EX- ANTE ECONOMIC IMPACT ASSESSMENT OF INTEGRATED CITRUS PESTS AND DISEASES MANAGEMENT INTERVENTIONS IN SELECTED COUNTIES, KENYA

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A Thesis Submitted to the Graduate School in partial fulfillment for the requirements of the award of Master of Science Degree in Agricultural Economics of Egerton University

EGERTON UNIVERSITY

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DECLARATION AND RECOMMENDATION

Declaration

I declare that this thesis is my original work and to the best of my knowledge has not been presented for award of any degree at any other university.

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Recommendation

This thesis has been submitted to graduate school for examination with our approval as university and academic supervisors.

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DEDICATION

This work is a special dedication to my daughter Keren Kabugi and my brother Alex Maina.

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ABSTRACT

In Kenya, citrus industry has been on the decline due to pests and diseases specifically African citrus triozid (ACT), false codling moth (FCM) pests and *Huánglóngbìng* (HLB) disease. Management of ACT, HLB and FCM is currently based on application of pesticides. Use of pesticides is associated with increased environmental risks, substantial increase in production costs and pesticide resistance. Furthermore, exports are limited due to non-compliance to maximum residue levels (MRLs) in the international markets especially the European Union (EU). This study aimed at contributing to strengthening citrus production system by assessing the magnitude of yield losses as a result of ACT, HLB and FCM as well as estimates the potential economic impacts of the proposed IPM strategy by *icipe* among smallholder citrus producers in Kenya. The study employed a multi-stage sampling technique where the first stage involved purposive selection of two counties; Machakos and Makueni, and then four sub-counties were purposively selected from the two counties across different altitude. Finally, probability proportional to size sampling method was used to select a sample size of 324 citrus growers. Expert opinions were sought from researchers, scientists and extension officers on several aspects such as, expected yield increases, adoption rate, adoption lag and success rate. The economic surplus model was used to measure the potential benefits of the research, using Dynamic Research Evaluation for Management (DREAM 3.0) software. Results on magnitude of citrus yield losses show that ACT, HLB and FCM leads to proportional losses of 8.6%, 10.6% and 15.86% respectively. This translates to economic losses of USD 933.88, 1528.27 and 2396 per hectare due to ACT, HLB and FCM respectively. The losses impact significantly on the livelihoods of the citrus farmers, and thus may render the citrus industry unsustainable if no intervention measures are put in place. Simulation results showed that investing in IPM was viable with an NPV of USD 51.3 Million over the simulated 15 years, approximately USD 3.4 million annually, IRR of 60.3% and BCR of 16.29. This means that the Kenyan citrus sector has the potential to derive benefits from adopting IPM with consumers gaining more than producers. The results help in setting policy intervention and strategies to enhance the dissemination and adoption of IPM strategies for suppression of citrus ACT, HLB and FCM. Sensitivity analysis shows that the results remain robust even when key parameters assumed from secondary data and expert opinion were varied on extreme low and high. Distribution of benefits to consumers and producers is very sensitive to price elasticity of demand and supply.

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LIST OF ABBREVIATIONS AND ACRONYMS

ACT	African citrus triozid
AT	Action Threshold
BCR	Benefit-cost ratio
CBA	Cost benefit analysis
EIA	Environment Investigation Agency
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FCM	False codling moth
FPEAK	Fresh produce exporters association of Kenya
Ha	Hectares
HCDA	Horticultural Crops Development Authority
HLB	*Huánglóngbìng*
IPM	Integrated Pest Management
IRR	Internal Rate of Return
ITK	Indigenous Technical Knowledge
KES	Kenya Shillings
MoA	Ministry of Agriculture
MoALD	Ministry of Agriculture and Livestock Development
MRLs	Maximum residue levels
MT	Metric tones
R&D	Research and Development
USD	United States Dollar

CHAPTER ONE
INTRODUCTION

1.1 Background Information

The horticultural industry (fruits, flowers and vegetables) is one of fastest growing sub-sectors in the Kenyan economy. The average annual growth rate of 20% in the sub-sector underscores the demand for Kenya's high quality produce in the world markets. It employs about 2 million people and 4.5 million directly or indirectly depend on horticulture with 95% of horticultural produce being traded domestically, and accounts for up to 21% of all agricultural exports (MoALD, 2012). In 2014, fruits contributed USD 0.514 billion accounting for 26 percent of the domestic value of horticultural produce. The area under fruit was 159,301 Ha with a production of 3.3 million MT. Although the area under fruits declined by 32 percent from the 2013 level, production and value increased by seven and three percent, respectively (HCDA, 2014). Production of fruits can contribute up to 18% of average household income (USAID, 2015).

Citrus fruits production in the world and Kenya in 2016 was 124, 246, 000.0 and 114,400 metric tons respectively. Oranges constituted the major share, globally at 66, 974.1 metric tons and 114.4 metric tons in Kenya (FAO, 2016). In Kenya, oranges production ranks fifth after bananas, mangoes, ovacado and pawpaw (HCDA, 2014). Citrus fruits are important source of income to farmers with scarce resources, provides employment in rural areas, and for human nourishment. In Kenya, the most common species planted are sweet oranges, lemons, limes, tangerines, grapefruits and pummelos. A report by HCDA (2014) showed total citrus production of 140 292 metric tons, valued at USD 0.0311 billion. The total annual production falls short of demand such that 5-21% of the demand is supplemented by imports from neighboring countries such as Uganda and Tanzania as well as South Africa and Egypt (icipe, 2015). However, according to FAO (2016) Kenya does not export or import any citrus fruits. Citrus market is mainly informal and hence the imports come in informally and no statistical record is found. Further, the relevant government bodies concentrate on database for major exports and imports products such as cut flowers, coffee, tea and on staples food such as maize and therefore data for citrus which is an economically viable crop are scarce.

Citrus growers in Kenya, consist mainly of small-scale farmers who realize on-farm yields of 4-10 t/ha Kilalo *et al*. (2009), while the crop has a potential capacity of producing up to 50 t/ha for countries that practice integrated pest management programmes FAO (2017) and 75 t/ha in high density plantings (Obukosia & Waithaka, 2000). The highest production is in the Coast, Eastern and Rift Valley provinces. Annual citrus production in Kenya has been declining since 1995 FAOSTAT (2015) with minimal efforts being put in place to solve the problem. The decline has been attributed mainly to constraints such as insect pests and diseases, inadequate capital, inadequate planting materials and poor orchard management practices (MoA, 2006). Cherunya *et al.* (2009) found that most smallholder farmers in North Rift had abandoned citrus orchards due to low yields caused by diseases and insect pests. Further, very few farmers are starting new citrus orchards due to lack of suitable planting materials and the high cost of production as result of high use of synthetic pesticides. The authors recommend use of pest and disease tolerant rootstock/scion combined with the appropriate spraying regime as an integrated pest management strategy. It is important to verify these technologies in order to scale it up for more adoption and increased production.

Over the years, the most common pressing insect pests that affect citrus fruit in Kenya have been identified to be the African citrus triozid (ACT), *Trioza erytreae* and the false codling moth (FCM), *Thaumatotibia leucotreta* with ACT being a vector for cause for the greening or Huánglóngbìng (HLB) disease. These pests and disease have contributed significantly to the poor performance of the Kenyan citrus industry. For instance, the Greening or Huánglóngbìng (HLB) disease of citrus has been identified as a major limitation (Ministry of Agriculture, 1982). Kenya Agricultural Research Institute (1991) reported that whole orchards had been lost due to HLB disease of citrus, while mild infestations caused from 25%- 100% yield loss. Huánglóngbìng disease is caused by an uncultured phloem restricted bacterium '*Candidatus' Liberobacter* spp which is spread by two vectors namely the African citrus psyllid (*Triozae erytreae* Del Guercio) and the Asian citrus psyllid (*Diaphorina citri* Kuyawama) (Jagouiex *et al*., 1994).

In efforts to curb these pest and diseases, farmers have adopted various pest control measures such as use of pesticides and Indigenous Technical Knowledge (ITK). According to Mallick

(2013) ITK is based mainly on availability of local materials and human resources to ensure minimal livelihoods for the local people. Some of the practices include use of wood ash, kerosene, table salt, lime, cow urine, cow dung among others. However, the growing population and demand for higher yields dictates for intensive farming and farmers tend to rely more on pesticides. According to Kilalo *et al*. (2009), 40% and 70% of farmers in Bungoma and Machakos region use pesticides to control pest and diseases respectively. The study concluded that insect pest management practices by citrus farmers in Kenya are inadequate to deal with the pest and diseases situations within farms with use of synthetic pesticides being the most prevalent among citrus fruits farmers.

Use of pesticides is not only expensive but also limits participation in the international market mainly to the EU market due to stringent measures of food quality and safety that are exerted to importers. Moreover, pesticides are designed to kill and since their mode of action is not specific to one species, they end up killing or harming other organisms other than pests including human beings. The World Health Organization (WHO) estimates that there are 3 million cases of pesticide poisoning each year and up to 220,000 deaths mostly in developing countries (WHO, 2004). The application of pesticides is often not very specific, and unintentional exposures occur to other organisms in the general area where pesticides are applied. The environment is therefore harshly affected with persistent use leading to pesticides resistance development by related pests and diseases. Being exposed to pesticide can lead to a range of neurological health effects such as memory loss, loss of coordination, reduced speed of response to stimuli, reduced visual ability, altered or uncontrollable mood and general behavior, and reduced motor skills. Other possible health effects include asthma, allergies, and hypersensitivity. Pesticides exposure is also linked with cancer, hormone disruption and reproduction and fetal development problems. Limited farmers' information about technologies to treat insects and diseases of citrus have also resulted in misuse of pesticides and in poor management practices.

Pests and diseases can also be managed through Integrated Pest Management (IPM). IPM is a strategy that draws on a range of management tools with the goal of using the least ecologically disruptive techniques to manage pests in a way that maintains their damage at economically acceptable levels (Preciados *et al.*, 2013). The distinguishing features of an IPM strategy are: the use of knowledge about the biology of pests and their interaction with their natural enemies, knowledge of cultural and chemical control strategies, the monitoring of pest and beneficial populations to allow growers to make profitable pest management decisions. Use of new scientific information has enabled farmers to make more profitable pest management decisions, particularly with respect to pesticides. Further it has also been a valuable input to the management of externalities associated with pests and the use of pesticides. IPM as part of wider pest management is an important issue for citrus producer and consumers. On-farm pest management impacts on the quantity and quality of produce and on costs of production. Producers benefit from potentially reduced costs of production and reduced crop damage, whereas consumers benefit from better quality and potentially lower priced produce. There may also be reduced risks to human and environmental health.

As resources for agricultural research and development become increasingly limited globally, *ex- ante* impact assessments of the potential benefits and costs of research investments are have become popular and crucial among national and international research centers to aid in priority setting, research planning and resource allocation (Kristjanson *et al*., 1999). An *ex-ante* analysis addresses issues that ensure the research is well targeted and the path from research station to the farmer is clear (Kristjanson *et al*., 1999). *Ex-ante* technology evaluation and impact assessment involves assessing the potential benefits of new technologies and management practices prior to adoption taking place. The assessment is based upon identifying the current practice that is the baseline or ('without technology' scenario) and comparing this with the expected impacts of the new technology (the 'with technology' scenario) (Preciados *et al*., 2013). Being undertaken before new technologies are released and adopted as in this case, ex-ante studies inevitably involve assessing impacts of technology adoption when data are limited or even non-existent.

1.2 Statement of the Problem

Citrus fruits are economically important in Kenya among farmers and traders. The sector has however depicted a decline in production majorly due to increased pests and diseases infestation specifically ACT, FCM pests and HLB disease. Little efforts have been made towards reviving the industry. ACT, FCM and HLB have led to lower productivity as well as quality of the produce reducing their marketability, especially in the international market. A loss of market opportunity leads to massive losses to producers and traders. In an attempt to manage the infestation, farmers have resulted to use of excessive pesticides leading to pest and diseases resistance and higher production cost. Integrated Pest Management practices (IPM) is a sustainable alternative in pest and disease management. IPM emphasizes on growth of healthy crops with least pesticides use and encourages natural pest and disease control mechanisms. Despite the positive impact of IPM, Kenyan citrus farmers have not yet adopted the IPM strategies. *Icipe* and its partners intend to develop and disseminate IPM strategies for control of ACT, FCM, and HLB on citrus production in Africa. Before the release and dissemination of the IPM strategy, it is important to provide a better understanding of the future economic impact of the IPM strategy to the citrus growers. This study, therefore, assessed the potential economic benefits of IPM interventions for controlling ACT, HLB and FCM to reduce them below the economic injury level in citrus production in Kenya.

1.3 Objectives

1.3.1 General Objective

The overall objective of the study was to contribute towards strengthening citrus production systems by assessing the potential economic impact of IPM strategies for control of ACT, HLB and FCM in citrus production.

1.3.2 Specific Objectives

1. To determine the magnitude of citrus yield losses as a result ACT, HLB and FCM in Kenya
2. To determine the potential economic returns of integrated pest management of ACT, HLB and FCM in citrus production in Kenya

1.4 Research Questions

1. What is the extent of citrus yield losses a result of ACT, HLB and FCM in Kenya?

2. What are the expected economic returns of integrated pest management of ACT, HLB and FCM in citrus production in Kenya?

1.5 Justification

Impact assessment of technologies, such as those used in agricultural production for instance the integrated pest management of citrus fruit pests and diseases are crucially important for researchers, policy makers and donors. Citrus fruit industry has immense benefits for the Kenyan economy. This ranges from nutritional benefits to foreign exchange earnings. This study is therefore important for the Kenyan economy because production and income losses caused by various pests are presently high on all agricultural crops, including citrus. Besides, a study on the economic evaluation of IPM practices for citrus in Kenya has never been conducted. The system for IPM impact assessment developed in this study will serve as a model to extend the impact analysis to other crops. Implications derived will help policy makers better understand that policy-making needs to be based on findings of empirical research. Policy makers and research individuals need to know the magnitude of citrus yield losses due to these pests and diseases as well as the net benefits of IPM to producers and consumers or to society at large in order for them to gain insight into the merits of supporting IPM strategies. Information on the social benefits of IPM practices could provide a basis for policy makers to design and formulate comprehensive agricultural policy programs that integrate IPM practices into a national strategy of pest control.

The global market for fruit and vegetable juices is growing fast and is forecasted to exceed 70 billion liters by year 2017. The growing consciousness to adopt fruit-rich diets is one of the major drivers of the growing demand for tropical fruits, which are abundant in Kenya. Moreover, a report by WHO shows that millions of people around the world die prematurely from diseases associated with low fruit consumption. Although this is unfortunate, it signals a promising and lucrative growth in the demand for African tropical fruits now and in the future as more people add fruits to their diets. This means that the demand for citrus fruit in Europe, the Middle East and USA will continue to grow. For Kenya to tap from this potential growth in demand for tropical fruits the challenges facing the citrus sub-sector should be addressed, among the solutions is introduction of the IPM strategy for management of related pests and disease. This study sheds light on the expected returns of IPM and therefore acts as guide to investors as successful IPM effects would attract both local and foreign agribusiness investors to citrus farming and across the value chain.

Ex-ante impact assessment study acts a guide to investors and donors. They can evaluate whether the investment is worthwhile before injecting funds into the project. *Ex-ante* study helps research institutes to systematically apply priority-setting methods to ensure limited resources are directed to those research areas that have the greatest potential to benefit the poor who mostly are small holder farmers in a sustainable manner. Information from ex-ante impact assessment can help to enhance the adoption of research recommendations where net benefits are demonstrated, and assist in identifying constraints to adoption, providing feedback to the research process and demonstrating the potential returns of research and development (R&D) to project stakeholders. For instance, the County Governments where citrus is grown will be in a better position to formulate policies and regulations which would promote the adoption of IPM by citrus farmers and therefore increase productivity in the region promoting economic growth through exports of surplus and enhance both rural and urban food security in Kenya and the world at large.

1.6 Scope and Limitations of the Study

The study was limited to smallholder citrus farmers from Kangundo, Kathiani, Mwala and Makueni sub-counties. Poor record keeping by farmers and organizations posed a challenge since *ex-ante* impact assessment have a reliance on secondary data. For instance, data on price elasticities of demand and supply for citrus in Kenya could not be obtained and hence data from countries with similar market conditions were used. The changes in supply or demand for citrus due to factors other than IPM research such as population and/or income growth are ignored.

Further, budgets provide a means of assessing whether a proposed plan will be viable. The quality of data used in estimating the budgets is a critical factor affecting their relevance. In the process of generating data needed to develop citrus sector budgets and estimate changes in costs and returns associated with citrus IPM adoption, variations in varieties grown, management levels, environmental conditions and agronomic practices must be accounted for. As mentioned above, there was no citrus specific budget capturing various production systems in the recent past in Kenya. Additionally, statistics on output, inputs, and prices for the Kenyan citrus sector are not updated frequently. Techniques used to collect the best available information at the time relied on: expert opinions of scientists, farmers and industry experts; and published information on prices and production (McClintock *et al.,* 2010).

1.7 Operational Definition of Terms

Action threshold: Point at which the farmer takes action to manage pests and disease to prevent further damage.

Consumer surplus: it's the extra citrus fruits that the consumers are willing and able to purchase.

Crop loss: is what citrus producers lose as a result of citrus pests and diseases only. It is the expected citrus yield minus the actual yield in presence of pest and diseases holding other factors constant.

Demand; Buyer's willingness and ability to pay a price for a specific quantity of a good or service. Demand refers to how much (quantity) of a product or service is desired by buyers at various prices.

Economic injury level: It's the least amount of injury due to pests and disease that will cause yield losses equal to the pest and disease management costs.

***Ex-ante* assessment:** It's the use of policy-screening scenarios to forecast the effects of alternative policy or management interventions on environmental outcomes.

IPM; it's a process used to solve pest problems while minimizing risks to people and the environment. It's from the idea that below a certain pest population density or economic threshold, the cost of control measure exceeds the value of losses from pest.

Producer surplus: it's the extra citrus fruits that farmers are able to supply and sell to the market above their cost of production.

Scenario; describes conditions under which a system that is being analyzed, designed, or evaluated is assumed to perform.

Smallholder farmers: these are citrus fruit farmers who cultivate no more than two Hectares or about 5 Acres.

CHAPTER TWO
LITERATURE REVIEW

2.1 Citrus Industry in Kenya

The main fruit categories grown in Kenya are the tropical and temperate fruits. Bananas (35.6%), Pineapples (20%), mangoes (17%), avocado (6%), pawpaw (6%), passion fruit (3.6%), oranges (3%), water melon (3%) and tangerines (2%) are the major fruits grown in Kenya. The potential of most fruits remains unexploited. However, there is potential for growth due to increasing demand both in domestic and export market for fresh fruits and fruit products such as juices and concentrates (HCDA, 2014). Challenges in fruit cultivation include low adoption of modern technologies, inadequate quality planting materials, high postharvest loses, and prevalence of pests and diseases. Among the industry mainly affected by these challenges is the citrus sector. Citrus industry has been on a decline trend mainly due to pest and disease specifically African Citrus Triozid, False Codling Moth and *Huánglóngbìng*. In the 1990's the industry was a great contributor to the national GDP and was ranked highly in the world. For instance, between 1992 and 1995, the Kenyan citrus industry was ranked position six worldwide with production going as high as 163,295 MT in 1993 (FAOSTAT, 2015). In 2013, production was at 109,771 MT, and the area under citrus was at 8,346 Ha while in 1993 the area under citrus fruits was 16,166. The decline in production is proportional to the decline in area under citrus cultivation; this can be attributed to farmers abandoning their citrus orchard due to ACT, FCM and HLB infestation. These pests and disease is the major contributor of the fall out of the citrus industry in some parts of Kenya.

2.2 Citrus Pests and Diseases and their Management

Pest management at farm level is not singly related to choice of pest control practices but also the optimal level of pest control by a particular practice or set of practices (Norton & Mullen, 1994). In the past, pest management in citrus depended on whether the fruits were destined for fresh or processed consumption (Michaud & Browning, 1999). Citrus fruits processed for juice requires fewer pest management inputs than that sold on the fresh market. Use of pesticides brings market issues on quarantine pests especially to countries that rely mostly on export such as South Africa. But with invasion of pests such as ACT, FCM and the Greening disease, use of pesticides is the norm. For instance, the introduction of *Huánglóngbìng* (HLB, or Asian citrus greening disease) into the new world caused a complete paradigm shift in the integrated pest management (IPM) programs of the world's largest producers. Orchards in Brazil and Florida that relied heavily on natural control of arthropod pests now apply chemical pesticides repeatedly throughout the year to reduce the population density of the HLB disease vector, the Asian citrus psyllid (*Diaphorina citri*), and will probably continue to do so until a sustainable means of disease management is discovered (Moore & Duncan, 2017).

Use of pesticides is not only cost prohibitive but also some degree of resistance to key insecticides has already been documented (Tiwari *et al*., 2011). Moreover, despite the proven high level of efficacy of many of the available insecticides Qureshi *et al*. (2014) there has been an intense decline in citrus production as a result of HLB, particularly in Florida (Hodges & Spreen, 2006). A successful management of pests requires an understanding of the target pest ecology and habits. There are a wide range of pests and diseases that can damage citrus fruits and threaten the health of citrus trees and they differ between countries and citrus production regions. However there are certain key pests that are common among most citrus-producing regions in the world (Moore & Duncan, 2017) . For instance, on citrus in California, around 53 different species of insect and mite pests are listed (Dreistadt, 2012). The most important of these include scale insects, citrus thrips, and certain mites. Duncan *et al*. (2001) lists 39 different insect and mite pests of citrus in Florida. On citrus in South Africa, Grout *et al*. (2015) only listed 63 insect pests of citrus, but this must have changed over years.

Due to the emphasis on exports, the most serious pests in southern Africa are the phytosanitary pests, false codling moth (*Thaumatotibia leucotreta*) and various fruit flies. In China, citrus orchard insect pests include more than 74 species among 36 families in nine orders (Niu *et al*., 2014). Nevertheless, only a few are widely distributed and are considered to have a significant economic importance. In Kenya, Kilalo *et al.* (2009) listed aphids, black flies, psyllids, False codling moth, scales, white flies, fruit flies, leaf miners and orange dogs as the pests of importance in citrus production. Recently a technical report by *icipe* (2015) outlined major pests and diseases of citrus in Kenya as;

I. False Codling Moth (*Thaumatotibia leucotreta*)

This is a major pest which originated from sub-Saharan Africa but has also been detected in Europe and United States. It thrives well under warm and humid conditions. In citrus production, FCM causes premature ripening of fruits, fruit drop and fruit scar on the surface of the fruit. An infested orange also shows brown, sunken spots with larval holes bored in the center of the spot (Bradley *et al*., 1979). In South Africa, *T. leucotreta* has caused yield losses as great as 10-20% Venette *et al*. (2003) in Valencia and navel oranges. Reed (1974) described losses of between 42 and 90% in late crops of cotton in Uganda while Blomefield (1989) reported losses of up to 28% in a late peach crop in South Africa. Other significant losses attributed to FCM is poor marketability of fruits as Love *et al*. (2014) explains that FCM leads to economic loss in South Africa through fruit rejection due to the phytosanitary status of this pest. To manage this pest, good sanitation, destroying wild and cultivated hosts as well as scouting regularly for early detection is recommended. In South Africa, a combination of cultural, chemical, microbial and augmentative biological measures is used suppress FCM (Bloem et al., 2007).

II. African Citrus Triozid (*Trioza erytreae)*

ACT, *Trioza erytreae* is one of the most damaging pests (Kilalo *et al.*, 2009; Ekesi, 2012). It has a wide geographical distribution in Africa with reports from Angola, Kenya, Ethiopia, Eritrea, Madagascar, Malawi, Mauritius, La Réunion, South Africa, Sudan, Swaziland, St. Helen, Tanzania, Uganda, Zambia, DR Congo, Rwanda, Comoros, and Cameroon (Aubert, 1987). ACT prefers cool areas and higher altitudes where young flushes survive longer Green & Catling (1971) as its reproduction and development mainly occur on young expanding leaves. Its direct feeding behavior causes leaf curling and notching and deposition of honeydew on infested plants favor the growth of sooty mould which lowers photosynthesis reducing plant potency and productivity (Khamis *et al*., 2017). ACT infestations of leaf clusters in the highlands of Kenya can be as high as 65%, and these distorted leaves provide refuge for other pests (Ekesi, Google scholar, 2012). Although direct damage to the plant can be significant, ACT is most known for the transmission of the bacterium, '*Candidatus* Liberibacter africanus', the causative agent for African Citrus Greening disease (Bové, 2006). Restricting citrus growing to hot, low-lying regions of the country, and strict vector control in nurseries is part of the pest management strategy (Van den Berg, 1990).

III. African Citrus Greening Disease

ACGD is the most distressing and seriously threatening microbial disease of citrus for which there is still no cure known, caused by the bacterium Candidatus *liberibacter,* spread by the psyllids *Trioza erytrea* (Halbert & Manjunath, 2004; Bové, 2006; Saponari *et al*., 2010). The disease is also propagated by grafting (Berk, 2016). ACG reduces yield of affected fruits through continuous fruit drop, dieback, and tree stunting and poor quality of fruits that remain on the trees which are inedible. Another early symptom is yellowing of the leaf veins, mottling and eventually fall of the leaves, loss of fibrous rootlets, and ultimately death of the plant. The name of "citrus greening disease" originated in South Africa where the disease was known for an extensive period but was mistaken for some sort of mineral deficiency of the tree (Berk, 2016). In Kenya and Tanzania, ACG is reported to have had the greatest impact on citrus production especially in the highlands, causing yield losses of 25–100% (Swai, 1992).

2.3 Decision Making Process in Pest and Disease Management

The process of choosing which way to manage pests and diseases revolves around the alternatives available and on the optimal use of pest management practices. Most decision makers consider increased returns as the main objective of the producers while others consider reduced risks in terms health, environmental and pest population management between seasons which may vary at times. The widespread concerns about the adverse effects of pesticide use including pesticide resistance, pest resurgence, secondary pest outbreaks, effects on non-target organisms such as natural enemies, and pesticide pollution to both flora and fauna for decades has made it clear that spraying by calendar was not the appropriate approach to pest control. This made experts from different agricultural disciplines appreciate that the question of how many pests cause how much damage should be addresses as a decision making process and not a list of individual practices for different objectives (Daku, 2002).

Like any other economic problems in agriculture, decision-making in pest management involves allocating limited resources to meet food demand of a growing population. In this process, agricultural producers have to make choices regarding the use of several inputs such as labor, insecticides, herbicides, fungicides, and consulting expenses related to the level and intensity of pest infestation and the timing of treatment. The process of decision making for pests and disease control happens at many stages in the farm and beyond involving farmer, managers, sprayers, pest control advisors, researchers, government representatives involved in regulation of pesticide use, chemical industry personnel, and pesticide dealers, among others. These various levels of decision making affect in one way or another the whole strategy of pest control on a given crop, region or country as well as the set of approaches and methods that are chosen to implement pest control programs (Daku, 2002).

Furthermore, the way pest populations interact with the broader environment in complexity demands adopting a system of approach to managing crop (Daku, 2002). According to research, pest control programs may differ dramatically for the same crop in different regions and micro-zones depending upon the pest complex and agro-climatic conditions (Mengech *et al*., 1995). In recognition of this complexity, Higley & Pedigo, (1996) noted that bio-economics, the study of the relationships between pest numbers, host responses to injury, and resultant economic losses, is the basis of assessment and decision-making in pest management. Though biological scientists are concerned with the effects of pesticides on the ecosystem, agricultural economists are concerned with their implications to the farmer, society, resource allocation since the goals of pest management are largely economic. Other than use of pesticides, scientist have designed and developed the integrated pest management strategies. The decision of choosing between use of pesticides and use of IPM is mainly guided by cost implication, yield increment and protection of the ecosystem.

2.4 Integrated Pest Management

Integrated Pest Management (IPM) is a systematic approach to crop protection integrating various pest suppression technologies including biological, chemical and cultural controls in a way that keep pest below their economic injury levels and minimizes economic, environmental and health risks (Allen & Rajotte, 1990). Biological control also known as natural control involves use of predators, pathogens, parasites, disruptions in breeding cycles and plant modifications. It is the conservation of natural enemies by preventing their destruction or preserving their habitat. To keep beneficial species active and populous enough to control pests; choice of plant varieties, maintenance of alternative hosts as well as proper soil management tactics need to be employed. For success, natural control should be practiced at community level where predators' level is at maximum (Braun & Duveskog, 2011). Cultural practices include physical manipulation of insect environment and exclude application of chemical pesticides or introduction of natural enemies of pests. It involves cultivation and rotation, timing of planting and harvesting and variation of plant density and nutrient use. Chemical use is very minimal in IPM and where used, they should be used in a narrow spectrum with a short residual effect so as to encourage beneficial predators and parasitoids.

Different pest control measures; biological, cultural and chemical are combined to form an IPM kit for effective results. For instance, *icipe* developed fruit fly IPM package for mango is a combination of various fruit fly management techniques; these include the use of the male annihilation technique (MAT), the application of protein bait spray, the use of fungus-based bio pesticide, releases of exotic parasitoids, and orchard sanitation that encompasses the use of augmentorium (Verghese *et al*, 2006). The MAT involves the use of carriers (fruit fly traps) containing male lure combined with an insecticide, which are distributed at regular intervals over a wide area in the mango orchard to reduce the male population of fruit flies to a low level so that mating does not occur or is extremely reduced (Allwood *et al*., 2002; Ekesi *et al*., 2007). The protein-baiting technique is based on the use of proteinaceous food baits combined with an insecticide, applied to localized spots of one square metre in the canopy of each tree in the orchard when fruits are 1.3 cm in size. Spraying is done weekly until the very end of harvest (Ekesi *et al*., 2007). The proteinaceous substance attracts the adult fruit flies, mainly females, from a distance to the bait spray droplets. The fruit flies ingest the bait, along with a toxic dose of insecticide, killing them before they infest the fruit (Prokopy *et al*., 2003).

Bio-pesticides are applied to the soil within the dripline of the canopy to kill the soil-dwelling pupariating larvae and puparia. The females of Fopius arisanus destroy fruit flies by laying eggs on fruit flies' eggs in previously damaged mango fruits. The parasitoid eggs hatch to produce larvae that grow by feeding on the internal tissue of the flies' larvae, ultimately killing the fruit flies (Mohamed *et al*., 2010). Orchard sanitation is the cultural method used to prevent fruit fly build up. The method involves the collection of infested fruit found on the trees or fallen on the ground and depositing them in an augmentorium. An augmentorium is a tent-like screen structure designed to sequester fruit flies emerging from infested fruits, but at the same time allows the escape of parasitoid wasps via a screen on the top so that they can re-enter the field, thus conserving the natural enemies of fruit flies (Ekesi *et al*., 2007). Ndiaye *et al.* (2008) found that an IPM package consisting of male annihilation technique, bait sprays and orchard sanitation to control fruit flies in mango orchards in Senegal resulted to an improvement from fruit fly infestations in the treated plot up to 83% compared to the untreated.

A study to evaluate the comparative effectiveness of three IPM packages on the basis of infestation level of brinjal shoot and fruit borer on shoots and fruits of eggplant. The IPM package 1 consisting of mechanical control on grafted eggplant; IPM package 2 comprising kerosene, neem oil and wild Ipomoea extract application on non-grafted eggplant; IPM package 3 containing Cymbush application on grafted eggplant and untreated plants. The grafted plants treated with Cymbush resulted significantly lowest shoot and fruit infestation compared to those of other treatments. Significantly the highest yield was obtained in plants treated with Cymbush. IPM packages with grafted plants produced more fruits than non-grafted ones. The diameter and weight of individual fruit was higher in plants under IPM package 1 and 3 utilizing grafted eggplant in late fruiting stage (Rahman *et al*., 2002).

2.4.1 Benefits of Adopting IPM

The benefits of adopting IPM can be classified broadly as economic, environmental and social benefits. The economic benefits of IPM over a chemical oriented pest control approach have been demonstrated in several studies. For instance, a detailed study of the respective costs of an IPM over a chemical-oriented approach for a number of different regions in South Africa demonstrates an average cost saving in the order of 10% for IPM production Hattingh (1996) cost efficiency of IPM production is related to reduce cost of production since less input are used in form of chemicals and higher prices attracted from pesticide free fruits.

Muriithi *et al*. (2016) assessed the impact of IPM strategy for controlling mango-infesting fruit flies in Kenya. The effects of five IPM practices were explored including parasitoids (p) and Metarhizium anisopliae-based biopesticides (biop), orchard sanitation (os), spot spray of food bait (fb) and male annihilation technique (mat) on three outcome indicators: farmer pesticide expenditure, farm-level mango fruit yield losses and profit. They study showed that application of the IPM strategy resulted in a 48% average increase in mango net income compared to the previous season irrespective of the IPM combination component used. The extent of improvement in net income, however, varied across treatments; treatments posfb and posmatfb registering the greatest improvements whereas the pos treatment generated the smallest increase in net income. The study findings further show mango yield losses due to fruit fly infestation reduced by an average of 19% among the IPM users. A reduction in expenditure on pesticides, albeit across all the households was also noted. Regression model estimates showed that, except for IPM combinations posbiop and pos, farmers using the rest of the IPM practices recorded significantly higher incomes from mango compared to their counterparts in the control group. It was also noted that although average expenditure on pesticides decreased across all mango farmer households, the reduction was comparable between the treated and control farmer households. Their findings however, showed significant decreases in mango damage due to fruit fly infestations among all farmers using the different IPM treatments.

Vayssieres *et al*. (2009) studied the effectiveness of Spinosad Bait Sprays (GF-120) in Controlling Mango-Infesting Fruit Flies (Diptera: Tephritidae) in Benin. They assessed the effectiveness of GF-120 (Dow Chemical) Fruit Fly Bait containing the insecticide spinosad in controlling mango-infesting fruit flies (Diptera: Tephritidae) by comparing treated orchards with untreated orchards. Twelve mango plantations located in six villages in northern Benin were monitored weekly with fly traps, and the fruit was sampled twice for larval infestation at the beginning and in the middle of May in both 2006 and 2007. The two-main mango fruit fly pests are *Ceratitis cosyra* (Walker) and *Bactrocera invadens* Drew, Tsuruta & White, an invasive species that recently spread throughout West Africa. In both the 2006 and 2007 seasons, *C. cosyra* had the earliest peak of abundance, and the difference between treated and untreated orchards, in terms of mean number of flies trapped per week and per trap, was significant only in 2007. *Bactrocera invadens* populations quickly increased with the onset of the rains, from mid-May onward, with no significant difference between treated and untreated orchards. In 2006 and 2007, the larval infestation by *B. invadens* was significantly lower in plots treated with GF-120 than in untreated control plots. GF-120 provided an 81% reduction in the number of pupae per kilogram of fruit after weekly applications for 7 weeks in 2006 and an 89% reduction after 10 week of weekly applications in 2007.

In an evaluation of the economic impact of nine IPM extension programs in several states (Indiana, Virginia, Georgia, New York, North Carolina, Texas, Massachusetts, Mississippi and Northwest region including Washington, Oregon, Idaho, Montana, and Nevada) Napit *et al*. (1988), seven programs had no significant profitability impact from IPM. For two, cotton in Texas and Mississippi, adopting IPM for cotton made a significant net revenue difference. Annual internal rates of return of 452% for Texas and 300% for Mississippi were reported respectively. Their higher rate of return estimate may be explained by at least three factors, 1) they covered more IPM practices including not only scouting but also biological control and change in cultural practices and, 2) their study embraced all target pests for a particular crop, 3) cotton has been a particularly successful crop for IPM programs historically.

Assessing the economic losses due to fruit fly infestation in mango and the willingness to pay for an IPM package, Mugure (2012) employed a contingent valuation method on a sample of 240 mango growing farmers in Embu District. Results indicated that the average percentage loss due to fruit fly infestation via rejections at the farm was 24 percent. The results also showed that 66 percent of respondents were willing to pay the cost of USD 11per acre for the IPM fruit fly control package. The study recommended for a more systematic ex-post impact assessment study after the release and adoption of the technology to evaluate the performance of IPM.

Reporting on the economic impact of investment in IPM from a symposium held in North Central Region, Minneapolis Araji (1981) based the work on an ex-ante evaluation of the impacts of present and future investments in IPM. Using the results of the benefit-cost ratios of various commodities, the author drew three fundamental conclusions: active extension involvement is required for IPM success, IPM leads to a dramatic aggregate reduction in pesticide misuse; and IPM technology could be transferable depending on the nature of the crops and pests. Norgaard (1988) employed a benefit-cost model to quantify the benefits of a biological control IPM technology called *E. Lopezi* for cassava mealybug in Africa. The study found *E. Lopezi* has a very high benefit-cost ratio and has enjoyed widespread popularity among farmers. It attributed its success to the very nature of the technology: it requires neither investment nor maintenance expenditures.

Kibira (2015) evaluated the economic benefits of managing mango-infesting fruit flies in Embu County, Kenya using an IPM package composed of MAT, protein bait spray, releases of exotic parasitoid Fopius arisanus and the use of augmentorium. The study evaluated the magnitude of mango rejection due to fruit fly damage, insecticide expenditure and net income from mango and also established households' perception of the effect of the intervention on human health. The results indicated that on average IPM participants had approximately 54.5% reduction in magnitude of mango rejection than the non-participants. The participants spent approximately 46.3% less on insecticide per acre than the non-participants and on average received approximately 22.4% more net income than the non-participants. Results also showed that 78% of households perceived the intervention improved human health.

An ex-ante analysis conducted by Preciados *et al*. (2013) in Southern Philippines showed use of IPM strategy can reduce crop damage by 20 percent per hectare, increase yield by 33 percent, and reduce pesticide expenditure and total cost of production by 75 percent and 16 percent, respectively. The author further reported that the IPM technology can cumulatively increase gross margin by about 156 percent per hectare. Switching from chemical to biological pest control management has served as a major stimulus for the development of IPM technology which has immense environmental benefits. Reduced pesticide pollution of land and water, improved functioning of the ecosystem; reduced effects on aquatic fauna and land are some of the many benefits. This in turn lowers the cost of the many negative environmental effects which will not be quantified within conventional cost benefit analyses. Hence IPM saves money on the economy as well.

Pimentel *et al*. (1992) estimated the environmental and social costs from pesticides in the United States. The study concluded that an investment of approximately $4 billion in pesticide control saves approximately $16 billion for a given year in US crops, based on direct costs and benefits. However, it was also noted that indirect environmental and public health costs of pesticide use need to be balanced against these benefits. The environmental and social costs of pesticide use total approximately $8 billion each year. Users of pesticides in agriculture pay directly for only approximately $3 billion of this cost, which includes problems arising from pesticide resistance and destruction of natural enemies. Society eventually pays this $3 billion plus the remaining $5 billion in environmental and public health costs. This therefore means that environmental costs associated with the use of chemical pesticides are not considered at the farm level but rather at societal level. IPM being environmentally friendly would save on these environmental and public health costs.

A study on the economic, environmental and social evaluation impacts of New South Wales Department of Primary Industries (NSW DPI) investments in IPM Research in Lettuce in Australia. The economic surplus model was employed and estimated the benefit-cost ratio (BCR), the net present value (NPV) and the internal rate of return (IRR) of NSW DPI lettuce IPM research from the year 1999 up to the year 2006 at 1.7, $1.63million and 46% respectively. When research benefits and costs were extended to the year 2020, a benefit-cost ratio of 2 was calculated for the return to NSW DPI investment in lettuce IPM research which while satisfactory, is lower than returns calculated for other agricultural R&D, the NPV was $5.4million and the IRR was 48%. The study found that there has been widespread adoption of IPM practices amongst NSW lettuce growers leading to a flow of economic benefits to the lettuce industry and the community. Important environmental and human health benefits were also identified. The model did not include ‘spillover’ benefits to other states nor has human health or environmental benefits been valued (Orr *et al*., 2008).

Significant health and safety benefits are associated with the use IPM as opposed to chemical pest control. Antle & Capalbo (1997) reviewed the principles and the applications of assessing IPM impacts on the economy, environment, and the public health sector. They argued that impact assessment should be an integral part of IPM research. The authors provided justification for why impact assessment should be part of IPM research. They argued that EIA facilitates interdisciplinary collaboration in the design and implementation of data collection and analysis; it ensures that IPM research is useful and relevant in economic, environmental, and public-health terms, and it affirms that impact assessments are timely and cost-effective. Furthermore, the authors indicated that a successful pest-management program must be profitable to farmers and for the industry if it is to be widely adopted; thus, implying economic impact assessments are critical to the success of IPM program. Other positive impacts of IPM has also been documented in other crop enterprises such coffee in Uganda Isoto *et al*. (2014), cotton production in Asian countries (Erickson, 2004; Ooi *et al*., 2005), onion production in Philippines (Cuyno *et al*., 2001; Yorobe Jr *et al*., 2011; Sanglestsawai *et al*., 2015). In summary, benefits from IPM can be categorized as those that go to citrus growers, their farm household, and society in general in terms of government savings, reduced environmental pollution, biodiversity and ecological sustainability as shown in Table 2.1.

Table 2.1: Benefits of Adopting IPM

farm level benefits	**societal benefits**
Lower pesticide use	Less government subsidies for pesticides
Lower production costs	Less government funds for pesticide-pollution control
Lower crop and crop product losses	Less domestic pesticide production
Higher yields	Fewer pesticide imports
Higher quality	Larger savings of foreign currency due to reduction of pesticide imports
Lower yield variability	Net economic benefits to producers and/or consumers
Enhanced efficiency of other inputs used	Better water quality
Higher net returns	Food safety for humans and wildlife
Better training for farmers	
Better access to information	
Conservation of beneficial organisms	
Reduction of pesticide resistance in pest population	
Reduction of pest resurgence	
Fewer secondary pest outbreaks	
Lower health risks	
Less ground water and surface water contamination	

Source: Norton & Mullen (1994)

2.5 Economic Evaluation

Guided by costs and benefits, economists differentiate between two broad types of evaluations: *ex-ante* and *ex-post. Ex-post* evaluations provide managers with evidence of the value of past research to justify or request for continued funds and support. *Ex-ante* evaluations can provide managers with a basis for allocating resources among competing research demands. Economic evaluation can assist in planning research, in estimating research payoffs and in guiding research and technology policies. There are several approaches for economic evaluation of agricultural research. Alston *et al*. (1995) provide an extensive review of models used in the economic evaluation of agricultural research. They discuss both the economic surplus analysis approach and econometric methods used in estimating the economic benefits of research on new agricultural technologies. Econometric estimation is suitable for *ex-post* studies where the effect of past investments in research can be estimated using data on inputs, outputs, and research expenditure. The most commonly used approach in the evaluations of both *ex-post* and *ex-ante* research and technology is the economic surplus method. The economic surplus approach estimates return to investment by quantifying the benefits from research in terms of the change in consumer and producer surpluses that result from technological change, and using the estimated economic surplus together with research costs to estimate an internal rate of return (IRR), or other benefit-cost measurements. The most common measures are benefit-cost ratios, internal rates of return, and net present values of benefits generated by agricultural research. Norton & Davis (1981) earlier reviewed and compared the most common approaches used to evaluate public-sector investments in agricultural research.

Norton (1987) gave a brief background of the nature of economic evaluations and extended previous studies by assessing the potential benefits of agricultural research and extension in Peru's agricultural research program. The benefits of agricultural research and extension were examined in an *ex-ante* consumer-producer surplus framework for five commodities. The effects of demand shift over time and government pricing policies on research and extension benefits were considered. The projected rates of return to research and extension indicate substantial returns to public investments.

2.5.1 Past Studies that Applied Economic Surplus Model

Though there are a number of studies that employed the economic surplus model, most of them have generally focused on *ex-ante* impact assessment mainly using economic surplus models, willingness to pay and cost benefit analyses for example (Macharia *et al*., 2005; Ainembabazi *et al*., 2013; Mulwa *et al*., 2013). The number of studies related to an *ex-ante* impact assessment of IPM programs is limited. Most of the literature has been on *ex-post* assessment of research programs. Song & Swinton (2009) evaluated the potential economic returns to integrated pest management research and outreach for soybean aphid in the United States of America. Employed the economic surplus model and assumed a closed economy. The research found out that gradual adoption of action threshold (AT)-based IPM over the 15 years since soybean aphid IPM research began in 2003 generated a projected economic net benefit of $1.3 billion, for an internal rate of return of 140%. Lower and upper bound sensitivity analysis bracketed the estimated net benefit to U.S. consumers and soybean growers in the range of $0.6 to 2.6 billion in 2005 dollars. Further, the study concluded that if a 10% rate of return is attributed to IPM applied research and outreach on soybean aphid, then that would leave nearly $800 million to compensate prior basic IPM research. Using benefit functions from two prior studies of consumer willingness to pay to avoid pesticide risk, they also found that the nonmarket environmental and human health benefits of reduced insecticide use due to adopting AT based IPM are less than five percent of the baseline market value estimate of economic net benefit.

Ex-ante evaluation of the economic impact of herbicide resistant transgenic rice in Uruguay used a stochastic simulation technique to estimate how benefits vary with changes in technology, yield, costs, and adoption parameters (Hareau *et al*., 2006). The results indicated a USD 1.82 million mean net present value for producers from the development and utilization of transgenic rice in Uruguay. They found out that the benefit for the multinational company that would develop the technology was $0.55 million. In a study of the potential economic returns to research on genetic enhancement of sorghum and millet residues fed to ruminants in India, Kristjanson *et al*. (1999) employed the economic surplus model. The net present value of the research was estimated between USD 42 and 208 million. Prediction of rate of return to the research investment varied from 28% to 43% with corresponding benefit: cost ratios of 15-69:1. Further, Kristjanson *et al*. (1999) used the economic surplus model to measure potential returns to the International Livestock Research Institute's research on trypanosomosis vaccine in Africa. The results indicated that the potential benefits of improved trypanosomosis control, in terms of meat and milk productivity alone, are USD 700 million per year in Africa. The disease now costs livestock producers and consumers an estimated USD 1340 million annually, without including indirect livestock benefits such as manure and traction. Given an adoption period of 12 years, a maximum adoption rate of 30%, a discount rate of 5%, and a 30% probability of the research being successful within 10 years, the net present value of the vaccine research was estimated to be at least $288 million, with an internal rate of return of 33%, and a benefit/cost ratio of 34:1

Using partial budgeting and ex-ante economic surplus analysis to estimate the aggregate benefits of the IPM-CRSP strategies in Bangladesh and Uganda, the study provided evidence that the welfare benefits were shared by both consumers and producers, and IPM strategies were more profitable than farmer practices (Debass, 2000). Kostandini *et al*. (2006) examined the potential size and distribution of welfare gains from bio pharming transgenic tobacco as a source of human serum albumin (HSA) in United States using an economic surplus model under imperfect competition. The results suggested that HSA from transgenic tobacco will generate annual profits for the innovating firm of between $25 million and $49 million. On the other hand, consumers are unlikely to benefit during the patent life of the product given the innovator's market power**.**

White & Wetzstein (1995) used economic surplus methods to address the distributional consequences of factor saving cotton IPM technological change in the US. Net social welfare from IPM in cotton was reported to be 0.55% of total receipts. Cotton production would increase by 0.10% and cotton price would decline by 0.13%. Consumer surplus would increase 0.13% and producer surplus would increase 0.61%. The revenue generated by the chemical tax would be 0.24% of farm marketing. Costs of the educational programs would be 0.09% of farm marketing. Ignoring the cost of the educational program financed by a chemical tax, the benefit-cost ratio would be 8.2 to 1 while accounting for all costs, the benefit-cost ratio would be 3.4 to 1. These authors concluded that increasing the use of IPM in cotton can reduce aggregate chemical use, which in turn can reduce some of the environmental problems associated with high chemical use in agricultural production. Adoption of cotton IPM is dependent on its effectiveness in increasing net returns.

A review of different methods employed to evaluate IPM programs within the context of economic principles and environmental and health assessment by (Norton *et al*., 1996). Farm level and aggregate level evaluation methods were discussed in detail. Economic surplus analysis is discussed as a primary tool for aggregate level economic evaluations of IPM programs. Moreover, the significance of benefit-cost analysis is discussed as a complementary tool to economic surplus measurements. Estimation of the magnitude of yield loss as a result of pest and diseases can be done in several ways. Direct measurement is more precise because actual loss can be defined as the difference between the amount of produce harvested in the absence of infestation (potential yield) and the amount harvested in the presence of infestation (actual yield). Economic value can then be obtained by multiplying the magnitude of crop loss by market prices. For instance, Macharia *et al*. (2005) in assessing the potential impact of biological control of *plutella xylostella* (diamond black moth) in cabbage production in Kenya, first established yield losses caused by DBM through two methods: measurements from farmer-managed fields and through farmers' interviews.

Most studies on IPM were conducted in developed countries. The studies also focused mostly on expected gains, they do not evaluate the losses caused by related pest and diseases without the IPM. This study therefore aimed to contribute to the existing literature on potential economic benefits of IPM by assessing the ex-ante impact of IPM in Africa, using a case of Kenya and determine the magnitude of yield losses caused by citrus pests and disease specifically ACT, HLB and FCM.

2.6 Theoretical Framework

Economic Surplus Approach

Economic surplus is concerned with the relationship of the adequacy of welfare measures as well as determinants of the size and distribution of research induced economic benefits and costs and the respective assumptions that are made on: functional forms for supply and demand functions, nature of research-induced shift of supply and demand curves, elasticities of demand and supply, dynamics of the stream of benefits and costs, trade issues and regional spillover effects and uncertainty considerations concerning the potential gains in output and quality improvement, research's success and adoption level. Measured in terms of consumer and producer surplus, Consumer surplus has three key components: a level of utility, a change in price, and a corresponding change in real income. Consumer surplus measures the change in income due to price change of a good or service with respect to a given level of utility. These measure can be in terms of the amount of additional income that would leave the consumer in the initial welfare position if it were possible to buy any quantity of the commodity at the new price or the additional income that would leave the consumer in the new welfare position if it were possible to buy any quantity of the commodity at the old price. Therefore, consumer surplus is the price the consumer would be willing to pay over the actual cost of the good. This difference between what the consumer would be willing to pay and what he actually pays is shown by the area under the demand curve and above the market price. Producer surplus on the other hand measures the producer welfare. Defined as the difference between what producers are willing and able to supply a good for and the price they actually receive. That is to mean, producer surplus is the excess of the return to the factor owner above that necessary to convince him/her to provide the factor. The level of producer surplus is shown by the area above the supply curve and below the market price.

The economic surplus approach estimates return on investment by; calculating the change in consumer and producer surpluses that results from technological change brought about through research. In this case the change brought about by IPM interventions and using estimated economic surplus together with research costs to estimate the NPV or IRR. The framework requires crop production and economic data. The concept of the economic surplus approach is based on the material benefits to society from technological change. The adoption of new technology reduces the unit cost of production, shifting the supply curve to the right and increasing consumer and producer surpluses. Consumers gain from the new technology because they can consume more at a lower price, and producers gain because their unit costs of production fall. The distribution of benefits between producers and consumers depends on the elasticities of the demand and supply curves and on the magnitude and nature of the supply shift. The combined total benefit to consumers and producers, measured in monetary units, is the change in economic surplus. The model assumes that the supply and demand curves are linear and vertical parallel shift of the supply function.

In this case, IPM interventions would cut down the production cost (pesticides) and hence raise the producer surplus. The basic formula for estimating the change in economic surplus in year *t* will be ΔES_t is:

$$\Delta ES_t = K_t P_t Q_t (1 + 0.5 Z_\eta) \quad \text{(2.1)}$$

Where P_t is the price of citrus fruits after IPM intervention in year t, Q_t is the quantity of production in year t of citrus fruits after IPM intervention, $Z = \varepsilon\eta/(\varepsilon+\eta)$ where ε is the elasticity of supply, η is the elasticity of demand, and K_t is the proportionate downward shift in the supply curve in year t due to IPM intervention. The most critical parameter, the variable K, is calculated as the net change in the cost of production due to new technology (IPM) which is sometimes approximated by the yield increment due to the new technology, weighted by the rate of adoption of the new technology in year t. The economic surplus approach was then used to calculate benefit–cost ratios, IRRs, and NPVs for benefits generated from IPM interventions in the citrus industry.

2.7 Conceptual Framework

The analysis starts with conceptualizing an estimate of the potential damage that ACT, HLB and FCM could have caused if left uncontrolled during this period. The "no control" scenario establishes the counterfactual baseline for evaluating two management alternatives for damage mitigation. This scenario attempts to capture the value of economic losses from these citrus diseases if no pest management tactics had been available. These ideas can be illustrated with supply and demand curves, as in Figure 2.1 below.

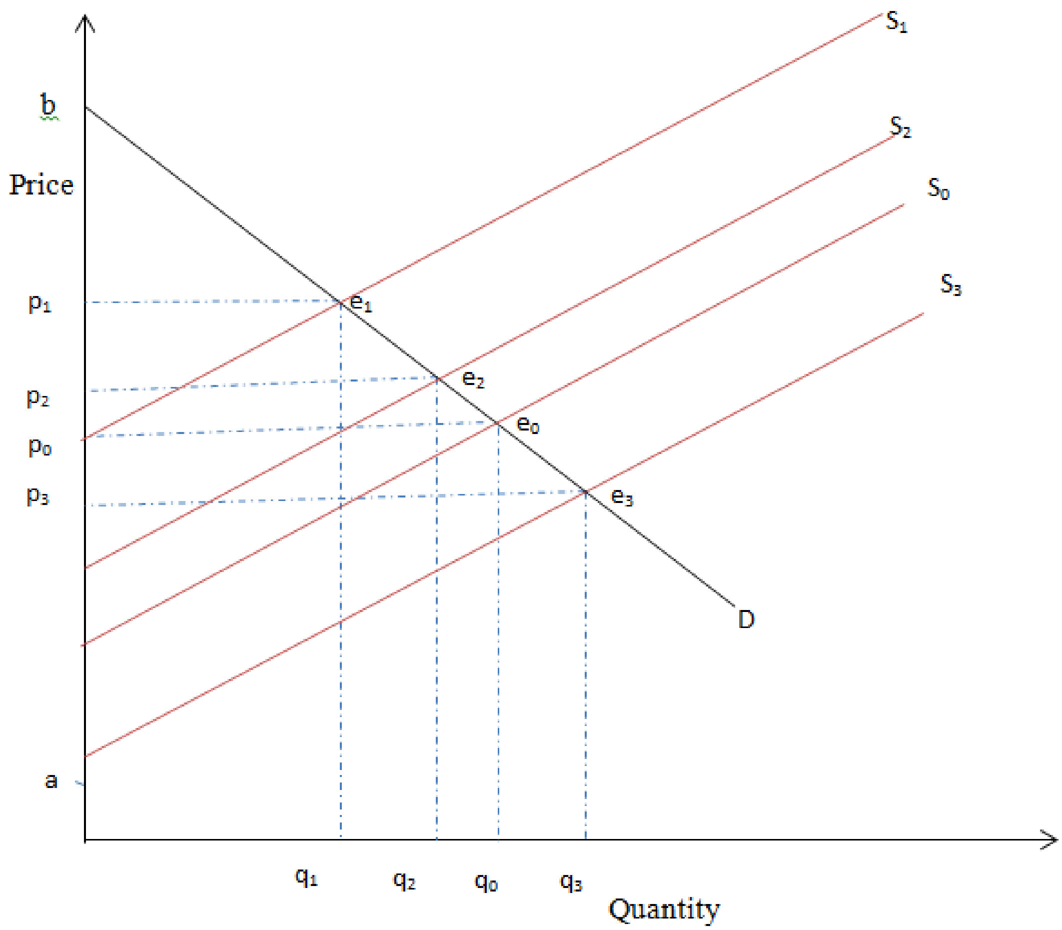

Figure 2.1: Economic Surplus Analysis Conceptualization

The citrus fruits supply curve (the quantities that farmers would be willing to supply at different prices) is represented by line S_0; D represents citrus fruits demand curve (the quantities that consumers would be willing to buy at different prices). The consumer surplus is the area e_0p_0b, the value of consumers' added satisfaction gained by being able to purchase citrus fruits for a price that is less than they would be willing to pay. The producer surplus is measured by area e_0p_0a, the added income above cost that producers earn by selling citrus fruits at a market price that is higher than they would be willing to sell for.

Economic surplus is equal to the sum of producer and consumer surplus. Since the supply curve represents marginal costs, uncontrolled yield loss due to citrus pests and diseases will increase marginal costs and shift supply upward and to the left from S_0 to S_1. The consumer surplus shrinks to area e_1p_1b, because citrus fruits consumers now pay a higher price and some who consumed at the original price can no longer afford to do so. The change of citrus fruits producer surplus is measured by area e_0p_0a- $e_1p_1p_0$. In general, the net welfare effect to producers may be positive or negative because there are two opposite effects. The producers sell fewer citrus fruits, but at a higher price. The sum of citrus fruits consumers' and producers' surplus changes measures the net welfare loss associated with uncontrolled FCM, ACT and HLB and can be represented by area $e_0e_1p_0a$. The benefits of citrus fruits pest and diseases management is modeled in two stages. In the first, farmers adjust to FCM, HLB and ACT by practicing chemical pesticides control. In so doing, they reduce the damage but sometimes spray unnecessarily. In a second stage, after exposure to the IPM idea, farmers begin to spray only when the value of expected yield loss exceeds the cost of control.

The two stages are captured in two analytical scenarios. First is a pesticides management scenario where a single insecticide treatment is applied regardless of the level of related citrus diseases pressure. Compared to the "no control" scenario, the new supply curve (S_2) will shift rightward because pesticides control can protect against yield loss. However, it will not return to the original market equilibrium because the control costs incurred raise production costs above the level prior to arrival of citrus pests and disease. The benefits of chemical pesticides control are measured by the reduced economic loss compared to no control. In the second stage, IPM intervention and chemical pesticides management coexist as IPM gradually replaces pesticides control. Since IPM is a newly proposed management alternative, it takes time for citrus fruits farmers to fully embrace it as a pest and disease control strategy. The averted pest control costs when ACT, HLB and FCM pressure is low will result in a rightward supply curve shift (S_3) compared to the pesticides control scenario curve at S_2. The gross benefits of IPM research and outreach are measured by the reduced economic loss compared to the chemical pesticides control scenario. Farmers enjoy more as producer surplus shift to area (p_3e_3a) as they are able to produce at a lower cost as well as high quality fruits and compliance with minimum residual levels. Consumers on the other side can purchase more at a lower price; more is available in the market therefore meeting their demand as well as less health and environmental risks, consumer surplus shifts from region bp_2e_2 to bp_3e_3.

CHAPTER THREE
METHODOLOGY

3.1 Research Design

This study used an exploratory survey research design. Exploratory survey design is used to define a problem more precisely, identify alternative course of action, gain insights for developing an approach to the problem and establish priorities for further research (Malhotra, 2006). This research design was appropriate since the study aimed at informing policies formulation, stressing the need to prioritize research and development of IPM and guide on resource allocation.

3.2 Study Area

The study was conducted in four sub-counties (Kangundo, Kathiani, Mwala, Makueni) selected from two counties (Machakos and Makueni), purposively selected on the basis of different altitudes above the sea level. The selection across different altitude zones helps in comparing pest infestations (Mwatawala *et al*., 2006). The sub-counties were also purposively selected on the basis of major citrus-producing areas and the incidence of ACT, FCM and HLB. All the regions receive two rainy seasons, long rains occur between March and June while the short rains fall between October and December.

Machakos county stretches from latitudes 0º 45’ south to 1º 31’ South and longitudes 36° 45’ east to 37° 45’ east. The annual rainfall ranges between a mean of 500 to 700mm. Temperatures range between 9.1ºC -26.7ºC with an altitude of 1000 to 2100 meters above sea level. Subsistence agriculture is practiced with Maize and drought-resistant crops such as sorghum and millet being grown. Other crops grown include fruits such as mango, avocado and citrus. Citrus production has been declining in this region with farmer replacing citrus orchards with mango. The county is well endowed with natural capital including livestock, minerals, wild game, tourists’ attraction sites and rangeland. Kangundo and Kathiani sub-county represented the semi humid agro-ecological zones while Mwala sub-county was studied for the mid altitude that is semi humid to semi-arid area (Government of Kenya, 2013a).

Makueni county lies at 1°48′South and 37°37′East with an annual rainfall range of 150 to 650 mm. Temperatures ranges between 12 °C- 28 °C. The study was conducted in Makueni sub-county since the area is a semi-arid agro-ecological zone lying at a low altitude above the sea-level. Citrus is grown as a cash crop and plays a great economic role for the household income.

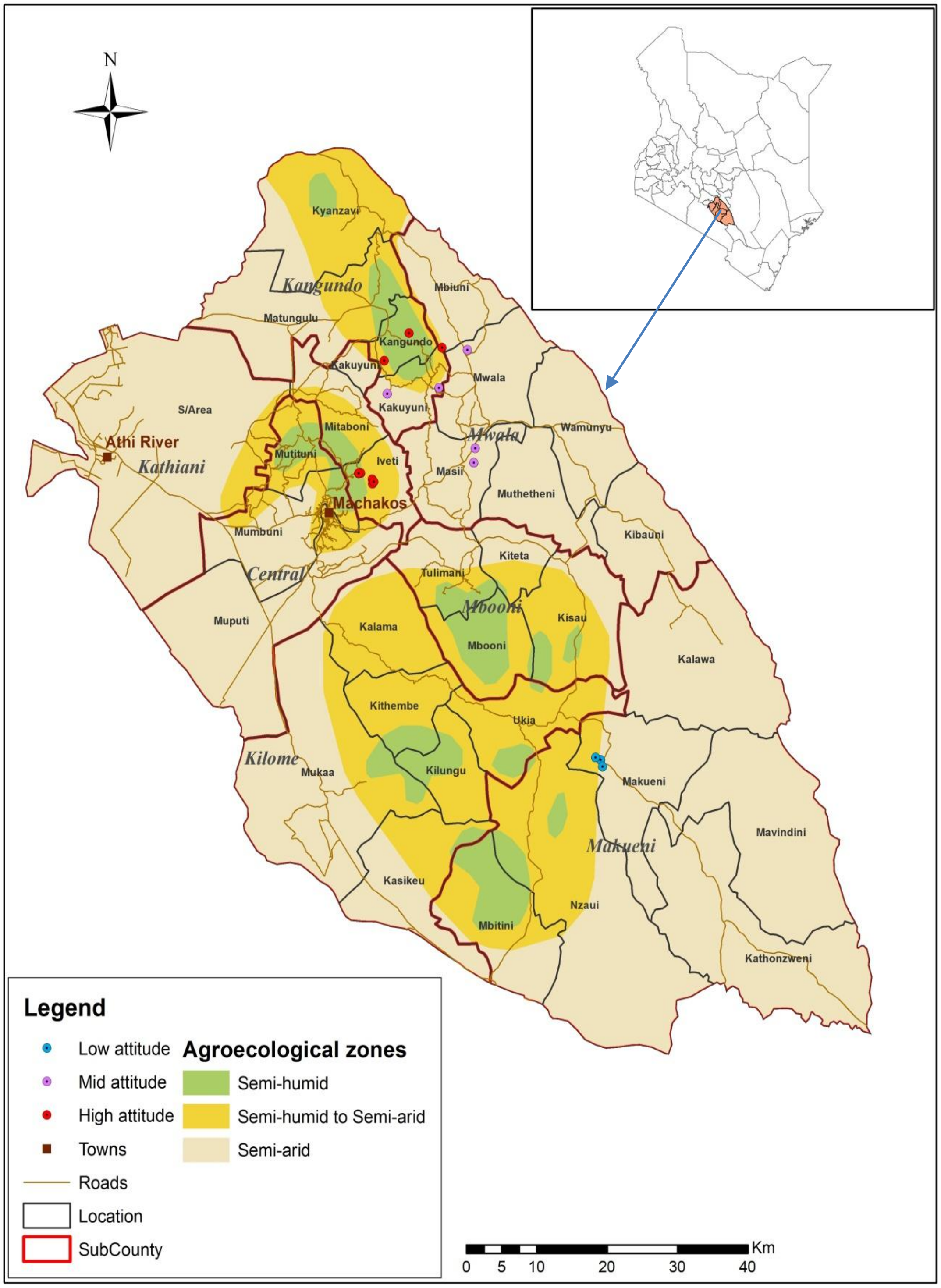

Figure 3.1: Map of the Study Areas

Source: World Resource Centre, (2016) The fruits are mainly traded locally, Nairobi and Mombasa being the largest target market. Other fruits grown in the area are mango, pawpaw and avocado. Drought resistant crops such as pigeon peas are grown for subsistence use. The high temperatures in the area make it non-conducive for ACT to prevail reducing the infections of HLB. Farmers however experience challenges of FCM which cause premature drying and falling of fruits (Government of Kenya, 2013b).

3.3 Sampling Procedure and Size

The study employed a multi-stage sampling technique where the first stage involved purposive selection of two counties where citrus production is predominant in Kenya. In stage two, four sub-counties, namely Kangundo, Kathiani, Mwala and Makueni were purposively selected across different agro-ecological zones to compare pests and disease prevalence. Finally, Probability Proportional to Size (PPS) sampling technique was used to attain required sample size. This was after obtaining the sampling frame of citrus growers from the extension officers (Anderson *et al*., 2007).

$$n = \frac{pqZ^2}{E^2} \qquad (3.1)$$

Where n = sample size, p = proportion of the population containing the major interest, $q = 1 - p$, Z = confidence level (α = 0.05), E = acceptable/allowable error. Since the proportion of the population is not known, $P = 0.5$, $q = 1 - 0.5$, $Z = 1.96$ and $E = 0.054$. This resulted to a sample of 329, out of this 5 were dropped due to high cases of missing data arriving at a sample of 324, 190 and 134 from Machakos and Makueni counties respectively.

Probability proportion to size is a sampling procedure under which the probability of a unit being selected is proportional to the size of the population unit, giving larger clusters a greater probability of selection and smaller clusters a lower probability. This method facilitates planning for field work because a pre-determined number of individuals are interviewed in each unit selected, and staff can be allocated accordingly. It is most useful when the sampling units vary considerably in size because it assures that those in larger sites have the same probability of getting into the sample as those in smaller sites, and vice versa.

3.4 Data Types and Methods of Collection

Both primary and secondary data were used. Secondary data on elasticity and discount rate was obtained from published journals and articles. For primary data, structured and semi-structured questionnaire were used to collect quantitative data for the study and were administered to the respondents by a team of trained enumerators. The developed questionnaire for the survey included other components from the project. I adopted the sections relevant for my study. The questionnaire was pretested to evaluate for consistency, clarity and to avoid duplication.

3.5 Methods of Data Analysis

Data from the field was cleaned, coded and encoded to ensure consistency, uniformity, and accuracy and then entered into computer software for analysis. Both qualitative and quantitative techniques were used to analyze the data collected. Qualitative data on social-economic characteristics of citrus fruit farmers was analyzed using descriptive statistics such as mean, percentage, standard deviation, tabulation, ratio and frequency distribution. Economic surplus was calculated using Dynamic Research Evaluation for Management (DREAM 3.0) software.

3.6 Empirical Framework

3.6.1 Simulation Scenarios

The evaluation of potential benefits of IPM for citrus research assumed three key scenarios. A scenario describes conditions under which a system that is being analyzed, designed, or evaluated is assumed to perform.

1st scenario: (without IPM/without pesticide). This is called the “do nothing” or the “business as usual” scenario in terms of pest control. Here it’s assumed that citrus farmers do not spray their trees and there is minimal use of indigenous technical knowledge. The “do nothing” scenario establishes the counterfactual baseline for evaluating two management alternatives for damage mitigation. The “no control” scenario attempts to capture the value of economic losses from these citrus diseases if no pest management tactics had been available.

2nd scenario: (without IPM /with pesticide). This is a pesticides management scenario where a single insecticide treatment is applied regardless of the level of related citrus diseases pressure. Farmers adjust to manage FCM, HLB and ACT by practicing chemical pesticides control and reduce the damage but sometimes spray unnecessarily. The "pesticide control scenario" raises production costs to the producer compared with the "no control scenario". The benefits of chemical pesticides control are however measured by the reduced economic loss compared to no control.

3rd scenario: (with IPM). In the "with IPM" scenario farmers are exposed to the IPM program and they will spray only when the value of expected yield loss exceeds the cost of control. IPM intervention and chemical pesticides management coexist as IPM gradually replaces pesticides control. Since IPM is a newly proposed management alternative, it takes time for citrus fruits farmers to fully embrace it as a pest and disease control strategy. The gross benefits of IPM research and outreach are measured by the reduced economic loss and welfare gain to both producers and consumers as economic surpluses. In summary, the first two scenarios represent the present "without" research situation, which is further sub-divided into "with" and "Without" pesticide use for controlling ACT, HLB and FCM. The third scenario considers the "with" IPM situation.

3.6.2 Objective One; Magnitude of Citrus Yield Losses as a Result of FCM, ACT and HLB

Crop loss data was obtained through farmers' interview and direct measurement from farmer managed fields. Crop loss is the difference between expected yield in absence of the diseases Y_p and actual yield in presence of the diseases Y_r. It is convenient to express this as proportion of the actual yield in absence of the pest and diseases, to obtain a proportional crop loss (r) (Macharia *et al*., 2005).

$$r = \frac{Y_p - Y_r}{Y_P} \qquad (3.2)$$

Since this ratio r was known from the farmers' estimates, citrus yield losses (CL) were then derived from actual yield in presence of FCM, ACT pests and HLB disease obtained from farmers' estimate with the following formula:

$$CL = Y_p - Y_r = Y_r \frac{r}{1-r} \qquad (3.3)$$

The ratio r can be obtained from different sources: farmer's estimates, experts' estimates, field trials and through remote sensing. This study relied on farmers' estimates. Alternatively, citrus yield losses can be obtained by estimating the relationship between yield (Y) and pest incidence (d) (Walker, 1987):

$$Y = Y(d) \qquad (3.4)$$

The same principle can be used with damage scores (ds):

$$Y = Y(ds) \qquad (3.5)$$

Assuming a linear relationship between yield and damage score, citrus losses would then be estimated by estimating following yield function:

$$Y = Y_p - \beta ds \qquad (3.6)$$

The intercept is then an estimation of Y_p, expected yield without FCM, ACT pest and HLB disease. Average yield losses will then be estimated by calculating Y_p (yield at zero damage score) and yield at the average damage score.

3.6.3 Objective Two; Assessment of Potential Economic Impact of IPM Interventions

Economic surplus model was used to measure the size and distribution of economic benefits which accounts for IPM research-induced supply shifts, increased demand owing to quality improvement and price reduction. Since in Kenya foreign trade in citrus fruits is negligible, the "with IPM research" scenario assumed closed economy, where the equilibrium price was entirely determined by domestic supply and demand. Spillovers to other markets were disregarded, which appears acceptable, as citrus production only employs a small fraction of all factors of production in Kenyan agriculture. The model also assumed that citrus was trading under a perfect competitive market where citrus prices were determined by market forces as well as perfect knowledge between producers and consumers. Linear demand and supply were also assumed with a parallel shift of the supply curve.

Following Alston *et al*. (1995), the annual change in consumer surplus (ΔCS), producer surplus (ΔPS) and Total economic surplus resulting from IPM intervention were calculated as,

$$\Delta CS_t = P_0 Q_0 Z(1+0.5Z_\eta) \qquad (3.7)$$

$$\Delta PS_t = P_0 Q_0 (K-Z)(1+0.5Z_\eta) \qquad (3.8)$$

$$\Delta TS_t = P_0 Q_0 K(1+0.5Z_\eta) \qquad (3.9)$$

Where: P_0 and Q_0 are initial equilibrium price and quantity, and K is the proportional vertical shift in supply curve due adoption of IPM technologies, expressed as cost reduction per unit of output.

Z is the reduction in price as a result of the supply shift, η is the absolute value of the price elasticity of demand, and ε is the price elasticity of supply. The vertical shift of the supply function at time t (K_t) and the relative reduction in price (Z_t) were calculated as:

$$K_t = \left(\frac{\Delta Y}{\varepsilon} - \frac{\Delta C}{1+\Delta Y}\right) \times A_t \qquad (3.10)$$

$$Z_t = K_t \times \frac{\varepsilon}{\varepsilon + \eta} \qquad (3.11)$$

Where;

ΔY is the expected proportionate change in citrus yield per acre due adoption of IPM technologies

ΔC is the expected proportionate change in variable input cost so as to achieve the expected yield increase

A_t is the adoption rate that is, the proportional area of citrus under IPM to total citrus acreage

Both logistic function/curve Alston *et al*. (1995) and creation of matrix from farmers' responses on willingness to adopt IPM in time t were used to describe adoption patterns of IPM practices on citrus production. Calculated as;

$$A_t = \frac{M}{1+e^{(-a+bt)}} \qquad (3.12)$$

This is transformed to equation (3.13) and the parameters estimated using ordinary least square (OLS).

$$\ln \frac{At}{M-At} = a + bt + \varepsilon \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.13)$$

M is the maximum adoption rate; b is the rate of adoption; a constant term, t is time in years and e is the base of the natural logarithm and ε is the error term.

Some of other key parameters needed for the economic surplus estimation included:

Probability of research success, defined as the likelihood of exceeding the expected yield gain and cost reduction threshold for the citrus IPM techniques to be released for dissemination.

Research lag, defined as the time path from when research is initiated to when the IPM package is developed and ready for dissemination.

Adoption profile; defined as proportion of citrus farmers who are likely to adopt the new IPM practices after dissemination. The chances that IPM will be used by farmers and the time it will take for them to adopt up to a maximum level is very important in determining the research induced shift of the supply curve. The adoption profile starts from research and development lag up to release of IPM then the adoption lag which is the period of successive adoption as more citrus farmers are exposed to IPM technology up to maximum adoption point. Adoption lag is measured in years. Maximum adoption rate on the other hand is when most farmers have been exposed to IPM and have made their decision whether to adopt or not. Highest level of adoption likely to be reached after the release of IPM. The adoption profile data was computed from the study's data as well as expert opinion.

Research costs, resources required for developing IPM technology and dissemination including extension costs. This was obtained from project documents.

Market related data; the economic surplus analysis in this study requires data on quantities produced, citrus fruits prices, price elasticities of supply and demand and discount rate.

Net Present Value (NPV) was then estimated using the total surplus and the research expenditure to assess the benefits.

$$NPV = \frac{\sum(\Delta TS_t - RC_t}{(1+i)^t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.14)}$$

Where;

ΔTS_t is the total economic surplus resulting from use of IPM strategies over time t

RC_t Research cost, that is cost of developing, disseminating and extension services relating to IPM over time t

i is the discount rate (rate of return that could be earned on an investment in the financial market with similar risks or the opportunity cost of capital. The market determined i take into account inflation for time t. Ideally NPV is determined by calculating the costs and benefits for each period of an investment. The period is typically one year, but could be measured in quarter-years, half-years or months. After the cash flow for each period is calculated, the present value (PV) of each one is achieved by discounting its future value at a periodic rate of return which is dictated by the market. NPV is the sum of all the discounted future cash flows. Because of its simplicity, NPV is a useful tool to determine whether a project or investment will result in a net profit or a loss. A positive NPV results in profit, while a negative NPV results in a loss. In the event that the NPVs of all investments are positive, the investment with the highest NPV is accepted. Each cash inflow/outflow is discounted back to its present value (PV) then summed. Therefore, NPV is the sum of all terms,

$$\frac{R_t}{(1+i)^t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.15)}$$

Where; t is time of the cash flow

R_t - the net cash flow i.e. cash inflow – cash outflow, at time *t*.

Benefits- Cost Ratios (BCR)

BCR is an indicator, used in cost benefit analysis that attempts to summarize the overall value for money of a project or proposal. It is the ratio of benefits of a project or proposal, expressed in monetary terms, relative to its costs. All benefits and costs should be expressed in discounted present values. It considers the amount of monetary gain realized by performing a project versus the amount it costs to execute the project. The higher the BCR, the better the investment.

Internal Rate of Return

The internal rate of return (IRR) is defined as the discount rate at which the NPV is exactly zero. This means that, the IRR is the interest rate that will make the implementation of the research program break even. Measured as;

$$\sum_{t}^{T} = 1\frac{R_t - C_t}{(1+IRR)^t} = 0 \qquad (3.16)$$

The decision criteria when using the IRR is to accept an investment if the IRR is higher than the opportunity cost of capital. IRR is obtained through interpolation as shown in the following formulae.

$$IRR = \alpha + \left[\frac{A}{A-B} \times (b-a)\right] \qquad (3.17)$$

Where: *a* is the lower discount rate

A is NPV at the lower discount rate

b is the higher discount rate

B is the NPV at the higher discount rate

Sensitivity Analysis

Agricultural researches are inherently risky. Since the economic analysis of research activities is based on uncertain future events, the measurement of costs and benefits inevitably involves explicit or implicit probability judgments. Tools for assessing risk include sensitivity analysis. It involves identifying the variables that most influence a project's net benefits, such as aggregate costs and benefits, critical cost and benefit items, and the effects of delays and then quantification of the extent of their influence. The preferred approach to sensitivity analysis is based on the switching value of a variable that is the value at which the project's NPV becomes zero (or the IRR equals the discount rate). Switching values are usually given in terms of the percentage change in the value of the variable needed to turn the project's NPV to zero. The switching values of the more important variables may be presented in order of declining sensitivity. For variables that are expected to vary together (such as price and quantity sold), sensitivity of the outcome to changes in combinations of those variables (such as in total revenues) should be examined.

This study assessed the potential economic returns to agricultural research with uncertain timing of benefits realization as well as adoption time lag. A sensitivity analysis was therefore an important tool in this research since economic surplus model relied on some parameters obtained from literature. Understanding the robustness of model results is important so as to take care of uncertainty of *ex-ante* analysis. Both optimistic and pessimistic scenarios were simulated. Appendix 2 gives a summary of equation of key parameters used for the calculation of economic surplus.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents analyses and discusses the findings of the study. The chapter is divided into four sub-sections. These include the socioeconomic characteristics of the sampled households, magnitude of crop yield loss, economic surplus analysis as well as the sensitivity analysis. Inferential statistics such as t-test and *chi*-square have been used to assess the strength of relationship between social-economic characteristics of farmers from Makueni and Machakos Counties, this is considered important since its hypothesized that prevalence of ACT, HLB and FCM is different across the two region and socio-economic characteristics have an impact on pest and disease management practices as well as the likelihood of IPM adoption. Literature on citrus production in Kenya was found to be scarce and studies from other countries were used to validate the results.

4.1 Socio-Economic Characteristics of Sampled Citrus Farmers

Demographic factors of farmers affect their production behavior and in turn will influence their knowledge on pest and disease control measures and willingness to adopt biotechnologies. This sub-section outlines the social-economic characteristics of citrus farmers from both counties as understanding demographic factors of the farmers is crucial in guiding dissemination. Table 4.1 presents selected socio-economic characteristics of the survey respondents. Average household size, computed in adult equivalent was statistically significant between the counties at 1% level. Adult equivalent in this study adopted the “OECD-modified scale" which assigns a value of 1 to the household head, of 0.5 to each additional adult member and of 0.3 to each child below the age of 18. The scale was first proposed by (Hagenaars *et al*., 1994). The average family size was found to be 2.71 with Makueni having a relatively larger family size than Machakos. The size of the household determines its basic needs requirements. A larger household is often faced with challenges of providing social and welfare facilities such as feeding, education and other living expenses for such a large number of dependents. These expenses as well as pressure on land, reduce saving and volume of marketed surplus at the end of every harvest season (Von Braun, 1995).

There was significant relationship between the average age between farmers from the two counties (T= 4.25, P=0.001).

Table 4.1: Selected Socio-Economic Characteristics of the Sampled Households

Characteristics		Mean/Percentages			
		Machakos N=190	**Makueni N=134**	**Overall N=324**	**T-test/ Chi2**
Household characteristics					
Family size in adult equivalent		2.55	2.93	2.71	-3.953***
Education of the household head(years)		9.81	9.75	9.78	0.150
Age of the household head (years)		58.53	52.75	56.14	4.250***
Location characteristics					
Distance to the village market (walking minutes)		25.84	29.58	27.39	-1.255
Distance to the nearest pest/herbicide dealer (walking minutes)		48.02	58.93	52.53	-1.803*
Distance to the nearest agricultural extension office (walking minutes)		76.43	84.36	79.72	-1.318
Distance to the nearest main output market (walking minutes)		59.48	68.83	63.35	-1.430
Resources					
Proportion of farm income on total household annual income (%)		58.35	61.02	59.45	-0.8279
Proportion of income from citrus on total annual household income (%)		15.83	25.91	20	-5.048***
Own Farm size (Hectares)		1.73	1.75	1.74	-0.118
Marital status	Married	89.47	92.54	90.74	0.878
	Otherwise	10.53	7.46	9.26	
Occupation	Farming	68.95	58.21	64.51	11.733**
	Others	31.05	41.79	35.49	
Labor contribution	Fulltime	68.95	58.21	64.51	3.958***
Social capital					
Visited by extension officer	Yes	54.21	33.58	45.68	13.476***
Contract Farming for citrus?	Yes	1.05	1.49	1.23	0.125
Knowledge IPM	Yes	24.21	35.07	28.70	4.532**

*Note: ***, **, * represent significance level at 1%, 5% and 10% respectively.*

Makueni County was characterized by a relatively younger farming community than Machakos though the overall average age shows that the smallholder citrus farmers are comprised of aged people (>56 years). The age difference between farmers from Makueni and Machakos can be attributed to the fact that citrus farming is a key venture in Makueni than Machakos due to its contribution to the household income as observed in the study, attracting a relatively younger age group. The age of farmers might have an effect on both labor contribution and also knowledge and willingness to try new technologies such as IPM. Due to lack of literature for a Kenyan case, the results conformed to those of Ortese *et al*. (2012) who reported that citrus farmers in Nigeria were relatively aged.

The study found that citrus yield was significantly high in Makueni at 13,482Kg/Ha compared to Machakos at 9692Kg/Ha. Citrus yield maybe influenced by farm size, pest and disease management strategies among many other factors. In this study, Makueni farmers had a larger farm than those in Machakos. Education influences knowledge on how to manage pests and diseases on the farm as well as early detection of pests before they reach the economic injury level. The study shows that the average education level was 9. 78 years of schooling meaning most of the farmers had attained secondary school education. The level of education might influence farmers' ability to access information easily and willingness to try out new technologies. Marenya & Barrett (2007) found out that education has a significant positive effect on the likelihood of adoption of improved natural resources management practices in western Kenya and was statistically significant in discouraging abandonment of the practices under study. In addition, Sullumbe (2004) argues that the level of formal education attained by an individual has an influence in shaping his personality, attitude to life and adoption of new and improved practice. The results may therefore lead to allusion that introduction and adoption of new ideas, innovations and technologies such as IPM in the selected counties in Kenya will be successful.

The distance to the nearest pesticide and herbicide dealer in walking minutes for citrus farmers in Machakos and Makueni had a significant relationship at 10% significance level. Closeness to both input and output market enables farmers to participate and have access to timely and reliable market for both inputs and outputs as reported by (Key *et al*., 2000; Makhura *et al*., 2001). Farmers in Makueni had to walk longer distances than those in Machakos to buy pesticides and herbicides. This could have significant effect in pest and disease management and could possibly translate to more losses reported in Makueni than in Machakos in Table 4.2. Makueni farmers reported a significantly higher proportion of farm income (61.02%), as compared to those from Machakos (58.35). Citrus production contributed a larger share of household income in Makueni in comparison with Machakos ($p<0.01$), suggesting that citrus is more significant in Makueni than Machakos. The contribution of citrus to the total household income could be attributed to report by Kilalo *et al*. (2009) that farmers in Machakos were abandoning their orchards and replacing citrus with mango due to prevalence of the greening disease.

Results in Table 4.1 further shows that primary occupation and labor contribution of the household head in the two counties were statistically different at ($p=0.05$ and $p=0.001$) respectively. Although farming was the main occupation in both counties, more respondents in Machakos relied on farming than in Makueni though citrus farmers in Makueni derived a higher proportion of their income from farming than those in Machakos. This was in line with labor contribution by the household head where Machakos was ahead of Makueni in terms of full-time labor allocation.

Concerning the visit to the agricultural extension offices, more farmers in Machakos had visited an agricultural officer than those in Makueni in the last one year prior to the survey. The distance to the nearest extension office could have contributed since it was shorter in Machakos (76.43 walking minutes) than in Makueni (84.36). Contact with an agricultural officer plays a key role in farm management, knowledge about agricultural technologies and social capital. Therefore, farmers who have frequent contact with extension officers may have access to information on biotechnologies such as IPM, how to manage pests such as ACT and FCM as well as expected higher adoption rates of IPM. Another factor that could explain the more visits to extension offices by farmers in Machakos could be sought for knowledge on the changing cropping pattern from citrus to mangoes and avocadoes as reported by (Kilalo *et al*., 2009).

According to the study, knowledge on Integrated Pest Management was minimal. A significant difference on knowledge of IPM among farmers from the two regions was observed. Makueni citrus farmers were more aware of IPM than those in Machakos. Awareness of how manage pests and diseases using IPM among other management practices other than use of pesticides influence cost of production and intern the total income from the venture. The more knowledgeable Makueni farmers are about IPM compared to those of Machakos can be linked to the higher contribution of income from citrus to total household income for Makueni households than in Machakos since they are able to cut on production costs.

4.2 Magnitude of Citrus Crop Loss Due to ACT, HLB and FCM

Following De Groote (2002) citrus crop loss in this study was calculated as the difference between expected yield in absence of the diseases Y_p and actual yield in presence of the diseases Y_r, holding other factors constant such as climate change, natural disasters for instance drought or flooding. In this study, crop loss was calculated from the ratio of proportional loss of citrus fruits due to various pests and diseases (r). Ratio r was obtained directly from farmers' estimate and then citrus yield losses were derived from actual yield in presence of FCM, ACT pests and HLB disease. Table 4.2 displays the magnitude of citrus crop loss. Results suggest that both counties suffered huge production loss due to ACT, HLB and FCM. The implication for the production loss is that producers lose revenue, incur high production cost in pest and disease management as well as lowering of national GDP through low output and limited ability to trade in the export market due to stringent phytosanitary rules.

Table 4.2: Citrus Crop Loss Due to African Citrus Triozid, False Codling Moth and the Greening Disease

Variables	Machakos		Makueni		Overall	
	N	Mean	N	Mean	Mean	T-test
Citrus farm size (Hectares)	190	0.32	134	0.40	0.35	-1.160
Citrus yield (kg/Ha)	182	9,692	132	13,482	11,285	-2.324**
Crop loss ACT (kg/Ha)	118	772.94	90	1,144.79	933.88	-1.90*
Crop loss FCM (kg/Ha)	151	2,021.09	103	2,945.65	2,396	-1.382
Crop loss HLB (kg/Ha)	146	1,527.28	99	1,529.73	1,528.27	-0.004
Crop loss all pests(kg/Ha)	182	3,786.54	132	5,374.40	4,454.05	-1.674*
Crop loss all diseases(kg/Ha)	182	2,558.42	132	3,804.91	3,082.42	-1.465
Total citrus quantity sold (Kg)	167	1562.05	123	3235.55	2271.84	-3.936***
Average price for citrus fruits (USD/Kg)	167	0.262	123	0.277	0.268	-0.808

*Note: *, ** and *** represent significance level at 10%, 5% and 1% respectively*

According to farmers' estimates, the proportion of citrus loss due to ACT was higher in Machakos (9.37%) than in Makueni (7.83%) as shown in Table 4.2. This was in line with expectation of the study, since African citrus Triozid does not survive in extreme hot temperatures. Under hot dry weather, eggs and nymphs are very vulnerable to desiccation. Espinosa and Hodges (2009), the pest have a preference of cool moist areas with an altitude over 500-600 meters like Machakos which has an altitude of 1000 to 2100 meters above sea level unlike Makueni which is a semiarid region low above the sea level.

On Average, citrus producers lost up to 933.88 Kg/Ha and 772.94, 1144.79 in Machakos and Makueni County respectively due to ACT. With an average price of citrus per Kilogram at USD 0.262 and 0.277 as reported in the study, producers are suffering an economic loss of USD 202.36 and USD 317.11 per hectare in Machakos and Makueni County respectively. HLB is vectored by ACT and the proportion of crop loss due to the disease was therefore higher in

Machakos (10.98) than Makueni (10.03) resulting to an average economic loss of about USD 409.58 per hectare. Greater losses were reported in other studies such as de Miranda *et al*. (2012) who examined yield loss caused by HLB in Brazil. He further noted that it would come a point in time where the tree no longer produces fruit and dies from the HLB infection. Honeydew excreted by Triozid coats the outside of the fruit and leaves which promotes development of sooty mold fungus that deters photosynthesis weakening the plant as well making the fruit unattractive (Hodges & Spreen, 2006). Lower productivity and marketability is therefore observed.

Citrus crop loss attributed to False Codling Moth corresponded to the expectation of this study as Makueni had the highest prevalence of the pest at 16.29% in comparison to Machakos at 15.27%. This study estimated about USD 529.53/Ha and USD 815.95/Ha losses in Machakos, Makueni respectively and an average of USD 642.13/Ha. Total economic losses in each county brought about by all pests and disease were USD 4,456.85/Ha in Machakos county and USD 6,428.36/Ha in Makueni county. Other than ACT, FCM and HLB, other pests and disease as well as farm practices contribute to citrus crop loss. Some of other pests reported from the study include; mealy bug, citrus thrips, red spider mite, scales, aphids, citrus leaf miner, fruit flies, *pseudocercospora angolensis*, sooty mould, anthracnose, citrus canker, bacterial spot among others. Data on citrus production from the previous season prior to the survey showed that farmers in Makueni produced almost twice of the production in Machakos. Machakos recorded lower citrus yield than Makueni. This can be attributed to the fact that farmers in Machakos are slowly replacing citrus with mango and avocado due to the persistent problem of ACT and the Greening disease which dries off the tree (Kilalo *et al*., 2009). Figure 4.1 further illustrates the proportion of crop losses due to ACT, FCM and HLB in Machakos and Makueni counties.

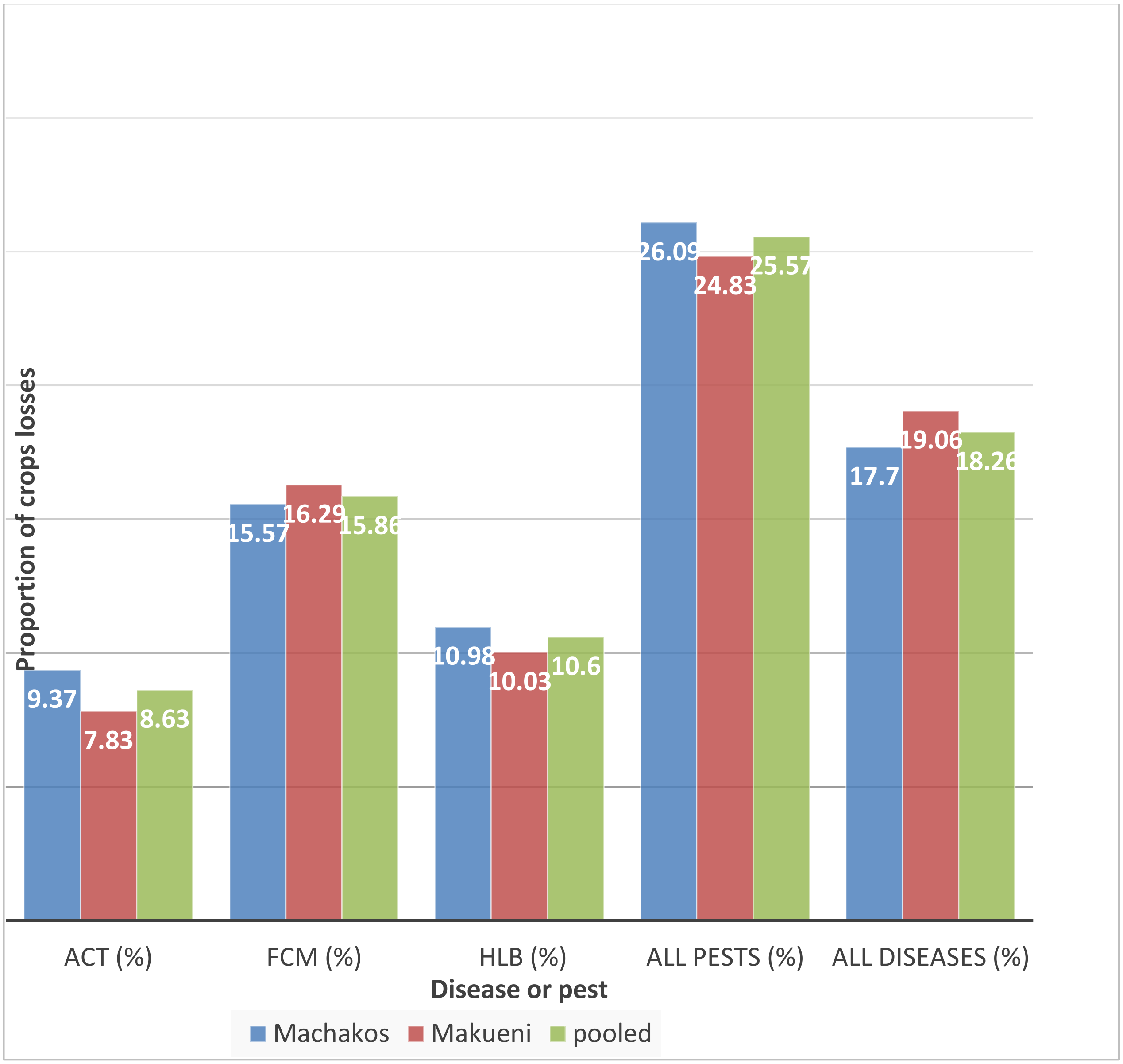

Figure 4.1: Proportional citrus yield losses

4.3 Potential Returns of Citrus IPM, Data, and Assumptions

The simulation of benefits of Integrated Pest Management (IPM) for citrus was done using DREAM 3.0 software developed for IFPRI by Wood *et al*. (2001). DREAM calculates and analyzes the benefits derived from technological change for instance IPM intervention, which are measured as producer and consumer economic surplus. Unlike other studies that relied heavily on secondary data and expert opinion, this study combined both farmers' estimates and secondary data. Baseline levels of production were adopted from HCDA (2014) and were consistent with those reported by the Ministry of Agriculture. Farm-gate price was computed from the primary data and compared well with that reported by the Ministry of Agriculture. Some of the proposed IPM components for management of citrus pests and diseases include; spot application of food bait, male annihilation technique, use of bio-pesticide, releases of parasitoids and use of orchard sanitation. Table 4.3 presents research costs over time for development and dissemination of IPM package for control of ACT, HLB and FCM.

Table 4.3: Research and Dissemination Expenditure

YEAR	AMOUNT (000' USD)
2015	672
2016	672
2017	320
2018	2404

Source: *icipe* Project documents

4.3.1 Parameters for the Economic Surplus Model

Estimates for price elasticity of supply and demand for citrus in Kenya or related countries could not be found in the recent literature. In this study, it seems that the only practical option was to approximate demand and supply elasticities. Domestic price elasticity of demand for a given commodity can be obtained from: published results of previous studies, estimation of demand equations and approximations using economic theory (Alston *et al*., 1995). Fundamentally, the demand elasticity depends mainly on the commodity. Since citrus has high rate of substitutability in consumption, its demand is more elastic than a commodity with lower substitutability. This study assumed a demand elasticity following Jedele *et al.* (2003) finding that, in developing countries the price elasticity of demand for tropical fruits is estimated to be –0.71.

According to Alston *et al.* (1995), most published elasticities of supply for agricultural products fall between 0.1 and 1. Further, Rao (1989) estimated the agricultural supply response to prices in developing countries and found crop-specific acreage elasticities varied from 0 to 0.8 in the short-run and from 0.3 to 1.2 in the long-run for a wide variety of crops. The supply elasticities depend on a number of factors such as long run or short run, the supply elasticity of the factors used to produce a commodity, the ease of factor substitutability and the nature of economies of size and scale in a given industry. Considering citrus is a perishable product with no alternative storage for the farmers and mainly produced by small scale farmers hence not enjoying economies of scale, this study estimated elasticity of supply to be 0.8 following further findings by (Napasintuwong & Traxler, 2009). The IPM technology being in the development stage, estimates of yield change and expected cost reduction as well probability of IPM success were estimated from literature and discussion with team of experts. Since the citrus farmers were currently using synthetic pesticides to manage the pests and diseases, the study assumed that there is expected cost savings. Further it is assumed that the cost of IPM package will be lower than the current cost of production in regard to pesticides. Table 4.4 summarizes parameters assumed in each scenario for the simulations.

Table 4.4: Parameters Used for the Economic Surplus Model

Parameter		**Source**
Elasticity of supply (ε)	0.8	Napasintuwong & Traxler (2009)
Elasticity of demand	-0.71	Jedele *et al.* (2003)
Expected yield gain	70%	Ekesi *et al*. (2014)
Expected reduction in cost	45%	Icipe (2015)
Probability of success in R&D	75%	Muriithi *et al.* (2015)
Discount rate	10%	AFC Bank (2017)

Table 4.5: Predicted Adoption Rates of IPM for Suppression of ACT, FCM and HLB

Year	Percentage (%)
1	38
2	58
3	61.73
4	62.04
5	62.35
6	62.65

The study results show that if IPM is released in 2018, the minimum adoption rates are quite high at 38% as shown in Table 4.5, this concurs with those reported by Ainembabazi *et al.* (2015) on adoption rates of Genetically Modified Banana for control of Xanthomonas Wilt. The high initial adoption rates could be attributed to the high magnitude of crop loss due to the citrus pests and diseases. With the first year of release expected to be 2018, the maximum adoption rate would be 80% within an adoption lag of nine years. However, the adoption path was simulated over 15 years.

Figure 4.2 further presents potential willingness to adoption of IPM by sampled citrus farmers. The majority intends to adopt immediately after dissemination to limit the spread of FCM, ACT and HLB and reduce huge economic losses associated with these pests and disease. Others would delay adoption possibly to learn the effects and performance of IPM from early adopters.

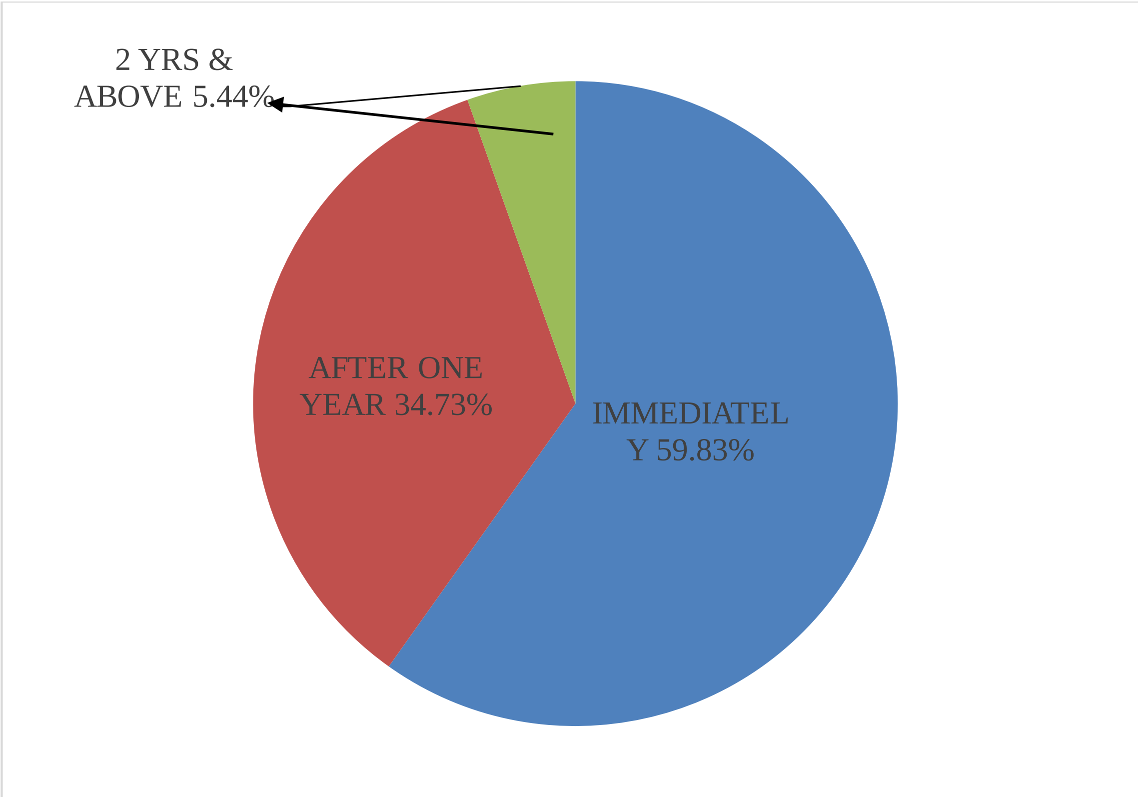

Figure 4.2: Predicted Adoption Rates of IPM for Suppression of ACT, FCM and HLB

4.3.2 Simulation Results

Table 4.6 shows the simulated supply and demand equilibrium changes of quantities of citrus produced and consumed. A closed economy was assumed in this case. Citrus produced and consumed was assumed to remain constant for four years during the research and development stage of IPM as other factors that could lead to changes in production and consumption data were disregarded. The scenario assumes fixed consumption and production data as the interest of the study is to estimate the change brought about by research (IPM) only. After full dissemination of IPM technology to farmers, both quantity demanded and supplied will start to rise as farmers start feeling the effect of IPM through higher yields and consumers can now buy more at a lower price. Farmers on the other hand sell at a lower price but maximize their profits through trading more volume.

Table 4.6: Projected Benefits ('000USD), changes in produced and consumed quantities (‘000 MT) and prices (USD) due to IPM intervention

	Producers					Consumers				
Year	No IPM		With IPM			No IPM		With IPM		
	Price	Quantity	Price	Quantity	Benefits	Price	Quantity	Price	Quantity	Benefits
2015	268.8	140.3	268.8	140.3	0.0	268.8	140.3	268.8	140.3	0.0
2016	268.8	140.3	268.8	140.3	0.0	268.8	140.3	268.8	140.3	0.0
2017	268.8	140.3	268.8	140.3	0.0	268.8	140.3	268.8	140.3	0.0
2018	268.8	140.3	268.8	140.3	0.0	268.8	140.3	268.8	140.3	0.0
2019	268.8	140.3	266.9	140.9	230.9	268.8	140.3	266.9	140.9	260.2
2020	268.8	140.3	263.7	142.1	635.0	268.8	140.3	263.7	142.1	715.5
2021	268.8	140.3	255.8	145.1	1643.7	268.8	140.3	255.8	145.1	1852.0
2022	268.8	140.3	240.1	150.9	3710.6	268.8	140.3	240.1	150.9	4180.9
2023	268.8	140.3	218.8	158.8	6631.4	268.8	140.3	218.8	158.8	7472.0
2024	268.8	140.3	201.3	165.3	9151.7	268.8	140.3	201.3	165.3	10311.8
2025	268.8	140.3	191.8	168.8	10555.7	268.8	140.3	191.8	168.8	11893.8
2026	268.8	140.3	187.8	170.2	11155.3	268.8	140.3	187.8	170.2	12569.4
2027	268.8	140.3	186.3	170.8	11382.1	268.8	140.3	186.3	170.8	12824.9
2028	268.8	140.3	186.3	170.8	11382.1	268.8	140.3	186.3	170.8	12824.9
2029	268.8	140.3	186.3	170.8	11382.1	268.8	140.3	186.3	170.8	12824.9

Figure 4.3 shows benefits from research measured in economic surplus grow at a slow rate initially but then rises steadily until maximum adoption is reached and economic surplus becomes constant. According to the figure, research benefits to consumers measured as consumer surplus rise more steadily than those of enjoyed by producers.

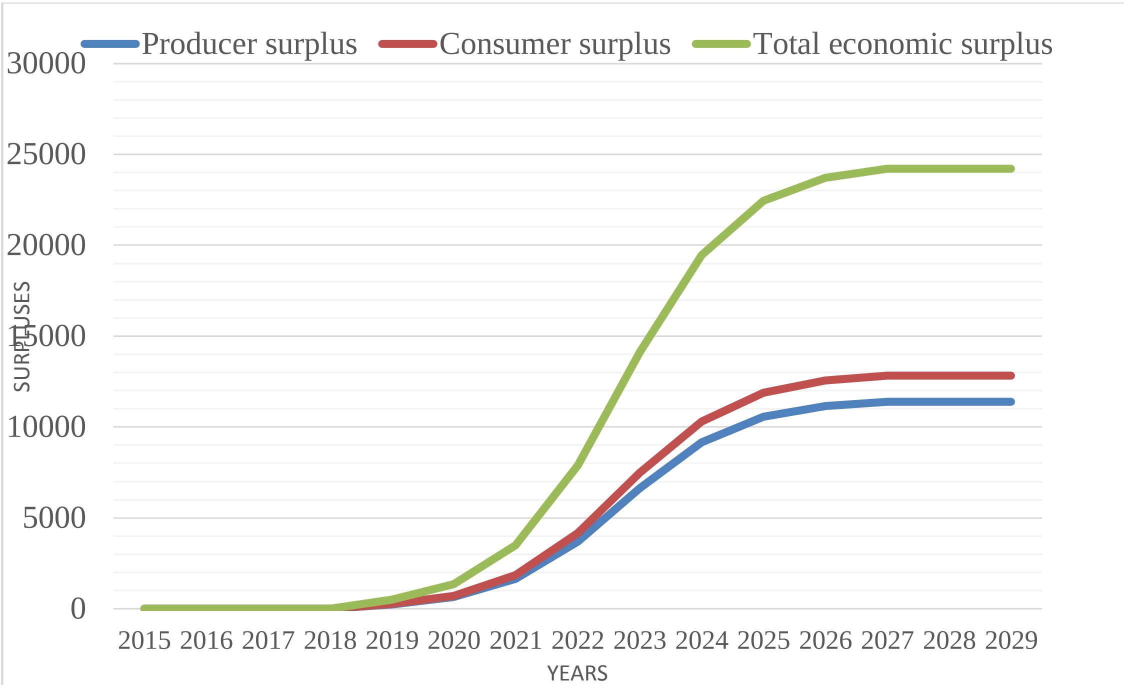

Figure 4.3: A comparison of Economic surpluses over time

The *ex-ante* analysis of a 15-year period at 10% discount rate show that research costs is highest during the IPM development stage. The economic surplus during this period is zero and the net present value reflecting the net benefit of IPM technology in present value remains negative until dissemination and spread of IPM is started. After the full roll out of IPM, the surplus resulting from IPM becomes positive and substantial every year in the period considered for simulation. Consumers gain more than producers with consumer surplus at USD 28,984,900 while producer surplus is at USD 25,690,300, as shown in Table 4.7. Producers gain by producing more but losses to consumers through lower prices. Producers however gain since the prices fetched are beyond the cost of production incurred and they can produce and sell more at lower cost since the technology is assumed to be cost saving and farmers will use less or no synthetic pesticides. By producing higher quality fruits and complying with MRLs thresholds, the producers may now be able to explore export market with ease though this study did not focus on that. More production would also mean that if the local demand is met, opportunity for export market arises fetching the economy more income through foreign exchange.

Table 4.7: Producer, Consumer and Total Economic Surplus ('000USD) over Time

Year	Producer Surplus	Consumer Surplus	Total Economic Surplus	Costs	NPV
2015	0.0	0.0	0.0	672.0	-672.0
2016	0.0	0.0	0.0	672.0	-672.0
2017	0.0	0.0	0.0	320	-320
2018	0.0	0.0	0.0	2404	-2404
2019	230.9	260.2	491.2	0.0	491.2
2020	635.0	715.5	1350.5	0.0	1350.5
2021	1643.7	1852.0	3495.7	0.0	3495.7
2022	3710.6	4180.9	7891.5	0.0	7891.5
2023	6631.4	7472.0	14103.5	0.0	14103.5
2024	9151.7	10311.8	19463.6	0.0	19463.6
2025	10555.7	11893.8	22449.6	0.0	22449.6
2026	11155.3	12569.4	23724.8	0.0	23724.8
2027	11382.1	12824.9	24207.0	0.0	24207.0
2028	11382.1	12824.9	24207.0	0.0	24207.0
2029	11382.1	12824.9	24207.0	0.0	24207.0
PRESENT VALUE SUMMARIES					
PRODUCER	CONSUMER	TOTAL	NPV	IRR	BCR
25690.3	28946.9	54637.3	51283.7	60.30%	16.29

Consumers on the other side benefit more since their purchasing power is enhanced and they can buy more for less. Those who could not afford at previous prices can do so. The higher buying power could also translate to economic saving since less is needed to buy more and therefore the resources channeled in other needs. Consumers will also benefit by consuming more quality fruits. Less environmental and health related issues associated with spraying of synthetic pesticides also sums up total economic surplus. Reduced pests and diseases resistances will also be achieved but this study did not quantify that.

Results show an impressive net present value (NPV) of USD 51,283,700. The NPV suggests that investment in IPM is not only essential but also economically viable. Returns on investment in IPM as estimated were 60.30%. This is above the cost of capital and even when NPV is zero, IRR shows that IPM compares well with other alternative capital investments. Further, the BCR estimates are high at 16.29:1. This suggests that IPM is feasible and has great potential to create a stream of paybacks in excess of costs as to every dollar invested in IPM development and dissemination gives a return of 16 times more.

4.4 Sensitivity Analysis

4.4.1 Effect of Discount Rate

There exists an inverse relationship between discount rate and Net present value. When discount rate rises, NPV declines. Varying discount rates is therefore critical in determining the feasibility of a project. Internal rate of return (IRR) is the interest rate at which the net present value of all the cash flows from a project or investment equal zero. IRR is used to evaluate the attractiveness of a project. In this study, the IRR is high enough such that it would not occur under normal economic scenario for discount rate to rise above it. The study therefore did not find need to lower the discount rate further since lowering the interest rates would mean higher Net Present Values. Under ideal economic scenario, it would be hard for interest rate to rise up to 60%, the study however considered rising the discount rate to show the rate at which the economic surplus would vary.

Table 4.8: Sensitivity Analysis with Respect to Varying Discount Rate (Economic Surplus in 000' USD)

Parameters	Producer Surplus	∆%	Consumer Surplus	∆%	Total Surplus	∆%	B/C	IRR (%)
Initial scenario	*25690.39*		*28946.92*		*54637.32*		*16.29*	*60.33*
(Baseline = 10%)								
12%	20947.76	-18.5	23603.11	-18.5	44550.87	-18.5	13.76	60.33
14%	17172.65	-33.2	19349.46	-33.2	36522.11	-33.2	11.67	60.33
20%	9751.39	-62	10987.48	-62	20738.87	-62	7.29	60.33

Raising discount rates to 12%, 14% and 20% lowered the economic surplus at an increasing rate respectively as well as the BCR. IRR remained constant. While a lower discount rate encourage investment, high discount rates discourage investments especially where long-term benefits are spread over a long period of time as in this case.

The results confirm those by Oleke *et al.* (2013) in his study on ex-ante economic analysis of biological control of coconut mite in Benin who found out that with the total discounted value of economic surplus being USD 155,213.40 at a discount rate of 12%, raising the discount rate to 15% economic surplus drops to USD 107,869.10, while the IRR remains the same (13.21%). While when a discount rate of 20% is used, it causes further drop in economic surplus to USD 61,002.80. Affognon (2010) further concluded that a credible and more useful range for the social discount rate is normally about 8-12% per annum, with a most likely value of 10% per year.

4.4.2 Effect of Probability of Success

Baseline probability of success was 75%, assuming a lower value of 25% resulted to a decline in both producer and consumer surplus with same magnitude of 68.5 with BCR and IRR dropping to 5.13 and 36.81 respectively as shown in Table 4.9. The prospected decline is magnificent and means that if the IPM technology is only successful to an extent of 25%, lower benefits would stream from it. However, the technology would still be viable with every dollar invested giving five times more returns. Further analysis by dropping the probability of success to 50% gives a drop in surpluses.

Table 4.9: Sensitivity Analysis with Respect to Varying Probability of Success (Economic Surplus in 000USD)

Parameters	Producer Surplus	Δ%	Consumer Surplus	Δ%	Total Surplus	Δ%	B/C	IRR
Initial scenario	*25690.39*		*28946.92*		*54637.32*		*16.29*	*60.33*
(Baseline = 75%)								
25%	8093.92	-68.5	9119.91	-68.5	17213.83	-68.5	5.13	36.81
50%	16657.38	-35.2	18768.88	-35.2	35426.26	-35.2	10.56	50.90
100%	35192.95	37	39654.03	37	74846.99	37	22.32	67.66

Nevertheless, assuming that the technology would be a success at 100% gives a rise of the economic surpluses by 37%, higher BCR and IRR. IRR and BCR being measure for economic viability of a project, results suggest that even if the probability of research success is below half, the technology would be economically feasible

4.4.3 Effect of Expected Yield Gain and Cost Reduction after IPM Intervention

With the expected reduction in cost of production lowered up to 20%, results show that the technology would still be viable though a drop in economic surpluses, BCR and IRR (Table 4.10). Raising the expected reduction in cost incurred by producers further raises the consumer and producer surplus as well as the BCR and IRR. Both expected yield gain and reduction in cost has an influence in magnitude of supply shift due to intervention of IPM. IPM is expected to result to an increase in productivity and as assumed that it would result to a yield gain of 70%, the returns are still positive even when the yield gain is lowered to extreme of 40%. Changing the expected yield gain to 100% results to an increase of both consumer and producer surpluses with BCR and IRR suggesting that, even when a pessimistic scenario is assumed, IPM technology would still be worthwhile.

Table 4.10: Sensitivity Analysis with Respect to Expected Yield Gain and Cost Reduction (000'USD)

Parameters	Producer surplus	∆%	Consumer surplus	∆%	Total surplus	∆%	B/C	IRR(%)
Initial scenario	*25690.39*		*28946.92*		*54637.32*		*16.29*	*60.33*
With respect to varying expected cost reduction due to IPM intervention (Baseline =45%)								
20%	21499.99	-16.3	24225.35	-16.3	45725.34	-16.3	13.63	56.36
70%	29984.95	16.8	33785.86	16.8	63770.81	16.8	19.01	63.88
100%	35245.45	37.2	39713.18	37.2	74958.63	37.2	22.35	67.69
With respect to varying expected yield gain due to IPM intervention (Baseline = 70%)								
40%	18812.71	-26.8	21197.42	-26.8	40010.13	-26.8	11.93	53.47
100%	33346.26	29.8	37573.26	29.8	70919.52	29.8	21.15	66.37

4.4.4 Effect of Price Elasticities

Price elasticities affect the distribution of benefits between producers and consumers much more than the size of total benefits as demonstrated in Table 4.11.

Table 4.11: Sensitivity Analysis with Respect to Varying Price Elasticities (Economic Surplus in 000USD)

Parameters	**Producer Surplus**	**∆%**	**Consumer Surplus**	**∆%**	**Total Surplus**	**∆%**	**B/C**	**IRR (%)**
Initial scenario	*25690.39*		*28946.92*		*54637.32*		*16.29*	*60.33*
With respect to varying elasticity of supply (Baseline = 0.8)								
0.6	29282.58	14	24745.85	-14.5	54028.43	-1.1	16.11	60.15
1	22879.35	-10.9	32224.43	11.3	55103.78	0.9	16.43	60.47
With respect to varying elasticity of demand (standard = -0.71)								
-0.8875	29057.51	13.1	26119.11	-9.8	55176.61	1	16.45	60.49
-0.5325	21499.69	-16.3	32452.36	12.1	53952.05	-1.3	16.08	60.12

Reducing price elasticity of supply by 25% has a slight negative impact on total estimated benefits but noticeably affects the distribution effects. This reduction in supply elasticity leads to an increase in the absolute unit cost reduction. That is, it raises producer surplus but lowers the purchasing power of consumers by lowering consumer surplus by 14.5%. On the other side, raising price elasticity of supply by 25% has a reverse effect. Though the total benefits are slightly affected, producers enjoy less absolute cost reduction with lower producer surplus by 10.9% while consumers gain by 11.3%. Both BCR and IRR are affected slightly by change in supply elasticity. Lowering the absolute value of demand elasticity by 25% reduces the size of economic surplus benefits slightly by 1% but has significant effect on individual benefits such that while producer surplus rises by 13.1%, consumer surplus drops by 9.8%. BCR and IRR rise slightly. An increase of price demand elasticity by 25% on the other hand lowers the total economic surplus by 1.3%. Both producers and consumers lose and gain with a bigger margin than the lower elasticity of demand by 25% respectively.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study aimed at contributing to strengthening of citrus production systems through assessing the potential economic impact of IPM as well as evaluating the magnitude of citrus yield losses as a result of African Citrus Triozid (ACT), The Greening disease (HLB) and False Codling Moth (FCM). Socio-economic characteristics of citrus farmers that would possibly influence their pest perceptions, pest management strategies and potential constraints to adoption of IPM were also discussed in brief. The main focus of this study was the economic surplus analysis as resources for agricultural research are scarce, efficient allocation is important and understanding the potential viability of a project cannot be underestimated. Further, understanding the potential benefits of IPM would be useful to national policy makers for widespread dissemination and up scaling. The baseline survey findings show that there is little knowledge on IPM and farmers' contact with extension officers is infrequent. Extension services play key role in adoption of any agricultural technology through information sharing.

The magnitude of citrus yield losses as a result of ACT, HLB and FCM were high. ACT and HLB prevailed more in Machakos than Makueni, FCM on the other hand was more prevalent in Makueni. The huge yield and economic losses impact significantly on the livelihoods of the citrus farmers, and thus may render the citrus industry unsustainable if no intervention measures are put in place.

Simulation results show that, Kenyan citrus industry has the potential to derive net benefits from investing in IPM with an NPV of 51,283,700 USD over 15 years that is approximately 3,418,913 USD annually, with internal rate of return of 60.3% and benefit cost ratio of 16.3: 1. Consumers are the major beneficiaries of citrus IPM due to price decline, additional citrus fruit supply and better quality fruits. The persistent high and positive BCR and IRR above the interest rates offered by most financial institution suggests potential sizable returns to investment in the development and dissemination of IPM. IPM adoption is expected to increase yield, reduce cost of production, lower environmental and health issues and improve quality of citrus fruits produced easing penetration of export market through compliance on global food standards and maximum residual levels.

5.2 Policy Recommendations

1. Following the high yield losses due to citrus pests and disease, revenue loss is evident and county governments are losing significant revenues and therefore efforts to curb these losses should be designed swiftly to avoid incurring further losses possibly institutionalization of IPM in the country's national strategy for overall crop protection.

2. The potential returns to investment of IPM are significant and economically viable therefore, *icipe* and partners should guide on development and dissemination of the strategy aiming at arriving maximum adoption and extend the welfare gains to the citrus farmers and consumers, working together with the ministry of Agriculture to ensure there are no cases of dis-adoption.

5.3 Recommendations for Further Research

1. This study assumed a parallel shift of the supply curve; further research may consider a pivotal shift in the supply as well as simultaneous shift of demand and supply curve to evaluate whether there would be parity in economic surplus.

2. Quantification of *ex-ante* impact of IPM on poverty reduction and health and environmental benefits accrued from IPM for citrus were not captured, it would be interesting to have that in future research.

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APPENDICES

Appendix 1: Survey Questionnaire Used for Data Collection

QUESTIONNAIRE MODULES FOR IPM ADOPTION AND IMPACTS STUDY

I am CHARITY MUTHONI WANGITHI, an MSc student at Egerton University in collaboration with *icipe*. I am conducting a baseline survey to establish the current status of citrus production under ACT, HLB and FCM constraints. This is part of a study to evaluate the potential economic impact of an integrated Pest Management (IPM) technology that the International Centre of Insect Physiology and Ecology (*icipe*), wish to develop to deal with citrus related pests and diseases in Kenya. Kindly note that the information offered herein shall be confidential.

MODULE 1. HOUSEHOLD AND VILLAGE IDENTIFICATION

1.1 Household Identification	**Code**		**1.2 Interview details**	**Code**
1. County			**14**. Date of interview (dd/mm/yyyy):	/ / 2016
2.Sub-County			**15.** Time started (24 HR)	
3. Ward			**16**. Name of enumerator	
4. Location			**17**. Name of supervisor:	
9. Name of the respondent (three names):			**GPS reading of homestead**	
10. Sex of respondent 1=Male			**18.** Way point number	
11. Name of respondent's spouse			**19.** Latitude (North)	
12. Cell phone number of household head			**20.** Longitude(East)	
13. Cell phone number of the spouse:			**21.** Altitude (meter above sea level)	

MODULE 2: HOUSEHOLD COMPOSITION AND CHARACTERISTICS AND HOUSING CONDITIONS

2.1 HOUSEHOLD COMPOSITION AND CHARACTERISTICS (Household members-persons who live together and eat together from the same pot (share food), including hired labour, students and spouse living and working in another location but excluding visitors)

ID CODE	Name of household member [Start with respondent]	Sex 1=M 0=F	Relationship to the household head **CODE 1**	Age (complete years)	Marital status? **CODE 2**	Education (years) **CODE 3**	Primary occupation **CODE 4**	How many months in the past year was [NAME] present in the household?	Labor contribution to farms cultivated by household in 2015/2016 **CODE 5**
	AA1	**AA2**	**AA3**	**AA4**	**AA5**	**AA6**	**AA7**	**AA8**	**AA9**
1									
2									
3									
4									
5									

CODE 1	**CODE 2**	**CODE 3**	**CODE 4**	**CODE5**
1.Household head 2.Spouse 3.Son/daughter 4.Parent 5.Son/daughter-in-law 6. Grandson/granddaughter 7.Other relative 8.Hired worker 9.Other, specify……………	1.Married living with spouse 2.Married living without spouse 3.Divorced/separated 4.Widow/widower 5.Never married	0. None/Illiterate 1. Adult education or 1 year of education * Give other education in years (e.g. 2 yrs for std 2, 8 yrs for class 8 etc) 100. Religious education	1.Farming (crop+ livestock) 2.Salaried employment 3.Self-employed off-farm 4.Casual labourer on-farm 5.Casual labouer off-farm 6.School/college child 7.Non-school child 8.Other, specify…………..	1. Full time 2. Part time 3. Not a worker

2.2 INFRASTRUCTURE (all distances in walking minutes)

1. Distance to the village market from residence……….

2. Distance to nearest source of herbicides and pesticides dealer from residence……....

3. Distance to the nearest source of other inputs (seeds, fertilizer,) from residence…….....

4. Distance to the nearest main output market from residence ………

5. Distance to the nearest agricultural extension office from residence …….

6. Distance to the nearest credit source from residence ………………

7. Distance to the nearest health center from residence ……………..

8. Distance to main water source for drinking from residence ……………..

MODEL 3: CIRTUS PRODUCTION AND MARKETING

3.1 Do you grow Citrus (*oranges, lemon, lime, grapefruit, clementine, tangerine ....?* (YES=1 NO=0)

3.2 What proportion of your total annual income comes from Citrus [_______%]

3.3 What percentage of your total annual income is from farm income? [_______%]

3.4 Have you been visited by agricultural extension agents or others in the last **3 YEARS**, who discussed non-pesticides means of controlling pests? [______] 0=No, 1=Yes

3.5 **KNOWLEGDE OF CTRUS PESTS, DISEASES, CONTROL STRATEGIES AND CONSTRAINTS IN ACCESSING KEY INPUTS AND CROP PRODUCTION**

3.5.1 Does False codling moth (FCM) cause damage to your Citrus crop [_______] **1=YES; 0=NO**

3.5.2 If YES, how severe do you believe False codling moth (FCM) are in terms of effects on yield/quality of your mango crops [_______] 1=high, 2= Medium, 3=low

3.5.3 What proportion of the citrus production do you believe you lose due to False codling moth (FCM) [_____%]?

3.5.4 Does African Citrus Trioza (ACT) cause damage to your Citrus crop [_______] **1=YES; 0=NO**

3.5.5 If YES, how severe do you believe African Citrus Trioza (ACT)) are in terms of effects on yield/quality of your mango crops [_______] 1=high, 2= Medium, 3=low

3.5.6 Does Citrus greening cause damage to your Citrus crop [_______] **1=YES; 0=NO**

3.5.7 If YES, how severe do you believe Citrus greening are in terms of effects on yield/quality of your mango crops [_______] 1=high, 2= Medium, 3=low

3.5.8 What proportion of the citrus production do you believe you lose due to African Citrus Trioza (ACT) and greening disease [_____%]? And all types of citrus pests [______%]

3.5.9 What proportion of the citrus production do you believe you lose due all types of diseases [_____%)

3.5.10 List other pests and diseases that affect your citrus crop (codes) Pests [__] [___] [__] [___] Diseases [___] [___] [____] [*Enumerator: use provided photos*]

Citrus insect pests				**Citrus diseases**		
1. Mealybug 2. Pugnacious ant 3.Citrus thrips 4. Beetles	5. Citrus Butterflies 6. Citrus Flower moth 7. Fruit flies 8. Red spider mite & other mites	9. Scales 10. Aphids 11. Bollworm	12. Citrus leaf miner 13. Other (specify)____ 14.	1.Pseudocercospora angolensis (fungal infection) 2. Bacterial blight 3. Citrus nematode	4. Dothiorella blight 5. Sooty mold 6. Anthracnose 7. Armiillaria root rot	8.Citrus canker 9.Bacterial spot 10.Other specify ________

3.5.11 Tell us the symptoms that you identify citrus False codling moth (FCM), African Citrus Trioza (ACT) and greening disease starting with the most common ones [*Enumerator note: Use provided photos to identify different insect pests and diseases symptoms.)*

False codling moth (FCM) symptoms **(CODE A)**	African Citrus Trioza (ACT) symptoms **(CODE B)**	Citrus greening disease symptoms **(CODE C)**
		C6

CODE A	***CODE B***	***CODE C***	
1.Fruit drop 2.Sliced fruits have larvae 3.Fras/excreta on the fruits 4.Black hard/sunken spots of the fruits	1.Pitted citrus leaves 2.Others (specify)_____	1.Yellow shoots 2.Leaf and flower drop 3.Lopsided fruits 4.Small fruits 5.Mottled tree leaves	6.Staining of the seeds and abortion 7.Twigs die back 8.others (specify)

3.5.12 How do you manage/ control the Citrus False codling moth (FCM), African Citrus Trioza (ACT) and greening disease?

Insect and disease	***Type of management/ control method used (****list more than one****)*** ***Code A***				
Citrus False codling moth (FCM),					
African Citrus Trioza (ACT)					
Citrus greening disease					

Code A	
1. Intercropping 2. Using resistant varieties 3. Spraying of plant based pesticides e.g. Neem, pyrethrum etc.	5. Spraying with synthetic pesticides 6. Biological control Irrigation 7. Planting disease/pest free materials 8. Other method (specify) ________

3.6 IPM KNOWLEDGE, SOURCES OF INFORMATION, PERCEPTIONS AND ADOPTION AND DIS-ADOPTION

3.6.1 Have you heard about **Integrated Pest Management or NON-PESTICIDE** practices for control of Citrus FCM, ACT or Greening disease [_______] **CODES 0=No; 1=Yes** (If YES, complete the table below) (*Enumerator note: If farmer says NO, try to probe further by mentioning some of the practices listed below then repeat the question; if NO second time, go to Question **3.6.11)***

Names of IPM component	Do you know [component] **1=yes; 0=no**	Which year did you hear about [component]? **(YYYY)**	How did you first learn about the component? **Code A**	Are you currently (LAST SEASON) using this component? **1=Yes 0=No**	When did you start using this component? **(YYYY)**	Will you continue using [component] in future? **1=Yes 0=No**	If **NO** to **C15**, Give the three main reasons for not wanting to use it **Code B**			If NOT USING currently or didn't use LAST SEASON, were you using and stopped? **1=Yes 0=No**	If **YES to C17,** Give the three main reasons why you stopped wanting to use it **Code B**			Do you know other farmers using this component? **1=Yes 0=No**
C9	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**	**C16a**	**C16b**	**C16c**	**C17**	**C18a**	**C18b**	**C18c**	**C19**
(A) Citrus False Codling Moth (FCM)														
1. Bio pesticide for soil inoculation (MET 69)														
2. Pheromone traps														
3. Last-call pheromone														
4. Orchard sanitation														
5. Other (specify) non-pesticide control method_________														
(B) African Citrus Trioza (ACT) and Citrus greening disease														
1. Bio pesticide														
2. Traps and attractant for African Cirtus Trioza														
3. Removing affected plant parts/chopping sick plant parts														
4. Planting disease free materials														
5. Other (specify) non-pesticide control method__________														

Codes A			**Codes B**		
1. icipe (trials/demos/field days) 2. Govt extension 3. Farmer Coop/Union 4. Farmer group 5. NGO/CBO	6. KARLO (trials/demos/field days 7. other Research centre (trials/demos/field days 8. Agro-dealers 9. Fellow farmers	10. Farmers field school 11. Radio/newspaper/TV 12. Other, Specify….........	1. Not available in the market 2. High prices/cost 3. Lack of cash to buy it 4. Is not effective not prevent the pest/disease	5. Lack of skilled labour to use it 6. Requires intensive labour to set up and monitor 7. No market for the crop 8.Small scale production/ does not sell	9. Lack of enough land 10. Theft during ripe stage 11. Wild animals spoil the crop 12. Other, specify……………….

3.6.2 What is your citrus harvested **area/tress** covered by IPM components? (***Enumerator note****: give the area in acres or trees or both depending on which the farmer prefers)*

	Total area under [crop]		Area under IPM	
	No. of trees	Acres	Area under IPM (acres)	No. of trees under IPM
Citrus crops				

3.6.3 Have you or any other member of the household received any training on Citrus crop management in the last two years [_____] 0=No, 1=Yes

3.6.4 If **YES (Qn. 3.9.12),** complete the table below

Type of training received **CODE A**	Target crop	Who offered the training? **CODE B**	Who in the household was trained? **CODE C**	Who in the household makes decision on who to attend the trainings & other related gatherings/meetings? **CODE C**

CODE A		CODE B		CODE C	
1.Pest and disease management 2.Soil and water use 3.Chemical handling 4.Product handling	5.Record keeping 6.Field hygiene 7.Chemical application 8.Others (specify) ____	1. icipe 2. Govt extension agent 3. Farmer Coop/Union 4. Farmer group 5. NGO/CBO	6. KARLO 7. Agro dealer 8. Fellow farmers 9. Other, Specify….........	1.Household head 2.Spouse 3. Household head and spouse jointly	4.Other household member 5.Other (specify)…………

MODULE 4: CROP PRODUCTION FOR CITRUS CROP GROWN BY THE HOUSEHOLD DURING THE 2015/16 CROPPING SEASON

(Definitions: A plot is a piece of land physically separated from others; a sub-plot is a sub-unit of a plot)

4.1 Please provide the following information about the land used by the household in the last 12 months (also include rented land, and fallow/ grazing land)

	Total agricultural cultivated land			Own land left fallow	Grazing land			Rented out	Home stead land
	Own land	Gift land	Rented-in		Own	Rented-in	Obtained as gift		
Acres									
	If you rented out land, how much did you earn in the last 12 months? Kshs								

4.2 PLOT INFORMATION: AGRICULTURAL PRACTICES, CROPS AND VARIETIES CULTIVATED AND CROPPING AREA OF CITRUS CROP

4.2.1 Citrus crop

Serial No	Plot ID (start with one next to residence)	Plot areas (acres)	Plot location name	Sub-plot ID	Sub plot area (acres)	Inter-cropping on this Sub-plot? (other crops or different citrus fruits? **0=No 1=Yes**	If different Citrus fruits, which ones are intercropped? **CODE 4**	If inter cropping with other crops, what is area under citrus **(acres)?**	Number of young trees (less than 3 years)	Number of trees in production	Average trees **spacing** (Meters)	Sub-plot distance to residence (walking minutes)	Land quality **CODE 1**	Sub-plot tenure **CODE 2**	Who in the hhld owns this sub-plot? **CODE 3**	Who in the hhld makes decisions on mango crops to be planted, input use, and timing of cropping activities on this [Sub-PLOT]? **CODE 3**	Who in the household manage this plot **CODE 3**
1																	
2																	
3																	
4																	
5																	
6																	

CODE 1	**CODE 2**		**CODE 3**		**CODE 4**	
1.Fertile 2.Moderately fertile 3.Infertile	1. Owned 2. Rented/shared in 3. Rented/shared out	4. Borrowed in 5. Borrowed out 6. Other, specify…..	1.Household head 2.Spouse 3. Household head and spouse jointly	4.Other household member 5.Other (specify)………………..	1. Oranges 2. lemon, 3. lime, 4. grapefruit	5. clementine, 6. tangerine 7.Other (specify)……

Enumerator Notes: Decisions on Citrus crop to be planted include the variety to be planted and the plot to be planted; (2) input use decisions include where to acquire inputs, how much to purchase, how much to use mango plot; (3) timing of cropping activities includes other mango management activities such as pruning, weeding, spraying etc. including how much labour to hired and distribution of labour among different plots.

4.3 CROP MANAGEMENT PRACTICES

4.3.1 Citrus management practices

Serial No	Plot ID (as given in 4.3 above)	Sub-plot ID as given in 4.3.2	Plot location name	Irrigated plot? **0=No 1=Yes**	Has this plot suffered from False codling moth (FCM)? **0=No ,1=Yes**	Has this plot suffered from African Citrus Trioza or Citrus greening disease? **0=No, 1=Yes**	Has this plot been treated with the following citrus pests control measures: Traps and attractant for African Citrus Trioza **1=yes; 0=No**	Pheromone traps **1=yes; 0=No**	Last-Call Pheromone **1=yes; 0=No**	Logging or leaving infected plant parts **0=No 1=Yes**	Are the Citrus varieties in this plot resistant to the diseases and pests? **0=No 1=Yes**
1											
2											
3											
4											
5											
6											

4.4 PLOT INFORMATION: UTILIZATION FERTILIZER AND MANURE IN CITRUS PRODUCTION FOR 2015/2016 CROPPING

4.4.1 Citrus crop

Serial No	Plot ID (as given in 4.3 above)	Sub-plot ID (as given in 4.3 above)	Fertilizer use: If no fertilizer was used on plot, write **0** — CAN /NPK/ boosters [sub-PLOT]?: Quantity (kg) **If none put 0**	Total cost (Ksh) **If 0 in A20a, put N/A**	Foliar feeds (sub-PLOT)?: Quantity (kg) **If none put 0**	Total cost (Ksh) **If 0 in A21a, put N/A**	Manure use: If no manure was used on plot, write **0** — 1= Own 0=Bought	If bought manure, total cost paid (Ksh)	Was compost applied to plot? **1=yes; 0=No**
1									
2									
3									
4									
5									
6									

4.5. PESTICIDES, FUNGICIDES, HERBICIDES USE IN CITRUS PRODUCTION AND LABOUR REQUIREMENT FOR APPLICATION FOR 2015/2016 CROPPING

4.5.1 Insecticides and herbicides for Citrus crop

Serial No	Plot ID (as given in 4.3 above)	Sub-plot ID (as given in 4.3 above)	Insecticides application									Herbicides application								Total family labour in person days for insecticide and herbicides in person days		Total hired labour in person days		Cost (if done by hired labour) (Kshs
			Used insecticide **0=No, 1=Yes**	Insecticide name **(Code E)**	Target pest **Code D**	Qnty	Unit **Code B**	Total cost Ksh	Number of application in a season	Source **(Code C)**	Who applied the chemical **(Code A)**	Used herbicides 0=No, 1=Yes	Herbicide name **(Code F)**	Qnty	Unit **Code B**	Total cost-Ksh	Number of application in a season	Source **Code C)**	Who applied the chemical **(Code A)**	Male	Female	Male	Female	
1																								
2																								
3																								
4																								
5																								
6																								

CODE A		**CODE B (Units)**	**CODE C**		**CODE D Citrus insect pests**			**CODE E Insecticides**						**CODE F Herbicides**
1=Head 2=Spouse 3=Household (all) 4=Son	5=Daughter 6=Hired labour ___ 7=Others (specify)	1=grams 2=Kgs 3=Liters 4=Milliliters	**1**=old stock (bought in previous season), **2**=other farmers, **3**=purchased from agrovet	4= farmer group 5= produce buyer 6=other (specify)…………	1.Mealybug 2. Pugnacious ant 3.Citrus thrips 4.Beetles 5.Citrus butterflies 6. Citrus Flower moth	7. Fruit flies 8.Red spider mite & other mites 9. Scales 10.Aphids 11.Bollworm 12.Citrus leaf miner	13. Other (specify)____	1. Acarin, 2. Actara, 3. Actellic 4. Agrinate, 5. Afla cyper 6. Alpha kill	7. Applaund 8. Atom 9. Bestox, 10.Bull dock 11.Brigade 12.Cyclon	13. Denadine 14. Diazol, 15. Dimekil, 16. Dimethoate 17. Dynamec 18. Jackpot	19.Folimat 20. Karate, 21. Kelthane 22. Marshal 23. Mitigan 24. Ogor	25. Polymart 26. Score 27. Simothion 28. Sumithion 29. Sevin 30. Tata Alfa	6. Thunder 7. thionex 8. Tedon 9. Zichron 0. Other (specify) _____	1. Diurex 2. Gramoxone 3. Sulfur, 4. Wetsurf 5. Other (specify)____

Enumerator Note: (1) 6 hours = 1 day; (2)1 person @ 6 hours = 6 man-hours = 1 man-day/person day; (3) 2 people @ 6 hours = 12 man-hours = 2 man-days

4.5.3. Fungicides and bio pesticides for citrus crop

Serial No	Plot ID (as given in 4.3 above)	Sub-plot ID (as given in 4.3 above)	Fungicide application									Bio pesticide application [**ask if mentioned in 3.9.1, otherwise skip]**								Total family labour in person days for fungicides and bio pesticides in person days		Total hired labour in person days		Cost (if done by hired labour) (Kshs
			Used insecticide **0=No, 1=Yes**	Fungicide name **(Code E)**	Target disease **Code D**	Quantity	Unit **Code B**	Total cost Ksh	Number of application in a season	Source (**Code C**)	Who applied the chemical (**Code A**)	Used herbicides 0=No, 1=Yes	Bio pesticide name **(Code F)**	Quantity	Unit **Code B**	Total cost-Ksh	Number of application in a season	Source **Code C**)	Who applied the chemical **(Code A)**	Male	Female	Male	Female	
1																								
2																								
3																								
4																								
5																								
6																								
7																								

CODE A		**CODE B (Units)**	**CODE C**		**CODE D: Citrus diseases**			**CODE E Fungicides**				**CODE F Bio-Pesticides**
1=Head 2=Spouse 3=Household (all) 4=Son	5=Daughter 6=Hired labour ____ 7=Others (specify)	1=grams 2=Kgs 3=Liters 4=Milliliters	**1**=old stock (bought in previous season), **2**=other farmers, **3**=purchased from agrovet	**4**= farmer group **5**= produce buyer **6**=other (specify)…………	1.Pseudocercospora angolensis (fungal infection) 2. Bacterial blight 3. Citrus nematode	4. Dothiorella blight 5. Sooty mold 6. Anthracnose 7. Armiillaria root rot	8.Citrus canker 9.Bacterial spot 10.Other specify ________	1. Aliette, 2. Balyfone, 3. Bendazim,	4. Bayleton, 5. Balyfone 6. Copper	7. Dithane, 8. Nustrar 9. Rodazim	10. Thiovit, 11. Topsin, 12. Other (specify)____	1.Campaign (Metarizium anisoplie, 69)

	Enumerator Note: (1) 6 hours = 1 day; (2)1 person @ 6 hours = 6 man-hours = 1 man-day/person day; (3) 2 people @ 6 hours = 12 man-hours = 2 man-days

4.6 What is the cost of hiring casual laborer in your village (Ksh/day)[__________]

4.7 How effective are the pesticides you use to control Citrus pests and diseases? [________] 1=effective; 2=not effective; 3= do not know

4.8 Who makes decision about pesticide use on your farm? (*code)/*__________/

1=Head	2=Spouse	3=Both head & spouse	4=Eldest son	3=Daughter	4=Produce buyer	5=Extension staff	6=Other (specify)____________

4.9 Do you have a separate storage place for chemicals and its equipment? /____/ (0=No, 1=Yes)

4.10 If NO, where do you store your pesticides? (code) /_______________/

1=Field	2=Granary	3=House	4=Others (specify)

4.11 Have you or any person in your household trained in First aid? /____/ (0=No, 1==Yes)

4.12 **Labour required for each CITRUS agricultural operation for 2015/2016 cropping**

4.12.1 Citrus crop

Serial No	Plot ID **[as given in 4.3 above]**	Sub-plot ID [as given in 4.3.2 above**]**	**Digging up**[*if planted in 2015/2016]*				**Weeding**				**Manure application**				**Fertilizer application**				**Pruning**			
			Total family labor in person days		Total hired labor in person days		Total family labor in person days		Total hired labor in person days		Total family labor in person days		Total hired labor in person days		Total family labor in person days		Total hired labor in person days		Total family labor in person days		Total hired labor in person days	
			Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
	A2	A3	A37a	A37b	A37c	A37d	A38a	A38b	A38c	A38d	A39a	A39b	A39c	A39d	A40a	A40b	A40c	A40d	A41a	A41b	A41c	A41d
1																						
2																						
3																						
4																						
5																						
6																						

4.13**Labour required for <u>CITRUS</u> agricultural operation *and production* for 2015/2016 cropping**

4.13.1 Citrus Crop

Serial No	Plot ID **[as given in 4.3 above]**	Sub-plot ID **[as given in 4.3 above**]	**Harvesting labour**				**Citrus production lost due to FCM & ACT CODE A**		**Citrus production lost due to diseases CODE A**		**Total Production net pest and disease damages (this include citrus consumed at home before harvest) CODE A**	
			Total family labor in person days		Total hired labor in person days							
			Male	Female	Male	Female	Qnty	unit	Qnty	unit	Qty	unit
1												
2												
3												
4												
5												
6												

CODES A				
1=pieces	3=4kgs carton	5=17kgs bucket	7=90kgs bag	9=Quintal (1Qt=48.95Kgs)
2=crate	4= 6kgs carton	6=50 kgs bag	8=120 kg bag	10= Other (specify)

Utilization & Marketing of CITRUS in 2015/2016 SEASON

4.13.2 Citrus

		Total production		Total quantity sold			Total consumed at home		Gift/donation		Post-harvest loss					Who make the decision to sale?	Who receives the money when sold?	Management of income from citrus sales		
	Citrus	Qty	Unit **Codes A**	Qty	Unit **Codes A**	Price per unit	Qty	Unit **Codes A**	Qty	Unit **Codes A**	Qty	Unit **Codes A**	Main buyer **Codes B**	Actual transport cost **(KSh)**	Who sold **1. Male 2. Female 3. Jointly**	**1. Hhld head 2. Spouse 3. Jointly 4. Other hhld member**	**1. Head 2. Spouse 3. Jointly 4=other hhld member**	%by male	%by female	% by both
1	Orange																			
2	Lemon																			
3	Lime																			
4	Grapefruit																			
5	Clementine																			
6	Tangerine																			
7	Other (specify)																			

CODES A					**CODES B**			
1=pieces 2=crate	3=4kgs carton 4= 6kgs carton	5=17kgs bucket 6=50 kgs bag	7=90kgs bag 8=120 kg bag	9=Quintal (1Qt=48.95Kgs) 10. Other (specify)	1. Farmer group 2. Farmer Union or Coop	3. Consumer or other farmer(s) 4. Local trader	5. Non-local trader 6. Exporter	7. Other, specify…….

4.14 . Do you have a contract for Citrus production/ marketing? [_________] **1.Yes 0.NO**

5.0 AN IPM STRATEGY FOR ACT, HLB AND FCM AS AN ALTERNATIVE TO HARMFUL PESTICIDES

- Although chemical pesticides have been extensively used by farmers to control insects and pests to produce high quantities of citrus, the pesticides and their handling practices expose growers and their environment to chemical risks.
- Immediate health effects include discomforts ranging from eye irritation, skin problems, nausea, headache, vomiting, convulsions, temporary paralysis and unconsciousness. Exposure to pesticides for longer periods may result to depression, muscle weakness and cancer complications, which may be difficult to treat.
- Synthetic pesticides also present a huge threat to beneficial insects, for instance bees that facilitate pollination. When sprayed near water bodies, the chemicals may kill valuable animals such as fish and others that live in the water, in addition to contaminating sources of drinking water (surface and ground water).
- Chemical residues in the fruits **reduce their marketability**, especially in the lucrative markets in Europe and other continents, resulting to loss of trade opportunities and limited returns from the fruit enterprises, besides being expensive and unaffordable to majority of the resource poor farmers.
- *Icipe* and partners intend to develop more sustainable alternative pest management approach**- Integrated Pest Management (IPM) strategy** – that reverse the above problems and lead to positive economic, environment and social impacts. The management strategy minimizes dependence on use of

chemical pesticides, reduces citrus fruits losses, increases returns, and in addition reduces health and environmental risks associated with use of chemical use. IPM strategy comprises 1) Spot application of food biat; 2) Male Inhalation technique, 3) Biopesticides, and 4) Orchard Sanitation.

5.1 Scientists in Kenya are doing research to develop an integrated pest management strategy (IPM) for effective suppression of False codling moth (FCM). The strategy will replace the expensive and harmful chemical pesticides that you are currently using to manage this pest.

5.1.1 Would you be willing to adopt the strategy [__________]?

0. Immediately 1. After 1 year	2. After 2 years 3.After how many years? Specify__________	4. Other (specify)________

5.1.2 What proportion of your Citrus farm you believe will be covered by the IPM strategy that increases income and replace the expensive and harmful chemical pesticides at the following periods?

	Citrus area in acres	Number of citrus trees
1. Initial application		
2. 1 year later		
3. 3 years later		
4. 5 years later		

5.2 Scientists in Kenya are doing research to develop an integrated pest management strategy (IPM) for control of African Citrus Trioza (ACT) and the Citrus greening disease. The strategy will replace the expensive and harmful chemical pesticides that you are currently using to manage this pest and disease.

5.2.1 would you be willing to adopt the strategy [__________]?

0.Immediately 1.After 1 year	2. After 2 years 3. After how many years? Specify__________	4. Other (specify)_______

What proportion of your Citrus farm you believe will be covered by the IPM strategy that increases income and replace the expensive and harmful chemical pesticides at the following periods?

	Citrus area in acres	Number of citrus trees
1. Initial application		
2. One year later		
3. 3 years later		
4. 5 years later		

MODULE 6: LIVESTOCK OWNERSHIP AND PRODUCTION

6.1: LIVESTOCK OWNERSHIP, MARKETING AND PRODUCTION COSTS IN THE LAST 12 MONTHS

No	Animal type	Does the household own […] **0=No; 1=Yes**	Total owned by household	Value of each if sold today **KSh**	Production and Marketing		
					Did the hhld sell […]? **0=No; 1=Yes**	Quantity sold (Number)	Average selling price **KSh**
	B29	**B30**	**B31**	**B32**	**B33a**	**B33b**	**B33c**
1	Indigenous cows						
2	Cross bred/exotic cow						
3	Oxen						
4	Bulls						
5	Heifers						
6	Calves						
7	Small livestock (goats + sheep)						
8	Pig						
9	Donkeys						
1	Horse						
11	Mule						
12	Poultry (local chicken, improved chicken, ducks, etc.)						

MODULE 7: HOUSEHOLD ASSETS, ACCESS TO CAPITAL AND INFORMATION

7.1 PRODUCTION EQUIPMENT AND MAJOR HOUSEHOLD FURNITURE

Asset Category	*Asset type*	Does the household own [...]:1= **Yes 0=No**	Total owned by Household	Current Value each **KSh)** if you can sell [item] today	Total value [**D3*D4**) (KSh)
	D1	**D2**	**D3**	**D4**	**D5**
Farm implements	Sickle				
	Hoe				
	Spade or shovel				
	Axe				
	Knapsack sprayer				
	Ox-plough				
	Water pump (manual)				
	Water pump (motorized)				
	Tractor				
Transport	Horse/mule cart				
	Donkey/oxen cart				
	Horse/mule saddle				
	Push cart				
	Bicycle				
	Motorbike				
	Car				
Household Furniture	Improved charcoal/wood stove				
	Kerosene stove				
	Water carrier				
	Fridge,				
	Table, sofas, chairs, and beds				
Communication	Radio				
	Mobile phone				
	Cassette or CD player				
	TV				
Jewelry	Gold,				

Asset Category	*Asset type*	Does the household own [...]:1= **Yes 0=No**	Total owned by Household	Current Value each **KSh)** if you can sell [item] today	Total value [**D3*D4**) (KSh)
	Silver,				
	Wristwatch				
Trees	Fruit trees				
	Other trees (e.g. eucalyptus)				
Land	Land owned (ha)				
House	House				

MODULE 8: SOCIAL CAPITAL, NETWORKING AND INFRASTRUCTURE

8.1: PARTICIPATION IN RURAL INSTITUTIONS

Variable Code	Institution Type	Are you currently a member of any of the following group? **0=No; 1=Yes**		Variable Code	Institution Type	Are you currently a member of any of the following group? **0=No; 1=Yes**	
D6	**D7**	**D8a**	**D8b**		**D7**	**D8a**	**D8b**
		Husband	**Wife**			**Husband**	**Wife**
1	Savings and credit association			6	Crop marketing group		
2	Merry-go-round			7	Women's Association/group		
3	Input supply group, farmer cooperative union			8	Youth Association		
4	Crop or seed production group			9	Church/mosque association/ congregation		
5	Water User's Association			10	Development group (*nyumba kumi*)		
CODE A	**1=**Head	2=Spouse	3=Household (all)	4=Son 5=Daughter	6=Hired labour	7=Others (specify) _____	

MODULE 9: HOUSEHOLD INCOME FOR THE LAST 12 MONTHS

What was your household's income from the following sources during the past 12 months? (*Include the income of all household members listed*)

What is the contribution of the following income sources to the total annual household income (%) – Enumerator: use 10 maize grains to represent total household annual income and then ask the contribution of each income source to the total annual income:

Income source	Did the household earn income? **0=No; 1=Yes**	Total income for the past 12 months		
		Cash **(KSh)**	In-kind (cash equivalent in **(KSh)**	Total **(KSh)**
	F20	**F23a**	**F24b**	**F25c**
1. Income from salaried employment				
2. Income from machinery services for other farms (plowing etc.)				
3. Income from casual labor (on-farm)				
4. Income from casual labor (off-farm)				
5. Income from own **non-agricultural** businesses (shops, saloons etc)				
6. Income from non-farm agribusiness (grain milling, grain trading etc)				
7. Selling charcoal, brick making, selling firewood etc				
8. Pensions				
9. Remittances from family members/friends who do not live in the household				
10. Revenues from leasing/renting out land				
11. Gift				
12. Other sources (specify)…………				

Appendix 2: Calculation of Change in Total surplus due to IPM

Parameter	**Formula**
Elasticity of supply	$\varepsilon = \frac{\Delta Qs}{Qs} \div \frac{\Delta Ps}{Ps}$
Elasticity of demand	$\eta = \frac{\Delta Qd}{Qd} \div \frac{\Delta Pd}{Pd}$
Proportionate increase in yield (%)	$\mathrm{E}(Y) = (Q_1 - Q_0) \div Q_0$
Cost change (%)	$\Delta C = E(Y)/\varepsilon$
vertical shift of the supply function at time t (Kt)	$K = \left(\frac{\Delta y}{\varepsilon} - \frac{\Delta C}{1 + \Delta Y}\right) * At$
Relative reduction in price (%)	$Z = \frac{K\varepsilon}{(\varepsilon + \eta)}$
Initial equilibrium price (before IPM)	P_0
Quantity (before research induced change)	Q_0
Change in consumer surplus	$\Delta CS_t = P_0 Q_0 Z(1 + 0.5 Z_\eta)$
Change in producer surplus	$\Delta PS_t = P_0 Q_0 (K - Z)(1 + 0.5 Z_\eta)$
Change in total surplus	$\Delta TS_t = P_0 Q_0 K(1 + 0.5 Z_\eta)$
Net Present Value	$NPV = \frac{\sum(\Delta TS_t - RC_t}{(1+i)^t}$

Appendix 3: DREAM Analysis Output

Year	K Total	K Base	K Spill	K Var	Price NoR&D	Price R&D	Production: R&D change in Price	Production: R&D change in Quantity	Production: Value of Productn	Production: Benefits /VoP (%)	Consumption: R&D change in Price	Consumption: R&D change in Quantity	Consumption: Value of Consumptn	Consumption: Benefits /VoC (%)
2015	0.00	0.00	0.0	0.00	268.8	268.8	0.00	0.0	37715	0.0	0.00	0.0	37715	0.0
2016	0.00	0.00	0.0	0.00	268.8	268.8	0.00	0.0	37715	0.0	0.00	0.0	37715	0.0
2017	0.00	0.00	0.0	0.00	268.8	268.8	0.00	0.0	37715	0.0	0.00	0.0	37715	0.0
2018	0.00	0.00	0.0	0.00	268.8	268.8	0.00	0.0	37715	0.0	0.00	0.0	37715	0.0
2019	3.49	3.49	0.0	0.00	268.8	266.9	-1.85	0.6	37638	0.6	-1.85	0.6	37638	0.6
2020	9.56	9.56	0.0	0.00	268.8	263.7	-5.06	1.8	37499	1.6	-5.06	1.8	37499	1.9
2021	24.49	24.49	0.0	0.00	268.8	255.8	-12.97	4.8	37124	4.4	-12.97	4.8	37124	4.9
2022	54.19	54.19	0.0	0.00	268.8	240.1	-28.71	10.6	36241	10.2	-28.71	10.6	36241	11.5
2023	94.30	94.30	0.0	0.00	268.8	218.8	-49.96	18.5	34757	19.0	-49.96	18.5	34757	21.4
2024	127.37	127.37	0.0	0.00	268.8	201.3	-67.48	25.0	33282	27.4	-67.48	25.0	33282	30.9
2025	145.25	145.25	0.0	0.00	268.8	191.8	-76.95	28.5	32390	32.5	-76.95	28.5	32390	36.7
2026	152.77	152.77	0.0	0.00	268.8	187.8	-80.93	29.9	31994	34.8	-80.93	29.9	31994	39.2
2027	155.59	155.59	0.0	0.00	268.8	186.3	-82.43	30.5	31843	35.7	-82.43	30.5	31843	40.2
2028	155.59	155.59	0.0	0.00	268.8	186.3	-82.43	30.5	31843	35.7	-82.43	30.5	31843	40.2
2029	155.59	155.59	0.0	0.00	268.8	186.3	-82.43	30.5	31843	35.7	-82.43	30.5	31843	40.2

PRESENT VALUE SUMMARIES

Group 01

Region	Present Value of R&D Benefits: Producer	Consumer	Government	Total	Costs	Returns: (B-C)	B/C	IRR
1 KENYA	25690.3	28946.9	0.0	54637.3	3353.5	51283.7	16.29	60.3%
Total NPV Benefits	25690.3	28946.9	0.0	54637.3	3353.5	51283.7	16.29	60.3%

Study: Ex-ante impact assessment of IPM
Scenario: CITRUS STUDY
Commodity: citrus Regions: 1 Single Closed Economy - Spillover: No
Period: 15 years Base year: 2015
Discount:10.0% Benefit:1000US$ Quantity: 1000T

SUMMARY OF INITIAL MARKET CONDITIONS

Region	Production	Consumptn	Price	Elasticity Sup.	Elasticity Dem.	Transmission Wedge	Transmission Elast	Exog. Growth Sup.	Exog. Growth Dem.	Tax/Sudsidy Sup.	Tax/Sudsidy Dem.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	<--quantity units--->		<pr units>			<pr un>		%/yr	%/yr	%/yr	%/yr
KENYA	140.3	140.3	268.82	0.800	-0.710	0.00	1.00	0.00	0.00	0.00	0.00
	140	140									

SUMMARY OF R&D & ADOPTION DATA

Region	K Pot.	Prob.of Success	Max. Adopt	Price	K Max	Shift Type	K Var	Time Lags R&D	Time Lags Adopt	Time Lags AtMax	Adopt Aband	Adopt Form
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	-%-	-%-	-%-	<price units>			%/yr	-yrs-	-yrs-	-yrs-	-yrs-	
KENYA	96.47	75.0	80.0	268.82	155.59	S	0.00	4.0	9.0	99.0	0.0	X

Kmax is maximum absolute unit cost reduction (in price units). Product of Cols 2-5
Kvar is the variable unit cost reduction (%/year), if specified.