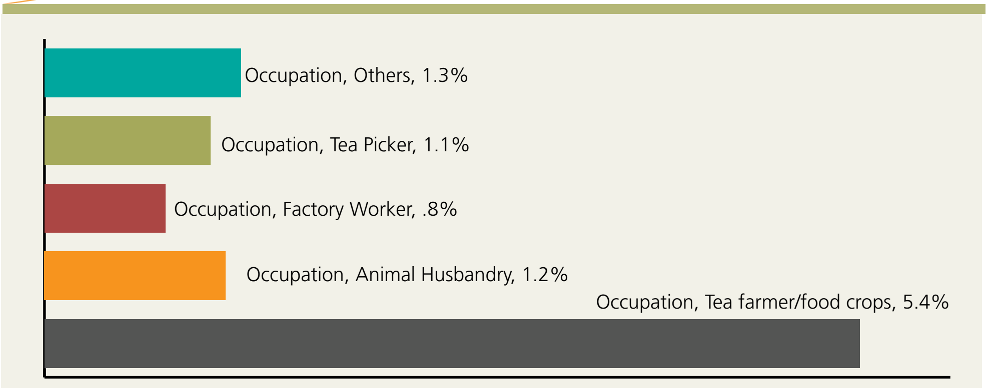


Table 55 Respondents' experiences and knowledge of climate change

Components of climate change	Frequency n=406	Percentages (%)
Changes in weather patterns Experienced weather changes in the last 10 years	360	88.7
Awareness Knowledge of the term climate change	341	84
Striking weather patterns in the last 10 years High Temperatures Low temperatures Above normal rainfall Below normal rainfall High quantities of frost Increased hailstorms	282 223 249 225 244 209	71.8 56.7 63.4 57.3 62.1 53.2
Experienced weather patterns Increased drought Unpredictable weather patterns Increased pest Increased frosts	269 229 232 227	67.4 63.9 58.1 56.9

percent, reported having experienced increased incidences of high temperature; 249 (63.4 percent), above-normal rainfall; and 244 (62.1 percent), a higher incidence of frost. The qualitative results from FGDs revealed that drought had been common in the past ten years, adversely affecting the production of tea and food crops in most of the factory catchments that were included in the study.

Figure 74 Respondents' experience of climate change in the past ten years

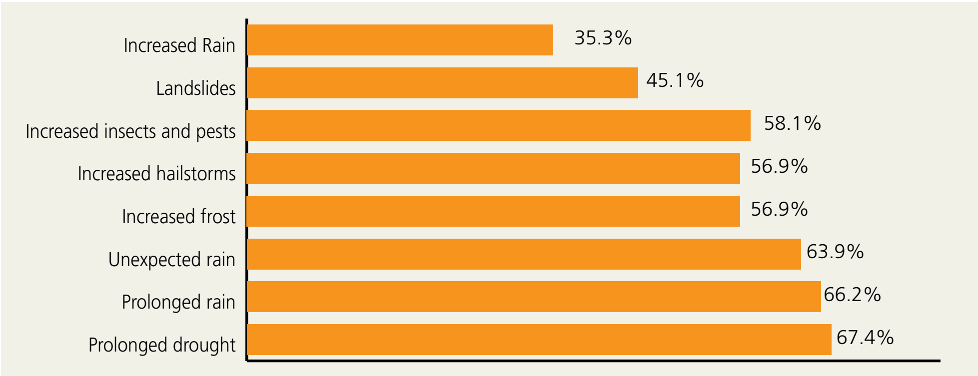
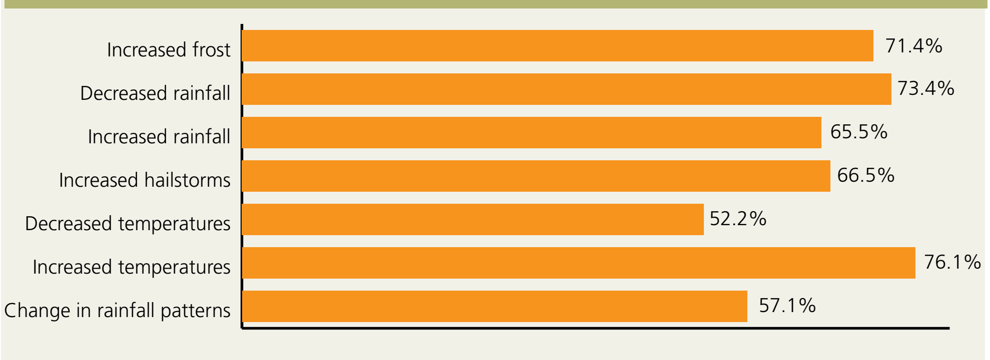


Figure 75 Respondents' knowledge of the term, "climate change"



6.2. Food security

With regard to the demographic correlation of food security in the tea producing areas of Kenya, chi-square tests were applied to assess whether or not the differences in the level of food security among households were coincidental. The impact of climate change on food availability and composition in households of tea farmers, factory workers and pickers was also discussed.

Change in food quantities to climate variability

Over half the respondents (232), representing 57.1 percent of the 406 surveyed, reported that they had sufficient food and were food secure. Most of them (249) - 63.4 percent - attributed the food security to climate change; specifically, an increase in rainfall that has led to higher yields of tea and food crops (Table 55).

Others who were questioned rated their households as sometimes food insecure/insufficient (125 - 30.8 percent) or food insecure/insufficient

(49 - 12.1 percent). The majority of respondents (325), representing 83.5 percent, attributed the reduced food quantities to climate change in the form of drought (269 - 67.4 percent), unpredictable weather patterns (255 - 63.9 percent), increased pests (232 - 58.1 percent) and frost (227 -56.9 percent) that destroy and compromise tea and food crops (Table 55).

Change in food composition and crops due to climate variability

Respondents who had observed that climate change had affected the choice of food in their household represented over half (265 - 65.3 percent) of the total surveyed (Table 56). Those living in the regions that received above-normal rainfall were more likely to consume the same food type consistently, compared to their counterparts who received less than normal rainfall and had to purchase a variety of food types from local markets.

Qualitative data also revealed that farmers in areas where there was more variable rainfall had planted a variety of food crops, such as sorghum, millet, cassava, bananas and yams to further improve their food security. They also spent their increased earnings from tea to purchase many food types, compared to what they did ten years ago.

Table 56 Respondents' knowledge of the impact of climate change on food production and composition

Issues of concern	Frequency N=406	Percentage
Impact of weather changes on food production	325	83.5
Reduced food production	172	44.2
Stunted maize	134	34.4
Potatoes gone rotten	130	33.4
Tomatoes gone rotten	139	35.7
Maize seeds not productive	119	30.6
Changed series of maize seeds	121	31.1
Disappearance of some food species	128	32.9
Introduction of new food crops	117	30.1
Preference for drought resistant crops		
Impact of weather changes on household food security	247	78.2
Reduced harvest	95	30.1
No harvest - fed on food (maize and beans) when green	121	38.3
Dependence on market for food		
Changes in Food Composition		
Whether climate change has affected the choice of food in the household	265	65.3
Changes in Crops		
Emergence of new crops in the area	128	32
Disappearance of some crop species	121	30
Preference for drought resistant crops	117	29

Emergence of new crops

Some of those questioned (128 - 31.5 percent) stated that due to climate change, new crops had emerged in their area. Temperatures had climbed in some regions, which allowed for new crops to be grown, such as banana. The qualitative results also established that new crops had been introduced in the areas under study, although in some, the temperatures had become cooler and unsuitable for banana.

Drought resistant tubers and cereals were identified by 117 survey respondents (29 percent) as the most common new types of crops to emerge. Sweet potato was introduced in the seven regions where tea is produced in Kenya. While other tubers that were introduced include cassava, yam and arrow root, the range of cereals included finger millet and sorghum. Evidence from the in-depth interviews also showed that farmers prefer to plant sorghum, cassava, banana, millet and yam, due to the persistent failure to grow maize.

Emergence of new species of existing food crops

New varieties of crops have been introduced in the tea growing areas in place of those affected food crops (maize, beans, sugar cane, sweet and Irish potatoes). Most FGD participants reported a change in the species of maize and beans that are grown.

New varieties of sweet and Irish potatoes have been introduced in Kisii and Ragati, respectively. The eastern part of the Great Rift Valley is higher in altitude and more suitable to the Irish potato.

Disappearance of some species of food crops

Some survey respondents (121 - 31 percent) indicated that some food crop species had disappeared altogether, due to the impact of climate change. These include Amaranth (terere) and black night shade (manage), which regenerate.

Pumpkin, tissue banana and certain species of fruit were also mentioned as becoming extinct in some regions. Whereas climate change had affected the production of tissue banana and pumpkin, the extinction of fruit species was attributed to human activity on their respective habitat.

Threatened species of food crops

Qualitative results also revealed that in some areas, various food crop species are threatened (Table 57). Examples include finger millet, Irish potato and Capsicum (*Capsicum (pili pili hoho)*).

Whereas some species are almost becoming extinct, others are now being grown in large quantity compared with previous years, due to the increased temperature and reduced rainfall in those areas. With the increase in temperature, beans - usually a lowland crop - are now easily grown.

Sources of income for food

Respondents referred to three major sources of income, used to purchase food during times of hunger. These are the production of tea, miraa [*Khat edulis*] and casual labour.

Table 57 An inventory of threatened species of food crops

Threatened species of food crops	Region	Statements by farmers from FGDs
Peas, njaye beans, sorghum, millet, sweet potatoes, hybrid maize.	Ragati	The crops that have reduced in quantity include peas, njaye beans, sorghum, millet, sweet potatoes, maize.
Beans (njaye) Peas	Ragati	There are too many insects in this area compared to previous years. Nnjaye (black and white variety of beans) is no longer harvested. Peas are destroyed by the insects that destroy beans.
Sweet potato	Keigoi	Previously, people used to plant sweet potato within coffee plantations. These days, the potatoes rot when farmers attempt to intercrop.
Banana	Kimunye	Bananas are disappearing or not producing well, unlike before, due to changing climate
Finger millet	Makomboki	Previously, plant millet was grown. These days, the farms are limited and people no longer grow the food crop. If they want it, they buy it from the marketplace at Thika.
Tissue Banana	Kimunye	Bananas are disappearing or not producing well, unlike before, due to changing climate change.
Sweet potato	Kiegoi	Long ago, people used to plant sweet potatoes in coffee plantations. But these days, the potatoes get rotten any time someone attempts to intercrop.

7. Gender and food security

7.1 Utilization of land by men and women

Men allocate to women certain parts of their land for the cultivation of food crops. Women on the eastern side of the Great Rift Valley are free to access and utilize land without permission from their respective spouse; however, most women on the western slopes are required to seek prior consent, but lack full rights to utilize it.

Results revealed differences between the way in which men and women utilized the land. While men prefer to plant cash crops to generate income, women prefer food crops to feed their family. Since men are the ones to make decisions with regard to land use, they tend to allocate more land to cash crops than food crops.

7.2 Nutrition status of households

Anthropometric results of children

As mentioned earlier, anthropometric data in the form of MUAC were collected from 335 (94.5 percent) children between 6 and 59 months. The nutrition status of children is based on four categories, which are recommended by the World Health Organization (WHO) (WHO, 2006), to analyse MUAC data. Results showed that there was no incidence of severe undernourishment among children in the study area. Most children (294, representing 87.8 percent) were well nourished; those at risk of undernourishment were 28 (8.4 percent); while the moderately undernourished totalled 13 (3.9 percent). Based on the WHO Global Nutrition Status indicator, the prevalence of undernourishment in the area of study was 12.3 percent, with a total of 41 children aged between 6 and 59 months. The 28 (8.4 percent) children who were at risk of undernourishment require urgent intervention to prevent the progress to severity. The children at Momul, Chebut and Makomboki appeared in better health than those from the other areas. Further analysis was made of the determinants of nutrition status in the study area by establishing a link between the MUAC and demographic, social and environmental factors. Apart from the monthly household income (15.683, $p<0.001$), other factors were not found to be significant.

Seven households (53.8 percent) of the 13 that were considered food secure had undernourished children. A T-test was conducted to compare the means of those households with undernourished/well-nourished children with the monthly earnings of the household. It was established that the households of the 41 undernourished children had an average income of KES 3 755.56, while 296 households with well-nourished children had a monthly income of KES. 5 923.70. The difference between the means was significant ($t=15.683$, $p= 0.000$). On average, there was a difference of between KES 2 000 between households with well-nourished children and those with severe undernourishment. The level of income, therefore, is a significant determinant of the nutrition status of a household.

Anthropometric results of mothers

The MUAC of caregivers was collected from 351 mothers (86.5 percent) of the sampled households. The evidence was that 334 mothers (95.2 percent) were well nourished, 14 (4.0 percent) were moderately undernourished, and 3 (0.9 percent) were severely undernourished. Based on the WHO indicator, the prevalence of undernourishment in the area of study is 13.0 percent, with a total of 17 mothers considered to be undernourished. The mean MUAC across the tea catchment areas was 27.7759, with the lowest mean of mothers' MUAC at 24.9224 in Tombe. Further analysis of the data showed that there were minor intra-group differences. For example, there was a difference of (4.35418, $p<0.05$) between the food-diversity scores of Kimunye and Tombe. This implies that households at Kimunye consume an average of four more food types in comparison to Tombe, where this is limited. Overall, however, these differences are not significant.

8. Coping strategies to food insecurity

8.1. Changes in the composition of food and food preparation practices

Survey results have established that 265 (65.3 percent) of the 406 respondents had altered their food composition due to climate change (Table 56). Many households had changed their sources of food from home-grown crops to markets and shops, given the increase in crop failure from drought and insects, as well as wastage from rotting. It was emphasized, however, that market food was expensive. One FGD participant noted, "These days, the cash from tea is inadequate [KES 8 per kilogram], yet we need to buy expensive food on a daily basis" (Kiegoi Factory catchment). Despite being expensive, FGD participants agreed that food types at markets were more diversified when compared to home-grown food crops, which mainly consisted of maize, beans, Irish potato, cabbage and kale, among others.

Qualitative results revealed several changes that had been introduced in the preparation of food, such as the rationing of quantities and a reduction in the size of pans used to cook food for the household. With regard to rationing, respondents stated that knives have been introduced to ration the portions for family members from a communal plate, whereas in the past, one could eat from one's own plate without restriction.

8.2. Remittances

Some farmers were found to have either migrated from their catchment area due to settlement schemes that have been offered or they receive remittances from relatives who have migrated. Approximately 136 (33.5 percent) reported that they depend on remittances as cash due to insufficient food as a result of climate change.

Other food-security coping methods that were mentioned by 79 (19.5 percent) respondents include food aid from the Government of Kenya and churches, food-for-cash payments and petty theft of foodstuff.

8.3. Diversification of sources of income and alternative livelihoods

A total of 41(12.57 percent) respondents had changed their livelihoods in order to cope with the challenges of food insecurity. Twenty-eight (6.9 percent) respondents on the western slopes have adopted strategies, compared to 23 (5.67percent) on the eastern side of the valley (Table 58). Many farmers have opted to engage in various socio-economic activities in order to maximize profits. Some respondents (79, representing19.5 percent) reported that they engage in motorcycle-based transport (boda boda), small and micro enterprises and fish farming. The in-depth interviews revealed that some farmers had saved sufficient cash from tea to invest in other businesses, such as the purchase of a grinding mill, a small-scale shop or hotel in their village. Respondents considered boda boda transport as a flexible business which can be done after picking tea in order to improve their economic power and enable them to purchase food for their households. In terms of alternative livelihoods, 41 (12.5 percent) respondents had adopted fish farming as a means to earn money.

Table 58 Changes in food composition, coping strategies and challenges

	Area in relation to the Great Rift Valley				
	Eastern Region	Western Region	Total	$\chi2$	Sign
Changes in food composition	40(9.85)	27(6.65)	67(16.5)	6.033	0.199
Food security coping strategies					
Skipping meals	35(8.62)	31(7.64)	66(16.26)	4.495	0.481
Borrowing from neighbours	59(14.53)	52(12.81)	111(27.34)	2.052	0.358
Borrowing from kiosk/shops	20(4.93)	16(3.94)	36(8.87)	1.572	0.456
Remittances from relatives	84(20.69)	52(12.81)	136(33.5)	4.394	0.111
Change of livelihoods	23(5.67)	28(6.9)	41(12.57)	2.361	0.501
Borrow from "merry-go round" groups	61(15.02)	45(11.08)	106(26.1)	1.72	0.423
Introduction of new food crops	21(5.17)	23(5.67)	44(10.84)	2.922	0.232
Planting of drought resistant crops	57(14.06)	45(11.08)	102(25.14)	2.845	0.416
Others	48(11.82)	31(7.64)	79	2.495	0.287
Food security coping strategies adopted in households					
Less land due to subdivisions	228(56.16)	178(43.84)	406(100)	213.332	0.041
Dependency on remittances	139(34.24)	89(21.92)	228(56.16)	6.935	0.031
High prices of food stuffs	8(1.97)	9(2.22)	17(4.19)	2.138	0.343
Inability to repay borrowed items	124(30.54)	100(24.63)	224(55.17)	1.639	0.441
Inability to repay borrowed loans	10(2.46)	4(0.99)	14(3.45)	2.982	0.225
Vulnerability of girl-child to unsafe sex	1(0.25)	5(1.23)	6(1.48)	5.385	0.068
School drop out to search for paid labour	226(55.67)	178(43.84)	404(99.51)	1.569	0.21
Others	3(0.74)	6(1.48)	9(2.22)	3.48	0.176
Opportunities that could improve existing coping strategies					
Availability of microfinance schemes	228(56.16)	178(43.84)	406(100)	53.719	0.334
Capacity building on utilization of loans	47(11.58)	35(8.62)	82(20.2)	1.648	0.439
Irrigation of food crops	21(5.17)	22(5.42)	43(10.59)	2.555	0.279
Strengthen extension services	118	53	171	22.126	0
Up-scale research on drought resistant crops	26(6.4)	32(7.88)	58(14.28)	4.996	0.083
Paradigm shift to alter crops grown based on changes in climatic conditions and altitude requirements	24(5.91)	24(5.91)	48(11.82)	2.35	0.309

8.4. Challenges to the implementation of coping strategies

Fragmentation of land

All 406 respondents reported that the fragmentation of land was a major setback in their regions. In the tea producing areas of Kiegoi and Tombe, most people own

Table 58 Changes in food composition, coping strategies and challenges (Cont'd)

	Area in relation to the Great Rift Valley				
	Eastern Region	**Western Region**	**Total**	**$\chi 2$**	**Sign**
Climate change coping strategies that have been adapted in households					
Efficient use of water resources	32(7.88)	24(5.91)	56(13.79)	1.607	0.448
Improved storage of water resources	81(19.95)	41(10.1)	122(13.05)	9.326	0.009
Conservation of the environment	21(5.17)	19(4.68)	40(9.85)	1.783	0.41
Crop diversification	25(6.16)	18(4.43)	43(10.59)	1.664	0.435
Focus on drought resistant crops	109(26.85)	76(18.72)	185(45.57)	2.799	0.247
Afforestation	28(6.9)	29(7.14)	57(14.04)	2.822	0.244
Soil moisture conservation-mulching	10(2.46)	12(2.96)	225.42	2.608	0.271
Others	19(4.68)	11(2.71)	30(7.39)	2.288	0.318
Challenges faced by households when utilizing available coping strategies					
Limited knowledge on climate change	228(56.16)	178(43.84)	406(100)	44.529	0.156
Limited knowledge of new technologies	84(20.69)	64(15.76)	148(36.45)	1.632	0.442
Limited funds for adoption of new technologies	52(12.81)	45(11.08)	97(23.89)	1.851	0.396
Limited land for expansion	57(14.04)	43(10.49)	100(24.53)	1.63	0.443
Others	113(27.83)	82(20.2)	195(48.03)	2.187	0.335

0.3-0.8 of an acre. Those with large farms own approximately one acre. The land is further subdivided for sons, such that some have only small sections on which to construct their house, leaving them no land on which to cultivate food crops.

Lack of markets for alternative livelihoods

All respondents concurred that market prices determine the quality of food that is purchased in households. When there is sufficient cash, many varieties of food can be bought.

While this study established that some farmers had attempted to adapt to alternative livelihoods, such as fish farming in Kimunye and the planting of French beans in Kiegoi, it also showed that they have become discouraged to find that there was no market for their products. The farmers in Kimunye, for example, were not interested in fish, while in Kiegoi, a non-governmental organization that initiated a French bean project never returned to collect the harvest.

Unreliability of remittances and inability to repay loans

Approximately half of the survey respondents (228, representing 56.2 percent) lamented that the remittances from relatives and friends were too unreliable and unsustainable. More than half (224, representing 55.17 percent) were unable to repay their loans - a major challenge.

School dropouts

Nearly all 404 (99.5 percent) respondents indicated the high rate of students who do not complete their school education is a major challenge in their respective area. Qualitative results have identified the severity of this issue.

Alternative sources of fuel

Trees that maintain rainfall in water catchment areas to ensure better food crop yields have been cut down by villagers for sale as fuel to the tea factories, thereby affecting the environment. One FGD participant from the Ragati factory catchment stated that trees, such as cyprus, are becoming extinct. He suggested that factories be encouraged to seek other fuel alternatives, such as the gravillea plant, which regenerates at a fast pace.

High price of food in the marketplace

Survey results show that some respondents 17 (4.19 percent) were disturbed by the high price of food products. In addition, high prices have hindered shops from stocking some items. Farmers are finding it hard to purchase the food they need for their households (Table 58).

9. Discussion

As indicated by the results of this study, climate change has had a precarious impact on food security in the tea producing areas of Kenya. Factory catchments, such those in Chebut, Tombe and Momul on the western side of the Great Rift Valley, have reported a decline in maize production due to reduced rainfall and unpredictable weather patterns. The situation worsened in 2012, when the maize crop was affected by disease in the region. There is widespread fear among farmers that maize yields will further decline in subsequent years. On the other hand, a total of 232 (57.1 percent) of those surveyed reported that their households were currently food secure/food sufficient, but most (249 - 63.4 percent) attributed it to climate change, specifically in that rainfall has increased, leading to higher yields of tea and food crops. While those farmers on the western part of the valley reported declines in food crop production, the areas on the eastern side, such as Makomboki, Kimunye and Ragati, were shown to have increased output, due to above-normal rainfall.

At the same time, however, Irish potato and beans have been affected by the increase in rainfall, which has affected the harvest used for household consumption. Climatic conditions, including shifts in the onset of the rain season, have resulted in reduced moisture, drought, increased frost, hailstorms and a rising incidence of pests and disease. In turn, the tea yield has dropped in the area and food crops have been destroyed, causing some households to become food insecure (49 - 12.1 percent) or nearly food insecure (125 - 30.8 percent).

Farmers in Ragati and some parts of Makomboki have stated that temperatures have become much cooler than in the past ten years. Consequently, tissue banana plants that had been introduced to Ragati now bear less fruit. Other crops that show a decreased yield include pepper Capsicum (Capsicum (pili pili hoho)) and arrow root in Ragati and Makomboki, respectively. These findings corroborate those from a study undertaken by the International Centre for Tropical Agriculture in Uganda that revealed that some of Uganda's most lucrative tea producing areas could completely disappear if average temperatures rise by 2.3oC by 2050 (Palmer, 2011). It also establishes that current food crops will be affected, while banana is likely to be sufficiently resilient. To this end, support should be provided to farmers to enable them to spread the risk of low tea yields by planting alternative crops that are more suitable to climate variability. The selection of another food crop is not unique in the tea-producing areas of Kenya.

While 282 (69.5 percent) of those surveyed reported that their households consumed a balanced diet, 124 (30.5 percent) were unable to have a variety of nutritious food groups because of a lack of funds. Reduced tea yields in some areas meant that there was less with which to purchase food. A majority of households, however, consume a balanced diet in terms of a mean food diversity score of 9.2479, based on 12 standard food groups (cereals, tubers, legumes, eggs, fish, beef, vegetables, milk, fruit, fat, sugar and spices). Those within the wealthier income range eat higher-priced food, such as beef, milk and legumes, suggesting that tea farmers, pickers and factory workers spend a substantial proportion of their income from tea to improve the nutrition status of their families. A study in the Philippines established the correlation between high income and the consumption of expensive varieties of food groups, specifically beef, while staples constituted a smaller proportion of food expenditure (Boius & Haddad, 1994).

In addition, food composition has changed due to the impact of climate change. While households eat home-grown food during harvest seasons, most of their food was purchased from the marketplace, far from the tea growing areas during periods of hunger. It was noted that the food bought from the market comprised more variety and contributed to positive nutrition outcomes, despite the limited quantity. The majority of people prefer to maintain some of their traditional staple dishes, despite the change in their diet. In the eastern part of the Great Rift Valley, there is a preference for githeri (a mixture of maize and beans) and mukimo (mashed vegetables). Some people only prepare ugali (maize meal) because it is less expensive to prepare than the staple food of the region. The same applies to the western area, where the staple food is ugali, although an effort is being made to serve the meal in the evening. These facts are corroborated by the transition of diet changes that were experienced in South Korea in the 1970s, where people maintained their traditional food types (Kim, Moon, & Popkin, 2000).

In terms of gender dynamics, men own the land in all the tea areas of Kenya. While some women may inherit land from their fathers on the eastern slopes of the Great Rift Valley, those on the western slopes are considered subordinate to men. There is indication from the study that men tend to allocate more land to tea - an average of 1.5 acres, compared to women at 0.4 acres. Men in Kiegoi also allocate land to miraa (Khat edulis), which is more income-generating than food crops. This also occurs with sugar cane, compared to corn (Boius & Haddad, 1994). Consequently, a woman is left with little land to grow food crops, thus resulting in a low yield of food for her household.

The money that is generated from tea for the purchase of food is paid to the male land owners. This is usually not shared with the spouse and, instead, is spent by the man on non-food items, such as school fees, electronic gadgets, alcohol and leisure. In some cases, a woman is paid in cash by her husband in return for picking the tea leaves on his own farm so that she can buy food for the family. Many of the women on the eastern slopes have formed savings and loan groups from which to obtain loans to invest in small micro-enterprises, involving poultry, rabbits, cabbage, and other products. Women manage the income from these small- and medium-sized enterprises and it mostly is put towards feeding their families. Indeed, an inter-group analysis of food diversity scores has indicated that households in the eastern part of the valley consume more food groups than do those on the western side. While it has already been established that households with a higher income - earned by the men from tea growing - have better nutrition outcomes, the income managed by women has a greater influence on food security. Kennedy (1989) has also established that it simply may not be a matter of total income; rather, it could be more about the control and source of income that are important in influencing household food security.

This evaluation has established that, in Kenya, the increased access of women to resources, such as land and money, can increase food crop production in tea producing areas. Women on the eastern slopes of the valley can generate an income, based on their activities on the portions of land that are allotted to them. This enables them to contribute to school fees, as well as buy food for their families. While some of the male respondents prefer to earn cash for food purchases, they acknowledged that women are better managers and are able to ensure that more food is available in varied quantities if they are given more access to land. There was concern among the men, however, that should a woman be involved in the decision-making, most of the land would be converted for food crops.

As previously mentioned in Section 7.1.1 above, the results have indicated that there is no severe undernourishment among children in the study area. A large percentage of children were well nourished, some were at risk of undernourishment and there were a few moderately undernourished. The food diversity score of children was limited since most care givers had fed children on only one type of food 24 hours prior to the survey. The 41 (12.3 percent) undernourished children identified from the survey, however, require urgent intervention to prevent them from becoming severely undernourished.

There were differences in the manner in which men and women spend their time. Men spend more time in shopping areas, socializing and taking tea at "hotels", while women pick the tea and wait for trucks to collect it for transport to collection centres before going to the marketplace to buy food and perform their household chores. The heavy workload saps women of their energy and can have a negative impact on the nutrition outcomes of their children due to the limited care they can provide.

From MUAC results in Section 7.1.2, most mothers were well nourished, some are moderately undernourished and only a few are severely undernourished. Based on the WHO Global Nutrition Status indicator, the prevalence of undernourishment in the area of study was 13.0 percent with a total of 17 (4.8 percent) mothers being undernourished. A Pearson correlation between the child's and mother's MUAC was statistically significant ($p<0.05$). Overall, there was no significant MUAC difference between children and caregivers across the study areas. There were few cases of undernourishment in areas where food was secure, such as in Makomboki. This finding corroborates with other evaluations that have demonstrated that undernourishment can be evident in areas with significant resources (Kennedy, 1989).

In terms of climate change mitigation, there have been signs of change in the food and crop composition in these tea growing areas. New crops have emerged, while some species have become extinct. Farmers in Momul reported an increase in bean and sweet potato, crops that did not previously grow in their area. This particular change can be attributed to the variability in the spatial distribution of rainfall (i.e. below-normal rainfall that is suitable for growing them). The results also revealed that banana now grows in some parts of Makomboki, whereas it did not in the past when temperatures were much cooler. The farmers close to the Ndakaini Dam, however, indicated below-normal temperatures, implying that the dam has caused a micro-climatic effect in the area.

Most of the new crops that have been introduced in these areas in Kenya are drought resistant, such as cassava, millet, sorghum and sweet potato. In addition, there has been a change in the variety of maize seeds: from hybrid series 614 and 628 to series 500 or the Katumani Composite B that is more tolerant to moisture stress. Other varieties/species that have been introduced include indigenous species of maize and beans and improved varieties of Irish and sweet potatoes on the eastern and western regions of the Great Rift Valley, respectively.

The study has established that a variety of coping mechanisms have been adopted in relation to food insufficiency caused by climate change. Food consumption and preparation practices have altered. Food grown at home, such as maize, beans and cabbage, are eaten during the harvest period, at which time most homesteads will serve the same type of food until it is finished before buying food at the marketplace. Many households consume a more diverse variety of food types during the periods of hunger, compared to the harvest season. The majority of farmers are usually unable to afford cereals, especially maize, whose market price usually escalates during the drought period. Instead, less expensive cereals, such as rice and potato, are bought.

Food is prepared in smaller pans as a means for less quantity. Food is rationed, using a knife, to enable all family members to share from one plate, unlike in the past when food was served on one's own plate to eat as much as wanted. Skipping meals - another coping strategy - also is new. Many households will only serve dinner and skip breakfast and lunch. Some people will borrow food from neighbours, work in exchange for cash, borrow from lending institutions or "merry-go-round" microfinance groups, lease land elsewhere to grow food crops and, while unreliable, depend on remittances from relatives who have live in cities or have moved to large-scale farms where there is more income from food crops.

Sources of income are now diverse so that cash can be accessed at all times due to climate variability. Alternative livelihoods have emerged, such as fish farming, motorcycle transport (boda boda) and owning grinding mills and shops. Some farmers are coping by adding value to their foods and cash crops; they now apply fertilizer and mulch to protect the soil and use integrated soil management practices. Agro-biodiversity is being practiced in order to promote food security. Water management has been improved and periodic cultivation is practiced, whereby farmers ensure that their land is utilized at all times to ensure food security for their family.

10. Conclusions

10.1 Changes in crop and food composition

The risk of climate change effects on food security in the tea producing areas of Kenya is considerable. Only 57.1 percent of those surveyed rated their households as being food secure, 30.8 percent rated them as sometimes food-sufficient, and 12.1 percent rated them as food-insufficient. Climate change has led to drought, increased frost, hailstorms and an increased incidence of pests and insects, affecting output in some areas. To cope with food insufficiency, the composition of food crops has changed. New crops have been introduced, such as banana in some parts of Makomboki; the output of sweet potato and beans in Momul has increased; and the tissue banana plant in Ragati bears little fruit. As a consequence of the variable temperatures and rainfall, people now plant drought-resistant crops, including cassava and sweet potato in quantity.

In terms of food composition changes, the food diversity score is of lower value during the harvest season, since most households consume one food type, depending on the harvest. During periods of hunger, a variety of food is purchased from the marketplace, such as rice, potato, beans and green grams (mung beans). Many of the farmers buy the most inexpensive food from the market, excluding maize which is sold at very high cost. The new foods are eaten along with traditional meals. While maize meal is still considered important on the western slopes of the Great Rift Valley, potato, mukimo and githeri (a mixture of maize and beans) is vital on the eastern side. In terms of rationing, smaller pans are used to prepare meals and knives are used to apportion the servings, ensuring that every member of the family has a share of the food.

10.2 Gender dynamics relating to access and utilization of resources

While it is primarily the men who own land in the tea growing areas of the country, some women on the eastern slopes of the valley inherit land from their parents and freely grow their own produce. From survey reports, there is also evidence that a man tends to co-own the land with his spouse. On the other hand, a woman in the western region is expected to request permission from her spouse to make use of certain parts of his land.

Men allocate less acreage of land to food crops than to cash crops. The mean acreage of tea plantations is 1.5 acres, while food crops are allotted only

0.4 acres. The income, generated to men from tea growing, usually is not shared with the spouse; nor do men inform their respective spouse when they lease their land or tea plantation. In some cases, women are expected by their husbands to perform the job of picking tea on their farms to earn the income to purchase food for the family.

The results revealed that men spend their earnings on non-food-related items, such as school fees and medical bills, socializing, alcohol, and leisure. Women spend most of their income on a variety of food types; men purchase only beef and cereal, such as maize - a more expensive type of cereal. Some men were in support of the proposal regarding women accessing financial resources and taking part in the decision-making. Women were considered to be better managers than men. There was a concern, however, that men would lose power and there would be conflict over land resources. A third group of respondents rejected the proposal due to cultural and personal interests. Evidence from the study demonstrated, nevertheless, that some women in areas in the east of the valley do, in fact, use their land for crop growing and they take part in the household decision-making. They may obtain a loan from women's groups (such as village savings and credit cooperatives - SACCOs) to start a business that can benefit all members of their family.

10.3 Nutrition status of children and women

No severe undernourishment was found among children in the study areas. Most of the children were well nourished, with a few moderately undernourished. Women tended to be well nourished, although a very small group was considered severely undernourished. The association of MUAC between mother and child was significant. Some of the carers were elderly grandparents who had no knowledge of the benefits of nutrition. Other women had very little energy due to their heavy workload, which impacted on their time to provide maximum attention to the children in their care. The results evidenced that the child food diversity score was low since approximately over half of the children had consumed more than one food type within 24 hours prior to the survey.

10.4 Food insecurity: coping strategies

Many coping strategies have been adopted in the face of food insufficiency as a result of climate change. They include the introduction of new crops and various species of food crops that were previously grown. For instance, the 600 series of maize seeds (which require significant moisture) have been replaced by the 500 series, requiring less moisture. Drought resistant crops have been planted in tea growing areas, which are more resilient and contribute to food security. Other coping measures include the skipping of one or two meals a day; borrowing from neighbours; government and church food aid; loans from Kenyan "merry-go-round" microfinance and other such groups; leasing of land; and remittances from relatives and friends.

11. Recommendations

Capacity development

Capacity building is essential to enable farmers to become knowledgeable of weather changes and the actions needed to enable them to continue producing food, irrespective of the effects of climate change. From the study, 82 (20.2 percent) respondents considered there is a need for skills to cope better with the challenges they face and improve production. "We really need capacity building on how to manage the soils in this area and add value to them to produce more crops for us." (Ragati Factory Catchment)

Opportunities for microfinance

All respondents indicated that microfinance was essential to produce and access food in the face of climate instability. In-depth interviews with women revealed that organizations such as SACCOs have empowered women to a great extent and have enabled them to purchase food easily. "I got support from our merry-go-round to initiate projects in my home that complement what my husband gets from tea." (Makomboki Tea Factory)

Improved use of farm inputs

There is an increased use of inputs, such as fertilizers, in the production of tea and food crops to maximize yield. Sufficient income from tea will enable farmers and tea pickers to become food secure.

Need for information of new technologies, farm planning and management

The need for information on new technologies is important for farmers in order to cope with the effects of variable weather patterns. Irrigation and the preparation of manure to replenish soil nutrients are necessary to ensure a high output of tea and food crops. The continuing alteration of seed type by the Government of Kenya should cease, and information regarding which seeds are suitable for specific areas should be disseminated to farmers. Where necessary, the Government of Kenya should ensure that there is a provision of water for irrigation during the prolonged drought season that may be a cause of climate variability. The Government should also ensure that it adopts an integrated approach towards climate change adaptation and mitigation.

Need for research and dissemination of results

More research needs to be conducted to establish the cause of poor crop output with a view to enabling access to high-quality seeds to ensure a high level of food production. The type of seeds that are sold in markets should be improved, given that there is evidence that farmers have been supplied by the Government of Kenya with seeds that are suspected of bearing seed-borne diseases. Tea factories should use alternative methods for energy and refrain from buying chopped trees from the villages, which contributes to environmental degradation.

Need for family planning

Education in family planning should be provided in tea growing areas. This would contribute to quality of life and affordability for families.

12. Limitations of the study

Four study limitations must be taken into consideration when interpreting the above results. First, the cross-sectional survey design that was adopted does not provide information on the causal direction of the association between climate change and food security/food insufficiency and nutrition. The cross-sectional research design applied, nevertheless, has enabled an insight into the nature of food security/food insufficiency and nutrition in the tea growing areas of the Great Rift Valley in the context of climate variability.

Second, the anthropometric measurements were based on only MUAC, rather than on the full approach to taking weight for height, height for weight and height for age. This was due to logistic and budget challenges and limitations. MUAC was applied to gauge the nutrition status of children and their mothers..

Third, a convenient rather than probability sampling was applied in the study. While a probability sampling may have been more effective, it could have provided an incomplete list of the farmers in these regions from which to draw the sample size. Furthermore, there was uncertainty of whether or not the lists, if any, would include the age of the youngest children in the households. This criterion was essential to allow the MUAC procedure to take place. Convenient random sampling of respondents was selected in order to avoid the sampling of irrelevant respondents.

The fourth limitation relates to the unwillingness of survey respondents to easily share information. Since the data collection was conducted prior to the general elections in Kenya, some respondents demanded tokens in exchange for information - not an option in this study due to its unethical nature and the fact that it could have compromised the quality of the data.

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CHAPTER NINE

TOWARDS A CLIMATE-SMART TEA INDUSTRY IN KENYA: KEY ELEMENTS OF A NEW STRATEGY *

John Nyangena, Mary Mwale and Aziz Elbehri

* This chapter summarizes the findings of a new tea strategy developed by a national Technical Committee under the coordination of FAO. Hernan Gonzalez and Barack Okoba (consultants with FAO) contributed to an earlier version.

In April 2013, a national multi-stakeholder workshop was held in Naivasha, Kenya to review the findings of the climate impact and socio-economic studies on tea in Kenya carried out by national and international researchers with FAO's support. Immediately afterwards, FAO coordinated the formation of a National Technical Committee to draft a new climate-smart evidence-based strategy for tea in Kenya. The Committee met during a two-day workshop in Naivasha Kenya in May 2013 to review the available evidence, summarized in a draft report produced jointly by FAO staff with assistance from Kenyan researchers. At this workshop a preliminary outline of the new strategy was sketched. Afterwards, a revised strategy document drafted and in October 2013, a second 2-day workshop was held to validate and finalize the strategy document. This chapter provides a summary of the new tea strategy for Kenya.*[1]

1. Overview

Kenya's tea output is substantially influenced by the effects of climate change. The impacts, presented in the previous chapters, have encouraged many farmers to take steps to temper the effects on their income from tea production. The strategies for adaptation and mitigation that are outlined in this chapter not only build upon the successful approaches that are practiced in the tea industry today; they also represent innovative practices.

Adaptation strategies strengthen farmers' capacity to better cope with and manage or adjust to changing conditions, hazards and risks. They also enable farmers to harness the opportunities that may arise from the effects of environmental changes. Mitigation strategies focus on curbing the GHG

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[1] The Technical Committee included representatives from the following agencies: Kenya's Ministry of Agriculture (Climate Change Unit), Ministry of Environment (Climate Change Secretariat), National Environment Management Authority, Tea Board of Kenya (TBK), Tea Research Foundation of Kenya (TRFK), Kenya Tea Development Agency Ltd., representatives of large tea plantations (KTDA), members of the Kenya Tea Growers Association (KTGA), Kenya Meteorological Department (KMD), Kenya Institute for Public Policy Research and Analysis (KIPPRA) and FAO.

Box 1 The benefits of purple tea

TRFK has released a unique purple variety of tea (TRFK 306) for commercial use, which is rich in anthocyanidins and from which anthocyanin is extracted. These are water-soluble pigments that contain powerful antioxidants. The clone has been developed over a 25-year period in Kenya and further research on its composition and antioxidant value has revealed that it is of considerable medicinal value. The clone was released in response to the Governmen's Kenya Vision 2030 and Medium-Term Plan (2008-2012), with a view to diversifying Kenya's tea products, increasing output by improving value addition and boosting economic growth in the agriculture sector.

Anthocyanin supplements (proanthocyanins) are widely marketed for their health-enhancing properties. Anthocyanins are also widely used as preservatives, especially in the food industry. The new tea variety will provide an alternative from which these flavonoids can be extracted. TRFK continues its research of this purple tea leaf variety for other products that can be extracted, such as catechins, tea seed oil and tea polyphenol for pharmacological and industrial use, manufacture of instant teas, and other consumer goods (e.g. health care products, foods and confectionary).

The special attributes of TRFK 306 are:

- richness in anthocyanins (purple pigmentation), suitable for high-value pharmacological tea products;
- tolerance of abiotic and biotic stress;
- high-yield potential, similar to that of the commercial clone, TRFK 31/8;
- moderate polyphenol content;
- low caffeine content;
- low catechin content and, therefore, not bitter;
- high-quality tea seed oil; and
- ability to grow in all tea growing regions.

Source: Survey data, 2012

emissions from the tea industry; they also increase carbon sequestration. In the short and long terms, mitigation can reduce the risks that result from climate change, as well as reduce the costs relating to adaptation. The measures for adaptation and mitigation that are proposed in this chapter - representing the entire value chain - could make Kenya's tea industry increasingly resilient to the changes, as well as maintain Kenya's global competitiveness.

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2. Adaptation strategies

2.1. Developing tea clones that are climate compatible

TFRK, which spearheads Kenya's research in the tea industry, has developed over 45 clones that have the potential to mature quickly; provide higher yields; are of better quality; and are drought-, disease- and pest-resistant. The uptake of these clones, however, is constrained by various factors, among which are (i) the length of time it takes to establish the tea bush, which discourages many smallholder farmers from replacing the old tea plants; and (ii) the limited land that is available to demonstrate the new clones, which challenges the transfer of knowledge to farmers. These constraints need to be addressed by not only strengthening research and development, but also increasing the number of climate-compatible clones. The adaptation strategy in this case should be viewed as anticipatory rather than as reactive. Shifting to higher-value tea clones has substantial financial benefits and, therefore, research should focus on improving the plant's tolerance of biotic and abiotic stress, increasing yields and shortening the maturing period, in order to speed up adoption by farmers and, thus, counter the effects of climate change.

Strategic interventions for consideration should include increasing the use of improved tea clones by smallholder farmers; strengthening the links between researchers, tea farmers and other stakeholders; and increasing the capacity of TRFK to develop additional adaptive clones.

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2.2. Improving farm management practices

Land degradation, due to erosion, exposes the tea roots to high radiation during drought periods. It also results in leaching, changes in the pH balance of soil, removal of soil and organic matter, thus predisposing the plants to poor soil fertility. In addition, it creates water pollution in rivers due to runoff, particularly from steep areas. By embracing sustainable agricultural farm management practices, Kenya's tea output and the income of farmers could be maintained.

Strategic interventions, in this case, should include the adoption of sustainable agricultural practices; investment in managing water catchments and water harvesting technologies; appropriate resumption of productivity after abiotic and biotic stress; and increased research on agroforestry in the context of tea production.

2.3. Diversifying crops

The anticipated rise in minimum and maximum temperatures in Kenya's tea growing areas is expected to drop by 22.5 percent and increase by 8 percent,


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respectively, by 2025. This implies a shift of the current demarcation of the Brown lines (see Chapter 2, Section 3) and a change in the use of land, calling for an alteration in people's livelihoods and the introduction of alternative cash crops in these regions. Support will need to be provided to smallholder tea farmers so that they can adapt to the emerging circumstances. The introduction of new high-yield crop varieties and drought-resistant plants, such as sweet potato, millet, sorghum and banana, has already taken place as a coping mechanism in the adaptation process. In particular, the growing of banana and sweet potato, as well as French beans, is mainly attributed to increased temperature and rainfall variability. Such diversity in crops can enhance food security and protect the farmers in the event of income decline.

As an income alternative, some farmers are now involved in fishing activities, which has been ambitiously promoted by Kenya's Economic Stimulus Programme. French beans and fish produce, however, have little if any links to market outlets and, thus, have failed to improve the welfare of farmers. As a result, the leasing of land has emerged as a coping strategy by some smallholder tea farmers.

The strategic objectives of crop variation are to enhance food and nutrition security and introduce new crops that are financially beneficial to smallholders in the tea regions so that they are protected from the negative impacts of climate change.

In order to achieve the objectives, there are five strategic interventions that can be implemented. These are to integrate crop diversification in tea plantations; to improve access by farmers to markets for the sale of alternative farm produce; to improve market infrastructure and storage facilities; to give guidance to farmers on land use changes due to the shift in the demarcation of the Brown lines; and to provide farmers with access to financial services so that they can diversify their crops.

2.4. Market diversification and value addition

Kenya relies on few markets for its black tea. Since some major tea-importing countries recently have faced domestic conflict, Kenya's export volume of tea could be negatively affected. Moreover, several non-tea-producing countries have increased their export revenue by adding value to Kenyan tea; for example, by blending Kenyan tea with other types of tea and then exporting it. Some tea clones, in particular, can be used for pharmaceutical, confectionary and cosmetic products. Given that the demand for Kenya's black tea has declined and that for green tea has climbed due to its health qualities, there

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should be more research on green tea and its consumption in order for Kenya to diversify and increase the number of its markets.

TRFK, in its effort to encourage product diversification, has released a number of varieties of tea. The most common variety is purple tea, which is high in anthocyanins, has a high yield and is tolerant to biotic and abiotic stress. In addition, TRFK has pre-released two low-caffeine clones of green and black tea, which will be launched formally for commercial use by 2014. An additional green tea clone that has been pre-released - potentially for commercial use - is one that can be used for its extracts, such as green tea polyphenols. Owing to the high levels of phytochemicals in the green tea extracts (used in the pharmaceutical, confectionary and cosmetics industries), the tea has gained wide acceptance.

Owing to the effects of climate change, the output of green leaf tea is anticipated to increase by 20 percent due to a rise in biomass and a decrease in the incidence of stress from cold temperatures. As a result, factories will need to build up their capacity to absorb the increased output. Global markets will also need to be expanded and market preferences satisfied by way of product diversification. The added value to Kenya's tea industry, such as the purple tea clone, will ensure the sustainability of its local and international markets and increase its competitive advantage.

Interventions that can be implemented strategically are the promotion of clones for product diversification; domestic blending and rebranding of Kenyan tea; support for research and product development; promotion of local tea consumption; diversification of Kenya's tea export markets; and promotion of carbon labelling/certification to gain worldwide acceptance.

2.5. Risk management

The climate-related risks that affect the tea industry are drought, frost and hail, as highlighted in Chapter 2. A risk management strategy should be put in place to increase the awareness of farmers so that they are prepared to respond to and protect themselves from the inherent risks of climate change. Risk management should include the monitoring of climate extremes, early warning systems and insurance (the Government of Kenya is currently formulating an agricultural insurance policy for livestock), as well as a list of continuously growing and short-cycle crops. The strategy should address the socio-economic and biophysical aspects relating to tea, in order to reduce the effects of environmental change and increase the adaptive capacity of tea farmers.

The strategic interventions recommended in this instance are to improve the access to climate information for farmers; map crop husbandry and land suitability; institute a crop insurance scheme; and monitor and measure the carbon footprint of the tea industry.

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2.6. Harmonized and standardized certification

The tariff barriers to Kenya's trade of tea are linked to its branding, packaging and export. The tea industry includes various regulatory agencies with differing standards requirements. A standards and certification strategy can establish the links between the various standards organizations and local tea stakeholders (TBK, Government of Kenya) in order to prepare the tea for trade. This would minimize the transactional cost for farmers and increase compliance for trade and consumer acceptance.

Four key strategic interventions will enable the above. These are to standardize and harmonize the certification process and its requirements; apply economic measures to strengthen trade; ensure compliance of standards and international trade regulations; and enforce existing legislation relating to the processing of tea.

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3. Mitigation strategies

3.1. Reduction of emissions

While the tea industry in Kenya does include the use of non-conventional renewable energy (solar driers) and the implementation of energy efficiency audits, many stakeholders continue to use fuel wood for processing due to the high cost of electricity, This adds to GHG emissions. The demand for fuel wood has generated the illicit practice by some farmers to clear forests to supply wood to the tea factories. In many of the tea growing areas, this has contributed to the growing of eucalyptus trees in hydrophilic soil along river sources, affecting water yields. Estimates indicate that 1 ha of fuel wood is required for every 3.3 to 4.0 ha of tea planted. Although factories have been establishing their own tree plantations/woodlots and farmers are encouraged to plant indigenous trees, the gap between demand and supply remains substantial. The population around the tea growing areas is high and in need of household energy; thus, the annual consumption of energy compared to factories is high. The GHG sequestration capacity of forests, therefore, is diminished.

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The recommended strategic interventions to reduce GHG emissions, therefore, lie in the following: to increase energy efficient technology; to promote agroforestry in tea growing areas to meet wood fuel demand; to research alternative sources of energy, such as wind, solar and hydro; and to improve road infrastructure. In addition, the requirement of 4 ha of tea to 1 ha of forest plantation should be enforced; factories should be regulated to condition wood prior to using it to improve burning efficiency; energy efficiency technologies relating to carbon credits should be adopted; and the high cost of wood for fuel in factories should be addressed.

3.2. Financing

Tea production in Kenya is dependent on private investment. Given the development of policies and legal frameworks by MALF, it is anticipated that tea production eventually will be financed through public-private partnerships. Action plans for implementation are being developed by relevant stakeholders across the value chain and will be followed by an implementation budget. The strategy will be implemented over ten years, after which there will be a review.

3.3. Institutional framework

Implementation of this strategy will be carried out in the context of the ongoing reforms being undertaken by the Government of Kenya and MALF. These include the enactment of Agriculture, Fisheries and Food Authority Act 2012, Crop Acts 2013 and the recommendations of the Presidential Taskforce on Parastatal Reforms.

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3.4. Stakeholder involvement and engagement

Stakeholder engagement should be determined by recommended interventions and performance indicators, based on a strategic results framework. Outcome or impact indicators should measure the effectiveness of strategic interventions and the extent to which they address the objectives. Stakeholders across the value chain, therefore, will have to ensure that the action plans are aligned to these strategic objectives. A Technical Working Group on Climate Change will be established to act as a think tank for the Inter-Ministerial Coordination Committee and to oversee the implementation of the strategy. The Technical Working Group will be chaired by TBK or its successor, with members drawn from relevant government agencies and the private sector.

4. Tea strategy implementation matrix

The Tea strategy implementation matrix is summarized in table below. The table describes the priority areas for action, their expected outcomes and specific activities as well as performance indicators and responsible institutions. The implementation matrix was the result of a collective multistakeholder process developed over the course of the year 2013.

Table 59 Tea industry implementation matrix

Goal	Expected outcomes	Activities	Indicators	Responsible institutions(s)
Increase uptake of improved tea clones	Improved productivity and quality of tea	Promote replacement of old tea bushes with improved clones	Percent of old tea bushes replaced	TRFK KTDA TBK MALF County Governments
		Increase availability and accessibility to improved tea-clone planting materials	Number of planting materials distributed	
		Create awareness of tea clones and their availability by training farmers	Number of farmers trained	
Strengthen linkages between researchers, smallholder farmers and other stakeholders	Improved adoption of technologies	Create a joint platform for all stakeholders to collaborate Establish a regular communication mechanism between researchers, extension officers and small tea farmers	Number of stakeholders forum; number of open days, field days, and demonstration days held Number of publications distributed	TRFK TBK KTDA KTGA EATTA MoA County Government NGOs and international development partners
		Capacity building for transfer of technologies	Number of stakeholders and categories trained	
Strengthen TRFK research capacity on climate adaptive technologies	More climate adaptive technologies developed	Staff development and capacity building	Number of staff employed Number of TRFK staff trained	TRFK TBK KTDA KTGA EATTA MALF County Governments NGOs and international development partners
		Provision of equipment and construction of a modern laboratory	Quantity of equipment provided/built	
Promote adoption of sustainable agricultural practices	Sustained production and incomes	Develop guidelines and other training material on good agriculture practices (GAPs)	Number of guidelines and training materials developed	TRFK KTDA MALF
		Sensitize local community leaders to GAPs	Numbers of leaders sensitized	
		Train farmers on GAPs	Numbers of farmers trained	

Table 59 Tea industry implementation matrix (cont'd)

Goal	Expected outcomes	Activities	Indicators	Responsible institutions(s)
Enhance research on agroforestry in tea production	Prevent and reduce loss in tea production due to environmental stress (frosts)	Identify and promote multipurpose trees for inter-cropping	Number of multipurpose trees identified and adopted Reduction of incidence of frost damage Reduction of loss in production due to hail damage	KTGA MALF County Government NGOs and international development partners
Promote investments in management of water harvesting and application technologies	Reduced environmental degradation	Conservation of riparian and water catchment	Percentage of area conserved	County Government TRFK MALF Ministry of Environment KTDA KFS TBK
		Carry out demonstrations on measures of water and soil conservation.	Number of demonstrations conducted	
		Enforce National Environment Management Authority (NEMA) regulations and the Agriculture Act	Evidence of activities related to NEMA and Agriculture Act enforcement	
Integrate crop diversification into tea extension and identification and prioritization of crop enterprises for diversification	Improved food security and nutrition at the household level	Identify alternative crops and enterprises	Number of alternative crops and enterprises identified	County Government MALF TRFK KTDA Partners and NGOs
		Promote alternative crops and enterprises identified	Number of alternative crops and enterprises adopted	
		Avail materials and farm inputs for alternative crops		

Table 59 Tea industry implementation matrix (cont'd)

Goal	Expected outcomes	Activities	Indicators	Responsible institutions(s)
Improve market access for alternative farm produce	Increased incomes and food security	Improve infrastructure and marketing systems	Percent increase in incomes from alternative produce	County governments MALF Ministry of industrialization
		Develop market information	Creation of a market information system	
		Capacity building on compliance to market requirements	Number of farmers trained; number of cooperatives, associations or marketing bodies formed	
		Provide credit to farmers	Amount of credit disbursed	
Market infrastructure and storage facilities	Improved marketing	Establish key infrastructure and storage	Number of marketing infrastructure components completed Capacity of storage	KTDA, KTGA, private tea companies
Provide guidance on land use change due to shift in demarcation of "Brown lines"		Establish the shift demarcation of "Brown lines" Sensitization of farmers on climate change and the shift in demarcation of "Brown lines"	Survey report and maps Number of farmers sensitized	TBK TRFK Universities Countries
Financial services to support smallholder farmers to diversify	Access to financial services	Link the farmers to microfinance and credit institutions/ system	Number of credit and microfinance institutions linked to the farmer groups Increase in number of farmers accessing credit	Microfinance institutions Ministry of Industrialization Ministry of Devolution and Planning
		Formation of farmers' cooperatives and groups	Number of farmers' cooperatives and groups formed	
		Promote the formation of savings and credit within farmers' organizations	Increase in number of farmers accessing credit	

Table 59 Tea industry implementation matrix (cont'd)

Goal	Expected outcomes	Activities	Indicators	Responsible institutions(s)
Undertake domestic blending and rebranding of Kenyan tea	Increased share of final products	Profile tea from various tea regions	Increase blending from 12 percent to 25 percent	TRFK KTDA
		Packing for specific markets		
		Blending of Kenya activity		
		Support market research and product development		TBK KTDA KTGA
Promote domestic tea consumption (health benefits?)	Increase share of domestic	Promotion of health benefits Diversify tea products	Double	TBK
Diversify Kenya's tea export destinations		Market survey		TBK
		Product development		
		Promotions		
Facilitate tea certification compliance to capture new markets	Lower transaction costs	Capacity building for compliance	Factories of certified tea	KTDA
Improve access to user-specific climate information services	Better preparedness	Climate needs assessment		KMS KTDA TRFK
		Repackaging tailor-made information		
		Information dissemination		
Establishment of a tea insurance scheme	Minimize risks of climate change on farmers	Feasibility study	Farmers covered by the insurance scheme	IRA KMS TRF TBK
Harmonization of certification of private standards, processes and requirements	Reduced cost of certification	Establish a national multistakeholder standardization agency		KTDA TBK KBS KTGA
Promote use of economic instruments for trade enhancement/ market access	Increased market access for Kenyan tea	Design and implement appropriate economic instruments in the tea industry	Number of instruments applied in the industry	MALF

Table 59 Tea industry implementation matrix (cont'd)

Goal	Expected outcomes	Activities	Indicators	Responsible institutions(s)
Enhance awareness to food safety standards and international trade regulations	Increased acceptance of Kenyan tea	Capacity building	Number of standards	TBK KeBS MoH
		Enforcement		
		Enforcement of good management practices in tea processing		
Promote and incentivize the use of energy efficient technology at the farm and factory level	Reduced cost; reduced GHG emissions	Identify and promote household energy efficient technologies (stoves, solar lanterns) Renewable energy efficient technologies at factory level		CPC KTDA
Promote agroforestry for small producers		Promote on-farm tree planting		KTDA MALF KFS TRFK
		Awareness creation		
Explore and invest in alternative sources of energy, such as oil, wind, solar and hydro		Comprehensive feasibility study on clean energy		TRFK MoE KMS
		Financing of identified technologies		
Incentivize the use of wood fuel plantation in tea processing	Forest deforestation	Cost-benefit analysis (CBA)		KTDA MWENRs KFS
		Targeted subsidies		
		Investment		
Develop measuring, reporting and verification (MRV) framework for mitigation actions in the tea sector		Develop MRV for tea linked to MoA		MALF KTDA MEWNR
		Capacity building		
		Operationalize MRV		

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