EFFECT OF PUSH-PULL TECHNOLOGY ADOPTION AND DIS-ADOPTION ON LIVELIHOOD OUTCOMES OF SMALLHOLDER MAIZE FARMERS IN HOMA BAY COUNTY, KENYA

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and to the best of my knowledge has not been submitted in this or any other university for the award of a degree.

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Recommendation

This work has been prepared under our supervision and submitted to Graduate school for examination with our recommendation as university supervisors.

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DEDICATION

I dedicate this thesis to my parents Mr. Samuel Gwada and Mrs. Susan Gwada, my wife Millicent Akinyi and my son Ivan Ouko.

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ABSTRACT

Dissemination of push-pull technology (PPT), continued use and expansion of land area under PPT remain critical requirements in addressing the major constraints facing maize production. These include infestation by *Striga* weed and stem borers, coupled with declining soil fertility conditions which jointly result in low yields and poverty in many developing countries. Despite the extensive literature on PPT adoption, its impacts as well as wider dissemination, little is known about drivers of farmers' decision to abandon it, or to expand the land area under the technology. Similarly, there is limited empirical evidence that demonstrate the effect of continued PPT adoption on smallholder livelihoods. Therefore, this study determined the rate and determinants of PPT dis-adoption and effect of dissemination pathways on the extent of PPT expansion. This study also evaluated the effect of continued PPT adoption on livelihoods of smallholder maize farmers in Homa Bay County. A multistage sampling procedure was used to select a sample of 240 smallholder maize farmers. Data were gathered through face-to-face interviews using a pretested semi-structured questionnaire. Seemly unrelated bivariate probit model, censored tobit model, and propensity score matching model were used to analyze the three objectives, respectively. Descriptive results indicated that adoption, dis-adoption and expansion rates of PPT were 51%, 39.94% and 48.59%, respectively. Bivariate probit results showed that level of education, greater access to extension services, positive perception of stem borer and *Striga* weed constraints, and smaller land size positively affected PPT adoption. In addition, male-headed households, high education level, large farm sizes, and a large number of livestock units negatively determined PPT dis-adoption decision. Similarly, greater access to extension service, positive perception of stem borer and *Striga* weed constraint, availability of napier and desmodium seeds, and longevity of PPT negatively and significantly influenced the PPT dis-adoption decision. Tobit results revealed that male-headed households, being in married households, greater access to extension services, longevity of PPT use and availability of napier or brachiaria seeds significantly affected the extent of PPT expansion with positive coefficients 0.146, 044, 0.156, 0.031 and 0.147, respectively. Similarly, the positive perception of the severity of stem borer, dissemination pathways, smaller land size and distance to the nearest market center significantly influenced the extent of PPT expansion. Interestingly, farmer-to-farmer, field days and farmer teachers were found to be the most important and effective dissemination pathways enhancing the extent of PPT expansion. Further, propensity score matching results revealed that continued PPT adoption had a positive and significant effect on household per capita consumption expenditure (KES 47.81 – 59.02 per day) and household dietary diversity (2.76- 2.87); but it had a negative impact on squared poverty gap (-0.07 to -0. 05). These call for policies that will ensure an integrated input development system which involves collaboration of all stakeholders in ensuring affordability, supply, and accessibility to not only desmodium seed but also other agricultural inputs by all gender. Again, there is a need to incorporate a model farmer as a key pathway in technology dissemination. Also, policies that ensure equitable access to quality education, output and input markets, and efficient and effective extension system should be put in place to ensure continuous and extensive use of PPT among maize farmers.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

AAEA	-	American Agricultural Economics Association
AERC	-	African Economic Research Consortium
AIAEE	-	Association for International Agricultural and Extension Education
ANOVA	-	Analysis of Variance
ATE	-	Average Treatment Effect
ATT	-	Average Treatment Effect on the Treated
DFID	-	Department for International Development
ERS	-	Economic Recovery Strategy
FAO	-	Food and Agriculture Organization
FGT	-	Foster, Greer and Thorbecke Poverty Index
GDP	-	Gross domestic products
GoK	-	Government of Kenya
GPS	-	Generalized Propensity Scores
HDDS	-	Household Dietary Diversity Scores
ICIPE	-	International Centre for Insect Physiology and Ecology
IV	-	Independent Variable
KALRO	-	Kenya Agricultural and Livestock Research Organisation
KNBS	-	Kenya National Bureau of Statistics
MOA	-	Ministry of Agriculture
NGOs	-	Non-Governmental Organizations
PPT	-	Push-pull Technology
PSM	-	Propensity Score Matching
SDGs	-	Sustainable Development Goals
SPSS	-	Statistical Package for Social Sciences
SRA	-	Strategy for Revitalizing Agriculture
SSA	-	Sub Saharan Africa

CHAPTER ONE
INTRODUCTION

1.1 Background Information

Agriculture plays a significant role in the global economy, and provides the main source of income, food, and employment to global populations. In sub-Saharan African (SSA) countries, Kenya included, agriculture remains the backbone as well as the major contributor to the national economy (McIntyre *et al*., 2009). In Kenya, agriculture is among the leading economic sectors, accounting directly to about 60% of the total export earnings as well as 26% of the Gross Domestic Product (GDP) (Kenya National Bureau of Statistics, 2017). It also provides both on-farm and off-farm employment opportunities, thereby contributing to more than 18% of total Kenyan formal employment. The sector supports livelihoods of about 80 percent of the total population, making national economic growth to be highly dependent on its growth and development (KNBS, 2017). Kenyan agricultural sector is still dominated by smallholder farmers producing over 75% of total agricultural output. However, they still over-rely on rain-fed farming taking place on small plots ranging from approximately 0.2 to 3 hectares in both high and low potential regions (Government of Kenya, 2010).

Despite being the leading economic and dominant sector in Kenya, agriculture is faced with a number of serious challenges. First, the exponentially growing population pressure, leading to increased demand for food and limited nutritional access vis a vis declining cultivated plot sizes. Second, declining agricultural or farm productivity due to climate change, degradation of natural resources, pest, weeds, diseases, limited access to credit, use of outdated technology and input, and low access to extension advice. Third, rising competition in both local and international output markets due to lack of infrastructure and institutional barriers (Kibet, 2014). Consequently, in order to realize its economic objectives, the Government of Kenya (GoK), through its Economic Recovery Strategy (ERS) and Vision 2030, identified agriculture as an important development tool and vehicle, therefore raising the need to mitigate the above-mentioned agricultural challenges (GoK, 2012). Among the fundamental strategies identified to mitigate these agricultural challenges includes the adoption of new and improved agricultural production technologies coupled with efficient marketing techniques. These efforts are, therefore, facilitated through effective dissemination pathways in order to boost agricultural production in various agro-ecological environments (Kibet, 2014).

Consequently, the Government of Kenya and Non-Governmental Organizations (NGOs) have introduced different new and improved agricultural technologies. These technologies aim at increasing agricultural productivity to match the growing population, thereby ensuring economic growth, poverty alleviation and arresting environmental degradation in Kenya (GoK, 2012). Such improved production techniques have been introduced to ensure efficient production of crops such as maize (Zea *mays* L.) and sorghum (*Sorghum bicolor* L. Moench) which are considered as major cash and food crops among the majority of the small scale farmers in Kenya (Romney *et al*., 2003). However, production of these crops in Kenya, especially in the western region, often faces several constraints that greatly contribute to food insecurity. The three major constraints experienced by almost all smallholder farmers in this region are infestation by parasitic *Striga* weed (*Striga hermonthica*), lepidopteran stem borers (*Busseola fusca* or *Chilo partellus*) and declining soil fertility (Reddy and Sum, 1992; Vanlauwe *et al*., 2008; Cairns *et al*., 2013).

Stem borers and parasitic *Striga* often make countless Kenyans go hungry since they constrain increased cereal production in the region, therefore, resulting in low yields (Midega *et al*., 2016). A study by Kfir *et al*. (2007) found that stem borers cause grain yield losses of about 10-80% of the grain output, depending on the phonological stage of the pest at infestation and population density. On the other hand, *Striga* weed competes for nutrient and moisture needs, thereby suppressing the growth of the sorghum and maize plant; thus, resulting to a severe reduction in the amount of grain output or even total crop damage in severe cases. Maize yield losses of about 30% to 100% have been reported on farm plots under *Striga* weed infestation in the southern part of western region such as Homa Bay County (Khan *et al*., 2008). This is common in this county because many farmers still practice subsistence farming with limited options for external inputs resulting into a degraded environment characterized by low rainfall and declining soil fertility (Rodenburg *et al*., 2005).

According to a study by Midega *et al*. (2016), controlling stem borers and parasitic *Striga* have been a difficult activity for smallholder farmers in this region largely because of biological and nocturnal characteristics of these weeds and pests. This is coupled with availability of impractical and uneconomical recommended control strategies for smallholder farmers. As a result, a majority of smallholder farmers in Homa Bay County do not effectively control these weeds and pests. This is because of persistent use of conventional and traditional methods such as repeated weeding, manure and fertilizer application, uprooting and crop rotation with the aim of reducing the number of the pests and weeds in the soils, as well as preventing reproduction and spread from infested to non-infested plots (Berner *et al*., 2005). These conventional methods have overtime shown minimal and localized success in controlling stem borers and parasitic *Striga* thus leading to continuous reduction in yields (Pickett *et al*., 2008).

In order to protect smallholder maize farmers from the devastating effect of *Striga* weed and stem borers, scientists at the International Centre of Insect Physiology and Ecology (ICIPE), Kenya Agricultural and Livestock Research Organisation (KALRO) and Rothamsted Research in the United Kingdom invented an integrated pest management system known as Push-pull technology (PPT) (Oswald, 2005). Push-pull technology, therefore, involves intercropping sorghum or maize with a stem borer moth repellent fodder legume called desmodium (*Desmodium uncinatum*), which uses stimuli-deterrent diversionary strategy to control cereal stem borers (Cook *et al*., 2007). Then an attractant trap plant, known as brachiaria grass or napier grass (*Pennisetum purpureum)* is planted along the border of the farm. The mechanism involves the *push* where desmodium repels stem borers and suppresses *Striga* attack and the *pull* where napier grass attracts and kills stem borers (Cook *et al*., 2007). This technology was largely introduced in Homa Bay County back in 2002 by ICIPE and its partners to not only control *Striga* and stem borer problems, but also to increase yields, improve soil fertility and moisture, and to provide fodder among other benefits.

1.2 Statement of the Problem

In recognition of the importance of maize on smallholder livelihoods, the Government of Kenya and ICIPE introduced push-pull technology with the view of ameliorating the devastating effects of *Striga* weed and stem borer pests. In addition, these stakeholders, through different dissemination pathways such as field days, farmer field school, public meetings, television, radio, farmer teachers, farmer-to-farmer, printed materials, agricultural shows, and participatory video, have consistently disseminated PPT for effective control of stem borers and *Striga* weed, and improvement of soil fertility, especially in Homa Bay County. Despite these efforts, expansion of areas under push-pull technology has remained low, with some farmers even abandoning the technology for unknown reasons. Maize farmers in Homa Bay County, therefore, resort to traditional and conventional management practices which have limited success in controlling these pests and weeds. As a result, maize farmers in this county still experience a variety of farming constraints such as *Striga* weed, stem borers, and low soil fertility, leading to devastating losses in cereal yields ranging from 10% to 100%. This results in low yields that translate into food insecurity and high levels of poverty. Even though numerous studies have assessed the rate, extent, and timing of PPT adoption as well as factors that influence its adoption decision, little is known about drivers of farmers' decision to abandon it as opposed to keeping it, or to expand the land area allocated to it, and the resulting effects on livelihood outcomes. This implies that there is information gap on the determinants of push-pull technology dis-adoption and extent of expansion as well as its direct impact on the livelihoods of smallholder maize farmers in Homa Bay County, as this has not been given proper attention in the past. Therefore, this study addressed this knowledge gap by econometrically analyzing the rate and determinants of PPT dis-adoption, the influence of dissemination pathways on the extent of PPT expansion, and lastly the effect of continued PPT adoption on the livelihoods of smallholder maize farmers in Homa Bay County.

1.3 Objectives

1.3.1 General Objective

The general objective of the study is to better understand the determinants and the effect of continued push-pull technology adoption on livelihood outcomes of resource-poor smallholder farmers in Kenya.

1.3.2 Specific Objectives

i. To determine the rate and determinants of push-pull technology dis-adoption among smallholder maize farmers in Homa Bay County.
ii. To determine the effects of dissemination pathways on the extent of push-pull technology expansion among smallholder maize farmers in Homa Bay County.
iii. To evaluate the effects of push-pull technology continued adoption on the livelihood outcomes among smallholder maize farmers in Homa Bay County.

1.4 Hypotheses

i. There are no significant differences in the determinants of push-pull technology adoption or dis-adoption among smallholder maize farmers in Homa Bay County.
ii. There are no significant differences in the effect of dissemination pathways on the extent of push-pull technology expansion among smallholder maize farmers in Homa Bay County.
iii. Push-pull technology continued adoption does not have a significant effect on the livelihood outcomes of smallholder maize farmers in Homa Bay County?

1.5 Justification of the Study

Maize crop has remained the most important food crop in Kenya. The crop plays a significant role in ensuring food security and alleviation of poverty through income generation since it serves as the source of livelihood for a majority of smallholder farmers as well as a source of employment. Over the past decades, the demand for cereals crops has been rising among rural and urban consumers. However, the overarching concern is that the current production is inadequate to meet the increasing demand for cereals. This is largely due to devastating effects of crop pest and weeds. Therefore, the development and diffusion of technologies with a potential of alleviating this problem are important in addressing the food-related problems in the country. Push-pull technology is one such technology that has a potential of effectively and efficiently addressing this problem.

An important consideration behind the development of push-pull technology is to ascertain that the maize crop is of high economic importance to the smallholder farmers through effective and efficient control of stem borers and *Striga* weed. However, even though some studies (Pickett *et al*., 2008; Murage *et al*., 2011; Murage *et al*., 2012; Backson *et al*., 2014) have been done extensively to understand the uptake determinants of push-pull technology and its performance on both on-farm and experimental plots. There has been no study conducted to determine its abandonment or discontinued use as well as its direct effect on the livelihood outcomes among smallholder maize farmers in Homa Bay County.

Therefore, understanding the rate and determinants push-pull technology adoption, expansion, and dis-adoption, as well as its direct effect on the livelihood outcomes among smallholder farmers through this study is helpful to policy-makers and other stakeholders. This helps them come up with policy recommendations that will ensure implementation of cost-effective extension approaches for increased adoption, expansion and continued/sustained use of push-pull technology, its efficiency as well as improving its profitability. This also helps in promoting the effective design, efficient implementation, and demand-driven diffusion plan of the PPT through extension, farmer-oriented research, and development. In turn, it improves smallholders' agricultural productivity and incomes from the maize farms that subsequently help in reducing the general poverty and food insecurity that affects many households currently. This eventually helps in improving the contribution of the agricultural sector to the country's economy thereby meeting its development goals such as sustainable development goals (SDGs). The study is also useful to the education fraternity since it provides knowledge and exposure to new research areas by contributing to the existing literature on adoption and diffusion by focusing on the conditions and issues for continued adoption and expansion of push-pull technology.

1.6 Scope of the Study

The study only focused on determining factors influencing push-pull technology adoption, expansion, and dis-adoption as well as the effect of push-pull technology continued adoption among smallholder maize farmers in Homa Bay County. This study only considered continued adopters, dis-adopter, and non-adopters of push-pull technology who have been growing maize for at least three years. The sample size was small and constituted of only a few farmers from approximately 422,110 smallholder maize farmers in Homa Bay County.

1.7 Limitations of the Study

On limitations, inadequate time and financial resource constrained the scope and sample size of this research. This was because the financial resources available was little to fully cover the entire selected areas despite the efforts to facilitate effective and sufficient research findings. Poor record keeping and language barrier in some parts of the county somehow affected the quality of data collected.

1.8 Definition of Terms

Continued use or adoption: Refers to farmers' decision or behavior to sustain technology use after adoption.

Dis-adoption or discontinued adoption: Farmers' behavior or decision to reject or stop using a technological innovation after having previously adopted it.

Dissemination pathways: Various methods applied by different extension groups in diffusing information and knowledge of push-pull technology among smallholder farmers.

Expansion: Farmer's willingness to increase the cultivable area under the push-pull technology for multiple cropping to maximize its benefits.

Extent of PPT expansion: Refers to total cultivable area under PPT expanded calculated in terms of current area under PPT minus area under PPT during first time of use divided by total size of land owned.

Food security: Refers to a situation where individuals have physical and economic access to sufficient, safe and nutritious food that at all times meets their preferences, dietary needs for active and healthy lives (FAO, 2011).

Household: It refers to people living together who make common provision for food or other essential for living.

Livelihood: It refers to various ways of making a living that involves individuals' assets, capabilities, activities and income needed to secure adequate basic needs.

Livelihood outcomes: They refer to welfare effects involving household consumption expenditure, nutritional status, poverty, and food security.

Performance: Capability or profitability of a given technological intervention obtained through assessment of its success in areas linked to its assets, market strength, and liabilities.

Poverty: It refers to the state of having little or no goods, money, or means of support. It also refers to a household deficiency regarding income and household expenditure (FAO, 2011).

Poverty reduction: Sets of humanitarian and economic interventions intended to permanently pull people out of poverty trap (FAO, 2011).

Push-pull technology: Refers to an integrated pest management system for effective control of stem borers and *striga* weed.

Smallholder farmers: Farmers characterized by limited amount of resources. They engage in small-scale production on small-based plots of land ranging from approximately 0.1 to 3ha for growing subsistence crops, and finally relying almost exclusively on labour from the family (Government of Kenya, 2011).

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

Many studies have been conducted on push-pull technology, most of which focused on its scientific development, dissemination, implementation, as well as its contribution to households' welfare across different agrological zones. However, this literature review concentrated much on push-pull technology (PPT) development, dissemination as well as its effectiveness in improving smallholder welfare. The bulk of this literature was accessed from printed texts and online databases, with only those studies written in English given priority. Without taking into consideration the given set timeframe, this review considered both international and local studies, where more than ten articles were reviewed. From the literature, several key topics and research gaps on PPT were identified and discussed, however, only relevant topics were discussed in detail due to word constraints. The main goal of the study was to determine the determinants of PPT dis-adoption and extent of expansion as well as its effect on the livelihoods of smallholder maize farmers in Homa Bay County, paying particular attention to the impact of PPT continued adoption on the household per capita consumption expenditure, nutritional outcome and poverty. This chapter was organized as follows: The first section provides an overview of PPT development. The second section provides insights on PPT dissemination, adoption, expansion, and dis-adoption. The third section discusses PPT and its impact on rural welfare. The fourth section provides a theoretical framework upon which this study was developed. Finally, the chapter ends with a conceptual framework outlining the determinants of PPT adoption, expansion and dis-adoption, and the resulting welfare effect.

2.2 Push-pull Technology Development

According to the World Bank (2008) and FAO (2011), East African countries often experience major constraints such as food insufficiency, increasing population pressure on resources, declining food production, high incidences of environmental unsustainability, as well as high food prices. Production of cereals such as maize which is considered as a major cash crop and staple food for majority of the people, is constrained by negative abiotic factors, such unpredicted rainfall, low soil fertility and land degradation, and biotic constraints, such as *Striga* weed and stem borer pests (Jones and Thornton, 2003; Khan and Pickett, 2004; Fischer *et al.*, 2005). These constraints result in high incidence of malnutrition, absolute poverty, and food insecurity. In sub-Saharan Africa (SSA), smallholder cereal production is majorly constrained by stem borer and *Striga* weed infestation as well as low and declining soil fertility (Kfir *et al*., 2002).

The two main devastating stem borer species found in SSA are *Busseola fusca* Fuller (Lepidoptera: Noctuidae) and *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae). (See adult stem borer, *Busseola fusca* on appendix 1 (a)). Kfir *et al*. (2002) estimated that stem borer infestation causes grain yield losses of up to 85% of the grain yields. The level of loss depends on the crop and pest phonological stage at infestation, environmental condition, as well as pest population density. Moreover, Oswald (2005) reported that the presence of cereal stem borer in the region, together with the parasitic *Striga* weeds could cause up to 100% cereal yield losses if appropriate and timely control measures are not undertaken. It was, therefore, estimated that stem borers alone could cause annual economic losses of approximately $7 to $13 billion and thereby threaten indirectly the lives of over 90 million people in the SSA region (Hassan *et al.*, 1994).

Striga infestation is another devastating agricultural constraint, responsible for major losses in cereals produced in four major cereal production zones in SSA. A study by Gressel *et al.* (2004) found that there exist more than 23 species of *Striga* weed in Africa. Among them are *Striga asiatica* (L.) O. Kuntz and *Striga hermonthica* (Del.) Benth (See appendix 1 (b)), which were later found to be the most important species socio-economically, especially in eastern Africa (Gethi *et al.*, 2005). The seeds of these parasitic weeds can lie dormant in the soil for more than ten years, waiting for a cereal host plant to attack. As an obligate root parasite of cereal crops, *Striga* weed germinates and attaches itself to the maize roots, especially when maize is planted on plot infested by *Striga* (Joel, 2000). *Striga* then inhibits normal cereal growth since it competes for nutrients, impairs photosynthesis as well as causing damage through phytotoxic effect (Joel, 2000; Gurney *et al.*, 2006). This, therefore, causes stress to the host plant, which interferes with the normal nutritional value of the maize crop. Again, it lowers host plant ability to tolerate insect attack thereby resulting to stunted growth and eventually damage to the entire maize plots (Bukovinszky *et al.*, 2004).

Striga weed is still found on many farms in Kenya especially in the western Kenya and throughout most areas of SSA. Kanampiu *et al*. (2002) reported that *Striga* weed causes up to 100% yield loss in SSA, which is equivalent to estimated annual economic losses of about $335 million. In western Kenya, it is estimated that more than 76% of land under maize production are infested with *Striga* weed, causing up to 100% losses in yield, which is equivalent to estimated annual economic losses of $40.8 million (Oswald, 2005; Kanampiu *et al.*, 2002). A study by Oswald (2005) on *Striga* weed control technologies and their diffusion revealed that effects of stem borers and *Striga* weed are severe under conditions of low and declining soil fertility where phosphorus and nitrogen deficiency exist, leading to rapid and severe damage to the maize plants. Also, it was discovered that maize crop infested by *Striga* is preferred by stem borer for oviposition compared to uninfected plants hence leading to severe damage (Mohamed *et al.*, 2007). Unfortunately, *Striga* weed and stem borer constraints are continuing to expand especially in western Kenya. Smallholder maize farmers find it difficult to apply effective and recommended control measures and again, instead of devoting their little resources in controlling them, many farmers leave heavily infested plots for new fields (Khan, 2002; Khan and Pickett, 2004).

Ampofo (1986) and Berner (1995) observed that resource-poor farmers have limited access to effective measures for controlling *Striga* weed and stem borers. For instance, nocturnal and cryptic habits of the adult stem borer moths as well as the protection brought about by the maize stem at larval stages make it very cumbersome to control (Ampofo, 1986). Again, the recommended conventional chemical and physical control measures for stem borers are often impractical and uneconomical for resource-poor smallholder farmers as well as having negative effects on human and environmental health (Van den Berg and Nur, 1998). On the other hand, in spite of the severe yield reduction resulting from *Striga* infestation, the control of *Striga* weed has been difficult due to several reasons. Firstly, the prolific nature of *Striga* and the dust-like seeds that can remain dormant for over ten years in the soils, which hamper the control of the weed (Parker and Riches, 1993). Secondly, the parasitic nature of the *Striga* weed and its vascular attachment to maize makes its control difficult (Parker and Riches, 1993). Thirdly, the commonly used conventional cultural methods such as uprooting, burning and much more are labour intensive and are perceived to be less effective (Oswald, 2005). Oswald (2005) further argued that adoption of recommended and effective *Striga* control strategies is limited by little knowledge on pest problems, lack of labour, as well as inadequate resources that are required to make the necessary investments.

Moreover, Parker and Riches (1993) argued that the effective control of parasitic weeds should ensure a reduction in the amount of *Striga* weed seeds in the soil, inhibit new seed reproduction, lower the spread of *Striga* from infested soils to the ones not infested, as well as improve soil fertility. Based on these principles, researchers have developed various technologies for controlling and managing stem borers and *Striga* weed such as Imapazyr herbicide-tolerant mutant maize. However, these efforts have only shown limited and localized success. In addition, a number of socio-economic and biological reasons slow the uptake of chemical control (Oswald, 2005). It is in recognition of the above problems that affordable alternative control strategies were indispensable in helping smallholder farmers to overcome adverse effects of stem borer and *Striga* weed. Consequently, scientists at the International Centre for Insect Physiology and Ecology in Kenya, KALRO, Rothamsted Research, and other research firms collaborated, and jointly worked together to developed PPT for stem borer and *Striga* control (Nielsen, 2001; Khan *et al.,* 2006; Midega *et al.,* 2007; Cook *et al.,* 2007; Khan *et al.,* 2014).

Push-pull technology is an integrated pest management system that was first developed in 1987, and later made formal in 1990 (Pyke *et al*., 1987; Miller and Cowles, 1990). It uses behavior-modifying stimuli in manipulating the abundance and distribution of beneficial insects for management of the pest (Cook *et al.,* 2007). The mechanisms by which PPT works for efficient and effective control of the stem borer and *Striga* weed have been intensely studied and reported. It involves an intercrop of maize with stem borer repellent plants known as desmodium (*Desmodium uncinatum* Jacq.), or a forage legume, and Molasses grass (*Melinis minutiflora).* Then an attractive trap plant known as napier grass (*Pennisetum purpureum* Schumach) is planted on the border of the plot, (See appendix 1 (c)). A study by Khan *et al.* (2000) noted that the repellent plants such as *Desmodium uncinatum* produce chemical substances that repel *"push"* the stem borer pests from the maize plant. Napier grass, on the other hand, produces other chemical compounds that evaporate easily and attracts *"pull"* stem borers to lay eggs (Khan *et al.,* 1997). Fortunately, the border plant, napier grass releases a gummy and attractive compound that traps the stem borer larvae and kill them, thus reducing their population density.

Desmodium as legume plant and cover crop also suppresses and reduces the *Striga* weed through other mechanisms such as soil shading, nitrogen fixation, and allelopathy (Whitney, 1966; Hooper *et al.,* 2009). Allelopathy is whereby a plant kills another by releasing chemical substances (Tsanuo *et al.,* 2003). The roots of desmodium release some chemical substances that stimulate germination of *Striga* weed seeds, thus inhibiting the attachment of the *Striga* roots to maize roots as well as lateral growth. This kills *Striga*, thus reducing the number of *Striga* seeds in the soil. Khan *et al.* (2000) argued that desmodium intercrop, especially silver leaf desmodium, also help in reducing general light intensity and soil temperature, thereby improving retention of soil temperature which further prevents *Striga* germination, development and seeding over time. According to Khan *et al.* (2008a), the amount of *Striga* weed seeds in the soil steadily decreases after every cropping season or even during off season, especially in maize–desmodium intercrop plots. This is due to the fact that desmodium is a perennial crop thus making it a better repellent plant than other legumes, unlike in maize mono-crop fields where it steadily rises.

Despite the multiple benefits of conventional push-pull technology in SSA, its continued adoption and expansion to drier areas have been constrained by the severe impacts of climate change. In order to tackle this problem, ICIPE and its partners developed climate-smart PPT to suit the adverse impacts of climate change. This was done by introducing drought-tolerant companion crops such as Greenleaf Desmodium (*D. intortum*) as an intercrop, and Brachiaria cv mulato (*Brachiaria spp*.), a drought tolerant grass as a border crop (Khan *et al.*, 2014), (See appendix 1 (d)).

2.3 Dissemination, Adoption, Expansion and Dis-adoption of Push-pull Technology

Dissemination and adoption of PPT were identified as avenues for increasing agricultural productivity and meeting the growing demand for food due to rapid population increase (Khan *et al.*, 2014). A mixture of factors such as information, human capital, location, institutional support, and resource endowments has influenced the dissemination, adoption and expansion of PPT. Within this framework, the dissemination, adoption and expansion of PPT have been demonstrated in some studies. This technology has been widely disseminated across East African countries to control insect stem borers and *Striga* with over 50,000 smallholder farmers practicing it in Kenya, especially in Western Kenya (Khan *et al.*, 2014). The technology is perceived as a low-cost conservation technology, and it has been promoted through different dissemination pathways with the aim of improving output in cereal production as well as minimizing negative environmental impacts (Amudavi *et al*., 2008; Khan *et al.*, 2008a).

Murage *et al*. (2011) used ordered probit regression and weighted score index to evaluate farmers' preferences for dissemination pathways such as farmer teachers, field days, radio, farmer field schools, public meetings, printed materials and fellow farmers. This study found that public meetings and radio pathways were least preferred in disseminating PPT knowledge. The study further revealed that less educated smallholder farmers which are belonging to farmer groups mostly prefer field days and field schools as effective extension pathways.

Farmers with small land holdings were found to prefer farmer teachers whereas young, educated farmers preferred printed materials as an appropriate and an optimal dissemination strategy for the effective transfer of push-pull knowledge. This study further looked at factors influencing the preference rating for the above dissemination pathways, where farmers' perceptions, socioeconomic conditions, and land characteristics were identified as determining factors. However, the study failed to take into account that the observed factors, in a given geographical location might not necessarily result in similar smallholder farmers' preference in other regions. Again, this study did not look at the effects of these dissemination strategies on the extent of PPT expansion as well as determinants of PPT dis-adoption decision among smallholder farmers, which the current study focused on.

Obare *et al.* (2011) conducted a duration analysis of PPT's adoption impacts of dissemination pathways in Western Kenya. The study found that for the attainment of maximum adoption, the most efficient and economic dissemination pathways should be employed. They identified most efficient and economical extension pathways as field days, which led to 26.8 %, increase in uptake, followed by farmers' field school (22.2%) and then farmer teacher (18.1%). Murage *et al.* (2012) also reaffirmed that farmer field schools, farmer teachers and field days were the most effective dissemination pathways enhancing uptake of PPT in Western Kenya. However, these studies never included some PPT dissemination strategies such as participatory video recently introduced by ICIPE and many more. The studies failed to evaluate how these dissemination pathways enhanced extent of PPT expansion and continued use of PPT among smallholder farmers (Obare *et al.* 2011; Murage *et al.* 2012). Amudavi *et al.* (2008) evaluated farmers' field days as a dissemination pathway for PPT in Western Kenya, and found that more than 80% of the smallholder farmers who have attended the initial field day training have adopted the PPT. The current study attempted to overcome the weakness of these studies by considering all possible extension pathways that influence farmers' decisions to expand the cultivable area under PPT.

In another study, Amudavi *et al.* (2009) assessed farmer teachers' technical efficiency in the adoption and dissemination of PPT in Western Kenya. The study indicated that through individual contact, each smallholder farmer would influence on average ten other smallholder farmers, and each farmer teacher would influence 17 additional farmers to take up PPT. This study only focused on farmer- teacher as dissemination pathway without looking into its effectiveness in influencing farmers' willingness to expand and continued use of PPT. The current study solved this gap by looking at how various extension pathways influence smallholder farmers' decisions to expand the land area under PPT as well as factors influencing the continued use of PPT.

Fischler (2010) conducted an impact assessment of PPT in Eastern Africa and found that the technology is widely accepted as a low-cost and effective technology. The study revealed PPT adoption rates stood at 30% annually with 50% annual adoption potential rate. Dissemination agents and extension staffs in transferring the agricultural technologies to the entire farming population in developing countries made this possible through extensive efforts. Backson *et al.* (2014) who applied the Average Treatment Effect (ATE) framework to estimate the adoption rates of IR maize technology and push-pull technology further reemphasized these results. The study revealed that the actual adoption rate and potential adoption rate of PPT were 37% and 56.3% respectively, which the authors noted that were higher compared to other technologies. The study noted that when extra extension efforts are made, PPT will be considered most attractive and effective stem borer and *Striga* control strategy. The study further analyzed factors influencing PPT adoption. The results revealed that age, gender, education, farmer group, access to extension advice and distance to nearest administration center were important factors influencing PPT adoption. However, this study did not examine the how the above-mentioned factors influence decision to expand and dis-adopt PPT besides adoption.

Khan *et al.* (2008a) used a random sample of 843 smallholder farmers in western Kenya to evaluate farmers' perceptions of PPT. The results of the study indicated that farmers perceive stem borers and *Striga* weed as serious cereal production constraints. PPT was perceived as an effective control strategy that has led to an increase in grain yields, therefore, significantly influencing its adoption. However, the study used descriptive statistics in analyzing how farmers' perceptions influence PPT adoption without taking into consideration selection bias, observed, and unobserved heterogeneity problem. The present study used censored tobit model and bivariate probit regression to eliminate the possibility of these statistical problems. Murage *et al.* (2015) used multinomial logit to analyze the determinants of climate-smart PPT adoption in eastern Africa. The study found that perceptions of *Striga* severity, gender, technology awareness, access to extension advice, and access to input and output market were the most important factors that positively and significantly influenced the PPT adoption decision. In addition, the study found that the main drivers of PPT uptake were to effectively control *Striga* weed and stem borers, to increase maize yields, to provide fodder, to improve soil fertility as well as controlling soil erosion. The results of this study coincide with those of Backson *et al.* (2014), which indicated significant gender variations in farmers' perception of PPT attributes.

Moreover, little literature exists on determinants of PPT expansion and discontinued use. Amudavi *et al*. (2008) assessed factors influencing the expansion of PPT among smallholder farmers in western Kenya using logistic regression. The econometric findings of the study showed that household size, the longevity of technology use, group membership, availability of desmodium seeds and geographical location had a significant positive effect on PPT expansion. However, this study failed to consider the individual effect of dissemination pathways or information source on the extent of PPT expansion, and it failed to consider farmers' decision to discontinue PPT use. The present study, therefore, included various dissemination pathways on the model to evaluate their effectiveness in enhancing the extent of PPT expansion since information is packaged and presented differently. The current study also looked at the rate as well as the factors influencing farmers' decision to abandon PPT, as this was not given much attention in the previous studies (Amudavi *et al*., 2008; Murage *et al*., 2011; Murage *et al*., 2012; Backson *et al*., 2014; Murage *et al.*, 2015).

Although dis-adoption of push-pull technology is a common occurrence as well as a crucial component of the technological innovation decision-making process among smallholder farmers, there is a deficit literature on this subject matter, since it has received little recent research attention. Dis-adoption or discontinued adoption refers to farmers' behavior or decision to reject or stop using a technological innovation such as PPT after having previously adopted or used it. Many studies on agricultural production and marketing technologies have been mainly concerned with factors affecting adoption of these technologies, with few having investigated reasons behind dis-adoption of these technologies. Rogers (2003) stated two major reasons for dis-adoption or discontinuing technology uptake on the part of farmers. The first reason is replacement discontinuance, where a farmer stops using the existing technology in order to adopt a superior one. The second reason is disenchantment discontinuance, where a farmer discontinues using technology, with or without replacement, due to ineffectiveness or dissatisfaction with its performance. Since no study has been done on the reason behind the discontinued use of push-pull technology, this literature will focus only on general agricultural technology dis-adoption studies. Neill and Lee (2001) used a bivariate probit model to examine the adoption and discontinued use of maize-*mucuna* farming systems in Honduras. The results of the study found that external factors such as road access to the community and farmer experience play important role in influencing the abandonment of the maize-*mucuna* system. Moser and Barrett (2002) used tobit model to analyze the extent of dis-adoption decision of the rice technology in Madagascar. The results showed that education, labor constraints, farmer experience, and liquidity were positively correlated with the abandonment of the new rice technology. Akinbode and Bamire (2015), used bivariate probit to study dis-adoption decision of improved maize varieties in Nigeria. The study found that off-farm income, membership in the group, level of education, and frequency of extension contact, were significantly influencing the discontinued use of improved maize varieties. Others studies showed that ownership of farm assets, market conditions, and institutional factors explained significantly the farmers' decisions to continue or not to continue using agricultural technologies (Feleke and Zegeye, 2006; Aklilu and Graaff, 2007). However, no study has accounted for farmers who adopt push-pull technology at one season and discontinue it afterward. The present study, therefore, analyzed why smallholder farmers adopt or not adopt and keep using or stop using push-pull technology based on the case of the Homa Bay County

One of the challenges currently facing PPT expansion and dis-adoption is access to information, seed availability, factor cost and absence of effective dissemination pathways necessary in optimizing the adoption, expansion and continued use of this knowledge-based strategy (Padel, 2001). A study by Genius *et al.* (2006) on information dissemination and uptake of organic farming practices found that information sources are more effective in enhancing uptake, expansion and continuous use of technology. These pathways present information on an innovation differently, which affects the understanding of different farmers. Being a knowledge-intensive innovation, it is hypothesized that potential for expanding the area under PPT and continuous use among the smallholder farmers would be limited if appropriate and most effective dissemination or extension pathways are not used for information and knowledge transfer. Previous studies put more emphasis on the factors influencing adoption of PPT, without considering how such factors impact smallholders' decisions to expand acreage area under PPT or dis-adopt it. Continuous use of PPT, however, relies on how well PPT dissemination is implemented using appropriate and effective pathways. It is important to note that an intensified dissemination of PPT would lead to maximum expansion as well as continuous use. Therefore, knowledge of the expansion and dis-adoption determinants that the current study establishes is necessary before appropriate dissemination resources are committed to work since it helps better in informing appropriate policy instruments to sustain the adoption and continued use of push-pull technology.

2.4 Push-pull Technology and Livelihood Outcomes

A series of studies have demonstrated the economic benefits of adopting and expanding PPT. Vanlauwe *et al.* (2008) evaluated economic benefits of four related technologies such as crotalaria-maize rotation, traditional maize-bean intercrop, push-pull intercrop, and soybean-maize rotation as pest management systems. The study findings showed that PPT system significantly reduces stem borer damage and *Striga* emergence from the second season onwards, thereby resulting in higher yields compared to other systems. The study concluded that PPT is most acceptable systems under the prevailing farming conditions to enhance food security and poverty alleviation. The results of this study coincides with those from a report presented by Khan (2005) which stated that PPT increases grain yield of maize in Kenya and Tanzania by suppressing stem borer damage and *Striga* emergence only after two seasons.

Khan *et al.* (2008c) used cost-benefit ratio analysis to calculate gross margins and net present values (NPV) of land and labour of PPT against other cropping systems in western Kenya. The results indicated that maize yields and associated gross margins were significantly higher for PPT farming than in the other systems. Even though, the results indicated higher production costs and net return to land and labor in the PPT system during first cropping year, a reduction in cost was evidenced from year two of operations onwards in most plots of the studied districts. These results showed that PPT is more profitable system thus a viable way of enhancing productivity, income from farm diversification and poverty alleviation for resource-poor smallholder farmers, hence the need to enhance quality farmer education, training and access to less costly materials for successful expansion. A similar study by Khan *et al.* (2008b) used farmers' conditions to assess the effects of PPT in 14 districts in western Kenya. The results indicated that *Striga* counts and stem borer damage were significantly lower in the PPT plots, and maize yields were significantly higher for PPT system than mono-crop plots. The study indicated that majority of smallholder farmers perceived PPT as the most effective and appropriate system in reducing stem borers and *Striga* weed infestation rates, increasing soil fertility as well as grain yields, thus helping them in increasing food security and alleviating poverty.

DeGroote *et al.* (2010) also applied marginal effect and discounted partial budget analysis to determine economic performance of different integrated soil fertility and pest management options in maize production systems in Western Kenya, and corroborated the above results. The study reaffirmed that PPT farming generated the highest income than other soil fertility and pest management practices, thereby making it appropriate technology for poverty reduction and food security. Amudavi *et al.* (2008) conducted a study in western Kenya to evaluate the influence of Push-pull technology on maize productivity and found that adoption of PPT significantly reduced maize production constraints such as stem borer and *Striga* infestation by 64%, thus contributing to increased maize production. In turn, increased maize productivity had a positive and significant effect on poverty reduction and food security among smallholder farmers. Based on the results of push-pull technology impact assessment conducted by Martin (2010) through a peer-review evaluation in 12 districts of eastern Uganda and western Kenya, the technology has been viewed as a springboard for a diversified farming system. It has significantly reduced the smallholder farmers' vulnerability by promoting better and higher maize and sorghum grain yields, reduced soil erosion, increased soil fertility, improved livestock health as well as extra income from diversified sources such as the sale of desmodium and napier fodder. These benefits have greatly contributed to the improved food security, increased well-being, and poverty reduction among those farmers (Martin, 2010).

Martin (2010), therefore, viewed PPT as one of the most efficient and effective low-cost agricultural technologies for ameliorating major production constraints facing the many farmers in the region, hence resulting to significant and overall improvement in the levels of well-being, food security, livelihood and poverty reduction. These results were reaffirmed by another study by Khan *et al.* (2011) which indicated that PPT is appropriate and effective pest control systems as it addresses important cereal production problems as well as increasing maize and sorghum yields from 0.1 to 3.5 tonnes per hectare. Being an economical technology, its expansion and continued use through effective dissemination pathways, multi-stakeholder collaboration, capacity building, improvement in external input accessibility, livestock production integration, improvement in companion plants and establishment of a supportive policy framework, are highly recommended for continued food security and poverty reduction among resource-poor farmers (Khan *et al.,* 2011).

Murage *et al. (*2015) interviewed over 898 respondents from Tanzania, Kenya, and Ethiopia to determine the potential ex-ante effect of climate-smart PPT with a view to promoting wide-scale dissemination. The authors used marginal rate of return methods, and the results indicated that the MRR for maize was 143.4 % and 109.2 % for sorghum. These results implied that there is an expected improvement in food security and poverty alleviation status among smallholder farmer once they make the decision to uptake and expand PPT. A recent study by Chepchirchir *et al*. (2016) used tobit model and generalized propensity scores (GPS) to quantify the impact of intensity of PPT uptake on household welfare regarding productivity, incomes, and poverty status in eastern part of Uganda. The findings of this study indicated that when the intensity of PPT uptake increases, on average, the probability of a farmer being poor reduces from 47% to 27% through improved crop output, farm incomes, and household per capita food consumption expenditure. In another recent study, Ogot *et al.* (2017) used descriptive statistics to study impact of PPT on the nutritional outcomes of children in western Kenya. They found that PPT technology positively impacted the nutritional outcomes of farmers' children. They argued that PPT elevates production, boost income and food expenditure thus resulting to higher and better nutritional status. However, a similar study has not been conducted in Homa Bay County.

However, it is important to note that a similar work has not been done in Homa Bay County. In fact, the previous studies reviewed did not look at the impact of PPT continued adoption. Again, such studies did not consider the application of propensity score matching or endogenous switching regression, as recommended models of eliminating selection bias and heterogeneity when analyzing the impact of PPT on consumption expenditure, nutritional status and poverty. Most of the studies used data from on-farm and on-station demonstration and pilot plots without taking into consideration main fields under PPT. The current study therefore, applied the above mentioned methods to meet its objectives. Effects of PPT continued adoption were considered on per capita consumption expenditure, household dietary diversity (HDDs), and poverty reduction as this was not given much attention in the previous studies. From the literature, it is therefore important to note that PPT adoption leads to significant improvements in soil fertility, increase cereal yields, milk, and dairy production. The productivity changes result in improved livelihoods, thus resulting in better nutritional and economic well-being and poverty alleviation in many areas it is being practiced. By doing this, PPT plays a significant role in the national economies since it contributes towards the attainment of the overall economic development goals (Khan *et al*., 2014).

It can be said that a lot of literature exists on PPT adoption, however, very little has been recorded on the impacts of PPT continued use on smallholder livelihood outcomes such as per capita consumption expenditure, household dietary diversity and poverty reduction. Literature reveals that most of these previous studies focused on PPT perception and adoption determinants without taking into consideration the effects of dissemination pathways on its extent of expansion as well as factors that greatly influence its discontinued use decision. The current study deviated from these studies (Vanlauwe *et al.*, 2008; Murage *et al*., 2012; Backson *et al*., 2014; Murage *et al.*, 2015; Chepchirchir *et al*., 2016; Ogot *et al.*, 2017) and evaluated the socio-economical, institutional and farm characteristics that influence the extent of PPT expansion and its dis-adoption decisions as well as determining the resulting impacts on livelihood outcomes among smallholder farmers in the study area.

2.5 Theoretical Framework

The theoretical framework for the current study was based on three theories, namely random utility, diffusion of innovation theory and sustainable livelihood framework.

2.5.1 Random Utility Theory

Random utility theory uses some economic theory to motivate and evaluate human decision regarding binary choices (Rogers, 1995; Greene, 2008). The set-up of this theory states that an individual has to choose between two or more alternatives such as a decision to adopt or not adopt, expand PPT or not or dis-adopt or continue with the technology. An individual will only choose an alternative that he or she perceives to maximize utility or perceives to have more net benefits. For instance, an individual farmer will choose to discontinue adoption of PPT if he or she perceives that this decision offers more benefit or utility than continued use as shown in equation 1and 2. The theory further states that these decisions depend on some observable and unobservable individual's socioeconomic, farm and institutional characteristics (Rogers, 1995):

$$y_i^* = \beta X_i + \varepsilon_i \; (i = 1, .. N) \qquad (1)$$

$$Y_i = 1 \; if \; y_i^* > 0, \; Y_i = 0 \; if \; y_i^* \leq 0 \qquad (2)$$

Where y* is latent variable which is unobserved, for instance, expected benefits from the decisions such as technology adoption, expansion or dis-adoption, X_i is a vector of the observed independent variables, Y_i= 1, if a farmer has adopted, expanded cultivable area under PPT, or dis-adopted PPT and 0 otherwise and ε_i is an error term which is independently distributed.

2.5.2 Diffusion of Innovation Theory

Diffusion of innovation theory tries to portray how a new technological idea moves from inception point to ultimate use. Arumapperuma (2008) defined technology diffusion as aggregate technology adoption which demonstrates how an innovation or information on a new idea is communicated or transferred to members of a given social system, in that the ability and willingness to uptake or discontinued usage of the new idea depend on interest, awareness, evaluation, and benefit of the technology perceived by such members. Rogers (1995) argued that technology adoption, expansion or continued use follows an innovation-decision making process which consists of a series of choice and actions over time through which a household or decision making units scrutinize an innovation or new idea and make a decision on whether or not to adopt, expand or continue using. Kiptot *et al.* (2007) demonstrated that technology uptake, expansion and continuous are part of the major contributory factors for improving agricultural productivity. Therefore, evaluating determinants of technology expansion and dis-adoption is important in making decisions regarding the design, dissemination, and implementation of effective agricultural interventions since it provides useful evidence-based information. Lessons learned from such diffusion studies helps in implementation of future programs aimed at supporting development objectives. These studies have revealed major problems in agricultural research and extension systems by identifying poor linkages in research and extension systems (Rogers, 1995; Chema *et al*., 2003). This has led to the development of the need for proper design and implementation of realistic and effective extension service approaches to help in enhancing technology continued adoption and expansion among smallholder farmer in developing countries including Kenya.

2.5.3 Sustainable Livelihoods Framework

This study is also based on sustainable livelihoods framework. This was developed by the Oxfam and British Department for International Development (DFID). The sustainable livelihoods framework has been largely adopted in conceptualizing in a holistic way the constraints, complexities, and opportunities in which livelihoods are subjected to (Eade and Williams, 1995; Ashley and Carney, 1999). Based on this framework, a poor rural household is used as a unit of analysis to conceptualize how livelihood opportunities and constraints are shaped by multiple factors, ranging from uncontrollable structures and trends either at global or national levels, to the assets to which such households have direct or indirect access, and, finally, the local institutions and norms to which they are subject to. See appendix 1(e) for the modified DFIDs and Oxfam livelihoods framework adopted for this study. According to the framework, vulnerability context explains the uncontrollable external environment comprising of trends (such as changes in agricultural technologies, and other global or national political and economic trends), seasonality (such as changes in output and inputs prices, production seasons among others), and shocks (such as poor weather, household illness or death, and wars). These three factors directly influence the likelihood that a poor rural household will have to live now or in the future by reducing opportunities as well as creating hardships.

Transforming processes and structures comprise of global and national or private and public institutions and policies (such as membership in groups) with possibilities of directly or indirectly changing both vulnerability context and the asset that poor rural households can access. Assets, on the other hand, are key to the sustainable livelihood approach because they play a pivotal role in sustaining an adequate income that poor rural households need in order to live. Assets are shaped by transforming structures and processes, and vulnerability context, and usually comprise of human capital (such as agricultural knowledge, skills, ability, and good health), social capital (such as trust, relationships, and reciprocity), natural capital (land, water, and air), physical capital (transport, communication, shelter, energy and water systems), and finally, financial capital (access to credit, income and savings). Therefore, through this assets, poor rural households are able to engage in a wide range of livelihood strategies, activities or choices such as subsistence farming, PPT farming and so on that ultimately influence their livelihood security outcomes such as increased well-being, more income, greater food and nutrition security, and reduced vulnerability to poverty.

There have been limited studies on the determinants of technology dis-adoption especially in the context of technology diffusion process. However, researchers continue to develop new agriculture technologies despite the challenges experienced in improving farmers' adoption, expansion, and continued use. The diffusion of innovation, sustainable livelihoods framework, and random utility theory, therefore, provided a tool or framework for analyzing empirical data aimed at addressing the research gap on the determinants on PPT adoption, expansion or dis-adoption, and their effect on livelihood outcomes among smallholder maize farmers in Homa Bay County.

2.6 Conceptual Framework

The conceptual framework was operationalized as indicated in Figure 1, which shows the interaction of various variables that are considered to have an influence on PPT adoption, expansion of cultivable land under PPT or discontinued use. Smallholder farmers often have different socio-economic characteristics such farmers' marital status, age, household size, gender, education, income, number of livestock, PPT awareness, PPT perception among others which influence their decision to adopt, expand or dis-adopt PPT. Again, institutional factors such as market access, credit access, group membership and access to dissemination pathways (farmer field school, farmer teachers, TV, field days, radio, fellow farmer, printed materials, agricultural shows, public meetings, and participatory video) also affect the possibility of a smallholder farmer adopting, expanding or dis-adopting PPT. Also, farm-level characteristics like farm size, soil fertility, land tenure, and the farming system practiced on the farm also influence the possibility of adopting, expanding or dis-adopting PPT. However, if a farmer adopts, expands or dis-adopt his or her level of cereal yields, livestock production, and human and animal health are expected to change, due to the effectiveness of PPT in controlling and reducing stem borer and *Striga* infestation, improving soil fertility through nitrogen fixation, conserving biodiversity and increasing forage production. These, therefore, lead to changes in expected level of per capita household consumption expenditure due to reduced cost of production and increased yields, thus ensuring better nutritional outcomes and poverty alleviation among smallholder maize farmers.

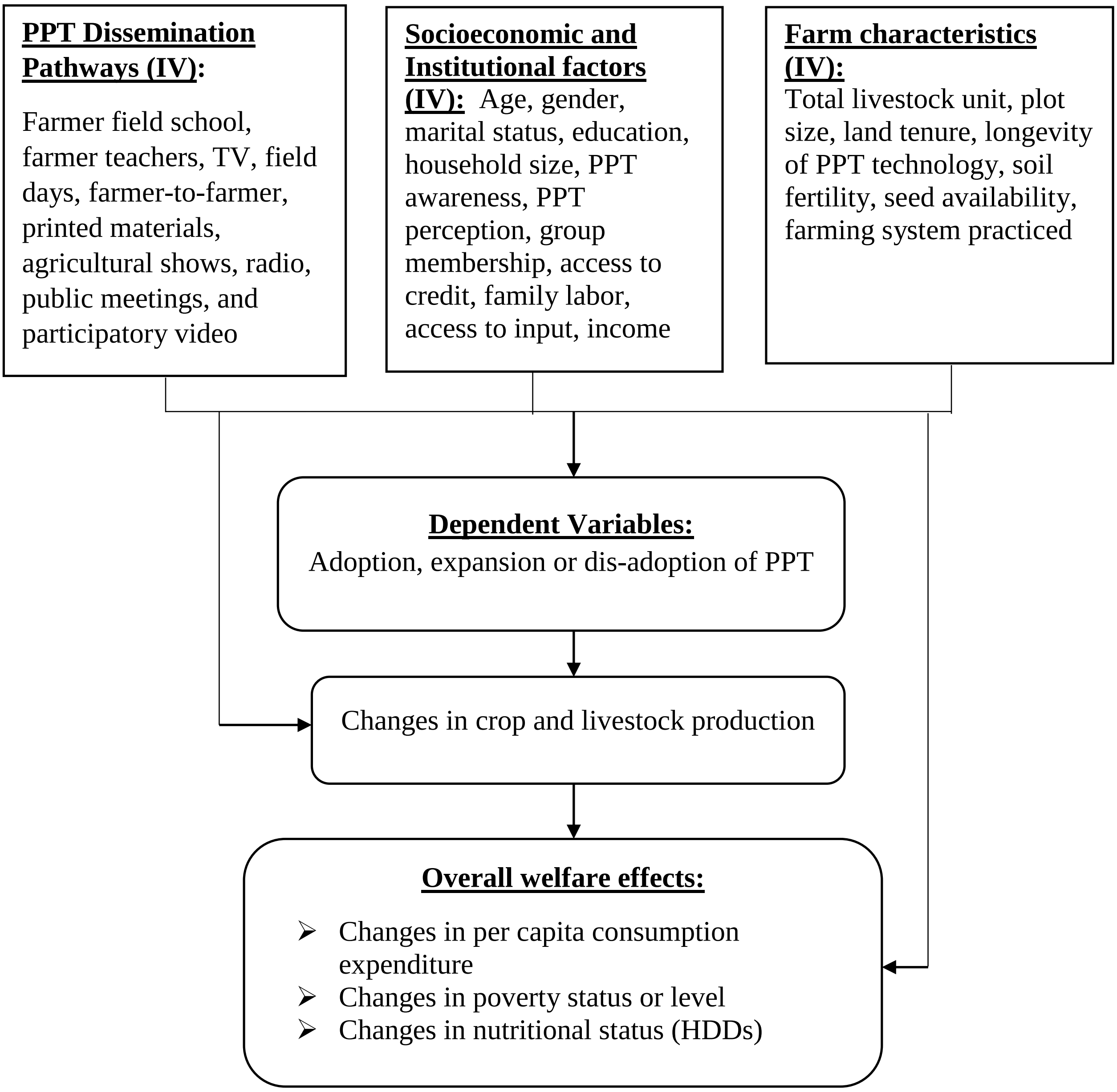

Figure 1: Conceptual Framework

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter presents information on the study area, research design, sample size determination, and sampling procedure, in section 2, 3, 4 and 5, respectively. The last three sections present data collection methods, analytical framework, and poverty model, respectively.

3.2 Study Area

This study was conducted in eight Sub-Counties in Homa Bay County namely Suba North, Kasipul, Homa Bay Town, Karachuonyo, Suba South, Kabondo-Kasipul and Rangwe as shown in Figure 2. The choice of Homa Bay County as a study area was motivated by three reasons. Firstly, Homa Bay County is one of the regions along the shore of Lake Victoria where stem borer, *Striga* weed, climate change and low and declining soil fertility are major problems to sustainable maize production thereby rendering the region low productive, food and nutrition insecure as well as high poverty levels (Murage *et al.,* 2015). Secondly, Homa Bay County is one of the areas where PPT has been widely promoted or disseminated for the effective control of *Striga* weed, stem borers, and declining soil fertility (Backson *et al.,* 2014). Finally, the area was convenient because it was easily accessible and familiar thus facilitated the process of establishing an immediate rapport with participants given the limited amount of time and funds. Administratively, Homa Bay County is located on upper and lower agro-ecological zone of lower midlands in former Nyanza province in western Kenya. It lies on latitude: 0˚ 40' 60.00" N and longitude: 34˚ 27' 0.00" E. With a population of approximately 963,794 people, it occupies an area of 3183.3 square kilometers.

The region experiences semi-arid climatic conditions with temperatures ranging from 26 – 34 degrees Celsius. It lies at an altitude ranging from 1134 to 1230m above the sea level, with bimodal rainfall pattern ranging from 250 to 1200mm annually capable of supporting production of various crops and livestock. The average annual rainfall is estimated as 1000m with 60% reliability level. Approximately, the long rains start from March to June of between 500mm to 1000mm per annum while short rains come from September to November of amounts between 250mm to 700 mm per annum. Agriculture, fishing, and tourism are the main economic activities in Homa Bay County. Moreover, due to continuous mono-cropping and low fertilizers application, soils in Homa Bay tend to be deficient in nitrogen and phosphorus thereby aggravating the severity of *Striga* and stem borers, which are the serious setback in all the sub-counties (Onduru *et al*., 2001).

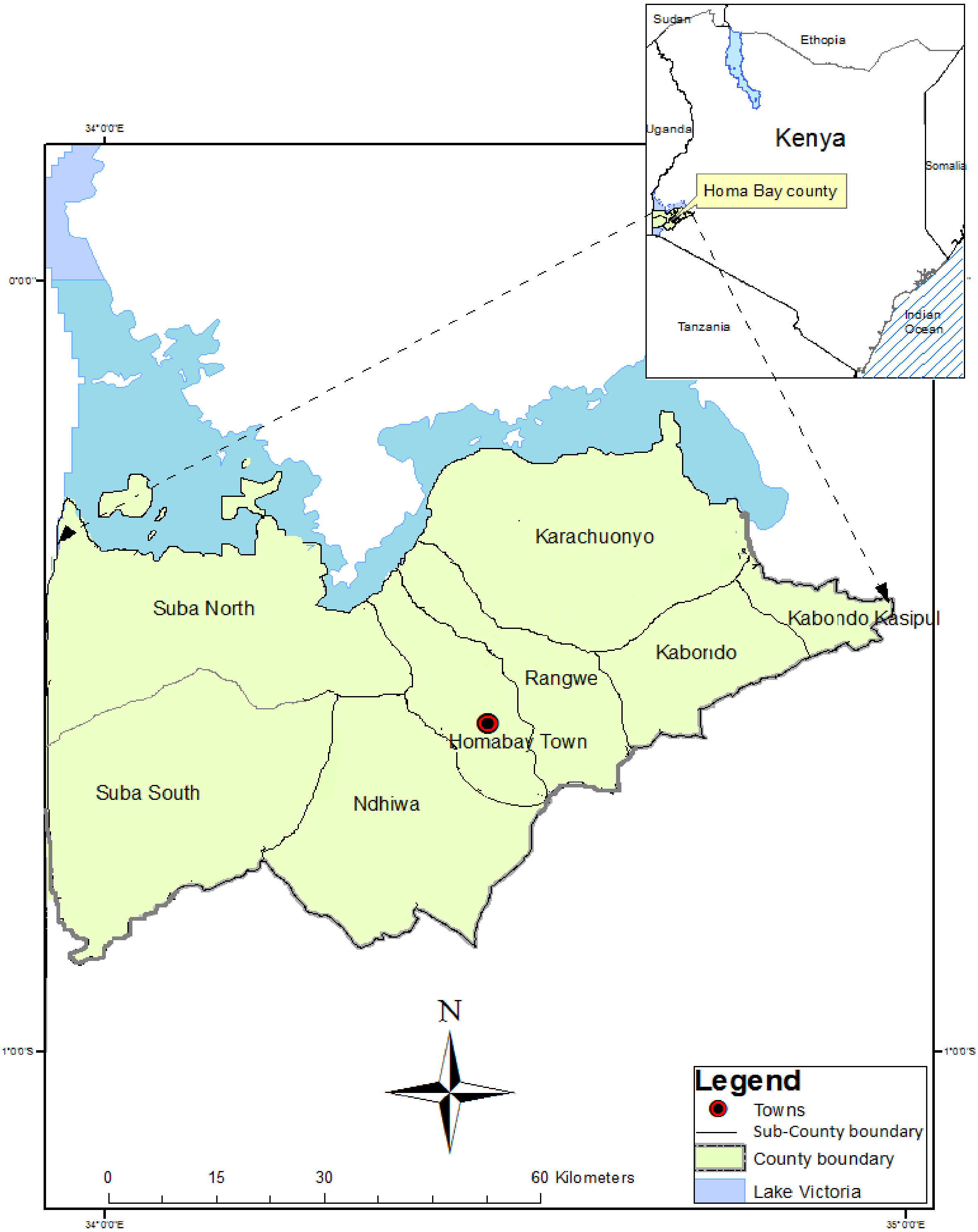

Figure 2: ArcGIS generated map of Homa Bay County showing the study area

3.3 Research Design

This study adopted quantitative research design in order to establish statistical conclusions on the rate and factors influencing PPT dis-adoption decision, the rate and determinants of the extent of PPT expansion, and the effect of PPT continued adoption on livelihoods of smallholder farmers in Homa Bay County. This research design was appropriate since the study aimed at exploring the aspects of PPT dis-adoption that had not been done by many researchers.

3.4 Sample Size Determination

The target population was smallholder farmers in Homa-Bay County. From the target population of approximately 449,315 smallholder farmers, the accessible population approximately included 385, 315 maize farmers (ICIPE, 2015). Since the proportion of PPT adopters and conventional maize farmers is known in the entire county, the required sample size was determined using the proportionate to number of households sampling methodology (Kothari, 2004).

$$n = \frac{z^2(p)(1-p)}{e^2} \quad \text{...(3)}$$

Where; n represented the sample size; z is 1.96 at 95% confidence level, p is the proportion of PPT adopters in the population which is 0.19(19%) and $1 - p$ is the proportion of non-adopters set at 0.81(81%) (ICIPE, 2015). Lastly, e is the allowable margin of error or degree of precision which is 0.05(5%). The formula resulted in a sample size of 240 respondents, which was divided equally between PPT adopters (dis-adopters included) and non-adopters in the county to achieve a perfect compliance.

$$240 = \frac{1.96^2(0.19)(0.81)}{0.05^2}$$

3.5 Sampling Design and Procedure

This study used a multistage sampling procedure to arrive at the required sample size of 240 households or maize farmers (PPT adopters, non-adopters, dis-adopters). In the first stage, Homa Bay County was purposively selected because it is one of the counties in western Kenya where stem borer and *Striga* are most prevalent, and soil fertility is declining. Purposive sampling was considered since it remains the appropriate and best way to obtain a correct representative sample for correct inferences as it ensures that important population segment rich in information is represented (Mugenda and Mugenda, 2003). In the second stage, eight sub-counties namely Suba North, Kasipul, Homa Bay town, Karachuonyo, Suba South, Ndhiwa, Kabondo-Kasipul, and Rangwe were purposively selected because they represent areas where PPT has been predominantly used and widely disseminated as a control strategy for *Striga* weed and stem borers. The third stage involved a random selection of six sample villages from each sub-county with the help of village leaders and PPT facilitators. Six villages were preferred because it made it easier to assign adopters' group that perfectly determines participation in PPT. In selecting the sample villages, equality in distribution was also considered where three villages per Sub-county where PPT have been introduced and practiced and another three villages per Sub-county without PPT were selected. To prevent spillover effect, this study ensured that non-PPT villages incorporated those villages without access to PPT information thus previously have not adopted PPT.

In total, 24 villages from PPT areas, and 24 villages from non-PPT areas were sampled. However, it the selected villages were agro climatically homogeneous. The fourth and the final stage involved a compilation of a complete list of all households in the sampled villages, where a sample of five (adopters or dis-adopters and non-adopter of PPT) maize farmers per village were randomly selected. This resulted in a total of 240 maize farmers, 120 PPT adopters (dis-adopters included), and 120 non-PPT maize farmers. However, two households were regarded as outliers and therefore excluded from the analysis.

3.6 Data Collection

This study adopted both qualitative and quantitative research design in order to establish statistical conclusions. This study used semi-structured questionnaires for face-to-face interviews with the selected respondents to collect primary data (see appendix 2). Secondary data for review of literature were sourced from relevant sources such as reports, newsletter, online databases, and unpublished data to supplement the primary data. Semi-structured questionnaires were preferred for this study since they were very economical in relation to time, as well as effective in yielding systematic and ordered data that are easy to collect and analyze (Kothari, 2004). The questionnaires were administered by a group of trained enumerators. Data collection instrument was pre-tested with five farmers to assess its clarity, validity, reliability, as well as its ease of use. This helped in modifying the instruments to eliminate the possible errors as well as acted as a way of training enumerators before the commencement of actual data collection (Mugenda and Mugenda, 2003). Face to face interview was preferred since it facilitated the use of questionnaires, created a good rapport with respondents as well as facilitated the process of the interview in a relaxed environment. It also helped in clarifying the purpose of the study hence eliminating the experience of negative attitudes when contributing to the study.

The structured questionnaire was used to gather information on farm and farmers' socioeconomic characteristics such as age, gender, farm size, tenure systems, education and family size, household incomes (both farm and non-farm), maize production characteristics, among others. Information on institutional characteristics such membership in farmer groups, credit access and distance to nearest market and administrative center, access to various dissemination pathways and much more were also collected. More specifically, adopters were asked if they were still practicing PPT or discontinued PPT use and if they have increased acreage land under PPT since adoption as well as stating the approximate amount of land expanded. All farmers in the sampling frame (PPT adopter, dis-adopters and non-adopters) were then asked to tick or indicate various information pathways or sources of getting PPT information as a strategy for stem borer and *Striga* control, to help in evaluating the determinants of PPT dis-adoption and extent of expansion.

To ease the analysis process, dissemination pathways were specified as a series of binary dummy variables of 1 if the farmer has gotten the PPT information from a particular approach, and 0 if otherwise, after which they were asked to give their main dissemination pathway as well as the frequency of extension contact. In the analysis, farmer-to-farmer extension was used as reference category. Therefore, the treatment or dependent variables for the study were whether a farmer has adopted PPT on his/her maize plot(s) or not and whether a farmer has dis-adopted PPT or not whereas livelihood outcome variables comprised of per capita consumption expenditure, household dietary diversity score, and poverty indices such as poverty and squared poverty gap index. All data that were obtained from the questionnaires were then entered and analyzed using the STATA and Statistical Package for Social Sciences (SPSS) computer software.

3.7 Analytical Framework

Objective 1: Determining the rate and determinants of push-pull technology dis-adoption among smallholder farmers in Homa Bay County.

Both inferential and descriptive statistical methods were applied to analyze this objective. In determining the rate of PPT dis-adoption, this study used descriptive statistics such as mean and analysis of variance (ANOVA). Again, to determine the determinant factors of PPT dis-adoption or discontinued use decision this study used bivariate probit model. In this study, a smallholder farmer was said to be dis-adopter if, he or she had practiced PPT previously. Push-pull technology adoption often happens before continuation or dis-adoption, therefore, the specified model relied on the assumption that PPT dis-adoption decision was likely to be influenced by a number of factors influencing its adoption decision. Farmers often decide to uptake or not to uptake the technology first. Later, they decide to either keep it or abandon it (dis-adoption or abandonment). These decisions, however, are based on random utility framework stated in the theoretical framework. Bivariate probit regression makes it easier to analyze factors that explain the probability of adoption as well as the likelihood of PPT dis-adoption decision. Other methods such as logit, tobit, and Heckman selection can as well be used. However, bivariate probit was proposed since it provides efficient estimates of the parameters of adoption and dis-adoption models by taking into account the potential correlation between the unobservable factors of the two decisions (Wooldridge, 2005; Greene, 2008).

According to Greene (2008), Y_{i1}^{*} and Y_{i2}^{*} were the underlying latent variables representing changes in net benefit or utility for adoption and dis-adoption of PPT respectively. The model was specified as follows;

$Y_{i1}^{*} = \beta_1 X_{i1} + \varepsilon_{i1}, Y_{i1} = 1, if Y_{i1}^{*} \succ 0$ and 0, Otherwise……………………...………………...(4)

$Y_{i2}^{*} = \beta_2 X_{i2} + \varepsilon_{i2}, Y_{i2} = 1 if Y_{i2}^{*} \succ 0$ and 0, Otherwise……………………………………...(5)

$E[\varepsilon_1 | X_1, X_2] = E[\varepsilon_2 | X_1, X_2] = 0$ ……………………………………………………….....(6)

$Var[\varepsilon_1 | X_1, X_2] = Var[\varepsilon_2 | X_1, X_2] = 1$ ……………………………………………………...(7)

$Cov[\varepsilon_1, \varepsilon_2 | X_1, X_2] = \rho$ ……………………………………..…………… …...…..…...(8)

Where, $Y_{i1} = 1$ was if the farmer adopted PPT, and 0 otherwise (non-adoption). $Y_{i2} = 1$ was if a farmer dis-adopted PPT or discontinued use decision, and 0 otherwise (continued use). β_1 and β_2 were the vector of parameters to be estimated. X_1, X_2 were the vector of explanatory variables and $\varepsilon_1, \varepsilon_2$ were independent identically distributed error terms. This model ensured that for a given individual in the sample, Y_{i2} was not observed unless $Y_{i1} = 1$, thus resulting in three different observations with different unconditional probabilities as shown below;

$Y_2 = 0: prob(Y_2 = 0) = 1 - \phi(\beta_2' X_2)$ ………………………………………….……….…(9)

$Y_1 = 0, Y_2 = 1: prob(Y_1 = 0, Y_2 = 1) = \phi_2(-\beta_1' X_1, \beta_2' X_2, -\rho)$ …………………………..….(10)

$Y_1 = 1, Y_2 = 1: prob(Y_1 = 1, Y_2 = 1) = \phi_2(\beta_1' X_1, \beta_2' X_2, \rho)$ ……...…………...……………(11)

Where, ϕ was the univariate standard normal cumulative distribution function, and ϕ_2 was the bivariate standard normal distribution function. The first probability referred to non-adopters, the second one refers to dis-adopters, and the third category referred to those who continue using ppt. The log-likelihood function to be maximized was based on these probabilities and was specified as;

$$\ln L = \sum_{i}^{N} \left\{ \begin{array}{l} y_{i1} y_{i2} \ln \phi_2 (\beta_1' X_1, \beta_2' X_2 ; \rho) \\ + y_{i1} (1 - y_{i2}) \ln [\phi(\beta_1' X_1) - \phi_2 (\beta_1' X_1, \beta_2' X_2 ; \rho)] \\ + (1 - y_{i1}) \ln \phi(- \beta_1' X_1) \end{array} \right\} \text{ i= number of observations….(12)}$$

The model coefficients were estimated by maximum log-likelihood function with respect to the known estimators.

Objective 2: Determining the effect of dissemination pathways on the extent of push-pull technology expansion among smallholder farmers in Homa Bay County.

Depending on the responses given by farmers, it is important to note that several econometric models exist that can be used to determine factors influencing the extent of expansion of push-pull technology among smallholder farmers. For example, farmers' decision to expand technology use can be determined by using limited dependent variable approaches such as logit model, especially where dependent responses involve 1 for Yes when the respondent has expanded acreage land under PPT technology and 0 for No. The limited dependent variable therefore, would have been preferred for the current study if it could have involved binary expansion models. However, since the PPT expansion decisions involved a simultaneous decision-making process, tobit model was preferred.

This implies that probit and logistic regression models that have been used in the previous studies to express the likelihood of a farmer making one choice among other possible choices, only provide insights on how changes in explanatory variables influence decision on choices guided by different levels of utilities attached to those choices (Newnan *et al.* 2003; Carroll *et al.* 2005; Useche *et al.*, 2005). However, when further evaluation of the effects of explanatory variables on the extent of such decisions such as the extent of PPT expansion is required, probit or logit models become ineffective to give the robust results (Moffat, 2005). This, therefore, motivated the use of two-step decision models such as double hurdle model. Double hurdle models help in analyzing decisions involving whether to undertake an activity such as PPT expansion decision, and the extent to which such task is undertaken (Cragg, 1971). This model was initially proposed by Cragg (1971) as an appropriate model for analyzing selection and outcome decision making problems such as this study objective. Heckman model could also be applied since it allows for the correction of selection bias on non-randomly selected samples. However, it was not considered in this case, because the sample was randomly selected. In current study, it was also expected that some smallholder farmers have reduced or even not expanded the area under PPT thereby resulting in some extent values being negatives and zero, respectively.

Therefore, the standard double hurdle tobit model developed by Tobin (1956) and Cragg (1971) was regarded as insufficient due to negative values. In this context, censored tobit model was then adopted to study factors affecting the extent of PPT expansion measured in terms of the proportion of profitable land area under PPT expanded. Censored tobit model was then conditioned by the farmers' socio-economic characteristics, selected dissemination pathways, farm and other institutional characteristics. A latent variable was used to model the censored tobit model for determining the extent of PPT expansion and specified as follows;

$y_{i1}^{*} = X_i\beta + v_i$ Extent of PPT expansion

$y_i = X_i\beta + v_i$ $y_i = y^*_{i1}$ if $y^*_{i1} \geq 0$ and $y_i = 0$ if $y^*_{i1} < 0$…………………………..….... (13)

Where, y_{i1}^{*} represented a latent variable describing the extent of PPT expansion for i^{th} household censored for values equal or less to 0 and observed for values greater than 0. The Tobit model can be generalized to take account of censoring both from below and from above. y_i represented the expanded size of profitable land under PPT while v_i was the respective error terms hypothesized to be independent and normally distributed as u_i ~ N (0, 1) and u_i ~N (0, $\partial^{2)}$. The estimated maximum likelihood of the model took the form of, (Carroll *et al.* 2005).

$$L(\alpha,\beta,\sigma^2) = \prod_0 \left[1 - \Phi(w_i'\alpha)\Phi\left(\frac{x_i'\beta}{\sigma}\right)\right] \times \prod_1 \left[\Phi(w_i'\alpha)\sigma^{-1}\phi\left(\frac{y_i - x_i'\beta}{\sigma}\right)\right] \text{……..……….....(14)}$$

Where, ϕ and Φ were the density function and standard normal cumulative distribution function, respectively. To assess the effect of explanatory variables on the extent of PPT expansion, it is important to analyze the marginal effects of the significant regressors. Therefore, to determine changes in the extent of PPT expansion, the following equation was used:

$$E(y_i / y_i > 0) = \Phi\left(\frac{x_i'\beta}{\sigma_i}\right)^{-1} \int_0^{\infty} \left(\frac{y_i}{\sigma_i\sqrt{1+\gamma^2 y_i^2}} \times \phi\left(\frac{T(\gamma y_i) - x_{i_i}'\beta}{\sigma_i}\right)\right) dy_i \text{ ………...……...…......(15)}$$

Differentiating equation (14) with respect to each explanatory variable yields the marginal effects on the extent of PPT expansion conditional. However, the study applied Variance Inflation Factor test to test for endogeneity or multicollinearity problems respectively between regressors, after which instrumental variable estimation was to be considered if tests could have emerged positive.

Equation 15 estimates various coefficients of the explanatory variables that influence the expansion of cultivable land under PPT (EXPANDPPT), which in the current study was used to measure the effectiveness of dissemination pathways after positing that the PPT expansion decision is subject to the amount of information received among other variables. It is important to note that PPT information reaches the farmers through different pathways, which varies in the manner the information is packaged and presented, therefore influencing the likelihood of the expansion decision differently (Mauceri *et al.*, 2005). This information further helps in reducing uncertainty perceived by farmers, in that those who are better informed about PPT are more likely to expand the cultivable land under PPT than those with less information. However, multiplicative interactive variables were not included in the model to capture interactive effects between the pathways under analysis since almost all were not delivered in a complimentary manner thus separable in influencing absorptive information capacity. However, only ten main dissemination pathways were included in the model with farmer-to-farmer extension used as reference category. Besides the inclusion of dissemination pathways in the model, other socio-economic, farm and institutional factors that influenced the farmers' decision and the extent of PPT expansion were also included in the model. These explanatory variables were mainly obtained from empirical findings of the literature review as well as from the general working hypothesis.

Objective 3: To evaluate the effect of push-pull technology continued adoption on livelihood outcomes among smallholder farmers in Homa Bay County.

Impact evaluation can be done for both experimental (randomized) and non-experimental programs or agricultural technology. For experimental studies, impact evaluation such as technology uptake or dis-adoption can be done by simply comparing individual welfare outcomes of adopters, dis-adopters and non-adopters to compute average treatment effect (ATT) (Becker and Ichino, 2002). However, many agricultural technologies such as PPT are not randomly assigned or distributed within adopters, dis-adopters and non-adopters, in that farmers' decision to adopt or not or to dis-adopt or not depend on the amount of information they have (Dehejia and Wahba, 2002). This brings the problem of a counterfactual outcome or intervention where it is difficult to determine the welfare outcome of farmers who adopted the technology had they not adopted that technology (Dehejia and Wahba, 2002). Previous studies have refuted the use of ordinal least squares (OLS) model in impact evaluations since it generates biased estimates by its assumption that adoption or dis-adoption of agricultural technology is determined exogenously, and yet it is potentially endogenous, voluntary and depends on individual self-selection and expected benefits which systematically differs across individuals (Heckman *et al*., 1998; Wooldridge, 2005).

This results in the problem of self-selection that make it difficult to directly compare welfare outcomes of adopters, dis-adopters, and non-adopter. Again, there are some unobserved individual, farm and institutional characteristics that may affect adoption and dis-adoption and the welfare variable, thus resulting in inconsistent estimates, due to endogeneity problem (Smith and Todd, 2005). It is, therefore, important to apply an econometric model that eliminates both endogeneity and selection bias while evaluating the impact of technology adoption on welfare outcome such as per capita consumption expenditure (Heckman *et al*., 1998). This motivated the use of propensity score matching (PSM) model to control for both endogeneity and sample selection bias between PPT continued adoption and other explanatory variables in analyzing objective three of the proposed study (confoundedness assumption). PSM was recommended because it does not depend on distributional assumptions and functional form, easy to compare the observed outcomes of PPT adopters with those of counterfactual non-adopters, and finally works well with a single cross-sectional dataset like the case of the proposed study (Heckman *et al*., 1998).

PSM method helped in matching the observations of PPT continued adopters and non-adopters, based on predicted propensity score or probability of adopting PPT continuously. This was done by creating the conditions of randomized experiment for evaluating the causal effect just like in a controlled experiment situation (Dehejia and Wahba, 2002). This ensured that all observational characteristics were controlled thereby making the PPT adoption or dis-adoption a random assignment and uncorrelated with the outcome variables which in this case is per capita consumption expenditure, household dietary diversity score and poverty indices (Smith and Todd, 2005). To arrive at robust results, chances of systematic difference between the outcomes of PPT continued adopters and non-adopters that are caused by selection of unmeasured characteristics were eliminated when conditioning as shown below (Smith and Todd, 2005).

Let A denotes a dummy variable for PPT continued adoption status where A_i = 1 is if *i^th^* individual adopted PPT technology continuously, and A_0 = 0, is otherwise. In addition, let Y_{1i} and Y_{2i} denote expected observed livelihood outcomes for PPT adopters and non-adopter or PPT dis-adopters and adopter respectively. Then treatment effect, TE is.

$TE = Y_{1i} - Y_{2I}$ ……………………………………………………..………….………. ...(16)

Equation 16 gives the impact or treatment effect of PPT technology continued adoption on the i^{th} individual. Since we only observe;

$Y_i = A_i Y_{1i} + (1 - A_I) Y_{2I}$ ………………………...………………………...……..……......(17)

Rather than Y_{1i} and Y_{2I} for same farmer, we find it difficult to arrive at treatment effect for every farmer. Therefore, we can only calculate the average effect of treatment on the treated, ATT as shown in equation 18 (Becker and Ichino, 2002).

$ATT = E(Y_{1i} - Y_{2i} / A_i = 1)$ …………………………………………………………….(18)

According to Rosenbaum and Rubin (1983), the propensity scores for continued adoption was estimated as shown in equation 19;

$\Pr ob(X) = \Pr ob(A_i = 1/X)$ ……………………………………………...…………(19)

Depending on the conditional independence assumptions, $Y_{1i}, Y_{2i} \perp A/X$ the potential livelihood outcomes are independent of technology continued adoption given X which represented vector of independent variable (see Table 1), which implies that,

$E(Y_{2i} / A = 1, \Pr ob(X)) = E(Y_{2i} / A = 0, \Pr ob(X))$ ……………………………………...….(20)

and

$0 \prec \Pr ob(X) \succ 1$ ………………………………...……………………….…………..(21)

For all X , there was a positive likelihood of either continuously adopting PPT ($A = 1$) or not uptaking ($A = 0$) as this guarantying every PPT continued adopter a counterpart in the non-adopter population. Therefore, resulting ATT can be estimated as;

$ATT = E(Y_{1i} - Y_{2i} / A_i = 1)$ ……………………………………..……………………...(22)

$ATT = E[E(Y_{1i} - Y_{2i} / A_i = 1, \Pr ob(X))]$ ……………………………………………...……(23)

$ATT = E[E(Y_{1i} / A_i = 1, \Pr ob(X)) - E(Y_{2i} / A_i = 0, \Pr ob(X))]$ …………………………….(24)

Since propensity scores or probabilities were continuous variables, there was no way of getting PPT continued adopter with the same score to be used as counterfactual, as this renders equation 23 insufficient in computing average treatment effect (Smith and Todd, 2005). Therefore, it was important to apply more than two matching methods to help in checking the robustness of result estimates. The current study therefore, applied three nearest neighbor matching and kernel matching techniques to ascertain the consistency and robustness of impact estimates. Therefore, PSM was used to assess and compare the impact or ATE of PPT continued adoption on smallholder per capita consumption expenditure, household dietary diversity score (HDDs) and poverty status measured by poverty gap index and poverty severity index. HDDs was used to measure dietary diversity as nutritional outcome based on the number of food groups households consumed. It accurately reflects the diversity of macro and micronutrient intake (Kennedy *et al*., 2011). HDDS, therefore, had 0-12 scores for 12 food groups consumed by household based on 24hr-recall. These include cereals, fish and seafood, root and tubers, pulses, legumes or nuts, vegetables, milk and milk products, fruits, oil or fats, meat, poultry, or offal, sugar or honey, eggs, and miscellaneous. These food groups were added to give HDDS for each household.

3.7.1 Poverty Measurement Model

To evaluate poverty levels among the households, this study adopted the Foster, Greer, and Thorbecke (FGT) poverty index (Foster *et al.,* 1984). FGT poverty index uses poverty line as the threshold level of wellbeing that distinguishes poor individuals from non-poor individuals, to compute some aggregate poverty measures. This study adopted mean consumption expenditure of KES. 154.28 as poverty line. The Foster, Greer and Thorbecke poverty index is measured as:

$$P_a = \frac{1}{N}\sum_{i=1}^{q}\left(\frac{Z - Y_i}{z}\right)^a \quad \ldots\ldots(25)$$

Where, P represents Foster, Greer and Thorbecke poverty indices ranging between 0 and 1. N is the total number of farmers in the study, q is the number of farmers leaving below the poverty line, Z is the national poverty line or mean consumption expenditure, and Y_i is household per capita expenditure on food and non-food items of the i^{th} individual. Therefore, the poverty status of the respondents was divided into three indicators as follows. When $\alpha=0$, P_0 gives the headcount index measuring the incidence of poverty. When $\alpha=1$, P_1 gives the poverty gap index measuring depth of poverty, and finally when $\alpha=2$, P_2 gives the poverty squared poverty gap index measuring severity of poverty among the household.

Table 1: Description of study variables and their expected signs

Variable Label	Description	Variable Type	Variable Measurement	Expected Sign
Dependent Variables				
PPTadopt	If the farmer has adopted PPT	Dummy	1=Yes, 0=NO	None
EXPANDPPT	If farmer has expanded cultivable land under PPT	Dummy	1=Yes, 0= No	None
Extend of PPT expansion	Total Cultivable area under Current Area under PPT minus Area under PPT during first time of use/total size of land owned	Continuous	Number	None
PPTdisadopt	If the farmer has dis-adopted PPT	Dummy	1= Yes (Dis-adoption), 0 = No 9 (Continued adoption),	None
Per capita consumption expenditure	Annual household expenditure on food and non-food items	Continuous	Kes.	None
Poverty gap index	A measure representing poverty intensity of a household	Continuous	Number	None
Squared Poverty gap index	A measure of severity of household poverty	Continuous	Number	None
HDD	Household Dietary Diversity	Continuous	Number	None
Independent Variables				
Socioeconomic characteristics				
Hage	Age of the household head	Continuous	Years	±
Hgender	Gender of the household head	Dummy	1=Male, 0=Female	±
Mstatus	Marital Status of household head	Categorical	1= Married, 0 = No spouse	±
Educationlevel	Years spent in school	Continuous	Number	±
L_Offincome	Natural logarithm of total income from off farm sources	Continuous	Kes	±
Hsize	Household Size	Continuous	Number of persons	±

Table 1 Cont….

Flabour	Family members that offer farm labour	Continuous	Number of persons	±
Dseed	How a farmer perceive availability of desmodium seed	Categorical	1 = Adequate, 0= Otherwise	±
NBseed	How a farmer perceive availability of napier/bracharia seed	Categorical	1 = Adequate, 0= Otherwise	±
SB_constraint	If a farmer perceives that he or she faced stem borer constraint in the last three years	Categorical	1=Yes, 0=No	-
SW_constraint	If a farmer perceives that he or she faced *Striga* weed constraint in the last three years	Categorical	1=Yes, 0=No	-
Striperception	Perception of *Striga* severity	Categorical	1= Major problem, 0 = not a problem	±
Stemperception	Perception of stem borer severity	Categorical	1= Major problem, 0 = not a problem	±
Institutional Characteristics				
Gmembership	If a farmer is member of productive group/union	Dummy	1=Yes, 0=No	±
Group membership	Number of group membership	Continuous	Number of groups	±
Acredit	Farmer has access to credit	Dummy	1=Yes, 0=Otherwise	±
Dmarket	Distance to the nearest market	Continuous	Walking minutes	±
Dadministration	Distance to the nearest administration center	Continuous	Walking minutes	±
Farm Characteristics				
Ltenure	Land ownership	Dummy	1=Owned with title, 0=Otherwise	±
Lsize	Total land size	Continuous	Acres	±
TLU	Total Livestock Unit	Continuous	Units	±
Fexperience	Farming experience	Continuous	Years	±

Table 1 Conti...

LTuse	Longevity of PPT use	Continuous	Years	±
Location Dummies				
Homa Bay Town	Sub-county dummy for Homa Bay Town	Dummy	1=Yes, 0=NO	±
Kasipul	Sub-county dummy for Kasipul	Dummy	1=Yes, 0=NO	±
Rangwe	Sub-county for Rangwe	Dummy	1=Yes, 0=NO	±
Kachuonyo	Sub-county dummy for Kachuonyo	Dummy	1=Yes, 0=NO	±
Suba South	Sub-county dummy for Suba South	Dummy	1=Yes, 0=NO	±
Ndhiwa	Sub-county dummy for Ndhiwa	Dummy	1=Yes, 0=NO	±
Suba North	Sub-county dummy for Suba North	Dummy	1=Yes, 0=NO	±
Kabondo	Sub county dummy for Kabondo	Dummy	1=Yes, 0=NO	±
Dissemination Pathways				
PM	If the farmer has heard about PPT from a public meeting	Dummy	1=Yes, 0=NO	+
TV	If the farmer has learnt about PPT from a television	Dummy	1=Yes, 0=NO	+
Radio	If the farmer has learnt about PPT from a radio	Dummy	1=Yes, 0=NO	+
FFschool	If the farmer has attended farmer field school on PPT	Dummy	1=Yes, 0=NO	+
Fdays	If the farmer has attended field days on PPT	Dummy	1=Yes, 0=NO	+
Fteacher	If farmer has been trained on PPT by the farmer teachers	Dummy	1=Yes, 0=NO	+
Ffarmer (Reference category)	If farmer has been trained on PPT by the fellow farmer	Dummy	1=Yes, 0=NO	+
Printmaterial	If farmer has read printed materials on PPT	Dummy	1=Yes, 0=NO	+
Agshows	If the farmer has learnt about PPT from agricultural shows	Dummy	1=Yes, 0=NO	+
Pvideo	If the farmer has learnt PPT from participatory video	Dummy	1=Yes, 0=NO	+

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Introduction

This section presents the results and discussion of this study. This study assessed the farmer socio-economic, institutional, and farm characteristics in order to explain the current conditions of the farmer. Generally, a number of variables show significant mean differences between different farmer categories in the study area.

4.2 Descriptive Statistics

4.2.1 Farmer, Farm and Institutional Characteristics

A one-way ANOVA was conducted to establish if there were significant differences in household socioeconomic, farm and institutional characteristics for various study groups, classified based on their PPT adoption status, and the results on continuous variables are presented in Table 2. Farmers were classified into three groups namely; continuous users (n = 74), dis-adopters (n = 49) and non-adopters (n = 115).

In terms of age of the household head, there was a statistically significant difference across groups (p = .003). The mean age of household heads for the entire sample was 52 years, with slightly more elderly household heads among continuous users (55 years), followed by dis-adopters (51 years) and lastly non-adopters (50 years). The mean age of the household heads for all adopters was 54 years. A Tukey post-hoc test further revealed that non-adopters of PPT were statistically significantly younger than continuous users (p = .002) (see appendix 3 for Tukey post-hoc test results). This implies that younger farmers mostly engage in other agricultural and non-agricultural activities as their main source of livelihoods other than PPT farming. Again, older farmers have more experience on agricultural production technologies such as PPT and, greater physical and social capital accumulation thus enabling them to adopt and continue using such technologies (Pender *et al*., 2007; Simtowe *et al.*, 2016). However, there were no statistically significant differences in mean ages between the dis-adopters and non-adopters, or between dis-adopters and continuous users.

Table 2: Descriptive statistics for continuous variables

	Push-Pull Technology Adoption Status					
	Overall sample *n*=238	**All Adopters *n*=123**	**Continuous Users *n*=74**	**Dis-adopters *n*=49**	**Non- adopters *n*=115**	**Statistics**
Variables	**Mean/std. dev.**	**Mean/std. dev.**	**Mean/std. dev.**	**Mean/std. dev.**	**Mean/std. dev.**	**F-test**
Age of household head (Years)	51.79	53.52	54.86	51.48	49.93	5.83***
	(9.92)	(10.33)	(10.44)	(9.91)	(9.14)	
Education level (Years)	8.73	10.43	10.82	9.84	6.91	31.61***
	(3.90)	(3.19)	(3.02)	(3.37)	(3.78)	
Household size (number)	7.03	7.63	7.84	7.33	6.38	4.59**
	(3.56)	(3.47)	(3.45)	(3.51)	(3.13)	
Farming experience (Years)	25.90	26.00	27.24	24.12	25.80	1.18
	(11.09)	(10.93)	(11.14)	(10.44)	(11.31)	
Land size (Acres)	2.12	2.39	2.97	1.52	1.82	27.31***
	(1.35)	(1.37)	(1.34)	(0.89)	(1.26)	
Distance to the nearest market center (Walking minutes)	22.91	16.02	13.32	20.10	30.28	16.66***
	(21.36)	(9.27)	(7.69)	(10.01)	(27.40)	
Distance to the nearest administrative center (walking minutes)	56.66	44.85	37.32	56.22	69.29	11.23***
	(47.17)	(43.16)	(33.39)	(53.10)	(48.17)	
Group membership (number of groups)	2.89	3.48	3.92	2.82	2.25	10.86***
	(2.50)	(2.51)	(2.49)	(2.42)	(2.34)	
Number of extension contacts	3.03	5.02	6.84	2.29	0.89	160.83***
	(3.45)	(3.70)	(3.13)	(2.66)	(1.08)	

Table 2 Continues

Tropical livestock units [a]	5.06	6.19	7.42	4.34	3.86	12.76***
	(5.10)	(5.87)	(6.07)	(5.06)	(3.80)	
Off farm income (KES)	161570.65	190356.30	245869.95	106519.37	130782.51	17.29***
	(160527.16)	(188233.9)	(221981.46)	(56480.23)	(117488.76)	

Note: Mean variables shown with standard deviations in parenthesis; ***, ** and * denote significance at 1%, 5% and 10% levels, respectively. [a] According to FAO (2015), TLU for Africa South of Sahara is typically taken to be equivalent to: Cattle=0.50, sheep=0.10, Goat=0.10, Pigs=0.25, Asses=0.50, Horses=0.50, Mules=0.60, Camels= 0.70, or Chicken = 0. 01.

The average years of education for the household heads were 8.73 and 10.43 years for the whole sample and adopters, respectively. There was a statistically significant difference in the mean years of education of household heads spent in school across the groups (p = .000), as shown in Table 2. The education level was highest among continuous users (10.82 years), followed by dis-adopters (9.84 years), and lastly non-adopters (6.91 years). A Tukey post hoc test revealed that the education level was statistically significantly lower for non-adopters compared to continuous users (p = .000) and dis-adopters (p = .000). This is an indication that farmers with higher levels of education are much more informed, thus able to effectively search and interpret information related to the importance of modern agricultural production technologies. Therefore, they choose to take up and continue using the appropriate technologies such as PPT to help them better overcome production constraints such as infestations by *Striga* and stem borer compared to less educated farmers. These results corroborate those of studies by Kassie *et al.* (2011) and Awotide *et al.* (2016) which posited that more educated farmers are more informed and also, they have more off-farm income that enables them to adopt, and continue using more modern technologies to overcome production constraints. However, the difference in mean years of education between the continuous users and dis-adopter groups was not statistically significant.

The average household size was largest among those who were continuing to practice PPT (8 members), followed by those who dis-adopted (7 members), and lastly, 6 members for the non-adopters as shown in Table 2. Overall, the mean household size was 8 and 7 members for all adopters and the whole sample respectively. These figures are slightly above the average value of 5 members per household which is Kenya's national mean household size (CBS, 2005). The ANOVA results revealed that there were statistically significant differences in the mean household sizes across the groups (p = .0111). A Tukey post hoc test further revealed that PPT continuous users had a significantly larger household size compared to non-adopters (p = .010). In most cases, household size has been used to calculate a household adult equivalent ratio which has been linked to on-farm labor availability in some adoption studies (Amudavi *et al.*, 2008; Murage *et al.*, 2011; Murage *et al.*, 2012; Tamru *et al.* 2017). Adoption and continued use of PPT require a high amount of labor in the first and second seasons; hence, households with larger household sizes will record high adopting level compared to those with smaller household sizes. These corroborate the results from studies by Amsalu and De Jan (2007) and Olatidoye *et al.* (2017) which found a positive and significant relationship between the household size and continued adoption of stone terraces for water and soil conservation in Ethiopia, and adoption of new cotton varieties in Nigeria, respectively. They argued that larger households possess the ability to reduce the labor constraints needed during the introduction of labor - intensive technologies. However, there were no statistically significant differences in mean household sizes between the dis-adopters and non-adopters, or between dis-adopters and continuous users.

The mean number of years in farming enterprise was found to be 27.24 years for continuous users, 25.80 years for non-adopters and finally 24.12 years for dis-adopters. Overall, the mean was 26.00 and 25.90 years for all adopters and whole sample respectively. The results indicated that dis-adopters had less experience in farming compared to continuous users and non-adopters; however, the one-way ANOVA results revealed that there were no statistically significant differences in the mean years in farming enterprises across the groups as shown in Table 2.

Tropical livestock unit (TLU) was measured using FAO (2015) guidelines. The mean value of tropical livestock units owned was highest among continuous users (7.42 units), followed by dis-adopters (4.34 units), with non-adopters registering the least number (3.86 units). The averages for the whole sample and all adopters were 5.06 and 6.19 units respectively. There were statistically significant differences in the mean tropical livestock units across the groups (p = .000). A Tukey post hoc test further revealed that PPT continuous users had statistically significantly higher tropical livestock units compared to non-adopters (p = .000) and dis-adopters (p = .002). However, there were no statistically significant differences in mean tropical livestock units between the dis-adopters and non-adopters. Tropical livestock unit has been used in many other studies as a measure of household wealth regarding animal assets (Khan and Pickett, 2004; Backson *et al.*, 2014). Thus, a higher value of tropical livestock units among continuous users is an indication that the household is more likely to adopt PPT continuously since PPT technology is a capital and labor intensive technology especially during the first time of use. Again, one of the benefits of PPT is fodder production. Therefore, households owning more livestock are more likely to adopt and continue using PPT in order to produce enough fodder in the form of crop residue, napier and desmodium. Similarly, a positive significant relationship was found in other studies between livestock ownership and adoption and continued use of fodder producing technologies such as improved pigeon pea, stress-tolerant maize hybrid technologies, and fodder tree technology (Salasya *et al.,* 2007; Simtowe *et al.*, 2011; Toth, *et al.*, 2017).

One-way ANOVA results showed that there was a statistically significant difference in mean land size owned by household heads across the groups (p = .000). Land size per household was smallest among the dis-adopters, with an average of 1.52 acres, followed by non-adopters (1.82 acres) while continuous users recorded the largest mean land size (2.97 acres). The mean land sizes recorded for all adopters, and the whole sample were 2.39 and 2.12 acres, respectively. This is a clear indication that the sample households comprised only of farmers engaging in small-scale subsistence production, on small plots of land ranging from approximately 0.1 to 3 hectares. Further, a Tukey post hoc test revealed that PPT continuous users had significantly larger land sizes compared to non-adopters (p = .000) and dis-adopters (p = .000). However, there was no significant difference in average land size between dis-adopters and non-adopters. Larger farm sizes among continuous users revealed a positive effect of land size on adoption and continued use of conservational and fodder producing agricultural technologies such as PPT. It was argued that large farm size encourages continued adoption due to larger capacity in terms of resource base, while small land sizes discourage continued adoption since there is competition for agricultural land between alternative crops to be cultivated (Tey *et al.,* 2017).

The average walking distances to the nearest market center were 16.02 and 22.91 walking minutes for all adopters and the whole sample, respectively. The results in Table 2 shows that there was a significant difference in the mean walking distances to the nearest market center across the groups (p = .0000). Distance to the nearest market center is used as a proxy for access to information as well as access to possible output and input markets. On average, continuous users live closer to the market centers (13.32 walking minutes) compared to dis-adopters (20.10 walking minutes) and non-adopters (30.28 walking minutes). These results show that households living nearer to the market centers have better access to information and markets for both inputs such as seeds, and output such as maize yield; thus, they are more likely to adopt and continue using new technologies being promoted including PPT (Iiyama *et al*., 2017). A Tukey post hoc test further revealed that PPT continuous users were living significantly closer to market centers compared to non-adopters (p = .000). Again, dis-adopters were staying significantly nearer to the market centers compared to non-adopters (p = .009). However, there was no significant difference in mean walking distance to the nearest market center between the dis-adopters and continuous users.

The average walking distance to the nearest administrative center was 56.66 minutes for the whole sample and 44.85 minutes for all adopters. The results also showed that there was a statistically significant difference in the mean walking distance to the nearest administrative center across groups (p = .0000). Averagely, continuous users had to travel approximately 37.32 minutes to the nearest administration center compared to 56.22 minutes travelled by the dis-adopters and 69.29 minutes travelled by non- adopters. A post hoc test further revealed that PPT continuous users were taking significantly lesser minutes to reach the nearest administrative center compared to non-adopters (p = .000). However, there were no significant differences in the mean walking distance to the nearest administrative center between the dis-adopters and continuous users, or between dis-adopters and non-adopters. Distance to the nearest administrative center is used as a proxy for access to extension information as well as access to credit markets. By implication, as the distance to the most adjacent administrative center increases, there is the possibility of increased transaction costs associated with accessing extension information and credit markets, thus reducing the likelihood of adoption and continued use of new technologies by a household. Similarly, Backson *et al.* (2014) and Awotide *et al.* (2016) found an inverse association between distance to the nearest administrative center and adoption of new technologies. The point of argument was that poor infrastructure resulting in longer travelling hours to input and output markets results in high transaction cost, which negatively affects adoption as well as the continuous use of new agricultural technologies.

One-way ANOVA results showed that there was a statistically significant difference in the mean number of group memberships across adoption categories (p = .0000), as shown in Table 2. On average, non-adopters recorded the smallest number of group memberships (2 groups), followed by dis-adopters (3 groups). On the other hand, continuous users recorded the highest mean number of group memberships of 4 groups, with the mean number of group memberships recorded for the all adopters and the whole sample being 4 and 3 groups, respectively. A Tukey post hoc test revealed that PPT continuous users had a significantly higher number of group memberships compared to non-adopters (p = .000) and dis-adopters (p = .036). However, there were no statistically significant differences in the average number of group memberships between the dis-adopters and non-adopters. A positive relationship between the number of groups participated in and continued PPT adoption could be attributed to the fact that farmers tend to increase bargaining power as well as reduce transaction costs by engaging in many social networks. For instance, farmers without contacts with extension providers may still learn more about the new technologies from their group networks, as they learn and share information with each other (Pender *et al*., 2007; Kassie *et al*., 2012; Gido *et al.* 2014).

Results also revealed that there was a statistically significant difference in a mean number of contacts with extension officers across the adoption categories (p = .000). On average, PPT continuous users were found to have the highest mean of 7 contacts with extension officers annually. This was followed by dis-adopters who had an average of 2 contacts, and lastly by non-adopters with 1 contact with extension officers in the last one year. Overall, the mean for all adopters was 5 contacts, and that for the entire sample was found to be 3 contacts. A Tukey post hoc test further revealed that continuous users had a significantly higher number of extension contacts compared to non-adopters (p = .000) and dis-adopters (p = .000). Again, dis-adopters had significantly higher contacts compared to non-adopters (p = .001). The low number of extension contacts recorded among dis-adopters and non-adopters could be linked to inadequacy in the agricultural extension system of Kenya. This normally arise because the majority of farmers get most of the agricultural extension services through the government extension agents than from non-governmental organizations. Extension contact has been used as a proxy for access to extension information, credit and input. Thus; any policy that results in high cost of accessing agricultural information, credit and input, negatively affects the return from uptake of technology, and hence discouraging adoption and continued use of technology such as PPT (Dolisca *et al*., 2006; Zerfu, 2010; Gido *et al.* 2014; Regmi *et al.*, 2017).

Off-farm income can have an influence on uptake and continued use of PPT. The results indicated that there was a statistically significant difference in mean level of off-farm income across groups (p = .000). The average off-farm incomes for the whole sample and all adopters were KES. 161,570.65 and KES. 190,356.30 per annum, respectively. A Tukey post hoc test further revealed that continuous users were having significantly higher annual off-farm income of KES. 245,869.95 compared to non-adopters with KES. 130,782.51 per annum (p = .000) and dis-adopters with KES. 106,519.37 per annum (p = .000). However, there was no statistically significant difference in average annual off-farm income between the dis-adopters and non-adopters. Similarly, Amsalu and De Jan (2007) and Mathenge *et al.* (2015) found a significant positive association between off-farm income and adoption of new technologies especially in less productive areas. It is argued that farmers use such income to facilitate uptake and continued use of modern technologies. In other words, off-farm income enhances the liquidity of the farm thus facilitating the purchase of other farm inputs as well as payment for hired labor through the provision of supplementary income. Nonetheless other studies have found contrary effects, hinting that off-farm income may compete with intensive adoption of modern technologies especially in high producing areas where agricultural labor is generally scarce (Mathenge *et al.,* 2015; Smale *et al.,* 2016).

Table 3 presents the results of categorical socioeconomic, farm and institutional characteristics for various study groups, classified based on their PPT adoption status and the resulting chi-square statistics. Gender of the household head also had the potential to influence the decision to adopt and continue using PPT, and the results are presented in Table 3. According to a study by Murage *et al.* (2015), gender-related constraints such as inadequate access to opportunities and productive agricultural resources has hindered adoption and continued use of new agricultural technologies thus lowering agricultural growth in many developing countries. In terms of gender of the household head, the sampled households composed of both female and male. Overall, the majority (64.71%) were male-headed households while 35.29% were headed by females. Similarly, the majority (74.80%) amongst adopters were male-headed compared to female-headed households (25.20%). The male-headed household’s proportion for continuous users, dis-adopters and non-adopters were 82.43%, 63.27%, and 53.91%, while female-headed household's proportion for the continuous user, dis-adopters and non-adopters were 17.57%, 36.73%, and 46.09%, respectively. This shows that female-headed households were significantly (p = .000) fewer than male-headed households for each adoption category. However, there was a higher proportion of female-headed households in the non-adopters group compared to other groups.

This difference can be attributed to the fact that male-headed households have higher access to necessary resources and agricultural information that increases their chances of adopting and continuously using new agricultural technologies. This is consistent with the findings by Backson *et al.* (2014) and yet contrary to those by Khan *et al.* (2008b), who found that female-headed households were more likely to uptake PPT compared to male-headed households. Mudege *et al.* (2016) also opined that existing discriminatory gender norms especially those linked to household decision-making had a negative influence on the women's ability to access extension or training opportunities thus hindering agricultural technology adoption among them.

Table 3: Descriptive statistics for categorical variables

	Push-Pull Technology Adoption Status										
	Overall Sample *n*=238		**All Adopters *n*=123**		**Continuous Users *n*=74**		**Dis-adopters *n*=49**		**Non- adopters *n*=115**		**Statistics**
Variables	**Freq**	**Percent**	**Freq**	**Percent**	**Freq**	**Percent**	**Freq**	**Percent**	**Freq**	**Percent**	**Chi^2-test**
Gender of household head (%)											
Female	84	35.29	31	25.20	13	17.57	18	36.73	53	46.09	16.09^{***}
Male	154	64.71	92	74.80	62	82.43	31	63.27	62	53.91	
Household head marital status (%)											
Married	170	71.43	91	78.98	56	75.68	35	71.43	79	68.70	6.41
Single	4	1.68	1	0.81	1	1.35	0	0.00	3	2.61	
Widowed	60	25.21	31	25.20	17	22.97	14	28.57	29	25.22	
Divorced	4	1.68	0	0.00	0	0.00	0	0.00	4	3.48	
Household primary occupation (%)											
Farming	144	60.50	72	58.54	40	54.05	32	65.31	72	62.61	6.09
Salaried employment	44	18.49	26	21.14	17	22.97	9	18.37	18	15.65	
Self-employment off-farm	34	14.49	19	15.45	12	16.22	7	14.29	15	13.04	
Casual laborer on-farm	2	0.84	0	0.00	0	0.00	0	0.00	2	1.74	
Casual laborer off-farm	14	5.88	6	4.88	5	6.76	1	2.04	8	6.96	
Farmer labor contribution (%)											
Not a worker	2	0.84	1	0.81	1	1.35	0	0.00	1	0.87	1.83
Part-time	109	45.80	57	46.34	37	50.00	20	40.82	52	45.22	
Fulltime	127	53.36	65	52.85	36	48.65	29	59.18	62	53.91	
Group membership (%)											
No	79	33.19	27	21.95	12	16.22	15	30.61	52	45.22	17.26^{***}

Table 3 Continues

Yes	159	66.81	96	78.05	62	83.78	34	69.39	63	54.78	
Access to credit (%)											
No	78	32.77	27	21.95	12	16.22	15	30.61	51	44.35	16.30***
Yes	160	67.23	96	78.05	62	83.78	34	69.39	64	55.65	
Perception on *Striga* weed severity (%)											
Not a problem	87	36.55	19	15.45	8	10.81	11	22.45	68	59.13	68.22***
Minor problem	58	24.37	30	24.39	14	18.92	16	32.65	28	24.35	
Major problem	93	39.08	74	60.16	52	70.27	22	44.90	19	16.52	
Perception on stem borer severity (%)											
Not a problem	82	34.45	19	15.45	8	10.81	11	22.45	63	54.78	68.22***
Minor problem	68	28.57	35	28.46	12	16.22	23	46.94	33	28.70	
Major problem	88	36.97	69	56.10	54	72.97	15	30.61	19	16.52	
Access to extension contact (%)											
No	76	31.93	21	17.07	2	2.7	19	38.78	55	47.83	43.51***
Yes	162	68.07	102	82.93	72	97.30	30	61.22	60	52.17	
Perception on *Striga* weed constraint (%)											
No	64	26.89	30	16.26	8	10.81	12	24.48	44	38.26	17.44***
Yes	174	73.11	103	83.74	66	89.19	37	75.51	71	61.74	
Perception on stem borer constraint (%)											
No	69	28.99	23	18.70	11	14.86	12	24.49	46	40.00	14.43***
Yes	169	71.01	100	81.30	63	85.14	37	75.51	69	60.00	
Land tenure (%)											
Otherwise	117	49.16	36	29.27	10	13.51	26	53.06	81	70.43	58.75***
Owned with title	121	50.84	87	70.73	84	86.49	23	46.94	34	29.57	
Perception on desmodium seed availability (%)											
Inadequate	192	80.67	84	68.29	38	51.35	46	93.88	108	93.91	59.21***

Table 3 Continues

Adequate	46	19.33	39	31.71	36	48.65	3	6.12	7	6.09	
Perception on napier or Brachiaria grass seed availability (%)											
Inadequate	147	61.76	60	48.78	20	27.03	40	81.63	87	75.65	55.39***
Adequate	91	38.24	63	51.22	54	72.97	9	18.37	28	24.35	

Note: ***, ** and * denote significance at 1%, 5% and 10% levels, respectively.

The results in Table 3 indicated that majority (71.43%) in the whole sample were married households, followed by widowed household (25.21%) and lastly by singled (1.68%) and divorced (1.68%) families. Similarly, among adopters, married households were many (78.98%), followed by widowed (25.20%) and singled households (0.81%). There were no divorced families in the adopters' sample. The proportion of married families for continuous users, dis-adopters and non-adopters were 75.68%, 71.43%, and 68.70%, respectively. The proportion of widowed households for continuous users, dis-adopters and non-adopters were 22.97%, 28.57%, and 25.22%, respectively. This shows that married households were higher than widowed, single and divorced households for each adoption category; however, these results were not significantly different across the groups.

Overall, majority (60.50%) in the whole sample practiced farming (crop and livestock) as their primary occupation, followed by salaried employment (18.49%), self-employment off-farm (14.49%), casual laborers off-farm (5.88%), and lastly casual laborers on-farm – that is, those household heads working on other peoples' farms for cash (0.84%). Similarly, among adopters, the majority (58.64%) practiced farming as their primary occupation followed by salaried employment (21.14%), self-employment off-farm (15.45%), and lastly casual laborers off-farm (4.88%). There were no households who were engaging in casual labor on other peoples' plots as their primary occupation in the adopters' sample. The proportion of households practicing farming as their main occupation for continuous users, dis-adopters and non-adopters were 54.05%, 65.31%, and 62.31%, respectively. The proportion of households having salaried employment as their primary occupation for continuous users, dis-adopters and non-adopters were 22.97%, 18.37%, and 15.65%, respectively. Again, the proportion of households having self-employment off-farm as their primary occupation for continuous user, dis-adopters and non-adopters were 16.22%, 14.29%, and 13.04%, respectively. This shows that majority of households were practicing farming as their primary occupation compared to other occupations for each category. However, these results were not significantly different across the groups.

Household head labor contribution on-farm activities play a significant role in influencing adoption and continued use of new capital and labor intensive agricultural technologies. Participation in off-farm activities often reduces time allocated for agricultural activities in that a farmer may decide to work fulltime, part-time or entirely choose not to work on their farms. In the whole sample, the majority (53.36%) provided fulltime labor on farms compared to the part-time laborers (45.80%) and those who chose not to work on their farms (0.84%). A similar case was also found amongst adopters where the majority (52.85%) provided fulltime labor on their farms compared to part-time laborers (46.34%) and those who were non-workers (0.81%). The proportion of households working fulltime on their farms for continuous users, dis-adopters and non-adopters were 48.65%, 59.18%, and 53.91%, respectively. Again, those working part-time on their farms were 50.00%, 40.82%, and 45.22% for continuous users, dis-adopters and non-adopters respectively. It is evidenced that the number of farmers working part-time on their farms was almost equal to those providing full-time labor. Mainly, the majority of PPT continuous users were working as part-time compared to full-time, which is an indication that they were engaging in other off-farm activities to boost their farm liquidity. As stated earlier, this could be one of the reasons why there was a high amount of off-farm income among continuous users compared to other groups. However, this is contrary to findings of Wollni *et al*. (2010), who found that household participation in off-farm duties limits time available for farming activities and hence discourages adoption of conservational and labor intensive agriculture technologies. Mponela *et al.* (2016) also argued that households with off-farm activities are more likely to use more of integrated soil fertility management technologies. They argued that farmers engage in many livelihood portfolios and often transfer revenues from one portfolio into another, thus resulting in interrelationships between activities at different times of the year. There were very few households who were not working on their farms as the majority indeed allocated some hours to work on their plots. Chi-square results, however, showed that there were no significant differences on forms of household labor contribution across these groups.

Participation in productive farmer groups was also given attention in this study. As an institutional factor it ensures agricultural technology uptake and continued use through resource mobilization, higher market bargaining power as well as information sharing (Kassie *et al*., 2012; Mmbando and Baiyegunhi, 2016). The results revealed that 66.81% of the sampled farmers were members of productive groups, while 33.19%, were not. Amongst adopters, a similar case was evidenced where over 78.05% households had membership in at least one productive group while 21.95% did not. Further, within each group, higher percentage of the continuous users (83.78%), dis-adopters (69.39%) and non-adopters (54.78%) were members in a productive farmer group compared to 16.22%, 30.61%, and 45.22% who were not, respectively. Chi-square results further revealed that continuous users had significantly (p = .000) higher group membership, followed by dis-adopters and lastly non-adopters.

Access to credit has been evidenced as one of the significant challenges most smallholder farmers face since they find it difficult to acquire credit that they need to boost their liquidity to help them uptake and continue using new technologies (Dolisca *et al.,* 2006; Mmbando and Baiyegunhi, 2016; Simtowe *et al.,* 2016). Furthermore, 67.23% of the farmers in the whole sample said they had access to credit either from informal or formal sectors in the last twelve months, while 32.77% said they did not have access to any source of credit. Moreover, amongst adopters, the majority (78.05%) had access to credit whereas only 21.95% did not have access to credit. Even though more than half of farmers in each category had access to credit, it was evident that there were significant differences (p = .000) in levels of credit access across these groups, where continuous users had highest level of credit access (83.78%), followed by dis-adopters (69.39%) and lastly by non-adopters (67.23%). High level of credit access could be attributed to the fact that there has been a consistent harmonization in the design and delivery system of formal financial services in rural areas. This is coupled with the emergence of many informal lending vehicles such as merry go rounds which significantly and positively influence access to credit, particularly to smallholder farmers. However, this is contrary to the findings of Gabagambi (2003) and Abdul-Hanan (2016) who reiterated that in developing countries, access to credit or credit market inefficiency has been a persistent problem to technology adoption process. They added that many financial institutions are reluctant in lending funds to smallholder farmers due to associated risk related to overreliance on rain-fed agriculture and lack of collateral, which results in to high cost of delivering lending services in rural area.

Since PPT is an integrated technology designed to control *Striga* weed and stem borer, farmers' perceptions of the severity of these pests could influence its adoption and continued use. The result on farmers' perception on the severity of *Striga* weed infestation indicated that cumulatively, over 30% of the entire sample perceived *Striga* infestation as a major problem. Cumulatively, over 74% of adopters perceived *Striga* weed infestation as a major problem. There was a significant difference (p = .000) between the level of perception on *striga* severity for each adoption category. The majority (70.27%) of continuous users perceived *Striga* infestation as a major constraint. Similarly, 44.90% of dis-adopters perceived *Striga* infestation as a major constraint. Contrary, the result indicated that over 50% of non-adopters perceived *Striga* infestation as not a problem, whereas only 24.35% and 16.52% perceived it as a minor problem and a major problem, respectively. This implies that farmers who perceived *Striga* infestation as one of the major agricultural problems adopted and continued using PPT compared to those who perceived it as not a problem. Similar results were also found by

Murage *et al*. (2015) who reiterated that farmers who perceived an agricultural problem as severe, would be more willing to adopt any technology available to combat it, than those who perceived it as less severe.

The figures derived from this analysis showed that 36.97%, 34.45%, and 28.57% of the whole sample perceived severity of stem borer as a major problem, not a problem or a minor problem, respectively. Among adopters, majority (56.10%) perceived that stem borer severity is a major problem. The severity of stem borer infestation was viewed as a major problem by over 70% of continuous users, with only 16.22% and 10.81% mentioning it as a minor and not a problem, respectively. Again, many (46.94%) of dis-adopters perceived the severity of stem borer infestation as a minor problem, with about 30.61% and 22.45% rating it as a major problem and not a problem, respectively. Furthermore, the percentages derived from the results indicated that 54.78% of non-adopters did not perceive stem borer infestation as a problem, with only 28.70% and 16.52% rating it as a minor problem and as a major problem, respectively. The perception results were significantly different (p = .000) across each category of farmers. These findings corroborated those by Khan and Pickett (2004) who stressed that positive farmer perceptions about *Striga* weed and stem borer infestation have a direct influence on decisions to adopt PPT technology.

In addition, over 68% of the sampled respondents had at least one contact with an extension agent in the last one year. Over 82.93% of adopters contacted extension provider as indicated in Table 3. Further results, revealed that there were significant differences (p = .000) in the level of extension contact between each category; with continuous users recording greatest proportion of extension contacts with extension agents (97.30%), followed by dis-adopters (61.22%) and lastly non-adopters (52.17%). Nearly half of non-adopters (47.83%) did not have contact with extension agents, compared to only 38.78% and 2.7% who did not have any contact among dis-adopters and continuous users, respectively. A higher percentage of extension contact amongst continuous users could be linked to the greater amount of agricultural information, technical assistance and improved inputs amongst continuous users which have enabled them to adopt and keep using PPT. This finding corroborated those from Asiabaka (2002), Gido *et al.* (2014) and Mutemim and Sakwa (2017) who opined that extension contact helps in disseminating agricultural innovation information, provision of technical assistance as well as improved inputs which enhance the likelihood of adoption and continuous use of new technology.

Since PPT is designed to effectively control *Striga* weed, farmers' experience on the *Striga* weed constraint in the last cropping seasons could influence its continued adoption and expansion. The results on farmers' perception on *Striga* weed constraint indicated that cumulatively, over 73% of the entire sample faced *Striga* weed constraint on their plots in the last three years while only 26.87% did not face it. The results further revealed that majority of adopters (83.74%) faced *Striga* weed constraint in the last three years, with only 31.71% agreeing that they did not face the problem. Further results showed that there were significant differences (*p* = .000) in the way farmers in each adoption category perceived *Striga* weed constraint. The results indicated that greatest percentage of PPT continuous users (89.19%) faced *Striga* weed constraint in the last three years, followed by dis-adopters (75.51%) and lastly by non-adopters (61.74%). This can be attributed to the fact that most farmers, while still faced with significant agricultural constraints such as infestation by *Striga* weed, they tend to continue applying available technologies that they perceive to address such problems. Only 10.81%, 24.48%, and 38.26 % of continuous users, dis-adopters and non-adopters, respectively, mentioned that they faced *Striga* weed constraint in the last three years. Similarly, over 71% of the entire sample faced stem borer constraint on their plots in the last three years while only 28.99% did not face it. The results further revealed that majority of adopters (81.30%) faced stem borer constraint in the last three years. Further, the results showed that there were significant differences (*p* = .000) in the way farmers in each adoption category experienced stem borer constraint. The results indicated that greatest percentage of PPT continuous users (85.14%) faced stem borer constraint in the last three years, followed by dis-adopters (75.51%) and lastly by non-adopters (60.00%).

Better land tenancy provides long-term security which raises the probability that farmers will adopt and continue using agricultural technologies, which require long-term investment such as PPT to capture their returns. The study results on Table 3 indicated that most of the households (50.84%) in the whole sample owned land with title deeds. Moreover, over 70% of adopters owned land with title deed, except for 29.27% who did not have land titles. The majority (86.49%) of continuous users held land with title deeds. In contrast, the majority of non-adopters (70.43%) and dis-adopters (53.06%) owned land without a title deed, with only 29.57% and 46.94% of them having title deeds, respectively. However, these percentages were significantly different (*p* = .000) across adoption categories, with continuous users recording a highest percentage of those farmers having title deeds compared to other categories. Non-adopters, on the other hand, had the majority of farmers without title deeds compared to other groups. A higher percentage of title deeds among continuous users could be linked to the reason behind the continued use of PPT, in that these farmers possess user rights and ownership which enable them to invest in long-term projects as well as collateral for accessing credit facilities to finance such PPT investment. Studies by Deininger *et al*. (2009) and Kpadonou *et al.* (2017) presented similar results that higher level of land ownership and user right security positively influence investments in long-term project such forest conservation project because of positive effect on farm productivity and increased returns for the future benefit of smallholder farmer and his family.

Many studies (Amudavi *et al.,* 2008; Obare *et al.,* 2011; Murage *et al.,* 2012) on PPT have indicated that one of the major problems affecting its adoption is the availability of desmodium seeds. This study found a similar result, where over 80.67% of the sampled respondents mentioned that desmodium seed was unavailable with only 19.33% agreeing that desmodium seeds were adequate. Results in Table 3 show that, for majority of adopters (68.29%) desmodium seed availability was unavailable, with only 31.71% agreeing that the seeds were adequate. Further results revealed that there were significant differences (p = .000) in the way farmers in each adoption category viewed the availability of desmodium seeds. The results indicated that greatest percentage of non-adopters (93.91%) mentioned desmodium seed as unavailable or inadequate, followed by dis-adopters (93.88%) and lastly by continuous users (51.35%). Only 48.65%, 6.12%, and 6.09% of continuous users, dis-adopters and non-adopters, respectively, mentioned that desmodium seeds were adequate. This is a clear indication that lack of desmodium seed had been a significant setback to PPT adoption and continued use. This also indicates that untimely and unavailability of desmodium seed, as well as the high cost associated with obtaining it, has remained one of the reasons behind the rejection of PPT and continued use by farmers. This finding also concurred with findings from studies by Kolawole *et al*. (2003), Ume and Uloh (2011) and Toth *et al.* (2017) who conducted related studies on cowpea, yam and fodder tree production technologies, respectively, and found that due to untimely and unavailability of production inputs such as seeds, fertilizer and labor, many farmers were more likely to reject the adoption and continued use of such technologies.

Since napier and brachiaria grass are also essential components of PPT, availability of their seeds also have a potential to influence the decision on PPT adoption and continued use, and the results are presented in Table 3. Overall, 61.76% of sampled respondents mentioned that napier or brachiaria grass seeds was inadequate while only 38.24% regarded them as adequate.

In contrast, for adopters the majority (51.22%) agreed that napier or brachiaria grass seeds were adequate, with 48.78% disagreeing. Chi-square result further revealed that there were significant differences (p = .000) in the way farmers viewed napier or brachiaria grass seed availability. The study found that 72.97% of continuous users mentioned that napier or brachiaria grass seed availability is adequate. This indicates that availability of napier or brachiaria grass seeds is one of the factors influencing uptake and continued adoption of PPT, in that PPT practicing farmers can get napier or brachiaria grass seeds from the cuttings or uprooted ones from the available stock on their farms. However, contrary results were found for dis-adopters and non-adopters, where the majority, 81.63%, and 75.65%, respectively, mentioned that napier or brachiaria grass seeds were inadequate.

4.2.2 Production Constraints by Push-pull Technology Adoption Status

Severity and perception on agricultural production constraints may induce smallholder farmers to decide whether to adopt and continue using, or not to adopt a technology depending on how they compare that technology with other technologies or practices. In relation to this, the respondents were asked to state which production constraints they perceive to be most important and require immediate attention, and the results presented in Table 4. Overall, *Striga* weed (33.19%), the high cost of input (21.10%) and stem borer (16.39%) were rated as most important maize and sorghum production constraints for the whole sample. This concurred with the findings by Murage *et al.* (2012) who asserted that *Striga* weed and stem borer remains the main constraints facing cereal production in western Kenya. Poor and declining soil fertility, diseases, soil erosion, fodder availability, other pest and low crop price were other cereal production constraints, listed by order of importance based on percentage of farmers. Among, adopters, *Striga* infestation (39.02%), high input price (17.89%), stem borer (15.45%), and poor and declining soil fertility (11.38%) accounted for more than 70% of cereal production constraints. Other production constraints for adopters were diseases (5.69%), fodder availability (5.69%), low crop price (2.44%), other pests (1.63%), and soil erosion (0.81%).

Table 4: Major production constraints by push-pull technology adoption status

	Push-Pull Technology Adoption Status										
	Overall sample *n*=238		All Adopters *n*=123		Continuous Users *n*=74		Dis-adopters *n*=49		Non- adopters *n*=115		Statistics
Variables	**Freq**	**Percent**	**Freq**	**Percent**	**Freq**	**Percent**	**Freq**	**Percent**	**Freq**	**Percent**	**Chi^2-test**
Main production constraint											
Stem borer	39	16.39	19	15.45	15	20.27	4	8.16	20	17.39	30.42^{***}
Striga weed	79	33.19	48	39.02	33	44.59	15	30.61	31	26.96	
Other pest	7	2.94	2	1.63	2	2.70	0	0.00	5	4.35	
Soil erosion	10	4.20	1	0.81	0	0.00	1	2.04	9	7.83	
Poor soil fertility	23	9.66	14	11.38	4	5.41	10	20.41	9	7.83	
Diseases	15	6.30	7	5.69	3	4.05	4	8.16	8	6.96	
Fodder availability	9	3.78	7	5.69	3	4.05	4	8.16	2	1.74	
High input prices	50	21.01	22	17.89	12	16.22	10	20.41	28	24.35	
Low crop price	6	2.52	3	2.44	2	2.70	1	2.04	3	2.61	
Total	**238**	**100.00**	**123**	**100.00**	**74**	**100.00**	**49**	**100.00**	**115**	**100.00**	

Note: *** denote significance at 1% level.

Across all adoption categories, there were statistically significant (*p*=000) differences in the rating of main production constraints, with *Striga* weed infestation being viewed as the main cereal production constraint across all groups, that is 44.59%, 30.61%, and 26.96% for continuous users, dis-adopters and non-adopters, respectively. Second most important constraint facing continuous users was stem borer (20.27%), followed by high input price (16.22%), poor and declining soil fertility (5.41%), diseases (4.05%), fodder availability (4.05%), other pest (2.70%), and low crop price (2.44%). Among dis-adopters, the second most important constraints were poor and declining soil fertility (20.41%) and high input price (20.41%), followed by diseases (8.16%), fodder availability (8.16%), soil erosion (2.04%), and low crop price (2.04%). However, soil erosion and other pests were not viewed as main production constraints by continuous users and dis-adopters, respectively. These results imply that PPT also has an added advantage when it comes to controlling not only stem borers but other pests too. Again, fibrous roots of napier and brachiaria grass also have a long-term effect when it comes to maintaining soil structure thus controlling soil erosion as well as loss of soil fertility through erosion. Finally, the second most important constraint among the non-adopters is high input prices (24.35%).

Since PPT requires more inputs in the first cropping season, high input price could be one of the factors leading to rejection of its continued adoption. However, Khan *et al.* (2008c) argued that even though PPT requires higher production costs during first cropping year, a reduction in cost is evidenced by the second year of operations onwards. Other production constraints amongst non-adopters are stem borer, soil erosion, poor and declining soil fertility, diseases, other pests, low crop price and fodder availability which account for 17.39%, 7.83%, 7.83%, 6.96%, 4.35%, 2.61%, and 1.74% of cereal production deficits. These constraints imply that they may tremendously increase the cost of production as smallholder farmers have to pay more for the limited resource available in addressing them, thus positively or negatively influencing PPT adoption and continued use. Generally, these results reaffirm the findings by Vanlauwe *et al*. (2008) who asserted that the three significant constraints experienced by almost all smallholder farmers in western Kenya are infestation by parasitic *Striga* weed, lepidopteran stem borers, and low soil fertility. Mrema *et al.* (2017) also asserted that major production constraints currently affecting smallholder farmers in Eastern Africa include *Striga* infestation, lack of access to production inputs such as improved varieties, drought and damage by other pests.

4.2.3 Level of Push-pull Technology Awareness by Adoption Status

Farmers' awareness of the upcoming and existing agricultural technologies is a critical and first stage in technology diffusion and adoption processes, in that it plays a crucial role in influencing the probability of technology adoption and continued use (Daberkow and McBride, 2003; Mango *et al.* 2017). Awareness of PPT was measured on whether a farmer has heard about PPT in the past given that the technology has been in existence for more than five years. The results are shown in Table 5. The results indicated that there were statistically significant (p=0.000) differences in the farmers' level of PPT awareness across adoption categories, with continuous and dis-adopters indicating 100% level of PPT awareness. However, this was expected as no farmer can practice a technology without being aware of it, in that technology, awareness reduces the probability of a farmer being uncertain.

Table 5: Level of PPT awareness by adoption status

PPT adoption status		**Farmer level push-pull technology awareness**			**Statistics**
		No	**Yes**	**Total**	**Chi^2-test**
Overall sample *N*=238	Frequency	89	149	238	152.05***
	Percent	37.39	62.61	100.00	
All Adopters *N*=123	Frequency	0	123	123	
	Percent	0.00	100.00	100.00	
Continuous Users *N*=74	Frequency	0	74	74	
	Percent	0.00	100.00	100.00	
Dis-adopters *N*=49	Frequency	0	49	49	
	Percent	0.00	100.00	100.00	
Non- adopters *N*=115	Frequency	89	26	115	
	Percent	77.39	22.61	100.00	
Overall sample *N*=238	Frequency	89	149	238	
	Percent	37.39	62.61	100.00	

Note: *** denote significance at 1% level.

Overall, the majority (62.61%) of the whole sample indicated that they were aware of the technology. This high level of PPT awareness is attributable to the effort being made by different extension agents especially from ICIPE, in constantly promoting wider demonstrations through different dissemination pathways aimed at up-scaling and out-scaling PPT. Conversely, in the non-adopter sample, there is a relatively low level of PPT awareness.

The result in Table 5 indicates that 77.39% of non-adopters were not aware of the PPT, with only 22.61% being aware of it. The results implied that the low level of PPT awareness observed amongst non-adopters might be negatively influencing the acceptance and subsequent PTT adoption and continuous use. This is also attributable to the fact that there are limited dissemination efforts extended to such areas. The observed low level of PPT awareness amongst non-adopters might have resulted from information sharing by smallholder farmers within groups as earlier noted (Murage *et al.*, 2015). Therefore, intensified awareness campaigns are essential through proper dissemination approaches that will increase the level of exposure to farmers thus enabling them to make an informed decision before embracing new agricultural technology. This will, in turn, maximize the possibility of adoption and continued use.

4.2.4 Sources of PPT Information

Respondents who were aware of PPT were then asked to state their primary sources of PPT information or dissemination pathways, and the results are presented in Figure 3.

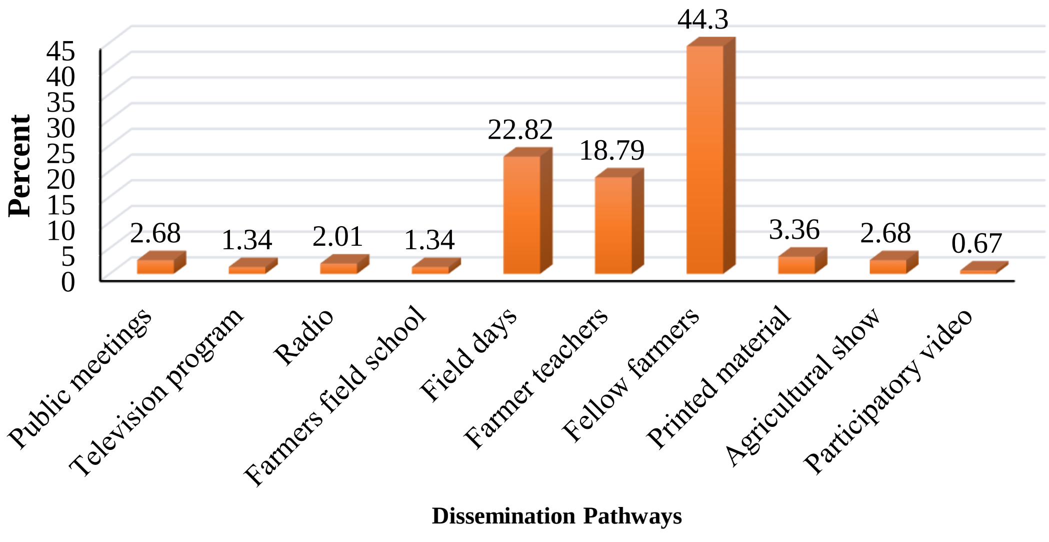

Figure 3: Main source of push-pull technology information or dissemination pathway

The results revealed that 44.30% of the respondents agreed that their primary source of PPT information was fellow farmers, followed by field days at 22.82%. Farmer teachers came third at 18.79% while printed material came fourth at 3.36%. Other PPT information sources were public meeting (2.68%), agricultural shows (2.68%), radio (2.01%), television program (1.34%), farmer field school (1.34%), and participatory video (0.67%). These results are consistent with those from studies by Amudavi *et al.* (2009), Murage *et al*. (2011) and Obare *et al.* (2011), who found that farmer teachers, field days and fellow farmer were the most effective and preferred dissemination pathways in diffusing PPT information in western Kenya. They argued that these pathways help in inducing the highest levels of adoption and subsequent management of PPT plot without further on-farm demonstration. Amudavi *et al.* (2008) and Martini *et al*. (2017) also established that farmer-to-farmer extension ensures rapid diffusion of agricultural technologies in that farmers need to be trained much on technology attributes such as risk management to make it spread further as well as making the technology more attractive. The implication of this result is that farmer-to-farmer is the common pathway for PPT information flow, demonstrated through the strong social capital. Therefore, there is need to incorporate the model farmers in other pathways available to create awareness as this will facilitate communication with the rest of the farmers.

4.2.5 Rate of Push-pull Technology Adoption, Continued Use and Dis-adoption

The results in Figure 4 shows that out of 238 randomly sampled households, more than half (51.68%) adopted PPT while 48.32% did not. This indicates that adoption rate of PPT in the study area is more than 50%. This is consistent with findings by Backson *et al.* (2014) who also found out that the actual and potential adoption rates of conventional PPT in Kenya were about 37% and 56.3%, respectively. Murage *et al*. (2015) also asserted that more than 87.8% in their study were willing to adopt climate-smart PPT on their farms, upon thorough explanation and pictorial demonstration by trained enumerators. This implies that with intensified awareness campaigns, through proper and effective dissemination approaches, the rate of adoption is expected to increase as earlier noted. The high adoption rate of PPT could be attributed to its benefits such as control of *Striga* weed and stem borer, improved crop and livestock production, improved soil fertility and control of social erosion.

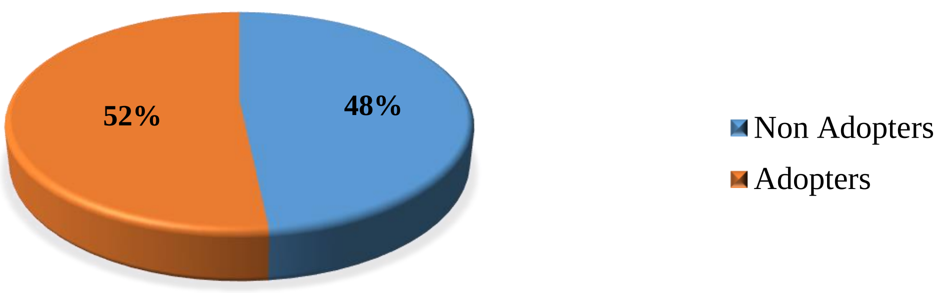

Figure 4: Rate of push-pull technology adoption

The households that adopted PPT were then asked to state the main reasons why they adopted PPT, and the results were presented in Figure 5. Most farmers (37.40%) identified control of *Striga* weed as the major incentive for PPT adoption, mainly due to higher economic losses of up to 100% caused by striga weed especially in Homa Bay County. Another second most important reason that farmers mentioned is increased crop production (20.33%), majorly because no farmer would expect zero returns after investing their limited inputs on their farms. Control of stem borer and increasing income through the sale of desmodium, napier or Brachiaria grass were mentioned as the third (13.82%) and fourth (6.50%) most important reasons for PPT adoption, respectively. Other reasons were control of soil erosion (5.69%), control of soil fertility (4.88%), increasing livestock production (4.07%), reduced labour requirement from the second season onwards (4.07%) and reduced cost of chemical requirement (3.25%). This concurred with the findings by Murage *et al*. (2012), who found that the main motivating factors cited by farmers in western Kenya as influencing their judgement to try and eventually uptake the PPT were controls of *Striga* weed and stem borers control, improving soil fertility, increased maize yield, and finally increased farm productivity.

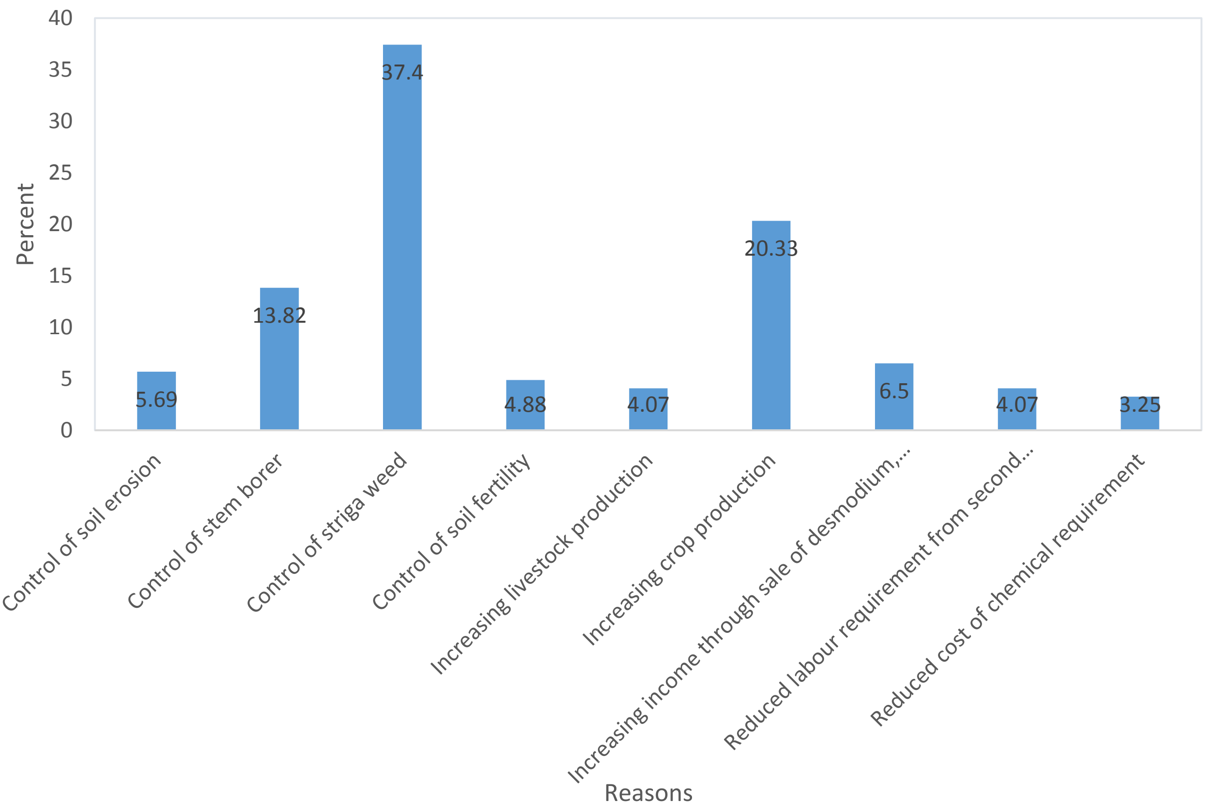

Figure 5: Main reason for push-pull technology adoption

Conversely, non-adopters were also asked to state their main reasons for not adopting PPT, and results were presented in Figure 6. Majority of farmers, over 77% cited lack of PPT awareness as their primary reason for not using PPT. As stated earlier, this is because technology awareness plays a pivotal role in ensuring technology diffusion and adoption processes, and thus influencing the probability of technology adoption. The second most important reason (among 10.43%) behind non-adoption was lack of access to desmodium seeds. Studies by Amudavi *et al.* (2008), Obare *et al.* (2011) and Murage *et al.* (2012) also found similar results that one of the major problems affecting PPT adoption is a shortage of desmodium seeds. This implies that there is a need for integrated seed development system which involves the collaboration of NGOs, seed companies and farmer groups in ensuring improved supply, affordability and accessibility of not only desmodium seeds but even other required inputs. Other vital factors hindering adoption of PPT are lack of support from NGOs (3.48%), lack of napier or brachiaria grass seed (2.61%), lack of cash or credit to buy fodder input (1.74%), difficulties in managing plot (1.74%), no livestock (0.87%), views that it is not effective to control stem borer and *Striga* (0.87%) and finally labour shortage (0.84%).

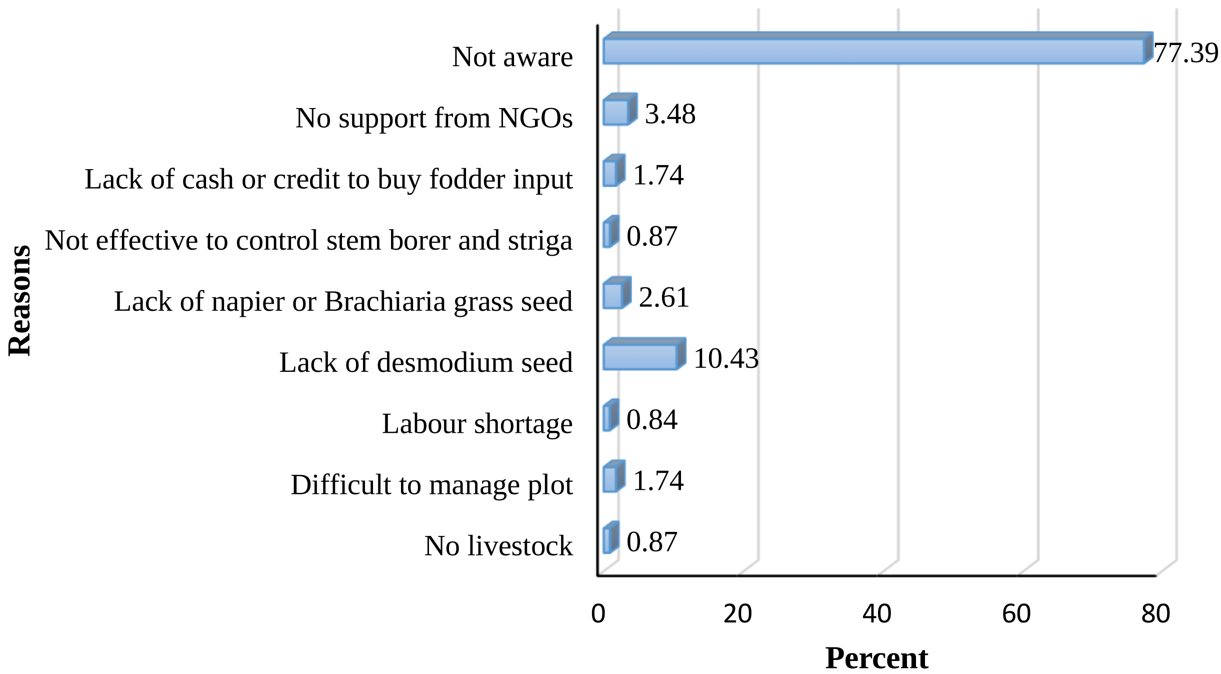

Figure 6: Main reason for not adopting push-pull technology

Further, results in Figure 7 shows that out of 123 households that adopted PPT, more than half (60.16%) continuously used PPT since they first adopted it, whereas the remaining 39.94% dis-adopted or abandoned the PPT. Accordingly, the adoption rate of PPT in the study area is more than 51.68% while the dis-adoption rate is about 39%. This implies that the rate of PPT dis-adoption in Homa-Bay County is still relatively low. However, these drop-out rates are expected to rise if not given proper attention by selecting appropriate and most effective dissemination pathways for information flow as well as provision of required inputs especially desmodium seeds, among other strategies outlined below in Figure 9.

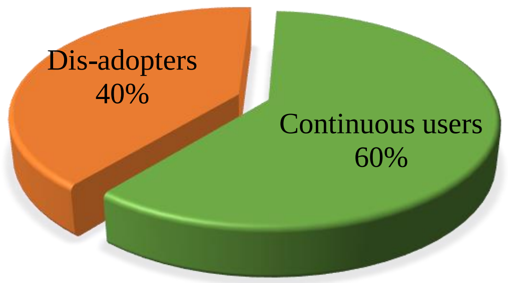

Figure 7: Rate of push-pull technology continued use and dis-adoption

Figure 8 shows the rate of PPT dis-adoption in all Sub-counties. Dis-adoption rate was slightly higher in Kasipul (20.41%), followed by Homa Bay Town (14.29%), Karachuonyo (14.29%), Rangwe (12.24%), Ndhiwa (10.20%), Kabondo-Kasipul (10.20%), Suba North (10.20%), and lowest in Suba South (8.16%).

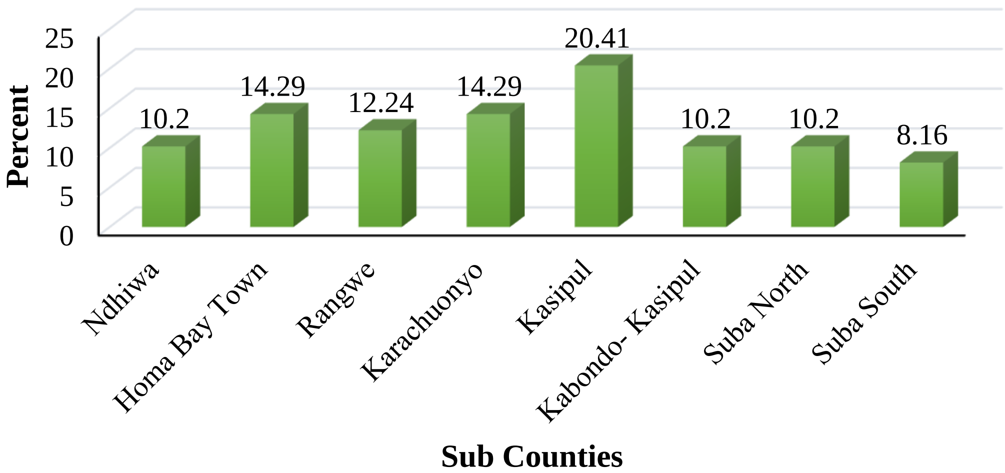

Figure 8: Rate of push-pull technology dis-adoption by Sub-County

Lowest dis-adoption rate was expected in Suba South as indicated by the results, since the region is where ICIPE offices are allocated, so it is likely that extension agents from ICIPE always monitor farmers' progress. Being closer to ICIPE offices is added advantage for farmers in Suba South over other farmers, since they frequently meet ICIPE staffs who provide the extension information as well as provision of other inputs, thus lowering their chances of discontinuing PPT adoption.

Farmers who dis-adopted PPT were asked to state the main reason why they could not continue using the PPT. Lack of access to desmodium seeds from ICIPE and other partners (42.86%) was the major reason cited by a majority of households for discontinued use of PPT followed by land shortage or smaller land size (28.57%) as shown in Figure 9.

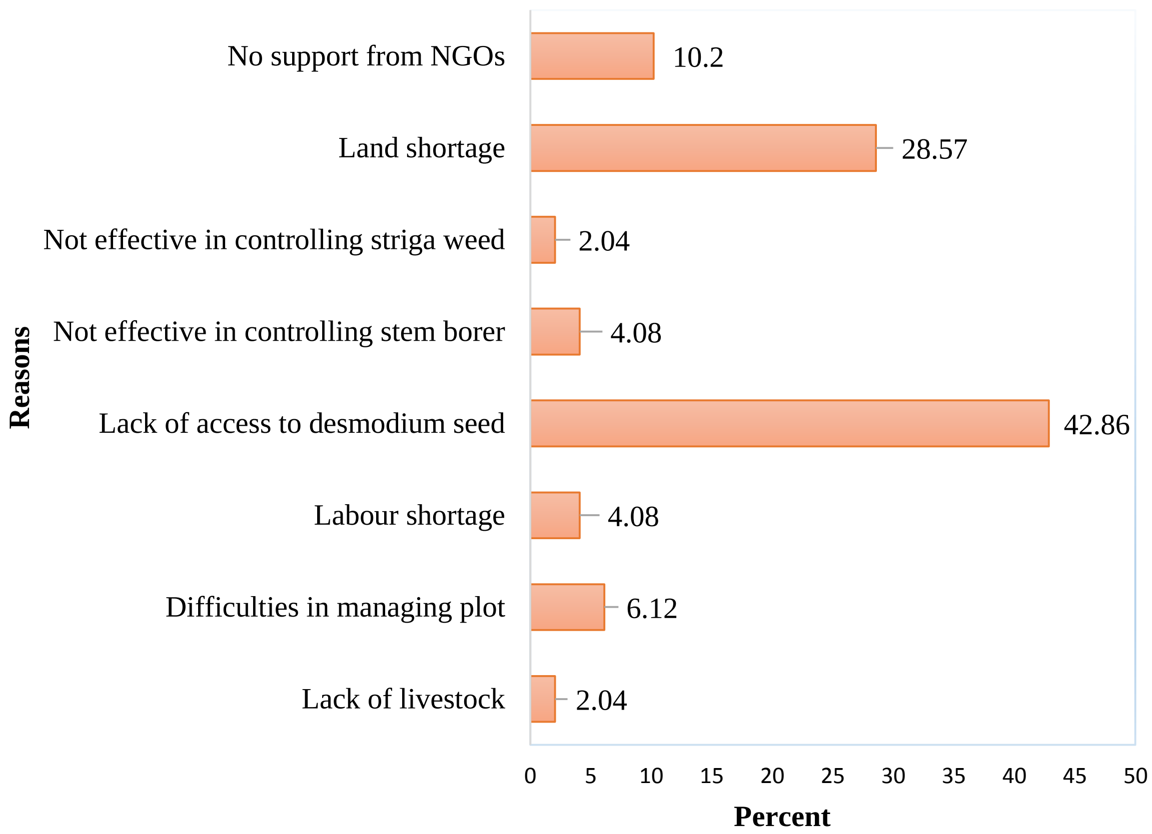

Figure 9: Main reasons for push-pull technology dis-adoption

Others were lack of support from NGOs (10.20%), difficulties in managing plots (6.12%), labor shortage (4.08%), the ineffectiveness of PPT in controlling stem borer (4.08%) and lack of livestock (2.04%). Only 2.04% indicted ineffectiveness in controlling *Striga* as a reason for

PPT discontinued use. This implies that government and NGOs should continue supplying desmodium seeds to farmers to enable them stock enough that will allow them to continue with PPT without external support.

Farmers who discontinued PPT were asked to state other strategies and methods they apply to replace PPT, and the results are presented in Table 6. However, it was observed that these farmers who dis-adopted PPT probably did so without replacing it with any modern or superior technologies to PPT. Rather, they resorted back to traditional and conventional pest and weed control practices in an attempt to address these constraints. This could be attributed to inadequate farm land, poor performance as well as financial constraint associated with modern and superior technologies such as *Striga* and stem borer resistant maize varieties.

Table 6: Push-pull technology replacement strategies and practices

		Level of use of push-pull technology replacement strategies		
		No	**Yes**	**Total**
Uprooting	Frequency	5	44	49
	Percent	10.20	89.80	100.00
Pesticide and herbicide	Frequency	47	2	49
	Percent	95.92	4.08	100.00
Intercropping	Frequency	2	47	49
	Percent	4.08	95.92	100.00
Organic manure application	Frequency	4	45	49
	Percent	8.16	91.84	100.00
Crop rotation	Frequency	4	45	49
	Percent	8.16	91.84	100.00
Inorganic fertilizer application	Frequency	29	20	49
	Percent	59.18	40.82	100.00

Majority of them, 89.80%, indicated that they uproot the *Striga* weed plus other weeds, and throw them outside the farm. Very few farmers (4.08%) indicated that they apply pesticide or herbicide to control *Striga* and stem borer, while the majority of farmers (95.92%) did not apply, perhaps due to the high cost of such inputs. Majority of them, 95.92%, indicated that they practice intercropping to replace PPT. This is perhaps due to small land sizes as farmers tend to diversify in order to get more returns form such plots. Some use manure (91.84%), to suppress germination of *Striga* weed. Other practices cited by farmers included the crop rotation (91.84%) and inorganic fertilizer (40.82%). This indicates that after adopting PPT, farmers who decide to discontinue from using PPT resort back to traditional and conventional practices which according to previous studies have shown minimum success in controlling *Striga* and stem borers (Amudavi *et al.*, 2008; Murage *et al.*, 2012).

4.3 Factors Influencing Adoption and Dis-adoption of Push-pull Technology

Even though the decisions to adopt and/or abandon PPT can be modeled independently, either by using a logit or probit models, such estimations would result in inefficient and biased estimates of the parameters of PPT adoption and dis-adoption models. This is because it ignores the potential correlation between the unobserved error terms of the two decisions; that is the decision to use PPT continuously or abandonment is contingent on the initial decision to adopt it first. Such problems were addressed by running a bivariate probit model with sample selection.

Various tests were carried out to examine the suitability of multiple variables included in the bivariate probit regression. First, the variance inflation factor (VIF) was undertaken to determine whether multicollinearity existed between variables, and the results are presented in Table 7.

Table 7: Multicollinearity diagnosis results of variance inflation factor (VIF)

Variable	**VIF**
Age of household head	1.56
Gender	1.49
Household head marital status	1.29
Education level	1.78
Household size	1.67
Household head labour contribution	1.45
Natural logarithm of off-farm income	1.82
Total farm size owned	2.04
Tropical livestock unit	2.21
Access to credit	1.48
Membership in farmer group	1.34
Distant to the nearest market center	1.18
Extension contact	1.36
Perception on *Striga* weed constraint	2.48
Perception on Stem borer constraint	2.36
Perception on desmodium seed availability	1.80
Perception on napier seed availability	1.84
Perception on *Striga* weed severity	2.92
Perception on stem borer severity	2.79
Mean VIF	**1.83**

Table 7 shows that VIF values of individual variables range from 1.18 to 2.92 with mean VIF of 1.83. Thus, it was concluded that no collinearity existed between these independent variables because VIF values were below recommended value of 10 (Greene, 2008). Second, the results of Breusch- Pagan test showed that we could not reject the null hypothesis of constant variance or homoscedasticity (p= 0.293) (see appendix 4). This implied that the model was free from heteroscedasticity problems. However, Ramsey RESET test results for omitted variables indicated the presence of omitted variables only at 10% significance level (p=0.0943), thus the null hypothesis of no omitted variables in the model was rejected (see appendix 4).

The results of the maximum likelihood estimation for bivariate probit model regressions, for adoption and dis-adoption of PPT, are presented in Table 8. An overlapping group of independent variables related to farmers' socioeconomic, institutional and farm characteristics was used to specify the estimated models. The variables such as age of household head (Hage), gender (Hgender), marital status (Mstatus, 1= Married, 0 = Otherwise), education level of household head (Educationlevel), household size (Hsize), labor contribution of household head (H_laborcontribution, 1 =Fulltime, 0 = Otherwise), natural logarithm of off-farm income (log_offfarmincome), total farm size owned by household head (Lsize), tropical livestock unit (TLU), membership in farmer group (Mfarmcooperative), distance to the nearest market center (Dmarket), perception on *Striga* weed severity (Striperception, 1= Major problem, 0 = not a problem), perception on stem borer severity (Stemperception, 1= Major problem, 0 = not a problem), access to credit (Acredict), extension contact (Ext_contact), perception on stem borer constraint (SW_constraint, 1 = Yes, 0 = No), perception on *Striga* constraint (SB_constraint, 1 = Yes, 0 = No), perception on desmodium seed availability (Dseed, 1= Adequately available, 0 = inadequate), perception on napier or brachiaria seed availability (NBseed, 1= Adequately available, 0 = inadequate) appear in both PPT adoption model and PPT abandonment models. However, the variable longevity of PPT use which was used as a proxy for farmers' experience with PPT (Longevity_PPTuse) only appears in the PPT dis-adoption decision model since it does not influence PPT adoption decision.

Table 8: Bivariate probit with selection estimation results for push-pull technology adoption and dis-adoption decisions, n = 238

	Push-pull technology adoption model (Selection equation)		**Push-pull technology dis-adoption model (Outcome equation)**	
Variable	**Coefficient**	**Standard Error**	**Coefficient**	**Standard Error**
Constant	-0.716	2.496	11.209**	4.412
Age of household head	0.074***	0.023	-0.011	0.020
Gender of household head	0.304	0.278	-0.660*	0.441
Marital status of household head	0.147	0.136	-0.156	0.241
Education Level of household head	0.151***	0.037	-0.122**	0.067
Household size	0.027	0.042	-0.027	0.072
Household head labour contribution	0.508**	0.273	-0.188	0.424
Natural Logarithm of off-farm income	-0.283	0.211	-0.314	0.303
Total land size owned	-0.147*	0.126	-0.030*	0.076
Tropical livestock unit	0.029	0.034	-0.016*	0.049
Access to credit	0.172	0.277	-0.191	0.429
Membership in farmer group	-0.186	0.336	0.418	0.425
Distant to the nearest market center	-0.021**	0.008	0.021	0.019
Extension contact	0.624**	0.257	-2.365***	0.717
Perception on *Striga* weed constraint	-0.598	0.383	-1.922**	0.769
Perception on Stem borer constraint	-0.322	0.427	-0.498	0.710
Perception on desmodium seed availability	0.562	0.404	-0.332*	0.498

Table 8 Continues

Perception on napier seed availability	0.200	0.310	-0.761*	0.445
Perception on *Striga* weed severity	0.609***	0.230	-0.133	0.360
Perception on stem borer severity	0.616***	0.206	-1.496***	0.429
Longevity of PPT use			-0.183**	0.083
Athrho	-58.234	2330.83		
rho	-1	0		

Note: Log likelihood = -120.780; Wald chi^2 (39): χ^2 = 118.20, Prob > χ^2= 0.000; Number of observation = 238; Likelihood ration test of rho=0: χ^2 (1) = 8.923, Prob > χ^2 = 0.003; *, ** and *** denote significant at 10%, 5% and 1% levels, respectively.

The bivariate probit regression model with outcome and selection models was found to be suitable for the analysis as the likelihood ratio test of independent equations (χ^2 (1) = 8.923, Prob > χ^2 = 0.003) was found to strongly reject the null hypothesis that the random error terms of the PPT adoption and dis-adoption decision equations are not correlated. This, however, implies that failure to include PPT adoption model (selection model) in the analysis would render the parameters of a univariate probit equation for PPT dis-adoption inconsistent and biased. Again, the log likelihood for the fitted model was -120.780 and Wald chi^2 (39) of 118.20, (Prob > χ^2= 0.000), indicating that all parameters are jointly significant and all covariates included in the models explained PPT adoption and dis-adoption decision at 1% significance level.

The model reported a set of variables significantly influencing PPT adoption and dis-adoption/ abandonment decisions. Regarding household characteristics, even though the age of the household head was not significant in influencing PPT dis-adoption, the study found that it was positively and significantly influencing the decision to adopt PPT at 1% significance level. This implies that the older the farmer is, the higher the likelihood of adopting PPT. This is attributable to the fact that older farmers have high accumulated knowledge and farming experience obtained from years of experimentation. Again, they have larger household size, and higher capital accumulation to adopt labor and capital intensive technology such as PPT, compared to younger farmers. In a related study, Onyenweaku *et al*. (2010) and Tey *et al*. (2017) established a similar positive association between farmers' age and uptake of agricultural technologies, largely due to immense knowledge and farming experience accumulated by the farmer overtime. This was, however, inconsistent with the finding of Oladele and Kareem (2005) and Onyeneke (2017) who opined that younger farmers are more innovative, adaptable and motivated to uptake and continue using new technologies than older farmers. Tanko (2004), Kathage *et al.* (2016) and Simtowe *et al.* (2016) established a positive and significant relationship between a number of years of farming experience gained overtime and adoption of technologies. They opined that farming experience helps farmers in setting as well as working towards given set of realistic goals.

Gender of household head had a negative significant relationship with PPT dis-adoption decision at 10% level. This implies that male farmers were less likely to abandon PPT use compared to their female counterparts. The implication of these results is that male farmers have higher access to necessary resources and agricultural information that increases their chances of continuous adoption of new agricultural technologies than female farmers. These results are consistent with the findings from a study by Murage *et al.* (2015) and Theriault *et al.* (2017) who reported that more male-headed households are probably continuing with technological use because of high-income levels compared to adopting female-headed households. However, gender of the household head was not a significant factor influencing PPT adoption. However, this is contrary to findings by Khan *et al.* (2008b), who asserted that female-headed households were more likely to uptake PPT compared to their male counterparts.

The level of education of household head who in the study was considered as the farm decision maker, positively and significantly influenced uptake of PPT, at 1% significance levels. However, the level of education was negative and significantly influenced PPT dis-adoption at 5% level of significance. This implies that the more educated a household head is, the higher the likelihood of adopting PPT and the lesser the likelihood of dis-adopting PPT. Educated farmers are well informed and are able to search, consolidate and interpret extension information related to practicability and gains associated with new technology thereby reducing their chances of dis-adopting them. The positive effect of education level on PPT adoption was consistent to findings from other studies (De Groote, 2011; Murage *et al.*, 2011; Backson *et al.* 2014; Murage *et al.*, 2015). In a related study, a higher level of education was also found to be important in changing perceptions of farmers towards continued adoption of competitiveness and environmental practices (Nunes *et al.*, 2014; Awotide *et al.*, 2016).

Type of labor contribution of household head was found to be significant and positively influencing adoption of PPT at 5% level of significance. By implication, farmers working full time or allocating more hours to work on their plots were more likely to adopt PPT compared to those assigning few hours (part-time or non-workers). This could be attributed to the fact that these farmers allocating fewer or completely no hours to work on their plots might be engaging in other off-farm activities, which limit their time to work on their farm, and thus discouraging adoption of labor-intensive technologies. This is corroborated by findings of Wollni *et al*. (2010), Mathenge *et al.* (2015) and Smale *et al*. (2016) who found that household participation in off-farm activities limits time available for farming activities and hence discourages adoption of intensification inputs or labor intensive agriculture technologies such as PPT. However, this is inconsistent with findings from studies by Amsalu and De Jan (2007) and Mango *et al.* (2018) who asserted that household participation in off-farm activities helps in generating off-farm income that can be used to finance the uptake of new technology. However, the kind of labor contribution of household head on their farms was found to be insignificant in influencing dis-adoption of PPT.

The adoption of PPT was significantly and negatively influenced by the size of land owned by farmers at 10% level of significance. By implications, farmers who have small pieces of land are more likely to uptake PPT on their subplots, compared those having a large tract of land. However, this is against the prior expectation, but the probable reason could be the fact that farmers with small pieces of land intended to increase crop and livestock production at the same time so as to have adequate food for their families from the small subplots. With the scarcity of land in place due to increasing population pressure, a farmer owning small pieces of land find it challenging to cultivate and graze their livestock on such plots, hence would be more than willing to invest in technology that provides food crop as well as a fodder crop. This finding is consistent with that of Pender *et al*. (2007), who found that population pressure leads to a land shortage in Ethiopia hence causing households to intensify or increase agricultural production using yield-augmenting and land-saving agricultural technologies. However, this was inconsistent with findings from Nowak (1997) and Tey *et al.* (2017), who ascertained that those with smaller farms have lower levels of land use diversification, due to conflicts and competition that arise on the number of possible uses on the piece of land.

Even though households with relatively large pieces of land were less likely to adopt PPT, they were found to be less likely to abandon PPT once they adopt it. This implies that size of land owned by the household was significantly and negatively associated with the decision to dis-adopt PPT (at 10% level of significance) since land is the scarcest agricultural production resource in this county. This can be attributed to the fact that farmers having small pieces of land tend to diversify production, especially with the unavailability of desmodium seeds as discussed earlier, they easily abandon PPT for other farm enterprises in order to maximize their farm returns. This result concurred with that from Amsalu and De Graaff (2006) who found a significant positive relationship between plot size and sustained use of soil conservation and management practices in Ethiopia. Oduol and Tsuji (2005) and Onyeneke (2017) also opined that growing land pressure causes farmers to increase crop intensity through the continuous use of land use practices and technologies that improve efficiency as well as productivity.

The results further indicated that livestock ownership (in tropical livestock units) only influenced abandonment of PPT, negatively and significantly at 10% level, but not PPT adoption decision. This is against the prior studies by Backson *et al.* (2014) who asserted that there is a probable increase in PPT adoption rate with every unit increase in TLU. This can be attributed to the fact that at PPT adoption stages, farmers are more concerned and focused on maximizing crop production compared to livestock production, then afterwards they come to realize PPT economic importance to livestock production. The negative and significant relationship between PPT dis-adoption and TLU is due to high demand for livestock fodder crops such napier, desmodium or brachiaria, and manure which are accrued benefits of continuing practicing PPT. Therefore, farmers owning more livestock are less likely to drop PPT as it helps them increase their livestock productivity (Khan and Pickett, 2004). Kassie *et al*. (2013) and Toth, *et al.* (2017) also established that livestock ownership enhanced the continued use of conservation agriculture and fodder production technologies.

The distance from the farm to the nearest market center negatively and significantly influenced PPT adoption decision at 5% level. By implication, the longer the farmer takes to access or reach the nearest market center, the lesser the possibility of adopting. This inverse relationship implies that, as the distance to the nearest market center increases, there is a high likelihood of an increase in transformation and transaction costs, thereby lowering the probability of farmers adopting PPT. Longer travel time or distance to the market centers due to the poor state of feeder roads leads to challenges in access input and output markets, such as difficulties in transporting produce to market or those associated with purchasing required input used in PPT such as seeds. This finding agrees with those from other studies conducted by Dorward *et al.* (2005) and Iiyama *et al*. (2017).

Access to extension contact positively and significantly influenced the decision to adopt PPT at 5% significance level. In contrast, access to extension contact was also found to negatively influence the decision to abandon PPT at 1% significance level. By implication, the more the farmer has access to extension service, the higher the likelihood of adopting PPT and the lesser the probability of dis-adopting PPT. This is because extension agents have a number of services they deliver to farmers in form of advice on crop pest and weed control, crop management, livestock management as well as provision of other agricultural inputs, which help in informing farmers, building their capacity, and increasing their knowledge thereby reducing uncertainties associated with their decision-making process. Extension information, skills, and knowledge enable farmers to be aware of different components of the technology, thus ensuring continuous use. These findings agreed with that of Knowler and Bradshaw (2007), Murage *et al.* (2011), Murage *et al.* (2015) and Habanyati *et al.* (2018) who similarly reported a positive relationship between extension contact and adoption and continued use of agricultural technologies.

The results also showed that farmers who faced *Striga* weed constraint on their farms in the last three years were less likely to abandon PPT than those who did not. This is evidenced by the negative and significant association between perception on *Striga* constraint and PPT dis-adoption decision at 5% significance level. This can be linked to the fact that most farmers, while still faced with significant agricultural constraints such as infestation by *Striga* weed, they tend to continue applying available technologies that they perceive to address such problems. But with the absence of such issues, they abandoned such practices (Sanou *et al*., 2017).

The perceptions on seed availability (for desmodium and napier or brachiaria seeds) significantly and negatively influenced PPT dis-adoption at 10% level. Availability of desmodium and napier seeds are crucial since they are a major component of PPT. The result indicates that farmers who perceive desmodium, napier and brachiaria seeds as adequately available were less likely to abandon PPT use while those who perceive them as inadequate were more likely to dis-adopt PPT. This finding also concurs with findings from studies by Kolawole *et al*. (2003), Ume and Uloh (2011) and Sanou *et al*. (2017) who argued that due to untimely provision and unavailability of improved seeds, many farmers were more likely to reject the adoption and continued use of such technologies. Amudavi *et al*. (2008) and Khan *et al.* (2014) also found a similar result. They opined that lack of access to desmodium seed was a major setback to the adoption of PPT.

The result also shows a significant positive relationship between farmers' perception of the severity of *Striga* weed and adoption of PPT, at 1% level of significance. This implies that farmers who perceived *Striga* weed infestation as a major production constraint were more likely to adopt PPT as opposed to those who perceived it as a minor problem. This can be attributed to the fact that farmers tend to respond quickly by adopting technology to address constraints they perceive as most severe. These findings corroborated those from a study by Khan and Pickett (2004) and Murage *et al*. (2015) who asserted that positive farmers' perceptions of *Striga* weed infestation have a direct influence on decisions to adopt PPT.

Similarly, a positive relationship was established between farmers' perception of the severity of stem borer and PPT adoption, at 1% significance level. Again, there was a significant negative relationship between farmers' perception on the severity of stem borer and PPT dis-adoption, at 1% significance level. This implies that farmers who perceived stem borer infestation as a major production constraint were more likely to adopt PPT continuously as opposed to those who perceived it as a minor problem. This coincides with previous studies that ascertained that farmers' perception of technology components or attributes affects their decision to adopt, adapt and continuous use of such technology (Khan and Pickett, 2004; Murage *et al.* 2011; D'Antoni *et al.*, 2012; Sanou *et al.*, 2017).

Finally, the significant negative relationship estimated between longevity of PPT use and PPT dis-adoption decision (at 5% level of significance) suggests that PPT experience and knowledge gained by a farmer over a period of PPT use coupled with perceived technology benefits, enable a farmer to adopt the technology continously. This finding is consisted with that by Amudavi *et al*. (2011) who found a significant positive relationship between longevity of PPT use on the farm and intensification decision. In addition, farmers with more PPT experience often set as well as work towards a given set of realistic goals that would help them continue practicing PPT (Sharma, 2016).

4.4 Push-pull Technology Expansion Rate and Determinants of Extent of Expansion

The study sought to investigate whether farmers who adopted PPT have expanded the area under PPT or intensified the use of PPT since adoption. In addition, the factors influencing the extent of PPT expansion were analyzed. Results in Figure 10 shows that over 50% of adopters did not expand the area under PPT since they first adopted it.

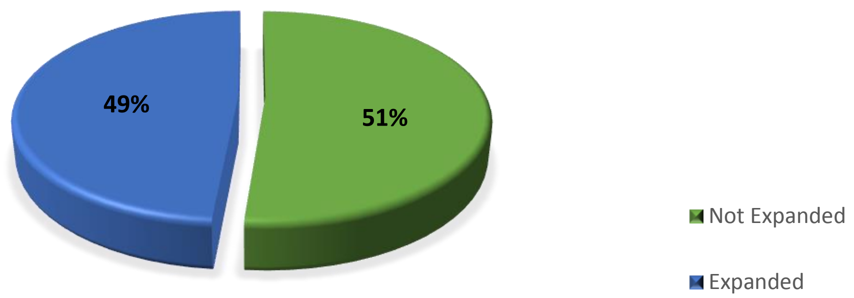

Figure 10: Rate of push-pull technology expansion

The majority have reduced the amount of land allocated to PPT, with some abandoning the technology as discussed in Figure 7. Only 48.59% of adopters have actually increased the area allocated to PPT since first they adopted it. This finding is consistent with that of Amudavi *et* *al.* (2011) who found that the average expansion rate of PPT in western Kenya is less than 50%. They reported that only 16% of the sampled farmer had expanded PPT use.

To identify the effects of farmer socioeconomic characteristics, farm characteristics and dissemination pathways on the extent of PPT expansion, a censored tobit model was used and the results presented in Table 9. A censored tobit model was preferred due to presence of many negative and zero values for farmers who reduced farm size allocated to practice PPT and those who did not expand the area under PPT since they first adopted, respectively. The extent of PPT adoption was investigated since it is an important innovative strategy that can help in the intensification of maize and livestock production in Kenya. The censored tobit model was estimated using maximum log likelihood estimation method, and the results presented in Table 9. The dependent variable was obtained as the ratio between the difference in the land sizes allocated to PPT during the first time of use and current PPT area to the total farm size.

$$Extent\ of\ PPT\ expansion\ = \left(\frac{Current\ Area\ under\ PPT - \text{Area during the first time of PPT use}}{Total\ land\ size\ owned}\right)..(26)$$

The log likelihood ratio of 26.478 indicates how the model quickly converges. The likelihood ratio chi-square statistic (LR $chi^2(25) = 142.31$, $p = 0.000$) and Pseudo R^2 of 1.592 shows that the model wholly and significantly fits the data well, in that the variation in extent of PPT expansion was explained by the regressors considered in the tobit model. The observations that were left censored at zero were 62 while uncensored observations were 61.

A joint or general test of significance was conducted and results presented in appendix 5 that showed that all explanatory variables were statistically significant (F = 5.89, p =0.000). According to the results in Table 9, gender had a positive and significant influence on the extent of PPT expansion at 1% level. By implication, households headed by a male were more likely to increase the area allocated to PPT compared to female-headed ones. The results showed that the extent of PPT expansion for households headed by male was significantly greater than those headed by female by 0.146 acres, all factors held constant. A possible explanation of this is that male farmers have higher access to necessary resources and agricultural information that increases their chances of intensifying the use of new agricultural technologies than female farmers. This is consistent with the findings by Backson *et al.* (2014) and Theriault *et al.* (2017). They argued that more male-headed households are probably intensifying technological use because of high-income levels compared to adopting female-headed households.

Table 9: A censored tobit results for factors influencing the extent of Push-pull technology expansion, n =123

Variable	Coefficient	Standard Error
Age of household head	0.003	0.003
Gender	0.146***	0.053
Marital status	0.044*	0.023
Education level	0.004	0.006
Household size	0.001	0.006
Farming experience	-0.006	0.003
Total size of cultivable land	-0.034**	0.017
Tropical livestock unit	0.003	0.004
Membership in farmer group	-0.009	0.039
Extension contact	0.156**	0.074
Distance to the nearest market center	-0.004*	0.002
Perception on the severity of stem borer	0.079***	0.026
Perception on the severity of *Striga* weed	-0.013	0.028
Perception on the availability of desmodium seeds	-0.013	0.043
Perception on the availability of napier or brachiaria seeds	0.147***	0.043
Longevity of PPT use	0.031***	0.006
Pathways		
Fellow farmer	Base category	
Field days	-0.016	0.046
Farmer teachers	-0.042	0.054
Farmer school	-0.132**	0.059
Radio	-0.115*	0.068
Television program	-0.305***	0.077
Print material	-0.222***	0.081
Public meeting	-0.233***	0.071
Agricultural show	-0.304***	0.091
Participatory video	-0.204**	0.094
Constant	-0.498**	0.190
/sigma	0.121	0.011

Note: Farmer to farmer extension used as reference category; Log likelihood =26.478; log likelihood χ^2 (25) = 142.31, Prob > χ^2 = 0.000; Pseudo R^2 = 1.593; Number of observation = 123; ***, ** and * denote significant at 1%, 5% and 10% probability levels, respectively.

As expected, marital status of the head had a significant positive influence on the extent of PPT expansion. This implies that the extent of PPT expansion for household heads without spouses was significantly lower than that of married farmers by 0.044 acres, at the 10% significance level, ceteris paribus. This can be attributed to the joint decision-making among married couples that helps them better appreciate the benefits of PPT compared to single, widowed and divorced families. The argument is that in married families, men are expected to engage women in decision-making on new technology attributes. Since women have limited access to opportunities and productive agricultural resources for commercial inputs than men as argued by Murage *et al.* (2015) and Tamru *et al.* (2017), engaging them in farm decision-making process grant them such access that enables them to extend the use of new agricultural technology for higher agricultural growth especially in developing countries. Married families could also be associated with higher own farm labor for extensive use of technology, where the spouses work together as opposed to widowed, single and divorced families that my lack resources and family labor for intensified use of PPT (Hakizimana *et al.* 2017).

Total size of cultivable land had a negative significant influence on the extent of PPT expansion at 5% level. However, this is against prior expectation. It implies that a unit increase in total size of cultivable land owned by a farmer reduces the extent of PPT expansion by 0. 034 acres, all other factors held constant. In other words, farmers with smaller land sizes were more likely to expand PPT use compared to those with large pieces of land. This is attributable to the fact that those farmers with small lands have got the incentive to improve the productivity of their small plots by intensifying integrated technologies compared to those with large farm sizes. Again, farmers with smaller land sizes are more willing to invest and expand the use of technologies that provides both food crop and fodder crop at the same time such as PPT compared to those with larger farms (Pender *et al.*, 2007). However, this finding was inconsistent with those from a study by Wimberly *et al.* (2017) who reported that households with larger farms were more likely to expand their cropland acreage than those with smaller farms.

Access to extension contact or service positively and significantly influenced the extent of PPT expansion at 5% level of significance. The positive influence of extension contacts implies that the more the PPT farmer has contacts with extension and development agents, the more they tend to increase the area allocated to PPT by 0.156 acres, ceteris paribus. This also implies that intensive discussions between farmers and agricultural extension officers help improve crop and livestock production. The agents deliver extension information, skills, knowledge, and resources that enable farmers to learn about different components of the technology, thus ensuring extensive use. These results are consistent with results of earlier studies (Murage *et al.*, 2011; Murage *et al.*, 2014; Regmi *et al.*, 2017; Mutemim and Sakwa, 2017).

Distance to the nearest market center had a negative significant influence on the extent of PPT expansion at 10% level of significance. This implies that as distance to the nearest market increase by one unit, the likelihood of PPT expansion reduces by 0.004 acres when all factors are held constant. These results imply that households living nearer the market centers have better access to information and markets for both inputs and outputs; thus, they are more likely to expand the use of new technologies being promoted including PPT. The longer the farmer takes to access or reach the most adjacent market center, the higher the probability of expanding area under PPT. This inverse relationship implies that, as the distance to the nearest market center increases, there is a high likelihood of an increase in transformation and transaction costs, thereby lowering the probability of PPT expansion (Dorward *et al.* (2005); Backson *et al.*, 2014; Iiyama *et al*., 2017).

Farmers perception on severity of stem borer infestation has a positive and significant influence on the extent of PPT at 1% significance level. The reason is that the central role of PPT is to fight stem borer, *Striga* weed and poor soil fertility which were earlier mentioned in Table 4 as major production constraints in the study area. As such, farmers' perceptions on severity of stem borer influenced the decision on how much land area to be added for practicing PPT. According to the results, when other factors are held constant, PPT farmers who perceive the stem borer as a major constraint broadly expanded the PPT use by 0.079 acres compared to those who perceived it as a minor problem.

Similarly, farmer perception on the availability of napier or brachiaria seeds had a positive significant influence on the extent of PPT at 1% significance level. This suggests that when other factors are held constant, PPT farmers who perceived that napier or brachiaria seed were adequately available were more likely to expand the PPT area use by 0.147 acres compared to their counterparts who perceived it as inadequate.

As expected, the influence of longevity of PPT use (number of years in PPT farming) on the extent of PPT expansion was positive and significant at 1% significance level as shown in Table 9. An increase in the experience a farmer has on PPT, the higher the likelihood to increase the area allocated to PPT by about 0.031 acres when other factors are held constant. This result is consisted with that by Amudavi *et al*. (2008b) who found a significant positive association between longevity of PPT use on the farm and PPT expansion decision. They argued that one-unit increase in the number of years a farmer has been enjoying the benefits of PPT increased the likelihood of PPT expansion by 0.43.

In order to evaluate the effectiveness of dissemination pathways on the extent of PPT expansion, PPT adopters were presented with a list of 10 dissemination pathways that have been commonly and widely used to catalyze PPT diffusion and asked to indicate the central pathway or information source they perceived to have influenced their PPT expansion decision greatly. Farmer-to-farmer extension being the commonly mentioned pathway, it was used as base or reference category in the censored Tobit regression, and results are presented in Table 9. The result generally shows that dissemination pathways positively influence the extent of PPT expansion due to the participatory and demand-driven approach followed by the extension agents. The null hypothesis of the study was that the effect of the farmer-to-farmer extension on the extent of PPT expansion is the same as those of other pathways.

From the results in Table 9, it can be concluded that the effect of the farmer-to-farmer extension on the extent of PPT expansion is significantly higher than that of farmer school by 0.132 acres at 5% significance level, ceteris paribus. The effect of the farmer-to-farmer extension on the extent of PPT expansion is also significantly higher than that of Radio by 0.115 acres at 10% significance level when other factors are held constant. The effect of a television program on the extent of PPT expansion is significantly lower by 0.305 acres than that of farmer-to-farmer extension, at 1% significance level and when other factors are held constant. The influence of print media on the extent of PPT expansion is significantly lower by 0.222 acres than that of farmer-to-farmer extension, at 1% significance level, ceteris paribus. Similarly, the influence of public meeting on the level of PPT expansion is 0.233 acres lower than that of farmer-to-farmer extension at 1% significance level when other factors are held constant. The marginal effect of the farmer-to-farmer extension on the extent of PPT expansion is significantly higher by 0.304 acres than that of the agricultural show, at 1% level of significance ceteris paribus. Finally, when other factors are held constant, the marginal influence of participatory video on the extent of PPT expansion is significantly lower by 0.204 acres than that of farmer-to-farmer extension at 5% significance level.

Looking at these marginal effects, it can be said that one of the most effective pathways, is farmer-to-farmer because it ensures clear demonstration of the PPT efficacy as well as ensuring mutual support that significantly increases the probability as well as the extent of PPT expansion compared to other pathways. In a related study, Martini *et al*. (2017) also revealed that farmers perform an essential role as reliable agricultural information disseminators. This includes areas related to agroforestry technologies especially where language barriers and limited access to government extension providers act as major constraints to such dissemination efforts. Even though there were no significant differences in the effect of farmer-to-farmer and field days and farmer teachers on the extent of PPT expansion, an F-test was conducted to estimate further whether their coefficients were the same. The F-statistic results in Table 10 showed that the coefficients of farmer-to-farmer extension and field day were not significantly different (p = 0.9618) from each other.

Table 10: A joint test of significance result for farmer-farmer extension and field days

(1) [model]0b. Pathways - [model]1. Pathways = 0
F (1,100) = 0.00
Prob > F = 0.9618

Again, the F-statistic results on Table 11 shows that the coefficient of farmer-to-farmer extension and farmer teachers are not significantly different (p = 0.7189) from each other. These results imply that the effect of farmer-to-farmer extension, field day, and farmer teachers on the extent of PPT expansion is almost the same.

Table 11: A joint test of significance result for farmer-farmer extension and farmer teachers

(1) [model]0b. Pathways - [model]2. Pathways = 0
F (1, 100) = 0.13
Prob > F = 0.7189

Farmer-to-farmer pathway being one of the most important and effective dissemination pathways, it can be said that field days and farmer teachers are also most effective and efficient pathways influencing expansion decision as well as the extent of PPT use significantly compared to other approaches. These findings are consistent with those from other studies that established that field days, farmer teachers, fellow farmer, and field school were the most preferred and effective pathways that significantly increase the likelihood of adopting PPT (Khan and Pickett, 2004; Amudavi *et al.*, 2008; Amudavi *et al.*, 2009; Murage *et al.*, 2011; Murage *et al.*, 2012; Murage *et al.*, 2014). Generally, a combination of dissemination pathways in the diffusion of PPT information is recommended as this will increase the likelihood of adopting, expanding and sustaining the use of such knowledge, capital and labor intensive technology.

4.5 Effect of PPT Continued Adoption on Livelihood Outcomes

4.5.1 Selection of Livelihood Outcome Variables

Table 12 shows one-way ANOVA and Chi-Square results for selected livelihood outcomes. One-way ANOVA results revealed there was a statistically significant difference in household per capita consumption expenditure per day across the adoption categories (p = 0.000). The average household per capita consumption expenditure per day for the entire sample was KES. 154.28. The average household per capita consumption expenditure per day for all adopters was KES. 166.16. Continuous users of PPT recorded higher average household per capita consumption expenditure per day of KES. 166.16, followed by non-adopters (KES. 141.57), and lastly dis-adopters (KES. 119.88). A Tukey post-hoc test further revealed that household per capita consumption expenditure per day was statistically significantly higher amongst continuous users compared to non-adopters (p = 0.000). The results also showed that the household per capita consumption expenditure per day was significantly higher for continuous users (p = 0.000) compared to dis-adopters. This implies that on average household consumption expenditure was highest among the PPT continuous users than non-adopters and dis-adopter categories. This is attributed to more income from PPT production used in purchasing various goods. However, there were no statistically significant differences in household per capita consumption expenditure per day between the dis-adopters and non-adopters. These results are consistent with those from a study by Chepchirchir *et al*. (2016) on the impact of intensity of PPT uptake on household welfare. They found a higher per capita consumption expenditure among PPT adopter than non-adopters.

Overall, the majority (62.18%) in the entire sample were living below poverty line with only 37.82% of the households living above the poverty line as shown in Table 12. Similarly, the majority (57.72%) amongst all PPT adopters were living below poverty line. The proportion of households living above the poverty line for continuous users, dis-adopters, and non-adopters were 60.81%, 14.29%, and 33.04%, respectively. Again, the proportion of households living below poverty line for continuous users, dis-adopters and non-adopters were 39.19%, 85.71%, and 66.96, respectively. This implies that majority of the continuous users were significantly (p = 0.000) living above poverty live compared to other adoption categories which recorded high percentage of households who live below poverty line.

Table 12: Statistics on livelihood outcomes

	Push-pull Technology Adoption Status					
	Overall sample *n*=238	**All Adopters *n*=123**	**Continuous Users *n*=74**	**Dis-adopters *n*=49**	**Non-adopters *n*=115**	**Statistics**
Variables	**Mean/std. dev.**	**Mean/std. dev.**	**Mean/std. dev.**	**Mean/std. dev.**	**Mean/std. dev.**	**F-test/ $\mathbf{Chi^2}$-test**
Per Capita Consumption	154.28	166.16	196.80	119.88	141.57	13.96***
Expenditure per Day (KES)	(91.41)	(91.67)	(91.46)	(70.75)	(89.78)	
Headcount Ratio (%)						
Above poverty line	37.82	42.28	60.81	14.29	33.04	29.29***
Below Poverty Line	62.18	57.72	39.19	85.71	66.96	
Poverty gap (Incidence of Poverty)	0.22	0.17	0.09	0.30	.27	22.68***
	(0.20)	(0.10)	(0.15)	(0.19)	(0.23)	
Squared Poverty Gap (Severity of	0.09	0.07	0.03	0.12	0.12	16.20***
poverty)	(0.12)	(0.10)	(0.08)	(0.11)	(0.13)	
Household Dietary Diversity Score	7.69	8.90	10.38	6.67	6.39	122.83***
	(2.53)	(2.36)	(1.24)	(1.84)	(2.02)	

Note: *** denote significance at 1% level.

The results revealed that regarding poverty gap, there was a statistically significant difference across adoption categories (*p* = 0.000). The poverty gap for the entire sample was 0.22, with a lower incidence of poverty among continuous users (0.09), followed by non-adopters (0.27) and lastly dis-adopters (0.30). The poverty gap for all adopters was 0.17. A Tukey post-hoc test further revealed that the incidence of poverty was statistically significantly lower among continuous users compared to non-adopters (*p* =0.000). This shows that the incidence of poverty was highest among the PPT non-adopters than adopters. The results also revealed that the incidence of poverty was statistically significantly higher for dis-adopters compared to continuous users (*p* = 0.000). However, there were no statistically significant differences in the incidence of poverty between the dis-adopters and non-adopters. Lower incidence of poverty witnessed among PPT continuous users compared to dis-adopter or non-adopters could be linked to the perceived benefits of PPT in terms of improved production or income received from its diversified outcomes.

The results also revealed that there was a statistically significant difference in severity of poverty across the groups (*p* = 0.000). The severity of poverty for the entire sample was 0.09, with significantly lower severity among continuous users (0.03), followed by non-adopters (0.12) and dis-adopters (0.12). The severity of poverty for all adopters was 0.07. A Tukey post-hoc test further revealed that the severity of poverty was statistically significantly lower among continuous users compared to non-adopters (*p* =0.000) and dis-adopters (*p* =0.000). However, there were no statistically significant differences in severity of poverty between the dis-adopters and non-adopters (*p* =0.999). Chepchirchir *et al*. (2016) also found a higher incidence and severity of poverty among non-adopters of PPT in Eastern Uganda.

One-way ANOVA results revealed there was a statistically significant difference in Household Dietary Diversity Score across the farmer groups (*p* = 0.000). The average Household Dietary Diversity Score for the entire sample was 7.69. The Household Dietary Diversity Score for all adopters was 8.90. On average, continuous users recorded higher Household Dietary Diversity Score of 10.38, followed by dis-adopters (6.67) and lastly non-adopters (6.39). A Tukey post-hoc test further revealed that, on average, Household Dietary Diversity Score was statistically significantly higher among continuous users compared to non-adopters (*p* =0.000). The results also revealed that the Household Dietary Diversity Score was statistically significantly higher for continuous users (*p* =0 .000) compared to dis-adopters. This implies that on average PPT continuous users have higher access to quality food diet compared to non-adopters and dis-adopters. This is attributed to more income from PPT production that can be used in purchasing various food groups. However, there were no statistically significant differences in Household Dietary Diversity Score between the dis-adopters and non-adopters. Ogot *et al.* (2017) in a related study also reported that PPT as an agricultural intervention has improved nutritional status of farmers' children in western Kenya.

4.5.2 Selection of Variables and Determination of Propensity Scores

In order to measure the causal effect of PPT continued use on selected livelihood outcomes, PPT dis-adopters were excluded from the sample, and another a probit model adopted to estimate the probability of continued PPT adoption. Based on the conditional independence assumption, only regressors that are significant determinants of livelihood outcomes, as well as PPT adoption, were selected. First, the variance inflation factor (VIF) was performed to examine the presence of multicollinearity among independent variables, and results are presented in Table 13.

Table 13: Multicollinearity diagnosis results of variance inflation factor (VIF)

Variable	**VIF**
Age of household head	1.46
Gender	1.50
Marital status	1.27
Education level	1.76
Household size	1.58
Natural logarithm of off-farm income	1.59
Total cultivated land	2.03
Tropical livestock unit	2.03
Land ownership	1.45
Perception on *striga* weed severity	1.86
Perception on stem borer severity	1.59
Number of farmer groups	1.54
Distance to nearest administrative center	1.22
Mean VIF	**1.61**

Table 13 shows that VIF values of individual variables range from 1.22 to 2.03 with mean VIF of 1.61. This presents that no collinearity existed between these independent variables since all VIF values were below recommended value of 10. The results of Breusch-Pagan test for heteroscedasticity (X^2=1.92, p=0.1658) (see appendix 6) showed that the model was free from heteroscedasticity problems, as the null hypothesis for homoscedasticity (constant variance) was not rejected. Table 14 presents the associated estimates of the probit model. Independent variables included age of household head (Hage), gender (Hgender,) household head marital status (Mstatus, 1= Married, 0 = Otherwise), education level of household head (Educationlevel), household size (Hsize), natural logarithm of off-farm income (log_offfarmincome), total farm size cultivated (Lsize), land ownership (Ltenure, 1= Owned with title, 0= Otherwise), tropical livestock unit (TLU), number of membership farmer groups (N_membership), perception on *striga* weed severity (Striperception, 0 = not a problem, 1= Major problem), perception on stem borer severity (Stemperception, 0 = not a problem, 1= Major problem), and distance to nearest administrative center (Daministration).

Table 14: Results of probit estimation of propensity scores

Variables	Coefficient	Standard Error	z-Value
Age of household head	0.033	0.019	1.74*
Gender	0.372	0.413	0.9
Household head Marital status	-0.549	0.427	-1.29
Education level	0.191	0.054	3.55***
Natural logarithm of off-farm income	0.0489	0.233	0.21
Household size	-0.023	0.058	-0.39
Tropical livestock unit	0.034	0.042	0.82
Total farm size owned	0.321	0.152	2.11**
Land ownership	1.042	0.327	3.18***
Perception on striga weed severity	0.298	0.194	1.53*
Perception on stem borer severity	0.64	0.197	3.24***
Distance to nearest administrative center	-0.013	0.004	-3.29***
Number of farmer groups	-0.08	0.075	-1.06
Constant	-5.687	2.788	-2.04**

Note: Number of observation = 189; Log likelihood =-47.35; log-likelihood χ^2 (13) = 158.34, Prob > χ^2 = 0.000; Pseudo R^2 = 0.626; ***, ** and * denote significant at 1%, 5% and 10% levels, respectively

Table 14 shows a log likelihood ratio of -47.35 indicating how the model quickly converges. The likelihood ratio chi-square statistic (LR $chi^2(13)$ = 158.34, p = 0.000) and Pseudo R^2 of 0.626 show that the model wholly and significantly fits the data well, and in that the decision to adopt and sustained used of PPT were attributed to the explanatory variables considered in the probit model. This also shows that the combination of explanatory variables meets the balance requirement. Table 14 also presents information about some of the factors influencing farmers' adoption decisions and continued use of PPT where the explained variable takes the value of one (1) if the farmer adopted and still practicing PPT, and zero (0) if the farmer completely never adopter.

4.5.3 Balancing Test and Common Support Determination

To determine the effect of PPT adoption and continued use, it is essential to consider the fact that PPT adopters might also have realized a higher level of livelihood outcomes, even if they had not practiced PPT. As a result, the study adopted propensity score matching techniques that account for all observable factors or characteristics to distinguish the intrinsic effect of PPT continued adoption on household livelihood outcome. Therefore, the "balance test" was performed to balance the relevant covariates distribution between PPT adopters and non-adopters, before and after matching. The common support condition or the overlap was checked using a line graph that presents the propensity scores distribution (x-axis) between PPT continuous user (treated) and non-adopters (untreated). The region of common support ranged from 0 to 0.999 as presented in Figure 11.

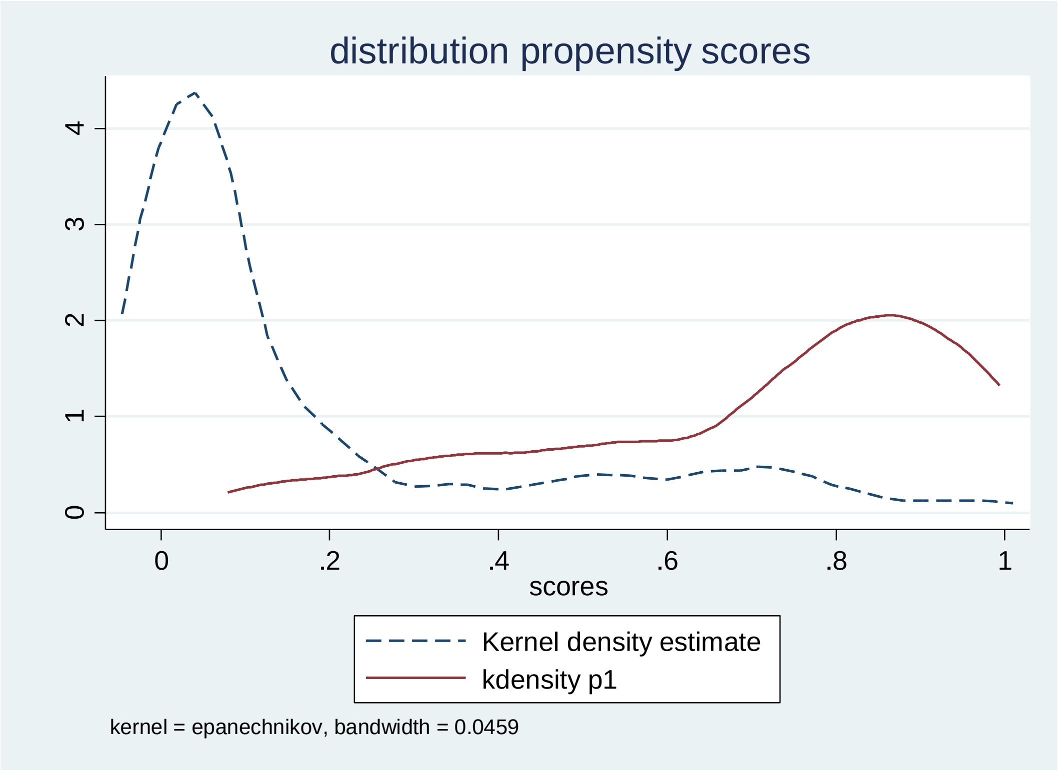

Figure 11: Common support graph

Common support condition helps in ensuring that all combination of observed household characteristics in the treatment and control group are matched. Looking at the propensity scores distributions based on the common support region and the overlaps, it can be seen that most of the scores between the PPT adopters' category and non-adopters' category were within the region of common support. This is also evidenced by more overlaps between the treated and untreated groups. As a consequence, only a few observations were rejected from the analysis; hence a good match was obtained.

4.5.4 Assessing the Matching Quality

It is essential to note that two matching algorithms namely kernel matching (KM) and nearest neighbor matching (NNM), were used to examine the effects of PPT adoption and continued use on farmer livelihood outcomes. However, these two different algorithms resulted in different quantitative findings, but with similar qualitative results. The matching algorithms resulted in unique common support area and were based on somewhat different samples, thus resulting to the selection of various observations. Therefore, in assessing the matching quality, balancing test was used to examine whether the differences in the explanatory variables or covariates in the matched sample category have been eliminated. Different propensity score quality indicators were used to check the quality of matching process, before and after matching to determine the balance in the distribution of the covariates in all groups. Results presented in Table 15, therefore, presents the mean differences, percent reduction in bias after completion of the matching algorithm and percent bias of the matched and unmatched group based on the observed characteristics used in the probit model of PPT continued adoption decision.

After controlling for bias, a better balance was achieved in the matched sample for all the covariates. According to Rosenbaum and Rubin (1983), a percentage bias after matching of each covariate and the mean absolute bias should be less than 20% for validation of the balancing property. Overall, all variables satisfied this criterion after matching thus validated the balancing property. Therefore, PPT adopters and non-adopters with similar observable characteristics have been successfully matched. Three nearest neighbor and Kernel matching were then considered as the best matching techniques for this study since they resulted in significant reduction in bias after matching all the covariates. Moreover, there were no significant differences in the mean distribution ($p>t$) in matched untreated and treated groups.

Table 15: Mean differences in covariates before and after matching

Variable	Sample	Mean Sample		Bias		t-test	
		Treated	Control	Bias (%)	Reduction bias (%)	t	p>t
Age of household head	Unmatched	54.865	49.93	50.3		3.42	0.001
	Matched	52.257	52.435	-1.8	96.4	-0.08	0.935
Gender	Unmatched	0.824	0.539	64		4.17	0.000
	Matched	0.714	0.831	-26.2	59	-1.16	0.249
Household head marital status	Unmatched	0.757	0.687	15.5		1.03	0.302
	Matched	0.686	0.803	-26	-67.3	-1.11	0.269
Education level of household head	Unmatched	10.824	6.913	114.3		7.49	0.000
	Matched	9.714	11.498	-52.1	54.4	-2.07	0.142
Natural logarithm of off-farm income	Unmatched	12.077	11.502	72.3		4.94	0.000
	Matched	11.856	11.915	-7.5	89.7	-0.34	0.736
Household size	Unmatched	7.838	6.383	44.2		3	0.003
	Matched	6.771	6.589	5.5	87.5	0.27	0.790
Tropical livestock unit	Unmatched	7.423	3.858	70.4		4.97	0.000
	Matched	5.528	5.686	-3.1	95.6	-0.15	0.881
Total cultivated land owned	Unmatched	2.969	1.819	88.6		5.98	0.000
	Matched	2.501	2.441	4.6	94.9	0.21	0.833
Land ownership	Unmatched	0.865	0.296	140.4		9.15	0.000
	Matched	0.714	0.739	-6	95.7	-0.23	0.821
Perception on striga weed severity	Unmatched	1.595	0.574	141.3		9.37	0.000
	Matched	1.314	1.156	22	84.5	0.78	0.437
Perception on stem borer severity	Unmatched	1.622	0.617	140		9.28	0.000
	Matched	1.371	1.028	47.8	65.8	1.69	0.096
Distance to nearest administrative center	Unmatched	37.324	69.287	-77.1		-4.99	0.000

Table 15 Continues

	Matched	50	58.169	-19.7	74.4	-0.87	0.385
Number of productive groups	Unmatched	3.919	2.252	69		4.66	0.000
	Matched	2.943	3.088	-6	91.3	-0.24	0.814

Generally, there was insignificant p-values of the likelihood ratio test, greater reduction in total bias, and low pseudo R^2 after matching for all algorithms as shown in Table 16. This implies that the propensity specification was successful with respect to balancing of covariates distribution between the treated and untreated groups.

Table 16: Propensity score quality indicators

Matching algorithms	Three nearest neighbors Matching NNM (3)	Kernel matching (KM)
Before Matching		
Pseudo R^2 before matching	0.626	0.626
LR chi^2 before matching	158.34	158.34
Mean standardized bias before matching	83.6	83.6
Prob > chi^2	0.000	0.000
After matching		
Pseudo R^2 after matching	0.078	0.090
LR chi^2 after matching	7.61	8.70
Mean standardized bias after matching	12.6	17.6
Prob > chi^2	0.868	0.795
Total % bias reduction	84.93	78.95

Specifically, the mean standardized biases for all variables observed was 83.6 before matching. However, after matching, mean standardized biases significantly reduced to 12.60 and 17.6 for three nearest neighbor and kernel matching, respectively. This implies that three nearest neighbor matching produced the best matching quality in terms of low mean standardized biases. The pseudo-R^2 value before matching was 0.626. By re-evaluating the scores based on matching the PPT adopter category and non-adopter category, and comparing the values of pseudo-R^2 before and after matching process, the finding revealed that the pseudo-R^2 values for the nearest neighbor matching (0.078) and the kernel matching were significantly reduced to lower values after matching process. This implied that the matching process significantly reduced the selection bias thus the balancing property was satisfied. In other words, it implied that the regressors were randomly distributed in the treated group and untreated group. Further, p-values were all rejected after matching for all the matching algorithms implying that there was no difference in the observed covariates distribution between treated and control groups. The total percentage reduction bias for NNM and KM were 84.93% and 78.95%, respectively.

However, this was above the recommended value of 20% suggested by Rosenbaum and Rubin (1983), thus indicating that the matching process significantly reduced the selection bias.

4.5.5 Hidden Bias and Sensitivity Analysis

It is vital to note that propensity score matching is designed to only control for the selection bias in the observable variables. This calls for the need to test or check for the hidden bias. This is based on the average treatment effect on the treated (ATT) sensitivity to hidden bias resulting from unobservable variables especially after matching. According to Rosenbaum (2002), an unobserved variable may simultaneously influence individual assignment into the treatment group as well as the welfare outcomes. This might result in hidden bias thus leading to inaccurate and non-robust matching estimators. To solve this issue, a bounding approach or sensitivity analysis is used to evaluate how strongly unobserved factors might affect the treatment selection process to alter the matching analysis implications (Rosenbaum and Rubin, 1983).

This bounding approach involves calculation of upper and lower bounds with a Wilcoxon sign-rank test to test the null hypothesis of no participation effect for different hypothesized values of unobserved selection bias (Rosenbaum and Rubin, 1983). The absence of a hidden bias means that the selection process indeed ensured that two parties having the same observed covariates have same chances of getting the treatment, resulting to odds ratio of one. Under the absence of hidden bias assumption, Q_Mh+ for overestimation of the treatment effect and Q_Mh- for underestimation of the treatment effect resulted in a similar result or rather an odd ratio of one, implying the unobserved selection bias or absence of hidden as shown in Table 17.

Table 17: Sensitivity analysis with Rosenbaum bounds

Gamma	Q_mh+	Q_mh-	p_mh+	p_mh-
1	.	.	.	.
1.05	.	-0.169	.	0.567
1.1	.	.	.	.
1.15	.	-0.1691	.	0.567
1.2	-0.169	.	0.567	.
1.25	.	-0.169	.	0.567
1.3	-0.169	-0.169	0.567	0.567
1.35	.	-0.169	.	0.567
1.4	-0.169	-0.169	0.567	0.567
1.45	-0.169	.	0.567	.
1.5	-0.169	-0.169	0.567	0.567
1.55	.	-0.169	.	0.567
1.6	-0.169	-0.169	0.567	0.567
1.65	-0.169	.	0.567	.
1.7	-0.169	-0.169	0.567	0.567
1.75	-0.169	-0.169	0.567	0.567
1.8	-0.169	.	0.567	.
1.85	-0.169	-0.169	0.567	0.567
1.9	-0.169	-0.169	0.567	0.567
1.95	-0.169	.	0.567	.
2	-0.169	-0.169	0.567	0.567

Note: Gamma : odds of differential assignment due to unobserved factors
Q_mh+ : Mantel-Haenszel statistic (assumption: overestimation of treatment effect)
Q_mh- : Mantel-Haenszel statistic (assumption: underestimation of treatment effect)
p_mh+ : significance level (assumption: overestimation of treatment effect)
p_mh- : significance level (assumption: underestimation of treatment effect)

4.5.6 Effect of PPT Adoption and Continued Use on Consumption Expenditure, Poverty Status, and Household Dietary Diversity

After getting a common support condition and the best matching algorithms selected to match the different propensity scores of PPT adopters (treated) to those of non-adopters, the average treatment effects on the treated (ATT) were estimated. The results of kernel matching (KM) and three nearest neighbor matching (NNM) showing the effect of PPT adoption and continued use on smallholder livelihood outcomes are presented in Table 18. The livelihood outcomes are measured by per capita household consumption expenditure per day, squared poverty gap and household dietary diversity.

Table 18: Effect of push-pull technology continued adoption on consumption expenditure, poverty status, and household dietary diversity

		Sample size		**Mean outcome**				
Matching Algorithm	**Livelihood Outcome**	**Treated**	**Control**	**Treated**	**Control**	**ATT**	**Standard error**	**t-Statistics**
Nearest neighbor matching (3)	Per capita consumption expenditure per day	35	115	203.570	144.550	59.019	25.778	2.29***
	Squared poverty gap	35	115	0.028	0.097	-0.069	0.037	-1.89**
	Household dietary diversity	35	115	10.114	7.352	2.762	0.672	4.11***
Kernel Matching	Per capita consumption expenditure per day	35	115	203.5570	155.761	47.809	27.471	1.72**
	Squared poverty gap	35	115	0.028	0.077	-0.049	0.036	-1.66*
	Household dietary diversity	35	115	10.114	7.240	2.874	0.560	5.13***

Note: *, ** and *** denote significant at 10%, 5%, and 1% levels, respectively; *t*-values are calculated using bootstrap with 50 replications. ATT denotes Average Treatment Effect on the Treated

Overall, using 50 times bootstrapping for testing of the statistical significance, the results of the two matching methods indicate that PPT adoption had a positive significant effect on per capita household consumption expenditure per day and household dietary diversity score. For three nearest neighbor matching method, per capita household consumption expenditure per day and household dietary diversity scores were positively influenced by PPT adoption and continued use and were both statistically significant at 1% level. For kernel matching method, per capita consumption expenditure per day and household dietary diversity score were positively influenced by PPT adoption and continued use and were statistically significant at 5% and 1% level, respectively as shown in Table 18. The average treatment on the treated (ATT) column shows the difference in these livelihood outcomes between the treated (PPT adopters and continuous users) and control (non-adopters) groups. On average, the treated group performed better than their counterparts as revealed by the positive difference. Overall, the results also indicated that PPT adoption and continued use has a significant negative effect on farmers' squared poverty gap. For three nearest neighbor matching method, squared poverty gap was negatively influenced by PPT adoption and continued use, and was statistically significant at 5% level. For kernel matching method, squared poverty gap was negatively influenced by PPT adoption and continued use, and was statistically significant at 10% level.

The effect of PPT adoption and continued use on household per capita consumption expenditure ranges from KES 47.81 to KES. 59.02 daily. This implies that on average PPT adopters and continuous users were spending more on food and non-food items more than non-adopter of PPT. The results imply that PPT technology has a positive impact on household consumption expenditure as it leads to significant improvements in soil fertility, increase cereal yields, milk, and dairy production. More income raised from different enterprises under PPT are, therefore, used to purchase many food and non-food items. Chepchirchir *et al*. (2016) used Tobit model and generalized propensity scores (GPS) to evaluate the effect of intensity of PPT uptake on household welfare in eastern Uganda, and found that there exists a significant and positive impact of the intensity of PPT adoption on per capita consumption expenditure. Kassie *et al*. (2014) and Lunduka *et al.* (2017) also revealed robust, significant, and positive effects of agricultural related technologies uptake on per capita household consumption expenditure.

Based on nearest neighbor and kernel matching methods used, the estimated effect of continued use PPT on farmers' squared poverty gap is estimated to range from -0.069 to -0.049. This implies that on average the severity of poverty among PPT adopters is estimated to be 4.9% to

6.9% much lower than the corresponding value for PPT non-adopters. This means that PPT results in high productivity and more income that enable its adopter to spend above the poverty line thus reducing the incidence of poverty. Nabasirye (2012) also used propensity score matching approach and found the same results where uptake of improved maize technology had a significant positive effect on productivity hence direct implications for alleviation of poverty in Uganda. Kassie *et al*. (2014) also used general propensity score methodology and found that adoption and continued use of improved maize technology significantly declined the extent of poverty in rural Tanzania.

Finally, based on nearest neighbor and kernel matching process used, the estimated effect of PPT adoption and continued use on farmers' household dietary diversity score ranges from 2.762 to 2.874. In other words, PPT adopters and the continuous users had access to approximately 3 food groups more than non-adopters. This also implies that PPT adopters had better food access and more diversified and quality diet thus higher nutritional outcome compared to their counterparts. The direct effects of PPT adoption and continued use on poverty alleviation are attributed to the productivity benefits PPT adopters enjoy over non-adopters, which usually come in the form of higher farm income leading to increases in consumption on various food items. The productivity changes result in improved livelihoods, thus resulting in better nutritional and economic well-being and poverty alleviation in many areas where it is being practiced. Ogot *et al.* (2017) and Zeng et al. (2017) also reported that agricultural technologies positively impact maize productivity, income and thus food expenditure resulting to a higher and better nutritional status.

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the summary of the study, conclusions, policy recommendations and areas of further research.

5.2 Summary

This study aimed to determine the rate and determinants of PPT dis-adoption, to determine the effects of dissemination pathways on the extent of PPT expansion, and to evaluate the effect of PPT continued adoption on livelihoods of smallholder farmers in Homa Bay County. To analyze these objectives, farmers were classified into three groups; continuous users (n = 74), dis-adopters (n = 49) and non-adopters (n = 115). The study revealed that there were significant variations in the socio-economic, farm and institutional characteristics across these farmer categories. It was established that PPT adoption and dis-adoption rates in the study area were 51% and 39.94%, respectively. This implies that the PPT dis-adoption rate in Homa-Bay county is still relatively low.

The results showed that important factors influencing PPT adoption decision also influence PPT dis-adoption. Bivariate probit model estimation revealed that age, education level, labor contribution of household head, access to extension services, perception on severity of *Striga* weed, and stem borer positively and significantly influenced the PPT adoption decision. However, total land size owned, and distant to the nearest market center negatively and significantly affected the PPT adoption. Further, it was established that PPT dis-adoption was significantly influenced by gender of household head, education level, total land size owned, tropical livestock unit, access to extension services, perception on *Striga* weed constraint, perception on desmodium and napier seed availability, perception on stem borer severity, and longevity of PPT use; all which had a negative effect as expected.

On PPT expansion, the results pinpoint that over 50% of adopters did not expand the area under PPT since they first adopted it; with many farmers reducing the amount of land allocated to PPT while some are abandoning the technology. Censored tobit model estimation revealed that the extent of PPT expansion was positively and significantly influenced by gender of household head, marital status, access to extension contact, perception on the severity of stem borer, perception on the availability of napier or brachiaria seeds, the longevity of PPT use and dissemination pathways while negatively influenced by total size of cultivable land and distance to the nearest market center. Further results revealed that the effect of farmer-to-farmer PPT dissemination pathway on the extent of PPT expansion is significantly higher than that of farmer school, radio, television program, print media, public meeting, agricultural show, and participatory video. However, there were no significant difference between farmer-to-farmer and field day dissemination pathways, nor farmer-to-farmer and farmer teacher pathways in terms of the effect on the extent of PPT expansion.

Propensity score matching estimation indicated a positive and significant average effect of PPT continued use on household per capita consumption expenditure. The results showed that due to more output and income raised from PPT production, on average PPT continuous users were spending between KES. 48 to KES. 59 daily on food and non-food items more than non-adopters of PPT. On the severity of poverty, the findings revealed that PPT continued use had a negative significant effect on poverty. On average, the severity of poverty among PPT adopters is estimated to be 5% to 7% lower than the corresponding value for PPT non-adopters. Finally, the results on the effect of PPT continued use demonstrate a positive impact on farmers' household dietary diversity scores (HDDS). In other words, HDDS was relatively high among PPT continuous users by three to five food groups compared to non-adopters. This implies that PPT adopters had better food access, more diversified and quality diet thus higher nutritional outcome compared to their counterparts. All these can be attributed to the general productivity and income changes from PPT production thus resulting in better nutritional and economic well-being and poverty alleviation in many areas where it is being practiced.

5.3 Conclusions

i. Econometric results showed that several variables influencing PPT adoption decision also influence its dis-adoption decision. Whereas the level of education, greater access to extension services, positive perception on stem borer and *Striga* weed constraints, smaller land size, and closeness to the market were significant in explaining the PPT adoption decision among the surveyed households. In addition, male-headed households, education level, large farm sizes, the large number of livestock units, greater access to extension service, positive perception on stem borer and *Striga* weed constraint, availability of napier and desmodium seeds, and longevity of PPT use significantly discouraged PPT dis-adoption.

ii. The results revealed that male headed households, married households, greater access to extension services, positive perception on the severity of stem borer, availability of napier or brachiaria seeds, the longevity of PPT use, dissemination pathways, smaller land size and closeness to the nearest market center are significant determinants of extent of PPT expansion. In addition, farmer-to-farmer, field days and farmer teachers are the most effective pathways significantly enhancing the extent of PPT expansion.

iii. The results significantly support the continued adoption of PPT in terms of its effect on the livelihood outcome among the surveyed households. Conclusively, continual adoption of PPT significantly improves consumption expenditure and access to a more diversified and nutritional diet. Also, the counterfactual results showed that the poverty gap between PPT continuous user and non-adopters could be closed if non-adopters were enabled to continuously practice the technology.

5.4 Policy Recommendations

i. In the context of PPT continued adoption, there is need for the government and other stakeholders to come up with policies to eliminate barriers to achieving gender equality to ensure equitable access to quality education and agricultural resources by both genders since female farmers also play an essential role in the adoption of technologies. In addition, there is a need for integrated seed development system which involves the collaboration of all stakeholders in ensuring improved supply, affordability and accessibility of not only desmodium seeds but also other required inputs. The concerned stakeholders including national and county governments should encourage policies that are likely to promote the development of rural infrastructure such as feeder roads to allow farmers have easy access to output and inputs markets. Also, there is a need for more support regarding extension service provision in relation to proper crop and pest management practices. This will ensure that extension services and market information are timely delivered to farmers so as to empower them. Concerned stakeholders such as government and NGOs should also consider policy interventions that encourage farmers to reinvest household incomes in related agricultural productive assets to enable them adopt agricultural technologies continuously.

ii. Concerning technology expansion, the government needs to consider introducing policies that target farmers with lower education levels as well as younger farmers to allow them uptake technologies extensively and thus providing them with employment opportunities. The government should also consider the implementation of policies that will enable farmers to have exclusive ownership of land through the provision of title deeds to create an incentive for expansion of long-term agricultural technologies like PPT thus helping in soil protection, increased farm output, and income. In this regard, extensive investment in rural extension services should again be implemented. Furthermore, policymakers should consider policies that will ensure the incorporation of "model farmers" as a key pathway in technology dissemination. This will facilitate communication and diffusion of agricultural information to the rest of the farmers, thus increasing the likelihood of adopting, expanding and continuously using such knowledge, capital, and labor-intensive technologies. There is need to strengthen societal ties through the formation of new local institutions or to strengthen existing ones as this will ensure perception and attitude change as well as bargaining power while offering platforms for knowledge and information transfers that are important for agricultural development.

iii. In order to close the expenditure gap, nutritional gap or the poverty gap between PPT-adopter and non-adopters, policymakers should consider policies that will improve efficiency or resource returns, and amount of resources of the non-adopters to the level of the PPT adopters.

5.5 Areas of Further Research

While this study only aimed to determine the rate and factors influencing PPT adoption, dis-adoption and expansion decisions, and to evaluate further the effect of PPT continued adoption on livelihoods of smallholder farmers in Homa Bay County, it may also be important for future research to evaluate the same in other areas. The study also failed to look at the complementarity and substitutability of agricultural technologies and their impact on livelihood outcomes using panel data, yet this is important in fully understanding the determinants and effect of the technology dis-adoption decision. Therefore, future research should be more comprehensive in modeling farmers' decision making process to study the complementarity and substitutability of numerous agricultural technologies in PPT adoption and dis-adoption decisions, using robust non-linear panel data and dynamic panel data models to control for unobserved heterogeneity in investigating overtime the determinants and effects of such decisions on livelihood outcomes.

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APPENDICES

Appendix 1

Stem Borer (1a)

Stem borers *Busseola fusca* found on large stems and leaves of maize plant.

Source: ICIPE (2015).

Striga Weed (1b)

Striga weed, *Striga hermonthica*

Source: ICIPE (2015)

Push-pull Technology Garden (1c)

Push-pull technology garden at Mbita Point, Kenya.

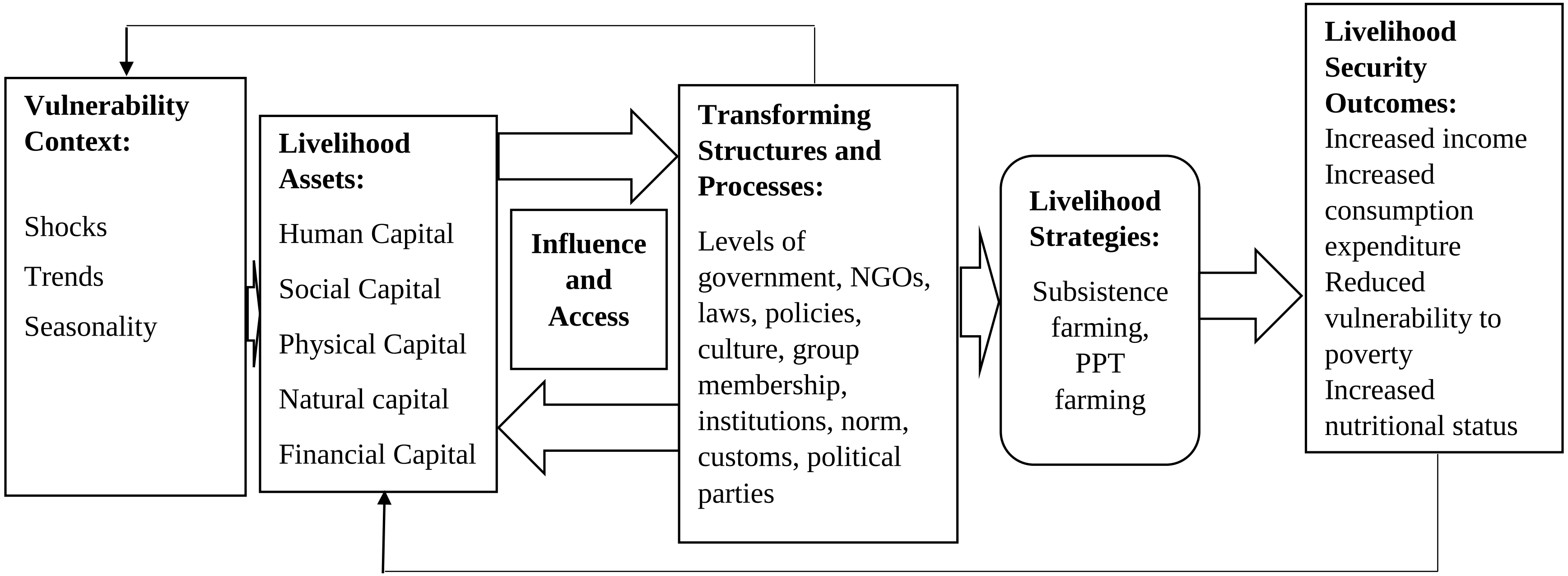
Source: ICIPE (2015)

Climate-smart Push-pull Technology (1d)

Climate-smart push-pull technology: Green leaf desmodium is planted as intercrop while Brachiaria cv mulato is planted as border plant.

Source: Murage *et al.* (2015)

Modified DFIDs and Oxfam Sustainable Livelihood Framework (1e)



Modified DFIDs and Oxfam sustainable livelihood framework

Source: Eade and Williams (1995) and Ashley and Carney (1999)

Appendix 2: Semi Structured Questionnaire

SAMPLE QUESTIONNAIRE SERIAL NUMBER/ HOUSEHOLD ID: …………..

This questionnaire is prepared to guide in the collection of data for the proposed study "Effect of push pull technology adoption and dis-adoption on poverty among smallholder maize farmers in Homa Bay County. The proposed study will be significant to farmers and government as it will provide more insights on the impact of push pull technology adoption and dis-adoption on poverty reduction. It will also in help setting dissemination priorities to policy makers, researchers, and technology disseminators to have a better understanding of the effective and efficient ways of assimilating and diffusing new technologies to ensure continuous use of such technologies for improvement in the standards of living among the farming communities. Privacy and confidentiality will be maintained at all times, all findings will be portrayed in a confidential manner as no personal or identifiable information of respondents will be recorded or printed in the study. Kindly take your time and fill in this questionnaire.

Section A: General Information

1. Name of the enumerator? ………………………………………..
2. Date of the interview? …………………………………………..
3. Name of the household head/respondent? ………………………………………..
4. County? ………………………………………….
5. Sub county? …………………………………….
6. Ward? ………………………………………….
7. Village? …………………………………………

Section B: Household Inventory, Institutional and Farmer Characteristics (Tick where appropriate)

8. Sex of the respondent/household head/Decision maker?

0= Female [ ] 1=Male [ ]

9. Marital status of the respondent/household head?

1= Married [ ] 2= Single [ ] 3= Widowed [ ] 4= Divorced [ ]

10. Cell phone number of the respondents?..

11. Age of respondent/household head? ……………………..

12. Education years of the respondent/household head?....................

13. Primary occupation of the household head / respondent?

1= Farming (crop/livestock farming) [ ]

2= Salaried employment [ ]

3 = Self-employed off farm [ ]

4 = Casual laborer on farm [ ]

5 = Casual laborer off farm [ ]

6 = School/college child [ ]

7 = Non-school child [ ]

6 = other specify [ ]

14. What is your labour contribution to cultivated farms?

0 = Not a worker [ ] 1= Part time [ ] 2 = Fulltime [ ]

15. What is the total number of household members at least in the last one year? …………..Please indicate the number of household members in the corresponding age bracket in the table below and resulting adult equivalent as per the guidelines………

Age	< 1yr	1-1.99	2-2.99	3-4.99	5-6.99	7-9.99	10-11.99	12-13.99	14-15.99	16-17.99	18-29.99	30-59.99	60 and over
Male													
Female													

16. What is the total number of family members that offer farm labour? ……………..

17. For how long have you been in farming enterprise? …………………….

18. What is the number and the value of livestock owned in last one year?

No.	Livestock list	Number owned in the last one year	Value in KES.
1	Cows		
2	Oxen		
3	Bulls		
4	Heifers		
5	Calves		
6	Goats		
7	Sheep		
8	Donkey		
9	Horses		
10	Poultry		

11	Others specify		

19. What is the total size of land owned in acres?...............

20. What is the walking distance in minutes from the farm to the nearest market center? ……

21. What is the walking distance in minutes from the farm to the nearest administrative center? ....

22. What is the walking distance in minutes from the farm to nearest source of seed dealer? ……..

23. What is the walking distance in minutes from the farm to nearest formal credit service source?.........

24. Are you a member of any productive community groups/ association?

0= No [ ] 1= Yes [ ]

25. If yes (24), are you a member of any of the following community groups? What is the main benefits you derive from the group? 1= Information [ ] 2= Advice 3 [ ] = Credit and savings [ ] 4 = Merry go round [ ] 5= Others (specify)…………………

No	Group type	1= Yes, 0=No	Benefit
1	Forest users' group		
2	Saving and credit group		
3	Mutual help or insurance group		
4	Input supply group or farmers cooperatives		
5	Trade and business group		
6	Water users group		
7	Crop/ livestock production or marketing group		
8	Women association group		
9	Civic or charitable group		
10	Religious group		
11	Development group/ nyumba kumi group		
12	Others specify		

26. Do you have access to credit facilities?

0= No [ ] 1= Yes [ ]

27. Have you ever borrowed money to use in the last one year?

0= No [ ] 1= Yes [ ]

28. If yes (27), state the amount borrowed? ………………and how much allocated for farming?………

29. Did you save money in the last 12 months?

0= No [ ] 1= Yes [ ]

30. If yes (29), how much did you save in the last 12 months?................

Section C: Production Constraints, Plot Allocation, Perception of Push pull technology and Extension Approaches

31. Have you ever faced the following constraints on your farm in the last three years? (Tick where appropriate). Indicate the most important constraints on your plot.

No	Constraints	1= Yes 0=No	Indicate the most important problem
1	Stem borers		
2	Striga weed		
3	Other pest		
4	Soil erosion		
5	Low/poor soil fertility		
6	Diseases		
7	Fodder availability		
8	High input prices		
9	Low crop price		

32. How do you perceive stem borer infestation as an agricultural constraint?

0 = Not a problem [ ] 1 = Minor problem [ ] 2= Major problem [ ]

33. How do you perceive striga weed infestation as an agricultural constraint?

0 = Not a problem [ ] 1 = Minor problem [ ] 2= Major problem [ ]

34. Are you aware of or heard about Push-pull technology?

0= No [ ] 1= Yes [ ]

35. If yes (34), please indicate how you first learnt about PPT or your main source of PPT information?

1= Public meetings [ ]

2= TV [ ]

3= Radio [ ]

4= Farmer field school [ ]

5= Field days [ ]

6= Farmer teachers [ ]

7= Fellow farmer [ ]

8= Printed materials [   ]

9= Agricultural shows [   ]

10= Participatory Video [   ]

36. If yes (34), have you received extension training, information or learnt about push pull technology from the following dissemination pathways?

Serial No.	Dissemination Pathways	1= Yes, 0= No	Indicate primary source of PPT information	Indicate the central pathway you perceived to have greatly influenced your PPT expansion decision
1	Public Meetings			
2	Television Program			
3	Radio			
4	Farmer Field School			
5	Field Days			
6	Farmer Teachers			
7	Fellow Farmer			
8	Printed Materials			
9	Agricultural Shows			
10	Participatory Video			

37. How many times do you receive extension services in a year?.........

38. Have you adopted push pull technology?

0= No [   ] 1= Yes [   ]

39. If yes (38), for how long have you been practicing push pull technology? ....

40. If yes (38), have you expanded cultivable area under PPT production from the first year of use?

0= No [   ] 1= Yes [   ]

41. Please indicate area planted from the first year of PPT use in the table below.

No	Crop	Total land Owned	Land tenure: 1= Owned with title deed 0= Otherwise	Push pull Area (Acre)		Area Expanded
				First time use Push pull **(A)**	2017 **(B)**	**(B-A)**
1.	Maize/sorghum/Desmodium-Brachiaria/napier					

42. Are you currently using PPT?

0= No [ ] 1= Yes [ ]

43. If No (42), give the two main reasons for disadopting PPT? (Please indicate first and second reasons)

1 = No livestock [ ]

2 = Difficult to manage plot [ ]

3 = Labour shortage [ ]

4 = Reduce maize yield [ ]

5 = Lack of desmodium [ ]

6 = Lack of napier or bracharia seed [ ]

7 = Lack of cash/credit to buy fodder seeds [ ]

8 = Not effective to control stem borer [ ]

9 = Not effective to control *striga* [ ]

10 = Land shortage [ ]

11 = No support from NGOs

12 = No other reason [ ]

13= Other reasons [ ]…………………..

44. How do you perceive desmodium seed availability?

0= otherwise [ ] 1= Adequate [ ]

45. How do you perceive napier or bracharia cutting or seed availability?

0= otherwise [ ] 1 = Adequate [ ]

46. How is the soil fertility of your plot now, compared to 5 years ago?

0 = Otherwise [ ] 1= Increased [ ]

47. If no (38), please indicate two main reasons for not using PPT? (Please indicate first and second reasons)

1 = No livestock [ ]

2 = Difficult to manage plot [ ]

3 = Labour shortage [ ]

4 = Reduce maize yield [ ]

5 = Lack of desmodium [ ]

6 = Lack of napier or bracharia seed [ ]

7 = Lack of cash/credit to buy fodder seeds [ ]

8 = Not effective to control stem borer [ ]

9 = Not effective to control *striga* [ ]

10 = Land shortage [ ]

11 = No support from NGOs

12 = Not aware

13 = No reason [ ]

14 = Other reasons [ ]…………………..

48. If no (38) and (42), have you ever used the following practice (s) to control stem borer, striga and poor soil fertility? (Tick practices)

No	Control practices	1= Yes 0=No
1	Uprooting	
2	Pesticide	
3	Intercropping	
4	Manure	
5	Crop rotation	
6	Fertilizer	
7	Others specify	

49. If yes (38), what is your first and second important reason for using push pull technology?

1 = Control soil erosion [ ]

2 = Control Stem borer [ ]

3 = Control striga weed [ ]

4 = Control soil fertility [ ]

5 = Increased fodder production [ ]

6 = Increasing livestock production [   ]

7 = Increased crop production [   ]

8 = Increased income through sale of desmodium, napier or Brachiaria [   ]

9 = Reduced labour requirement from second production season [   ]

10 = Reduce cost of chemical requirements [   ]

11 = Others specify………

Section D: Household Income and Consumption expenditure

51. On the following enterprises in the farm, provide the yield/acre in the last one year (short season 2016/long season 2017) together with its unit price and total income?

Farm enterprises	Yield/acre (kg/acre)						Unit Price	Total in cash	
	From PPT plots (s2 and s1)		From non PPT plots (s2 and s1)		Total yield from PPT	Total yield from non PPT		PPT	non-PPT
Maize									
Desmodium									
Napier/ Brachiaria									
Sorghum									
Milk									

52. Do you have any other source of income apart from farming? i.e. off-farm income

0= No [   ] 1= Yes [   ]

53. If yes (52), how much did you receive in the last one year month/year?...........................

54. Kindly fill in the consumption expenditure table below?

Item	Consumption from own production in the last 12 months (members of the family only)			Bought in the last 12 months only for consumption							Quantity of food aid/borrowed/gifts received
	Quantity	**Unit** (e.g. kg, liter, packet, bundle)	Convert quantity/value to **Kg/liter/no. in Kes**	**Unit** (e.g. kg, liter, packet, bundle)	Freq. of buying (e.g., 2 times per month)	Total number of times bought in the year	Avg. qty each time bundles	Total qty per year	Avg. price per unit**(KES)**	Total cost of purchased **(KES)**	
A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**	**A11=9x10**	
Staple foods											
1. Maize grain											
2. Rice											
3. Sorghum											
4. Millet											
5. Cassava											
6. Potatoes											

7. Beans											
8. Cowpea grain											
9. Groundnut											
10. Pigeon pea											
Total- Staple Food											
Vegetables and fruits											
11. Tomato											
12. Onions											
13. Cabbage											
14. Kale											
15. Carrot											
16. Pumpkin											
17. Pepper											
18. Garlic											
19. Oranges											
20. Mangoes											

21. Pawpaw											
22.Pineapple											
23.Sugarcane											
24. Bananas											
Total vegetables and fruits											
Other foods											
25. Beef											
26. Pork											
27. Poultry meat											
28. Fish											
29. Milk											
30. Eggs											
31. Cheese											
32. Butter											
33. Honey											
Total other food											

Beverages, drinks and breakfast											
34. Tea											
35. Coffee											
36. Soft drinks											
37. Beer											
38. Cooking fat											
39. Bread											
40. Sugar											
41. Salt											
42. Ginger											
Total											

Expense Item	Unit(e.g. numbers, bundles etc.)	Frequency of purchase(e.g., 2 times per month)	Total number of times bought in the year	Average quantity each time	Total quantity per year	Average per unit price(KES)	Total cost of purchase(KES)
B1	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8=6*7**
1. Clothing							

2. Beddings							
3. Electricity							
4. Fuel wood							
5. Charcoal							
6. Kerosene							
7. Batteries							
8. School fees							
9. School items							
10. Health care							
11. Grain milling							
12. Church contributions							
13. Contributions to associations/cooperatives							
14. House construction							
15. Newspapers etc							
16. Travel expenses							
17. Phone air time							
18. Kitchen utensils							
19. Household hygiene							
20. Furnitures							

21. Home repairs							
22. Purchase of bicycle, motorcycle							
23. Repairs for vehicles, bicycles etc							
24. Petrol and engine oils for cars							
25. House rent							
26. Utility bills (water, telephone etc)							
27. Cigarettes etc							
28. Remittances paid							
29. Ceremony and other entertainments							
Total expenditure on food items							

SECTION E: HOUSEHOLD NUTRITION

55. Did **YOU OR ANYONE ELSE IN YOUR HOUSEHOLD** eat any kind of the following foods yesterday during the day and at night*? (Probe to know if yesterday was a normal day or there was any function, for example, Marriage ceremony, funeral, family party among others. If so, you should concentrate on day before yesterday*

FOOD GROUP	**EXAMPLES**	**Code** **1 =Yes** **2 =No**
Cereals	Millet, sorghum, maize, rice, Wheat	
Roots and tubers	Potatoes, yams, manioc, cassava or any other foods	
Vegetables	Kales, cabbage, carrots, French beans,	
Fruits	Mangoes, oranges, pawpaws, Pineapples, water melons, passion fruits	
Meat	Beef, pork, lamb, goat, rabbit wild game, chicken, duck, or other birds, liver, kidney, heart, or other organ	
Eggs	Eggs	
Fish and sea foods	Fresh or dried fish or shellfish	
Pulses/ legumes/ nuts	Beans, peas, lentils, Groundnuts	
Milk and milk products	Cheese, yogurt, milk or other milk products	
Oils/fats	Oil/ fat	
Sugar/honey	Sugar, honey	
Miscellaneous	Coffee, tea, spices, condiments	

Appendix 3: ANOVA Results

```
. use "C:\Users\user\Desktop\PUSH PULL\New folder\Final Template PPT.dta"

. *********The codes below show how descriptive statistics for the proposed study was conducted*****

.
. *******Continuous descriptors of sample households******

.
. sum Hage if PPTadopt ==1

    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
        Hage |        123    53.52033    10.32532         29         76

.
. oneway Hage Adopt_status, tabulate

            |   Summary of Age of the household
   Adoption |                head
     status |        Mean   Std. Dev.       Freq.
------------+------------------------------------
  Non-adopt |   49.930435   9.1485995         115
  Continuou |   54.864865   10.440076          74
  Disadopte |   51.489796   9.9102692          49
------------+------------------------------------
      Total |   51.785714   9.9182463         238

                        Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups       1101.7344      2   550.867202      5.83     0.0034
 Within groups       22212.337    235   94.5205831
------------------------------------------------------------------------
    Total           23314.0714    237   98.3716094

Bartlett's test for equal variances:  chi2(2) =   1.6126  Prob>chi2 = 0.447

.
. pwmean Hage, over(Adopt_status) mcompare(tukey) effects

Pairwise comparisons of means with equal variances

over         : Adopt_status

---------------------------
             |    Number of
```

```
             |  Comparisons
-------------+-------------
Adopt_status |            3
---------------------------

--------------------------------------------------------------------------------------------------
                                |                              Tukey                Tukey
                           Hage |   Contrast   Std. Err.      t    P>|t|     [95% Conf. Interval]
--------------------------------+-----------------------------------------------------------------
                   Adopt_status |
Continuous users vs Non-adopter  |    4.93443    1.44887     3.41   0.002     1.517038    8.351822
     Disadopters vs Non-adopter  |   1.559361   1.658587     0.94   0.615    -2.352682    5.471405
Disadopters vs Continuous users  |  -3.375069   1.790613    -1.88   0.145    -7.598519    .8483813
--------------------------------------------------------------------------------------------------

.
. sum Educationlevel if PPTadopt ==1

    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
Educationl~l |        123    10.43089    3.188302          3         17

.
. oneway Educationlevel Adopt_status, tabulate

            |     Summary of Number of years
   Adoption |   household head spent in school
     status |        Mean   Std. Dev.       Freq.
------------+------------------------------------
  Non-adopt |   6.9130435   3.7802934         115
  Continuou |   10.824324   3.0221017          74
  Disadopte |   9.8367347    3.368648          49
------------+------------------------------------
      Total |   8.7310924   3.9000108         238

                        Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups      764.249387      2   382.124694     31.61     0.0000
 Within groups      2840.54053    235   12.0874065
------------------------------------------------------------------------
    Total           3604.78992    237    15.210084

Bartlett's test for equal variances:  chi2(2) =   4.3732  Prob>chi2 = 0.112

.
. pwmean Educationlevel , over(Adopt_status) mcompare(tukey) effects

Pairwise comparisons of means with equal variances
```

```
over         : Adopt_status

---------------------------
             |    Number of
             |  Comparisons
-------------+-------------
Adopt_status |            3
---------------------------

-------------------------------------------------------------------------------------------------
                                  |                                 Tukey                 Tukey
                   Educationlevel |   Contrast   Std. Err.      t    P>|t|     [95% Conf. Interval]
----------------------------------+--------------------------------------------------------------
                     Adopt_status |
Continuous users vs Non-adopter   |   3.911281   .5181228     7.55   0.000     2.689205    5.133357
     Disadopters vs Non-adopter   |   2.923691   .5931186     4.93   0.000     1.524726    4.322657
Disadopters vs Continuous users   |  -.9875896    .640332    -1.54   0.273    -2.497916    .5227365
-------------------------------------------------------------------------------------------------

.
. sum Hsize if PPTadopt ==1

    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
       Hsize |        123    7.634146    3.469465          2         19

.
. oneway Hsize Adopt_status, tabulate

            |     Summary of Total number of
            |  household members in the last one
   Adoption |                year
     status |        Mean   Std. Dev.       Freq.
------------+------------------------------------
  Non-adopt |   6.3826087   3.1332473         115
  Continuou |   7.8378378   3.4483549          74
  Disadopte |   7.3265306   3.5141841          49
------------+------------------------------------
      Total |   7.0294118   3.3632377         238

                        Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups      100.799336      2    50.399668      4.59     0.0111
 Within groups      2579.99478    235   10.9787012
------------------------------------------------------------------------
    Total           2680.79412    237   11.3113676
```

```
Bartlett's test for equal variances:  chi2(2) =   1.2632  Prob>chi2 = 0.532

.
. pwmean Hsize , over(Adopt_status) mcompare(tukey) effects

Pairwise comparisons of means with equal variances

over         : Adopt_status

---------------------------
             |    Number of
             |  Comparisons
-------------+-------------
Adopt_status |            3
---------------------------

---------------------------------------------------------------------------------------------------
                                  |                               Tukey                Tukey
                            Hsize |   Contrast   Std. Err.      t    P>|t|     [95% Conf. Interval]
----------------------------------+----------------------------------------------------------------
                     Adopt_status |
Continuous users vs Non-adopter  |   1.455229   .4937892     2.95   0.010     .2905478    2.619911
     Disadopters vs Non-adopter  |   .9439219   .5652629     1.67   0.219    -.3893415    2.277185
Disadopters vs Continuous users  |  -.5113072   .6102589    -0.84   0.680    -1.950701    .9280867
---------------------------------------------------------------------------------------------------

.
. sum Fexperience if PPTadopt ==1

    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
 Fexperience |        123          26    10.92898          4         52

.
. oneway Fexperience Adopt_status, tabulate

            |    Summary of Number of years in
   Adoption |         farming enterprise
     status |        Mean   Std. Dev.       Freq.
------------+------------------------------------
  Non-adopt |        25.8   11.309986         115
  Continuou |   27.243243   11.136526          74
  Disadopte |   24.122449   10.439573          49
------------+------------------------------------
      Total |   25.903361   11.091635         238

                        Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
```

```
Between groups      289.490383      2   144.745192      1.18     0.3096
 Within groups      28867.2869    235   122.839519
------------------------------------------------------------------------
    Total           29156.7773    237   123.024377

Bartlett's test for equal variances:  chi2(2) =   0.4257  Prob>chi2 = 0.808

.
. pwmean Fexperience , over(Adopt_status) mcompare(tukey) effects

Pairwise comparisons of means with equal variances

over         : Adopt_status

---------------------------
             |    Number of
             |  Comparisons
-------------+-------------
Adopt_status |            3
---------------------------

-------------------------------------------------------------------------------------------------
                                |                                 Tukey                 Tukey
                    Fexperience |   Contrast   Std. Err.      t    P>|t|     [95% Conf. Interval]
--------------------------------+----------------------------------------------------------------
                   Adopt_status |
Continuous users vs Non-adopter  |   1.443243   1.651715     0.87   0.657    -2.452593     5.33908
     Disadopters vs Non-adopter  |  -1.677551   1.890793    -0.89   0.649    -6.137291    2.782189
Disadopters vs Continuous users  |  -3.120794   2.041304    -1.53   0.279    -7.935539     1.69395
-------------------------------------------------------------------------------------------------

.
. sum TLU if PPTadopt ==1

    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
         TLU |        123    6.194634    5.868468        .09      30.41

.
. oneway TLU Adopt_status, tabulate

            |  Summary of Livestock ownership in
   Adoption |       tropical livestock unit
     status |        Mean   Std. Dev.       Freq.
------------+------------------------------------
  Non-adopt |   3.8581739   3.8014537         115
  Continuou |   7.4227027   6.0723057          74
  Disadopte |        4.34   5.0614549          49
------------+------------------------------------
```

```
      Total |   5.0656723   5.1037399        238

                        Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups      604.593277      2   302.296639     12.76     0.0000
 Within groups      5568.82077    235   23.6971097
------------------------------------------------------------------------
    Total           6173.41405    237   26.0481605

Bartlett's test for equal variances:  chi2(2) =  20.2343  Prob>chi2 = 0.000

.
. pwmean TLU , over(Adopt_status) mcompare(tukey) effects

Pairwise comparisons of means with equal variances

over         : Adopt_status

---------------------------
             |    Number of
             |  Comparisons
-------------+-------------
Adopt_status |            3
---------------------------

---------------------------------------------------------------------------------------------------
                                 |                                Tukey              Tukey
                             TLU |   Contrast   Std. Err.      t    P>|t|     [95% Conf. Interval]
---------------------------------+-----------------------------------------------------------------
                    Adopt_status |
Continuous users vs Non-adopter  |   3.564529   .7254606     4.91   0.000     1.853413    5.275644
     Disadopters vs Non-adopter  |   .4818261   .8304675     0.58   0.831    -1.476965    2.440617
Disadopters vs Continuous users  |  -3.082703   .8965744    -3.44   0.002    -5.197418   -.9679876
---------------------------------------------------------------------------------------------------

.
. sum Lsize if PPTadopt ==1

    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
       Lsize |        123    2.393577    1.374361        .25       6.78

.
. oneway Lsize Adopt_status, tabulate

            | Summary of Total size of land owned
   Adoption |             in acres
     status |        Mean   Std. Dev.       Freq.
```

```
------------+-----------------------------------
  Non-adopt |   1.8186957   1.2592023        115
  Continuou |   2.9694595   1.3376599         74
  Disadopte |   1.5238776   .89229063         49
------------+-----------------------------------
      Total |   2.1157983   1.3482935        238

                        Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups      81.2457523      2   40.6228762     27.31     0.0000
 Within groups      349.595446    235    1.4876402
------------------------------------------------------------------------
    Total           430.841198    237   1.81789535

Bartlett's test for equal variances:  chi2(2) =   9.1969  Prob>chi2 = 0.010

.
. pwmean Lsize , over(Adopt_status) mcompare(tukey) effects

Pairwise comparisons of means with equal variances

over         : Adopt_status

---------------------------
             |    Number of
             |  Comparisons
-------------+-------------
Adopt_status |            3
---------------------------

---------------------------------------------------------------------------------------------------
                                 |                              Tukey               Tukey
                           Lsize |   Contrast   Std. Err.      t    P>|t|     [95% Conf. Interval]
---------------------------------+-----------------------------------------------------------------
                    Adopt_status |
Continuous users vs Non-adopter  |   1.150764    .181767     6.33   0.000      .722037    1.579491
     Disadopters vs Non-adopter  |  -.2948181   .2080769    -1.42   0.334     -.785601    .1959648
Disadopters vs Continuous users  |  -1.445582   .2246403    -6.44   0.000    -1.975432   -.9157317
---------------------------------------------------------------------------------------------------

.
. sum Dmarket if PPTadopt ==1

    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
     Dmarket |        123    16.02439    9.268724          5         45

.
```

```
. oneway Dmarket Adopt_status, tabulate

            |   Summary of Walking distance in
            |    minutes from the farm to the
   Adoption |        nearest market center
     status |        Mean   Std. Dev.       Freq.
------------+------------------------------------
  Non-adopt |   30.278261   27.401994         115
  Continuou |   13.324324   7.6911408          74
  Disadopte |   20.102041    10.00884          49
------------+------------------------------------
      Total |   22.911765    21.36237         238

                        Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups      13429.3454      2    6714.6727     16.66     0.0000
 Within groups      94725.8017    235   403.088518
------------------------------------------------------------------------
    Total
108155.147    237   456.350831

Bartlett's test for equal variances:  chi2(2) = 135.1189  Prob>chi2 = 0.000

.
. pwmean Dmarket , over(Adopt_status) mcompare(tukey) effects

Pairwise comparisons of means with equal variances

over         : Adopt_status

---------------------------
             |    Number of
             |  Comparisons
-------------+-------------
Adopt_status |            3
---------------------------

-------------------------------------------------------------------------------------------------
                                 |                              Tukey                Tukey
                         Dmarket |   Contrast   Std. Err.      t    P>|t|     [95% Conf. Interval]
---------------------------------+---------------------------------------------------------------
                    Adopt_status |
Continuous users vs Non-adopter  |  -16.95394   2.992033    -5.67   0.000    -24.01113   -9.896746
     Disadopters vs Non-adopter  |  -10.17622   3.425115    -2.97   0.009    -18.25491   -2.097534
Disadopters vs Continuous users  |   6.777716   3.697761     1.83   0.161    -1.944049    15.49948
-------------------------------------------------------------------------------------------------

.
```

```
. sum Dadministration if PPTadopt ==1

    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
Dadministr~n |        123    44.85366    43.16432          5        180

.
. oneway Dadministration Adopt_status, tabulate

            |   Summary of Walking distance in
            |    minutes from the farm to the
   Adoption |    nearest administrative center
     status |        Mean   Std. Dev.       Freq.
------------+------------------------------------
  Non-adopt |   69.286957   48.176533         115
  Continuou |   37.324324   33.394737          74
  Disadopte |    56.22449   53.104561          49
------------+------------------------------------
      Total |   56.659664   47.172251         238

                        Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups      46011.1555      2   23005.5778     11.23     0.0000
 Within groups      481366.277    235   2048.36714
------------------------------------------------------------------------
    Total           527377.433    237   2225.22124

Bartlett's test for equal variances:  chi2(2) =  14.6977  Prob>chi2 = 0.001

.
. pwmean Dadministration , over(Adopt_status) mcompare(tukey) effects

Pairwise comparisons of means with equal variances

over         : Adopt_status

---------------------------
             |    Number of
             |  Comparisons
-------------+-------------
Adopt_status |            3
---------------------------

---------------------------------------------------------------------------------------------------
                                 |                              Tukey                Tukey
                 Dadministration |   Contrast   Std. Err.      t    P>|t|     [95% Conf. Interval]
---------------------------------+-----------------------------------------------------------------
                    Adopt_status |
```

```
Continuous users vs Non-adopter  |  -31.96263   6.744815    -4.74   0.000    -47.87136    -16.0539
     Disadopters vs Non-adopter  |  -13.06247   7.721094    -1.69   0.210    -31.27391    5.148978
Disadopters vs Continuous users  |   18.90017   8.335709     2.27   0.062    -.7609468    38.56128
-------------------------------------------------------------------------------------------------

.
. sum N_Gmembership if PPTadopt ==1

    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
N_Gmembers~p |        123    3.479675    2.513405          0          9

.
. oneway N_Gmembership Adopt_status, tabulate

            |    Summary of Number of groups a
   Adoption |    household head had membership
     status |        Mean   Std. Dev.       Freq.
------------+------------------------------------
  Non-adopt |   2.2521739   2.3352504         115
  Continuou |   3.9189189   2.4924915          74
  Disadopte |   2.8163265   2.4210317          49
------------+------------------------------------
      Total |   2.8865546   2.5005797         238

                        Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups      125.389566      2    62.694783     10.86     0.0000
 Within groups      1356.54741    235   5.77254217
------------------------------------------------------------------------
    Total           1481.93697    237   6.25289863

Bartlett's test for equal variances:  chi2(2) =   0.3859  Prob>chi2 = 0.825

.
. pwmean N_Gmembership , over(Adopt_status) mcompare(tukey) effects

Pairwise comparisons of means with equal variances

over         : Adopt_status

---------------------------
             |    Number of
             |  Comparisons
-------------+-------------
Adopt_status |            3
---------------------------
```

```
-------------------------------------------------------------------------------------------------
                                 |                                Tukey                Tukey
                   N_Gmembership |   Contrast   Std. Err.      t    P>|t|     [95% Conf. Interval]
---------------------------------+---------------------------------------------------------------
                    Adopt_status |
Continuous users vs Non-adopter  |   1.666745   .3580549     4.65   0.000     .8222148    2.511275
     Disadopters vs Non-adopter  |   .5641526   .4098817     1.38   0.355    -.4026193    1.530925
Disadopters vs Continuous users  |  -1.102592   .4425091    -2.49   0.036    -2.146321   -.0588634
-------------------------------------------------------------------------------------------------

.
. sum Econtact if PPTadopt ==1

    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
    Econtact |        123     5.02439    3.696395          0         13

.
. oneway Econtact Adopt_status, tabulate

            |  Summary of Frequency of extension
   Adoption |          contact in a year
     status |        Mean   Std. Dev.       Freq.
------------+------------------------------------
  Non-adopt |   .88695652   1.0822752         115
  Continuou |   6.8378378   3.1319259          74
  Disadopte |   2.2857143   2.6614532          49
------------+------------------------------------
      Total |   3.0252101   3.4481382         238

                        Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups      1628.26425      2   814.132125    160.83     0.0000
 Within groups      1189.58449    235   5.06206165
------------------------------------------------------------------------
    Total           2817.84874    237   11.8896571

Bartlett's test for equal variances:  chi2(2) = 101.7752  Prob>chi2 = 0.000

.
. pwmean Econtact , over(Adopt_status) mcompare(tukey) effects

Pairwise comparisons of means with equal variances

over         : Adopt_status

---------------------------
             |    Number of
```

```
             |  Comparisons
-------------+-------------
Adopt_status |            3
---------------------------

-------------------------------------------------------------------------------------------------
                                |                               Tukey                Tukey
                        Econtact |   Contrast   Std. Err.      t    P>|t|     [95% Conf. Interval]
--------------------------------+----------------------------------------------------------------
                    Adopt_status |
Continuous users vs Non-adopter  |   5.950881   .3352971    17.75   0.000     5.160029    6.741734
     Disadopters vs Non-adopter  |   1.398758   .3838298     3.64   0.001     .4934334    2.304082
Disadopters vs Continuous users  |  -4.552124   .4143834   -10.99   0.000    -5.529514   -3.574734
-------------------------------------------------------------------------------------------------

.
. sum Offfarm_income if PPTadopt ==1

    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
Offfarm_in~e |        123    190356.3    188233.9      15400    1336000

.
. oneway Offfarm_income Adopt_status, tabulate

            |  Summary of Total income from off
   Adoption |  farm sources in the last one year
     status |        Mean   Std. Dev.       Freq.
------------+------------------------------------
  Non-adopt |   130782.51   117488.76         115
  Continuou |   245869.95   221981.46          74
  Disadopte |   106519.37   56480.234          49
------------+------------------------------------
      Total |   161570.65   160527.16         238

                        Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups      7.8338e+11      2   3.9169e+11     17.29     0.0000
 Within groups      5.3239e+12    235   2.2655e+10
------------------------------------------------------------------------
    Total           6.1072e+12    237   2.5769e+10

Bartlett's test for equal variances:  chi2(2) =  93.2440  Prob>chi2 = 0.000

.
. pwmean Offfarm_income , over(Adopt_status) mcompare(tukey) effects

Pairwise comparisons of means with equal variances
```

```
over         : Adopt_status

---------------------------
             |    Number of
             |  Comparisons
-------------+-------------
Adopt_status |            3
---------------------------

-------------------------------------------------------------------------------------------------
                                  |                              Tukey                Tukey
                   Offfarm_income |   Contrast   Std. Err.      t    P>|t|     [95% Conf. Interval]
----------------------------------+--------------------------------------------------------------
                     Adopt_status |
Continuous users vs Non-adopter   |   115087.4   22430.85     5.13   0.000     62180.67    167994.2
     Disadopters vs Non-adopter   |  -24263.15    25677.6    -0.94   0.612    -84827.91    36301.62
Disadopters vs Continuous users   |  -139350.6   27721.59    -5.03   0.000    -204736.4   -73964.74
-------------------------------------------------------------------------------------------------
```

Appendix 4: Bivariate Probit Results

```
. reg PPTadopt Hage Hgender Mstatus Educationlevel Hsize H_laborcontribution log_offfarmincome
Lsize TLU Acredit Mfarmcooperative Dmarke
> t Ext_Contact SW_constraint SB_constraint Dseed NBseed Striperception Stemperception

      Source |       SS           df       MS      Number of obs   =       238
-------------+----------------------------------   F(19, 218)      =     11.90
       Model |  30.2607808        19  1.59267267   Prob > F        =    0.0000
    Residual |  29.1719923       218  .133816478   R-squared       =    0.5092
-------------+----------------------------------   Adj R-squared   =    0.4664
       Total |  59.4327731       237  .250771195   Root MSE        =    .36581

-------------------------------------------------------------------------------------
           PPTadopt |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
--------------------+----------------------------------------------------------------
               Hage |   .0050172   .0029922     1.68   0.095    -.0008801    .0109145
            Hgender |     .02359   .0605743     0.39   0.697    -.0957962    .1429762
            Mstatus |   .0185977   .0291618     0.64   0.524    -.0388775    .0760728
     Educationlevel |   .0427224   .0081378     5.25   0.000     .0266835    .0587612
              Hsize |   .0043182   .0091346     0.47   0.637    -.0136853    .0223217
H_laborcontribution |   .1055605   .0554079     1.91   0.058    -.0036433    .2147642
  log_offfarmincome |  -.0488735    .041241    -1.19   0.237    -.1301557    .0324087
              Lsize |  -.0395492    .025163    -1.57   0.117     -.089143    .0100447
                TLU |   .0074752   .0069168     1.08   0.281    -.0061572    .0211076
            Acredit |   .0470084   .0614342     0.77   0.445    -.0740726    .1680895
   Mfarmcooperative |  -.0807568   .0713469    -1.13   0.259    -.2213747    .0598611
            Dmarket |  -.0036106   .0012073    -2.99   0.003    -.0059901   -.0012312
        Ext_Contact |   .1750091   .0593247     2.95   0.004     .0580857    .2919326
      SW_constraint |  -.1607392   .0842906    -1.91   0.058     -.326868    .0053896
      SB_constraint |  -.0535582   .0803545    -0.67   0.506    -.2119294    .1048129
              Dseed |   .1245681   .0805549     1.55   0.123    -.0341979    .2833342
             NBseed |   .0516517    .066177     0.78   0.436    -.0787769    .1820803
     Striperception |   .1422614   .0466147     3.05   0.003     .0503881    .2341346
     Stemperception |   .1606289   .0468683     3.43   0.001     .0682559    .2530019
              _cons |   .0121871   .4971273     0.02   0.980    -.9676039    .9919781
-------------------------------------------------------------------------------------
. vif

    Variable |       VIF       1/VIF  
-------------+----------------------
Stripercep~n |      2.92    0.342418
Stempercep~n |      2.79    0.358665
SW_constra~t |      2.48    0.402531
SB_constra~t |      2.36    0.422990
         TLU |      2.21    0.453076
       Lsize |      2.04    0.490532
      NBseed |      1.84    0.543643
log_offfar~e |      1.82    0.549755
       Dseed |      1.80    0.555704
Educationl~l |      1.78    0.560549
       Hsize |      1.67    0.598226
        Hage |      1.56    0.641086
     Hgender |      1.49    0.670981
     Acredit |      1.48    0.676163
H_laborcon~n |      1.45    0.688063
 Ext_Contact |      1.36    0.734998
Mfarmcoope~e |      1.34    0.746163
     Mstatus |      1.29    0.777885
     Dmarket |      1.18    0.848870
-------------+----------------------
    Mean VIF |      1.83
. linktest

      Source |       SS           df       MS      Number of obs   =       238
-------------+----------------------------------   F(2, 235)       =    122.66
       Model |  30.3544932         2  15.1772466   Prob > F        =    0.0000
    Residual |  29.0782799       235  .123737361   R-squared       =    0.5107
-------------+----------------------------------   Adj R-squared   =    0.5066
       Total |  59.4327731       237  .250771195   Root MSE        =    .35176
```

```
------------------------------------------------------------------------------
    PPTadopt |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        _hat |   1.161009   .1957522     5.93   0.000     .7753558    1.546662
      _hatsq |  -.1601217   .1839934    -0.87   0.385    -.5226089    .2023656
       _cons |   -.020085   .0463109    -0.43   0.665    -.1113225    .0711526
------------------------------------------------------------------------------
. estat hettest

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: fitted values of PPTadopt

         chi2(1)      =     1.11
         Prob > chi2  =   0.2930

. ovtest

Ramsey RESET test using powers of the fitted values of PPTadopt
       Ho:  model has no omitted variables
                 F(3, 215) =      4.52
                  Prob > F =      0.0943

. global y1list PPTadopt

. global xlist Hage Hgender Mstatus Educationlevel Hsize H_laborcontribution log_offfarmincome
Lsize TLU Acredit Mfarmcooperative Dmarke
> t Ext_Contact SW_constraint SB_constraint Dseed NBseed Striperception Stemperception

. global y2list PPTdisadopt

. global zlist Hage Hgender Mstatus Educationlevel Hsize H_laborcontribution log_offfarmincome
Lsize TLU Acredit Mfarmcooperative Dmarke
> t Ext_Contact SW_constraint SB_constraint Dseed NBseed Striperception Stemperception
Longevity_PPTuse

. biprobit ($y1list = $xlist) ($y2list = $zlist)

Fitting comparison equation 1:

Iteration 0:   log likelihood = -164.83455
Iteration 1:   log likelihood = -82.025526
Iteration 2:   log likelihood = -80.110906
Iteration 3:   log likelihood = -80.082073
Iteration 4:   log likelihood = -80.082051
Iteration 5:   log likelihood = -80.082051

Fitting comparison equation 2:

Iteration 0:   log likelihood = -147.52151
Iteration 1:   log likelihood = -47.599088
Iteration 2:   log likelihood = -39.087651
Iteration 3:   log likelihood = -36.952433
Iteration 4:   log likelihood =  -36.83725
Iteration 5:   log likelihood = -36.836981
Iteration 6:   log likelihood = -36.836981

Comparison:    log likelihood = -116.91903

Fitting full model:

Iteration 0:   log likelihood = -116.91903
Iteration 1:   log likelihood = -114.09181
Iteration 2:   log likelihood =  -113.1564
Iteration 3:   log likelihood = -112.70489
Iteration 4:   log likelihood = -112.50419
Iteration 5:   log likelihood = -112.46124
Iteration 6:   log likelihood = -112.44899
Iteration 7:   log likelihood = -112.44535
Iteration 8:   log likelihood =  -112.4434
Iteration 9:   log likelihood = -112.44254
Iteration 10:  log likelihood = -112.44191
Iteration 11:  log likelihood = -112.44169
Iteration 12:  log likelihood = -112.44156
```

```
Iteration 13:  log likelihood = -112.44152
Iteration 14:  log likelihood = -112.44147
Iteration 15:  log likelihood = -112.44146
Iteration 16:  log likelihood = -112.44145
Iteration 17:  log likelihood = -112.44144

Seemingly unrelated bivariate probit            Number of obs     =        238
                                                Wald chi2(39)     =     118.20
Log likelihood =  -120.7801                     Prob > chi2       =     0.0000

-------------------------------------------------------------------------------------
                     |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
---------------------+---------------------------------------------------------------
PPTadopt             |
                Hage |   .0739671   .0232229     3.16   0.003      .018393    .1446663
             Hgender |   .3038933   .2781037     1.09   0.275      -.24118    .8489666
             Mstatus |   .1470378    .135955     1.08   0.279    -.1194292    .4135048
      Educationlevel |   .1507706   .0373535     4.04   0.000      .077559    .2239822
               Hsize |   .0271071   .0422696     0.64   0.521    -.0557398     .109954
H_laborcontribution  |   .5084776   .2726906     1.86   0.042    -.0259863    1.042941
  log_offfarmincome  |   -.282579   .2107721    -1.34   0.180    -.6956848    .1305269
               Lsize |  -.1465296   .1266212    -1.16   0.087    -.3947025    .1016433
                 TLU |   .0288001   .0336304     0.86   0.392    -.0371143    .0947145
             Acredit |   .1723875   .2768024     0.62   0.533    -.3701353    .7149104
    Mfarmcooperative |  -.1862393   .3362332    -0.55   0.580    -.8452443    .4727657
             Dmarket |   -.020669   .0084626    -2.44   0.015    -.0372554   -.0040826
         Ext_Contact |     .62419   .2567887     2.43   0.015     .1208934    1.127487
       SW_constraint |  -.5984725   .3825992    -1.56   0.118    -1.348353    .1514082
       SB_constraint |  -.3221194   .4274287    -0.75   0.451    -1.159864    .5156255
               Dseed |   .5621084   .4040871     1.39   0.164    -.2298878    1.354105
              NBseed |      .2097   .3096359     0.68   0.498    -.3971753    .8165752
      Striperception |   .6090077   .2303653     2.64   0.008        .1575    1.060516
      Stemperception |   .6161234   .2057899     2.99   0.003     .2127826    1.019464
               _cons |  -.7155847   2.495618    -0.29   0.774    -5.606906    4.175737
---------------------+---------------------------------------------------------------
PPTdisadopt          |
                Hage |  -.0113667   .0195707    -0.58   0.561    -.0497246    .0269911
             Hgender |   -.659966   .4406408    -1.50   0.064    -1.523606    .2036742
             Mstatus |  -.1562398   .2410876    -0.65   0.517    -.6287629    .3162832
      Educationlevel |  -.1216548   .0671424    -1.81   0.040    -.2532515     .009942
               Hsize |  -.0270096   .0723704    -0.37   0.709    -.1688529    .1148338
H_laborcontribution  |  -.1880995   .4243803    -0.44   0.658     -1.01987    .6436706
  log_offfarmincome  |  -.3139409   .3032091    -1.04   0.300    -.9082198     .280338
               Lsize |  -.0297612    .075799    -0.17   0.066    -.3743208    .3147985
                 TLU |  -.0157449   .0494336    -0.32   0.075    -.1126331    .0811432
             Acredit |   -.191313   .4288279    -0.45   0.656      -1.0318    .6491742
    Mfarmcooperative |   .4180996    .425138     0.98   0.325    -.4151555    1.251355
             Dmarket |   .0209143   .0189993     1.10   0.271    -.0163236    .0581521
         Ext_Contact |  -2.365248   .7166529    -3.30   0.001    -3.769862   -.9606344
       SW_constraint |   -1.92243   .7687874     2.50   0.012     .4156348    3.429226
       SB_constraint |  -.4976408   .7100397    -0.70   0.483    -1.889293    .8940115
               Dseed |  -.3317472   .4980157    -0.67   0.095     -1.30784    .6443457
              NBseed |  -.7610403    .444771    -1.71   0.087    -1.632775    .1106948
      Striperception |  -.1325703   .3600385    -0.37   0.713    -.8382328    .5730923
      Stemperception |  -1.496175   .4291779    -3.49   0.000    -2.337348   -.6550015
    Longevity_PPTuse |  -.1830118   .0831203    -2.20   0.028    -.3459245   -.0200991
               _cons |   11.20949   4.412091     2.54   0.011     2.561947    19.85702
---------------------+---------------------------------------------------------------
             /athrho |  -58.23431    2330.83    -0.02   0.980    -4626.576    4510.108
---------------------+---------------------------------------------------------------
                 rho |         -1          0                            -1           1
-------------------------------------------------------------------------------------
LR test of rho=0: chi2(1) = 8.92284                       Prob > chi2 = 0.0028
```

Appendix 5: Censored Tobit Results

```
. tobit ext_expan Hage Hgender Mstatus  Educationlevel Hsize Fexperience Lsize TLU
Mfarmcooperative Ext_Contact Dmarket Stemperception S
> triperception Dseed NBseed LTuse i.Pathways,ll(0)

Tobit regression                                Number of obs     =        123
                                                LR chi2(25)       =     142.31
                                                Prob > chi2       =     0.0000
Log likelihood =  26.477915                     Pseudo R2         =     1.5927

------------------------------------------------------------------------------------
          ext_expan |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
--------------------+---------------------------------------------------------------
               Hage |   .0030067   .0032846     0.92   0.362    -.0035115     .009525
            Hgender |    .145763   .0525593     2.77   0.007     .0414608    .2500651
            Mstatus |   .0435451   .0226937     1.92   0.058    -.0014898      .08858
     Educationlevel |   .0041974   .0057898     0.72   0.470    -.0072924    .0156871
              Hsize |   .0016211   .0063192     0.26   0.798    -.0109191    .0141613
        Fexperience |  -.0045791   .0028944    -1.58   0.117    -.0103229    .0011647
              Lsize |  -.0344167   .0172949    -1.99   0.049    -.0687379   -.0000955
                TLU |   .0033583   .0040167     0.84   0.405    -.0046127    .0113292
   Mfarmcooperative |  -.0092276   .0391602    -0.24   0.814    -.0869397    .0684846
        Ext_Contact |   .1562679   .0735649     2.12   0.036     .0102808     .302255
            Dmarket |  -.0036752   .0021496    -1.71   0.090     -.007941    .0005907
     Stemperception |   .0786231   .0264968     2.97   0.004     .0260411     .131205
     Striperception |  -.0134628   .0279383    -0.48   0.631    -.0689054    .0419798
              Dseed |  -.0139143    .043262    -0.32   0.748    -.0997662    .0719377
             NBseed |   .1469122   .0428684     3.43   0.001     .0618413    .2319831
              LTuse |   .0311063   .0063902     4.87   0.000     .0184252    .0437875
                    |
           Pathways |
        Field days  |  -.0160023    .045628    -0.35   0.727    -.1065495    .0745449
    Farmer teachers |  -.0422207    .053563    -0.79   0.432    -.1485148    .0640733
      Farmer school |  -.1315604   .0587297    -2.24   0.027    -.2481076   -.0150132
             Radio  |  -.1146244   .0677486    -1.69   0.094    -.2490693    .0198205
 Television program |  -.3046887   .0765893    -3.98   0.000    -.4566776   -.1526997
     Print material |  -.2220045    .081227    -2.73   0.007    -.3831967   -.0608122
     Public meeting |  -.2330311   .0709273    -3.29   0.001     -.373784   -.0922782
  Agricultural show |  -.3045258   .0911336    -3.34   0.001    -.4853774   -.1236742
Participatory video |  -.2049341   .0940555    -2.18   0.032    -.3915842    -.018284
                    |
              _cons |  -.4980346   .1904195    -2.62   0.010     -.875916   -.1201532
--------------------+---------------------------------------------------------------
             /sigma |   .1214485   .0114929                      .0986411    .1442559
------------------------------------------------------------------------------------
            62  left-censored observations at ext_expan <= 0
            61     uncensored observations
             0 right-censored observations
. test Hage Hgender Mstatus  Educationlevel Hsize Fexperience Lsize TLU Mfarmcooperative
Ext_Contact Dmarket Stemperception Stripercepti
> on Dseed NBseed LTuse Pathways

 ( 1)  [model]Hage = 0
 ( 2)  [model]Hgender = 0
 ( 3)  [model]Mstatus = 0
 ( 4)  [model]Educationlevel = 0
 ( 5)  [model]Hsize = 0
 ( 6)  [model]Fexperience = 0
 ( 7)  [model]Lsize = 0
 ( 8)  [model]TLU = 0
 ( 9)  [model]Mfarmcooperative = 0
 (10)  [model]Ext_Contact = 0
 (11)  [model]Dmarket = 0
 (12)  [model]Stemperception = 0
 (13)  [model]Striperception = 0
 (14)  [model]Dseed = 0
 (15)  [model]NBseed = 0
 (16)  [model]LTuse = 0
 (17)  [model]Pathways = 0

       F( 17,   106) =    5.89
            Prob > F =    0.0000

.
```

Appendix 6: Propensity Score Matching Output

```
----------------------------------------------------------------------------------------------
------------------------------------------
      name:  <unnamed>
       log:  C:\Users\user\Desktop\Effects of PPT Log file.log
  log type:  text
 opened on:  14 Jun 2018, 08:16:30

. do "C:\Users\user\AppData\Local\Temp\STD04000000.tmp"

. ********Propensity Score Matching Results********
. ******** Effect of PPT on Per capita consumption per day*********
. use "C:\Users\user\Desktop\PP\PSM NO DISADOPTERS.dta"

. *********GRAPH***********
. pscore PPTadopt Educationlevel Hage Ltenure Striperception, pscore(p1) blockid(Blocks)comsup
level(0.001)



****************************************************
Algorithm to estimate the propensity score
****************************************************


The treatment is PPTadopt

If a farmer |
has adopted |
  push pull |
 technology |      Freq.     Percent        Cum.
------------+-----------------------------------
         No |        115       60.85       60.85
        Yes |         74       39.15      100.00
------------+-----------------------------------
      Total |        189      100.00



Estimation of the propensity score

Iteration 0:   log likelihood = -126.52217
Iteration 1:   log likelihood = -72.081823
Iteration 2:   log likelihood = -66.570965
Iteration 3:   log likelihood = -66.209279
Iteration 4:   log likelihood = -66.206371

Probit regression                                 Number of obs   =        189
                                                  LR chi2(4)      =     120.63
                                                  Prob > chi2     =     0.0000
Log likelihood = -66.206371                       Pseudo R2       =     0.4767

------------------------------------------------------------------------------
    PPTadopt |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
Educationl~l |   .1525263   .0359785     4.24   0.000     .0820098    .2230428
        Hage |   .0349368   .0137604     2.54   0.011     .0079668    .0619067
     Ltenure |   1.131082   .2670034     4.24   0.000     .6077646    1.654399
Stripercep~n |   .6458649   .1520236     4.25   0.000     .3479041    .9438257
       _cons |  -4.867371   .8786339    -5.54   0.000    -6.589462    -3.14528
------------------------------------------------------------------------------



Note: the common support option has been selected
The region of common support is [.07909197, .99398581]



Description of the estimated propensity score
in region of common support

                 Estimated propensity score
-------------------------------------------------------------
      Percentiles      Smallest
 1%     .0870311        .079092
```

```
 5%     .1121267       .0870311
10%     .1560749       .0870311       Obs                 121
25%     .2999022       .1002701       Sum of Wgt.         121

50%     .6484346                      Mean           .5893336
                        Largest       Std. Dev.      .2953558
75%     .8479746       .9735748
90%     .9210383       .9838139       Variance        .087235
95%     .9633066       .9933638       Skewness      -.3511331
99%     .9933638       .9939858       Kurtosis       1.680434


******************************************************
Step 1: Identification of the optimal number of blocks
Use option detail if you want more detailed output
******************************************************


The final number of blocks is 5

This number of blocks ensures that the mean propensity score
is not different for treated and controls in each blocks



**********************************************************
Step 2: Test of balancing property of the propensity score
Use option detail if you want more detailed output
**********************************************************


The balancing property is satisfied


This table shows the inferior bound, the number of treated
and the number of controls for each block

           |    If a farmer has
  Inferior |   adopted push pull
  of block |      technology
of pscore  |        No        Yes |     Total
-----------+----------------------+----------
   .079092 |        19          3 |        22
        .2 |         7          7 |        14
        .4 |         8         11 |        19
        .6 |        10         14 |        24
        .8 |         3         39 |        42
-----------+----------------------+----------
     Total |        47         74 |       121

Note: the common support option has been selected


*******************************************
End of the algorithm to estimate the pscore
*******************************************

. psgraph, treated( PPTadopt ) pscore(p1) bin(50)

. kdensity p1 if PPTadopt ==0, lpattern(dash) addplot (kdensity p1 if PPTadopt ==1) title
("distribution propensity scores") xtitle("sco
> res") ytitle("density")

. *********ATT and Biases***********
. **************Nearest Neighbour Matching*******************
.
. ***************NNM(3)***********************************
. psmatch2 PPTadopt Hage Hgender M_status Educationlevel log_offfarmincome Hsize TLU Lsize
Ltenure Striperception Stemperception Dadmini
> stration N_Gmembership, outcome ( per_capita_exp_day )  neighbor (3) common

Probit regression                                 Number of obs     =        189
                                                  LR chi2(13)       =     158.34
                                                  Prob > chi2       =     0.0000
Log likelihood = -47.351957                       Pseudo R2         =     0.6257
```

PPTadopt	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Hage	.0331789	.0190798	1.74	0.082	-.0042167	.0705745
Hgender	.372465	.4130099	0.90	0.367	-.4370194	1.181949
M_status	-.5494474	.4269297	-1.29	0.198	-1.386214	.2873194
Educationlevel	.1913729	.0538886	3.55	0.000	.0857533	.2969925
log_offfarmincome	.0485013	.2327411	0.21	0.835	-.4076628	.5046655
Hsize	-.0225178	.057749	-0.39	0.697	-.1357039	.0906682
TLU	.0344346	.0420275	0.82	0.413	-.0479378	.116807
Lsize	.3205501	.1522408	2.11	0.035	.0221636	.6189366
Ltenure	1.042755	.3274979	3.18	0.001	.4008712	1.68464
Striperception	.2976603	.1941116	1.53	0.125	-.0827915	.6781121
Stemperception	.6398745	.197496	3.24	0.001	.2527895	1.02696
Dadministration	-.0131555	.0039965	-3.29	0.001	-.0209884	-.0053226
N_Gmembership	-.0802131	.0754558	-1.06	0.288	-.2281038	.0676776
_cons	-5.686565	2.787562	-2.04	0.041	-11.15009	-.2230432

Variable	Sample	Treated	Controls	Difference	S.E.	T-stat
per_capita_exp~y	Unmatched	196.798356	141.573557	55.2247987	13.4794115	4.10
	ATT	203.569505	144.550364	59.0191411	25.7780821	2.29

Note: S.E. does not take into account that the propensity score is estimated.

psmatch2: Treatment assignment	psmatch2: Common support Off suppo	On suppor	Total
Untreated	0	115	115
Treated	39	35	74
Total	39	150	189

. pstest, both

Variable	Unmatched Matched	Mean Treated	Control	%bias	%reduct |bias|	t-test t	p>|t|	V(T)/ V(C)
Hage	U	54.865	49.93	50.3		3.42	0.001	1.30
	M	52.257	53.467	-12.3	75.5	-0.56	0.578	1.71
Hgender	U	.82432	.53913	64.0		4.17	0.000	.
	M	.71429	.77143	-12.8	80.0	-0.54	0.591	.
M_status	U	.75676	.68696	15.5		1.03	0.302	.
	M	.68571	.77143	-19.1	-22.8	-0.80	0.427	.
Educationlevel	U	10.824	6.913	114.3		7.49	0.000	0.64
	M	9.7143	10.933	-35.6	68.8	-1.50	0.139	0.58
log_offfarmincome	U	12.077	11.502	72.3		4.94	0.000	1.35
	M	11.856	11.857	-0.1	99.8	-0.01	0.995	0.83
Hsize	U	7.8378	6.3826	44.2		3.00	0.003	1.21
	M	6.7714	6.8762	-3.2	92.8	-0.16	0.876	1.10
TLU	U	7.4227	3.8582	70.4		4.97	0.000	2.55*
	M	5.5283	5.792	-5.2	92.6	-0.26	0.798	1.28
Lsize	U	2.9695	1.8187	88.6		5.98	0.000	1.13
	M	2.5006	2.3719	9.9	88.8	0.46	0.650	1.45
Ltenure	U	.86486	.29565	140.4		9.15	0.000	.
	M	.71429	.73333	-4.7	96.7	-0.18	0.861	.
Striperception	U	1.5946	.57391	141.3		9.37	0.000	0.80
	M	1.3143	1.3048	1.3	99.1	0.05	0.962	1.03
Stemperception	U	1.6216	.61739	140.0		9.28	0.000	0.80
	M	1.3714	1.1238	34.5	75.3	1.22	0.228	0.96
Dadministration	U	37.324	69.287	-77.1		-4.99	0.000	0.48*
	M	50	54.705	-11.4	85.3	-0.53	0.600	1.01

```
                         |                                  |               |
N_Gmembership          U | 3.9189   2.2522     69.0         |   4.66  0.000 |  1.14
                       M | 2.9429   3.2667    -13.4    80.6 |  -0.53  0.598 |  0.94
                         |                                  |               |
-----------------------------------------------------------------------------------------
* if variance ratio outside [0.63; 1.59] for U and [0.50; 1.98] for M

------------------------------------------------------------------------------------
 Sample     | Ps R2   LR chi2   p>chi2   MeanBias   MedBias      B      R     %Var
-----------+------------------------------------------------------------------------
 Unmatched | 0.626    158.34    0.000     83.6       72.3     248.4*  0.77     20
 Matched   | 0.078      7.61    0.868     12.6       11.4      67.2*  1.37      0
------------------------------------------------------------------------------------
* if B>25%, R outside [0.5; 2]

. ******************Kernel Matching***************
.
. psmatch2 PPTadopt Hage Hgender M_status Educationlevel log_offfarmincome Hsize TLU Lsize
Ltenure Striperception Stemperception Dadmini
> stration N_Gmembership, outcome ( per_capita_exp_day ) kernel common

Probit regression                                 Number of obs     =        189
                                                  LR chi2(13)       =     158.34
                                                  Prob > chi2       =     0.0000
Log likelihood = -47.351957                       Pseudo R2         =     0.6257

------------------------------------------------------------------------------------
         PPTadopt |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
------------------+-----------------------------------------------------------------
             Hage |   .0331789   .0190798     1.74   0.082    -.0042167    .0705745
          Hgender |    .372465   .4130099     0.90   0.367    -.4370194    1.181949
         M_status |  -.5494474   .4269297    -1.29   0.198    -1.386214    .2873194
   Educationlevel |   .1913729   .0538886     3.55   0.000     .0857533    .2969925
log_offfarmincome |   .0485013   .2327411     0.21   0.835    -.4076628    .5046655
            Hsize |  -.0225178    .057749    -0.39   0.697    -.1357039    .0906682
              TLU |   .0344346   .0420275     0.82   0.413    -.0479378     .116807
            Lsize |   .3205501   .1522408     2.11   0.035     .0221636    .6189366
          Ltenure |   1.042755   .3274979     3.18   0.001     .4008712     1.68464
   Striperception |   .2976603   .1941116     1.53   0.125    -.0827915    .6781121
   Stemperception |   .6398745    .197496     3.24   0.001     .2527895     1.02696
  Dadministration |  -.0131555   .0039965    -3.29   0.001    -.0209884   -.0053226
    N_Gmembership |  -.0802131   .0754558    -1.06   0.288    -.2281038    .0676776
            _cons |  -5.686565   2.787562    -2.04   0.041    -11.15009   -.2230432
------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------
        Variable     Sample |    Treated     Controls   Difference         S.E.   T-stat
----------------------------+------------------------------------------------------------
per_capita_exp~y  Unmatched | 196.798356   141.573557   55.2247987   13.4794115     4.10
                        ATT | 203.569505   155.760839   47.8086653   27.7409716     1.72
----------------------------+------------------------------------------------------------
Note: S.E. does not take into account that the propensity score is estimated.

 psmatch2: |   psmatch2: Common
 Treatment |        support
assignment | Off suppo  On suppor |     Total
-----------+----------------------+----------
 Untreated |         0        115 |       115
   Treated |        39         35 |        74
-----------+----------------------+----------
     Total |        39        150 |       189


. pstest, both

-----------------------------------------------------------------------------------------
                Unmatched |       Mean               %reduct |     t-test    |  V(T)/
Variable          Matched | Treated Control    %bias  |bias| |    t    p>|t| |  V(C)
--------------------------+----------------------------------+---------------+----------
Hage                   U | 54.865    49.93     50.3         |   3.42  0.001 |  1.30
                       M | 52.257   52.435     -1.8    96.4 |  -0.08  0.935 |  1.62
                         |                                  |               |
Hgender                U | .82432   .53913     64.0         |   4.17  0.000 |     .
                       M | .71429   .83121    -26.2    59.0 |  -1.16  0.249 |     .
                         |                                  |               |
M_status               U | .75676   .68696     15.5         |   1.03  0.302 |     .
                       M | .68571   .80252    -26.0   -67.3 |  -1.11  0.269 |     .
                         |                                  |               |
```

```
Educationlevel       U  | 10.824    6.913    114.3          |  7.49  0.000 |  0.64
                     M  | 9.7143   11.498    -52.1     54.4 | -2.07  0.042 |  0.49*
                        |                                   |              |
log_offarmincome     U  | 12.077   11.502     72.3          |  4.94  0.000 |  1.35
                     M  | 11.856   11.915     -7.5     89.7 | -0.34  0.736 |  1.09
                        |                                   |              |
Hsize                U  | 7.8378   6.3826     44.2          |  3.00  0.003 |  1.21
                     M  | 6.7714   6.5895      5.5     87.5 |  0.27  0.790 |  1.01
                        |                                   |              |
TLU                  U  | 7.4227   3.8582     70.4          |  4.97  0.000 |  2.55*
                     M  | 5.5283   5.6862     -3.1     95.6 | -0.15  0.881 |  1.16
                        |                                   |              |
Lsize                U  | 2.9695   1.8187     88.6          |  5.98  0.000 |  1.13
                     M  | 2.5006   2.4414      4.6     94.9 |  0.21  0.833 |  1.54
                        |                                   |              |
Ltenure              U  | .86486   .29565    140.4          |  9.15  0.000 |     .
                     M  | .71429    .7388     -6.0     95.7 | -0.23  0.821 |     .
                        |                                   |              |
Striperception       U  | 1.5946   .57391    141.3          |  9.37  0.000 |  0.80
                     M  | 1.3143   1.1556     22.0     84.5 |  0.78  0.437 |  0.93
                        |                                   |              |
Stemperception       U  | 1.6216   .61739    140.0          |  9.28  0.000 |  0.80
                     M  | 1.3714   1.0283     47.8     65.8 |  1.69  0.096 |  0.97
                        |                                   |              |
Dadministration      U  | 37.324   69.287    -77.1          | -4.99  0.000 |  0.48*
                     M  |     50   58.169    -19.7     74.4 | -0.87  0.385 |  0.85
                        |                                   |              |
N_Gmembership        U  | 3.9189   2.2522     69.0          |  4.66  0.000 |  1.14
                     M  | 2.9429   3.0886     -6.0     91.3 | -0.24  0.814 |  0.90
                        |                                   |              |
-----------------------------------------------------------------------------------------
* if variance ratio outside [0.63; 1.59] for U and [0.50; 1.98] for M

-----------------------------------------------------------------------------------
 Sample    | Ps R2   LR chi2   p>chi2   MeanBias   MedBias      B      R     %Var
-----------+-----------------------------------------------------------------------
 Unmatched | 0.626    158.34    0.000     83.6       72.3     248.4*  0.77     20
 Matched   | 0.090      8.70    0.795     17.6        7.5      72.8*  1.14     10
-----------------------------------------------------------------------------------
* if B>25%, R outside [0.5; 2]


. rename _treated t

. mhbounds per_capita_exp_day , gamma (1 (0.05)2) treated( PPTadopt )

Mantel-Haenszel (1959) bounds for variable per_capita_exp_day

Gamma         Q_mh+     Q_mh-     p_mh+     p_mh-
-------------------------------------------------
    1             .         .         .         .
 1.05             .    -.1691         .   .567141
  1.1             .         .         .         .
 1.15             .    -.1691         .   .567141
  1.2        -.1691         .   .567141         .
 1.25             .    -.1691         .   .567141
  1.3        -.1691    -.1691   .567141   .567141
 1.35             .    -.1691         .   .567141
  1.4        -.1691    -.1691   .567141   .567141
 1.45        -.1691         .   .567141         .
  1.5        -.1691    -.1691   .567141   .567141
 1.55             .    -.1691         .   .567141
  1.6        -.1691    -.1691   .567141   .567141
 1.65        -.1691         .   .567141         .
  1.7        -.1691    -.1691   .567141   .567141
 1.75        -.1691    -.1691   .567141   .567141
  1.8        -.1691         .   .567141         .
 1.85        -.1691    -.1691   .567141   .567141
  1.9        -.1691    -.1691   .567141   .567141
 1.95        -.1691         .   .567141         .
    2        -.1691    -.1691   .567141   .567141

Gamma : odds of differential assignment due to unobserved factors
Q_mh+ : Mantel-Haenszel statistic (assumption: overestimation of treatment effect)
Q_mh- : Mantel-Haenszel statistic (assumption: underestimation of treatment effect)
p_mh+ : significance level (assumption: overestimation of treatment effect)
p_mh- : significance level (assumption: underestimation of treatment effect)
```

```
.
. ******** Effect of PPT on Squared Poverty Gap**********************
. **************Nearest Neighbour Matching*******************
. psmatch2 PPTadopt Hage Hgender M_status Educationlevel log_offfarmincome Hsize TLU Lsize
Ltenure Striperception Stemperception Dadmini
> stration N_Gmembership, outcome ( SqPG )  neighbor (3) common

Probit regression                               Number of obs     =        189
                                                LR chi2(13)       =     158.34
                                                Prob > chi2       =     0.0000
Log likelihood = -47.351957                     Pseudo R2         =     0.6257

------------------------------------------------------------------------------------
         PPTadopt |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
------------------+-----------------------------------------------------------------
             Hage |   .0331789   .0190798     1.74   0.082    -.0042167    .0705745
          Hgender |    .372465   .4130099     0.90   0.367    -.4370194    1.181949
         M_status |  -.5494474   .4269297    -1.29   0.198    -1.386214    .2873194
   Educationlevel |   .1913729   .0538886     3.55   0.000     .0857533    .2969925
log_offfarmincome |   .0485013   .2327411     0.21   0.835    -.4076628    .5046655
            Hsize |  -.0225178    .057749    -0.39   0.697    -.1357039    .0906682
              TLU |   .0344346   .0420275     0.82   0.413    -.0479378     .116807
            Lsize |   .3205501   .1522408     2.11   0.035     .0221636    .6189366
          Ltenure |   1.042755   .3274979     3.18   0.001     .4008712     1.68464
   Striperception |   .2976603   .1941116     1.53   0.125    -.0827915    .6781121
   Stemperception |   .6398745    .197496     3.24   0.001     .2527895     1.02696
  Dadministration |  -.0131555   .0039965    -3.29   0.001    -.0209884   -.0053226
    N_Gmembership |  -.0802131   .0754558    -1.06   0.288    -.2281038    .0676776
            _cons |  -5.686565   2.787562    -2.04   0.041    -11.15009   -.2230432
------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------
        Variable     Sample |    Treated     Controls   Difference         S.E.   T-stat
----------------------------+------------------------------------------------------------
            SqPG  Unmatched |  .03080658   .124137398  -.093330818   .017429379    -5.35
                        ATT |   .0277772    .09702512  -.069247921   .036552956    -1.89
----------------------------+------------------------------------------------------------
Note: S.E. does not take into account that the propensity score is estimated.

 psmatch2: |   psmatch2: Common
 Treatment |        support
assignment | Off suppo  On suppor |     Total
-----------+----------------------+----------
 Untreated |         0        115 |       115
   Treated |        39         35 |        74
-----------+----------------------+----------
     Total |        39        150 |       189


. pstest, both

-----------------------------------------------------------------------------------------
                Unmatched |       Mean               %reduct |     t-test    |  V(T)/
Variable          Matched | Treated Control    %bias  |bias| |    t    p>|t| |  V(C)
--------------------------+----------------------------------+---------------+----------
Hage                    U | 54.865    49.93     50.3         |   3.42  0.001 |  1.30
                        M | 52.257   53.467    -12.3    75.5 |  -0.56  0.578 |  1.71
                          |                                  |               |
Hgender                 U | .82432   .53913     64.0         |   4.17  0.000 |     .
                        M | .71429   .77143    -12.8    80.0 |  -0.54  0.591 |     .
                          |                                  |               |
M_status                U | .75676   .68696     15.5         |   1.03  0.302 |     .
                        M | .68571   .77143    -19.1   -22.8 |  -0.80  0.427 |     .
                          |                                  |               |
Educationlevel          U | 10.824    6.913    114.3         |   7.49  0.000 |  0.64
                        M | 9.7143   10.933    -35.6    68.8 |  -1.50  0.139 |  0.58
                          |                                  |               |
log_offfarmincome       U | 12.077   11.502     72.3         |   4.94  0.000 |  1.35
                        M | 11.856   11.857     -0.1    99.8 |  -0.01  0.995 |  0.83
                          |                                  |               |
Hsize                   U | 7.8378   6.3826     44.2         |   3.00  0.003 |  1.21
                        M | 6.7714   6.8762     -3.2    92.8 |  -0.16  0.876 |  1.10
                          |                                  |               |
TLU                     U | 7.4227   3.8582     70.4         |   4.97  0.000 |  2.55*
                        M | 5.5283    5.792     -5.2    92.6 |  -0.26  0.798 |  1.28
                          |                                  |               |
Lsize                   U | 2.9695   1.8187     88.6         |   5.98  0.000 |  1.13
```

```
                    M  | 2.5006   2.3719      9.9    88.8 |   0.46  0.650 |  1.45
                       |                                  |               |
Ltenure             U  | .86486   .29565    140.4         |   9.15  0.000 |     .
                    M  | .71429   .73333     -4.7    96.7 |  -0.18  0.861 |     .
                       |                                  |               |
Striperception      U  | 1.5946   .57391    141.3         |   9.37  0.000 |  0.80
                    M  | 1.3143   1.3048      1.3    99.1 |   0.05  0.962 |  1.03
                       |                                  |               |
Stemperception      U  | 1.6216   .61739    140.0         |   9.28  0.000 |  0.80
                    M  | 1.3714   1.1238     34.5    75.3 |   1.22  0.228 |  0.96
                       |                                  |               |
Dadministration     U  | 37.324   69.287    -77.1         |  -4.99  0.000 |  0.48*
                    M  |     50   54.705    -11.4    85.3 |  -0.53  0.600 |  1.01
                       |                                  |               |
N_Gmembership       U  | 3.9189   2.2522     69.0         |   4.66  0.000 |  1.14
                    M  | 2.9429   3.2667    -13.4    80.6 |  -0.53  0.598 |  0.94
                       |                                  |               |
-----------------------------------------------------------------------------------------
* if variance ratio outside [0.63; 1.59] for U and [0.50; 1.98] for M

-----------------------------------------------------------------------------------
 Sample     | Ps R2   LR chi2   p>chi2   MeanBias   MedBias      B      R     %Var
------------+----------------------------------------------------------------------
 Unmatched  | 0.626    158.34    0.000     83.6      72.3     248.4*   0.77     20
 Matched    | 0.078      7.61    0.868     12.6      11.4      67.2*   1.37      0
-----------------------------------------------------------------------------------
* if B>25%, R outside [0.5; 2]


. ******************Kernel Matching***************
. psmatch2 PPTadopt Hage Hgender M_status Educationlevel log_offfarmincome Hsize TLU Lsize
Ltenure Striperception Stemperception Dadmini
> stration N_Gmembership, outcome ( SqPG ) kernel common

Probit regression                                Number of obs     =        189
                                                 LR chi2(13)       =     158.34
                                                 Prob > chi2       =     0.0000
Log likelihood = -47.351957                      Pseudo R2         =     0.6257

-----------------------------------------------------------------------------------
         PPTadopt |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
------------------+----------------------------------------------------------------
             Hage |   .0331789   .0190798     1.74   0.082    -.0042167    .0705745
          Hgender |    .372465   .4130099     0.90   0.367    -.4370194    1.181949
         M_status |  -.5494474   .4269297    -1.29   0.198    -1.386214    .2873194
   Educationlevel |   .1913729   .0538886     3.55   0.000     .0857533    .2969925
log_offfarmincome |   .0485013   .2327411     0.21   0.835    -.4076628    .5046655
            Hsize |  -.0225178    .057749    -0.39   0.697    -.1357039    .0906682
              TLU |   .0344346   .0420275     0.82   0.413    -.0479378     .116807
            Lsize |   .3205501   .1522408     2.11   0.035     .0221636    .6189366
          Ltenure |   1.042755   .3274979     3.18   0.001     .4008712     1.68464
   Striperception |   .2976603   .1941116     1.53   0.125    -.0827915    .6781121
   Stemperception |   .6398745    .197496     3.24   0.001     .2527895     1.02696
  Dadministration |  -.0131555   .0039965    -3.29   0.001    -.0209884   -.0053226
    N_Gmembership |  -.0802131   .0754558    -1.06   0.288    -.2281038    .0676776
            _cons |  -5.686565   2.787562    -2.04   0.041    -11.15009   -.2230432
-----------------------------------------------------------------------------------
----------------------------------------------------------------------------------------
        Variable     Sample |    Treated     Controls   Difference         S.E.   T-stat
----------------------------+-----------------------------------------------------------
            SqPG  Unmatched |  .03080658   .124137398  -.093330818   .017429379    -5.35
                        ATT |   .0277772   .077173363  -.049396164   .036369887    -1.66
----------------------------+-----------------------------------------------------------
Note: S.E. does not take into account that the propensity score is estimated.

 psmatch2: |   psmatch2: Common
 Treatment |        support
assignment | Off suppo  On suppor |     Total
-----------+----------------------+----------
 Untreated |         0        115 |       115
   Treated |        39         35 |        74
-----------+----------------------+----------
     Total |        39        150 |       189


. pstest, both
```

Variable	Unmatched Matched	Mean Treated	Mean Control	%bias	%reduct |bias|	t-test t	t-test p>|t|	V(T)/ V(C)
Hage	U	54.865	49.93	50.3		3.42	0.001	1.30
	M	52.257	52.435	-1.8	96.4	-0.08	0.935	1.62
Hgender	U	.82432	.53913	64.0		4.17	0.000	.
	M	.71429	.83121	-26.2	59.0	-1.16	0.249	.
M_status	U	.75676	.68696	15.5		1.03	0.302	.
	M	.68571	.80252	-26.0	-67.3	-1.11	0.269	.
Educationlevel	U	10.824	6.913	114.3		7.49	0.000	0.64
	M	9.7143	11.498	-52.1	54.4	-2.07	0.042	0.49*
log_offfarmincome	U	12.077	11.502	72.3		4.94	0.000	1.35
	M	11.856	11.915	-7.5	89.7	-0.34	0.736	1.09
Hsize	U	7.8378	6.3826	44.2		3.00	0.003	1.21
	M	6.7714	6.5895	5.5	87.5	0.27	0.790	1.01
TLU	U	7.4227	3.8582	70.4		4.97	0.000	2.55*
	M	5.5283	5.6862	-3.1	95.6	-0.15	0.881	1.16
Lsize	U	2.9695	1.8187	88.6		5.98	0.000	1.13
	M	2.5006	2.4414	4.6	94.9	0.21	0.833	1.54
Ltenure	U	.86486	.29565	140.4		9.15	0.000	.
	M	.71429	.7388	-6.0	95.7	-0.23	0.821	.
Striperception	U	1.5946	.57391	141.3		9.37	0.000	0.80
	M	1.3143	1.1556	22.0	84.5	0.78	0.437	0.93
Stemperception	U	1.6216	.61739	140.0		9.28	0.000	0.80
	M	1.3714	1.0283	47.8	65.8	1.69	0.096	0.97
Dadministration	U	37.324	69.287	-77.1		-4.99	0.000	0.48*
	M	50	58.169	-19.7	74.4	-0.87	0.385	0.85
N_Gmembership	U	3.9189	2.2522	69.0		4.66	0.000	1.14
	M	2.9429	3.0886	-6.0	91.3	-0.24	0.814	0.90

* if variance ratio outside [0.63; 1.59] for U and [0.50; 1.98] for M

Sample	Ps R2	LR chi2	p>chi2	MeanBias	MedBias	B	R	%Var
Unmatched	0.626	158.34	0.000	83.6	72.3	248.4*	0.77	20
Matched	0.090	8.70	0.795	17.6	7.5	72.8*	1.14	10

* if B>25%, R outside [0.5; 2]

```
. ******** Effect of PPT on HDD*******************
. **************Nearest Neighbour Matching*******************
. psmatch2 PPTadopt Hage Hgender M_status Educationlevel log_offfarmincome Hsize TLU Lsize
Ltenure Striperception Stemperception Dadmini
> stration N_Gmembership, outcome ( HDD )  neighbor (3) common
```

Probit regression

	Number of obs	=	189
	LR chi2(13)	=	158.34
	Prob > chi2	=	0.0000
Log likelihood = -47.351957	Pseudo R2	=	0.6257

PPTadopt	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Hage	.0331789	.0190798	1.74	0.082	-.0042167	.0705745
Hgender	.372465	.4130099	0.90	0.367	-.4370194	1.181949
M_status	-.5494474	.4269297	-1.29	0.198	-1.386214	.2873194
Educationlevel	.1913729	.0538886	3.55	0.000	.0857533	.2969925
log_offfarmincome	.0485013	.2327411	0.21	0.835	-.4076628	.5046655
Hsize	-.0225178	.057749	-0.39	0.697	-.1357039	.0906682
TLU	.0344346	.0420275	0.82	0.413	-.0479378	.116807
Lsize	.3205501	.1522408	2.11	0.035	.0221636	.6189366
Ltenure	1.042755	.3274979	3.18	0.001	.4008712	1.68464

Striperception	.2976603	.1941116	1.53	0.125	-.0827915	.6781121
Stemperception	.6398745	.197496	3.24	0.001	.2527895	1.02696
Dadministration	-.0131555	.0039965	-3.29	0.001	-.0209884	-.0053226
N_Gmembership	-.0802131	.0754558	-1.06	0.288	-.2281038	.0676776
_cons	-5.686565	2.787562	-2.04	0.041	-11.15009	-.2230432

Variable	Sample	Treated	Controls	Difference	S.E.	T-stat
HDD	Unmatched	10.3783784	6.39130435	3.98707403	.263089711	15.15
	ATT	10.1142857	7.35238095	2.76190476	.67177151	4.11

Note: S.E. does not take into account that the propensity score is estimated.

psmatch2: Treatment assignment	psmatch2: Common support Off suppo	On suppor	Total
Untreated	0	115	115
Treated	39	35	74
Total	39	150	189

. pstest, both

Variable	Unmatched Matched	Mean Treated	Control	%bias	%reduct |bias|	t-test t	p>|t|	V(T)/ V(C)
Hage	U	54.865	49.93	50.3		3.42	0.001	1.30
	M	52.257	53.467	-12.3	75.5	-0.56	0.578	1.71
Hgender	U	.82432	.53913	64.0		4.17	0.000	.
	M	.71429	.77143	-12.8	80.0	-0.54	0.591	.
M_status	U	.75676	.68696	15.5		1.03	0.302	.
	M	.68571	.77143	-19.1	-22.8	-0.80	0.427	.
Educationlevel	U	10.824	6.913	114.3		7.49	0.000	0.64
	M	9.7143	10.933	-35.6	68.8	-1.50	0.139	0.58
log_offfarmincome	U	12.077	11.502	72.3		4.94	0.000	1.35
	M	11.856	11.857	-0.1	99.8	-0.01	0.995	0.83
Hsize	U	7.8378	6.3826	44.2		3.00	0.003	1.21
	M	6.7714	6.8762	-3.2	92.8	-0.16	0.876	1.10
TLU	U	7.4227	3.8582	70.4		4.97	0.000	2.55*
	M	5.5283	5.792	-5.2	92.6	-0.26	0.798	1.28
Lsize	U	2.9695	1.8187	88.6		5.98	0.000	1.13
	M	2.5006	2.3719	9.9	88.8	0.46	0.650	1.45
Ltenure	U	.86486	.29565	140.4		9.15	0.000	.
	M	.71429	.73333	-4.7	96.7	-0.18	0.861	.
Striperception	U	1.5946	.57391	141.3		9.37	0.000	0.80
	M	1.3143	1.3048	1.3	99.1	0.05	0.962	1.03
Stemperception	U	1.6216	.61739	140.0		9.28	0.000	0.80
	M	1.3714	1.1238	34.5	75.3	1.22	0.228	0.96
Dadministration	U	37.324	69.287	-77.1		-4.99	0.000	0.48*
	M	50	54.705	-11.4	85.3	-0.53	0.600	1.01
N_Gmembership	U	3.9189	2.2522	69.0		4.66	0.000	1.14
	M	2.9429	3.2667	-13.4	80.6	-0.53	0.598	0.94

* if variance ratio outside [0.63; 1.59] for U and [0.50; 1.98] for M

Sample	Ps R2	LR chi2	p>chi2	MeanBias	MedBias	B	R	%Var
Unmatched	0.626	158.34	0.000	83.6	72.3	248.4*	0.77	20
Matched	0.078	7.61	0.868	12.6	11.4	67.2*	1.37	0

```
-----------------------------------------------------------------------------------
* if B>25%, R outside [0.5; 2]


. *****************Kernel Matching**************
. psmatch2 PPTadopt Hage Hgender M_status Educationlevel log_offfarmincome Hsize TLU Lsize
Ltenure Striperception Stemperception Dadmini
> stration N_Gmembership, outcome ( HDD )  kernel common

Probit regression                                 Number of obs     =        189
                                                  LR chi2(13)       =     158.34
                                                  Prob > chi2       =     0.0000
Log likelihood = -47.351957                       Pseudo R2         =     0.6257

-----------------------------------------------------------------------------------
         PPTadopt |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
------------------+----------------------------------------------------------------
             Hage |   .0331789   .0190798     1.74   0.082    -.0042167    .0705745
          Hgender |    .372465   .4130099     0.90   0.367    -.4370194    1.181949
         M_status |  -.5494474   .4269297    -1.29   0.198    -1.386214    .2873194
   Educationlevel |   .1913729   .0538886     3.55   0.000     .0857533    .2969925
log_offfarmincome |   .0485013   .2327411     0.21   0.835    -.4076628    .5046655
            Hsize |  -.0225178    .057749    -0.39   0.697    -.1357039    .0906682
              TLU |   .0344346   .0420275     0.82   0.413    -.0479378     .116807
            Lsize |   .3205501   .1522408     2.11   0.035     .0221636    .6189366
          Ltenure |   1.042755   .3274979     3.18   0.001     .4008712     1.68464
   Striperception |   .2976603   .1941116     1.53   0.125    -.0827915    .6781121
   Stemperception |   .6398745    .197496     3.24   0.001     .2527895     1.02696
  Dadministration |  -.0131555   .0039965    -3.29   0.001    -.0209884   -.0053226
    N_Gmembership |  -.0802131   .0754558    -1.06   0.288    -.2281038    .0676776
            _cons |  -5.686565   2.787562    -2.04   0.041    -11.15009   -.2230432
-----------------------------------------------------------------------------------
----------------------------------------------------------------------------------------
        Variable     Sample |    Treated     Controls   Difference         S.E.   T-stat
----------------------------+-----------------------------------------------------------
             HDD  Unmatched | 10.3783784   6.39130435   3.98707403   .263089711    15.15
                        ATT | 10.1142857   7.24009638   2.87418933   .559912211     5.13
----------------------------+-----------------------------------------------------------
Note: S.E. does not take into account that the propensity score is estimated.

 psmatch2: |   psmatch2: Common
 Treatment |        support
assignment | Off suppo  On suppor |     Total
-----------+----------------------+----------
 Untreated |         0        115 |       115
   Treated |        39         35 |        74
-----------+----------------------+----------
     Total |        39        150 |       189


. pstest, both

----------------------------------------------------------------------------------------
                Unmatched |       Mean               %reduct |     t-test    |  V(T)/
Variable          Matched | Treated Control    %bias  |bias| |    t    p>|t| |  V(C)
--------------------------+----------------------------------+---------------+----------
Hage                    U | 54.865    49.93     50.3         |   3.42  0.001 |  1.30
                        M | 52.257   52.435     -1.8    96.4 |  -0.08  0.935 |  1.62
                          |                                  |               |
Hgender                 U | .82432   .53913     64.0         |   4.17  0.000 |     .
                        M | .71429   .83121    -26.2    59.0 |  -1.16  0.249 |     .
                          |                                  |               |
M_status                U | .75676   .68696     15.5         |   1.03  0.302 |     .
                        M | .68571   .80252    -26.0   -67.3 |  -1.11  0.269 |     .
                          |                                  |               |
Educationlevel          U | 10.824    6.913    114.3         |   7.49  0.000 |  0.64
                        M | 9.7143   11.498    -52.1    54.4 |  -2.07  0.042 |  0.49*
                          |                                  |               |
log_offfarmincome       U | 12.077   11.502     72.3         |   4.94  0.000 |  1.35
                        M | 11.856   11.915     -7.5    89.7 |  -0.34  0.736 |  1.09
                          |                                  |               |
Hsize                   U | 7.8378   6.3826     44.2         |   3.00  0.003 |  1.21
                        M | 6.7714   6.5895      5.5    87.5 |   0.27  0.790 |  1.01
                          |                                  |               |
TLU                     U | 7.4227   3.8582     70.4         |   4.97  0.000 |  2.55*
                        M | 5.5283   5.6862     -3.1    95.6 |  -0.15  0.881 |  1.16
                          |                                  |               |
```

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Lsize                  U  | 2.9695   1.8187     88.6           |   5.98  0.000 |  1.13
                       M  | 2.5006   2.4414      4.6    94.9 |   0.21  0.833 |  1.54
                          |                                 |                |
Ltenure                U  | .86486   .29565    140.4           |   9.15  0.000 |     .
                       M  | .71429    .7388     -6.0    95.7 |  -0.23  0.821 |     .
                          |                                 |                |
Striperception         U  | 1.5946   .57391    141.3           |   9.37  0.000 |  0.80
                       M  | 1.3143   1.1556     22.0    84.5 |   0.78  0.437 |  0.93
                          |                                 |                |
Stemperception         U  | 1.6216   .61739    140.0           |   9.28  0.000 |  0.80
                       M  | 1.3714   1.0283     47.8    65.8 |   1.69  0.096 |  0.97
                          |                                 |                |
Dadministration        U  | 37.324   69.287    -77.1           |  -4.99  0.000 |  0.48*
                       M  |     50   58.169    -19.7    74.4 |  -0.87  0.385 |  0.85
                          |                                 |                |
N_Gmembership          U  | 3.9189   2.2522     69.0           |   4.66  0.000 |  1.14
                       M  | 2.9429   3.0886     -6.0    91.3 |  -0.24  0.814 |  0.90
                          |                                 |                |
-----------------------------------------------------------------------------------------
* if variance ratio outside [0.63; 1.59] for U and [0.50; 1.98] for M

-----------------------------------------------------------------------------------
 Sample    | Ps R2   LR chi2   p>chi2   MeanBias   MedBias      B       R     %Var
-----------+-----------------------------------------------------------------------
 Unmatched | 0.626    158.34    0.000     83.6       72.3     248.4*   0.77     20
 Matched   | 0.090      8.70    0.795     17.6        7.5      72.8*   1.14     10
-----------------------------------------------------------------------------------
* if B>25%, R outside [0.5; 2]

.
.
end of do-file

. close log
command close is unrecognized
r(199);

. log close
      name:  <unnamed>
       log:  C:\Users\user\Desktop\Effects of PPT Log file.log
  log type:  text
 closed on:  14 Jun 2018, 08:18:01
----------------------------------------------------------------------------------------------
------------------------------------------
```

Appendix 7: Research Permit

THIS IS TO CERTIFY THAT:
MR. ROBERT OUKO GWADA
of EGERTON UNIVERSITY, 0-40300
HOMA BAY,has been permitted to
conduct research in *Homabay County*

on the topic: *EFFECT OF PUSH PULL TECHNOLOGY ADOPTION AND DIS-ADOPTION ON POVERTY AMONG SMALLHOLDER MAIZE FARMERS IN HOMA BAY COUNTY.*

for the period ending:
3rd January,2019

Permit No : NACOSTI/P/18/83031/20618
Date Of Issue : 4th January,2018
Fee Recieved :Ksh 1000

....
Applicant's Signature

....
Director General
National Commission for Science, Technology & Innovation