ECONOMICS OF INTEGRATING PUSH-PULL TECHNOLOGY IN MAIZE-DAIRY FARMING SYSTEMS IN EASTERN UGANDA

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DECLARATION

I, Ruth Chepchirchir declare that this thesis is my original work and has not been presented for the award of a degree in any other university or any other award.

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DEDICATION

To my beloved parents Mr. Kipsaina Tarus and Mrs. Christina Tarus, and Kapchepchoge family at large who taught me the imperative value of education.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACIAR:	Australian Centre for International Agricultural Research
ADRF:	Average Dose Response Function
ADOPT:	Adaptation and Dissemination of 'Push-Pull' Technology to Climate Change
ARPPIS:	African Regional Postgraduate Programme in Insect Science
ATE:	Average Treatment Effect
ATT:	Average Treatment Effect on the Treated
BCR:	Benefit Cost Ratio
CA:	Cluster Analysis
CIAT:	International Center for Tropical Agriculture
CIMMYT:	International Maize and Wheat Improvement Center
DREAM:	Dynamic Research for EvAluation Management
GPS:	Generalized propensity score
GM:	Gross Margin
ha:	Hectare
ICIPE:	International Centre of Insect Physiology and Ecology
IFPRI:	International Food Policy Research Institute
IITA:	International Institute for Tropical Agriculture
IR:	Imazapyr Resistant
IRR:	Internal Rate of Return
KARLO:	Kenya Agricultural and Livestock Research Organization
MAAIF:	Ministry of Agriculture, Animal Industry and Fisheries
MRR:	Marginal Rate of Return
NPV:	Net Present Value

PCA:	Principal Component Analysis
PPT:	Push-Pull Technology
PSM:	Propensity Score Matching
SSA:	Sub-Saharan Africa
TR:	Total Revenue
TVC:	Total Variable Cost
US$:	US dollar

ABSTRACT

Cereals particularly maize, are the most essential food and cash crops for majority of smallholder households in Sub-Saharan Africa (SSA). In maize production, small-sized producers are confronted with different constraints including stemborers, Striga and degraded soil leading to poor crop yields. In response to these challenges, the International Centre of Insect Physiology and Ecology (icipe) and collaborators came up with a habitat management approach; the Push-pull Technology (PPT) for simultaneous restrain of the three key constraints. Despite high adoption of PPT in East Africa, its impact has not been fully understood in the region. This study characterizes farming systems and assesses factors that instigate their preference; it evaluates the economic performance of PPT when integrated in maize-dairy farming systems and determines the impact of PPT on household welfare. The study uses both primary and secondary data and simple random sampling to collect data from 560 households. Multivariate analysis, Binomial logit, Dynamic Research for Evaluation Management (DREAM) model, and Generalized Propensity Score (GPS) were utilized in the analysis. Outcomes confirm that household size, age, farm size, membership to community groups, and participation in PPT significantly influence the choice of farming system. Net Present Value, the Internal Rate of Return, the Benefit to Cost Ratio and gains to households supported the economic viability PPT. GPS dose-response function estimates revealed a positive and significant average effect of the intensity of PPT adoption on maize yield, incomes and poverty reduction. This study concludes that proper implementation of PPT offers the prospect of monetary benefits to households; also PPT has a positive impact on rural poverty in Uganda. Agricultural policies that target farm household food security and poverty reduction in maize-dairy based systems in Uganda and elsewhere should explicitly encourage further up-scaling and dissemination of PPT.

CHAPTER ONE: INTRODUCTION

1.1 Background Information

Maize (*Zea mays L.*) is among the essential and crucial cereal crops in Africa. It is grown in various regions of the continent on a wide range of climatic and ecological setting. As a result of its ever-increasing significance, maize has turned out to be a most important staple and cash crop for smallholder farmers (Macauley & Ramadjita, 2015). Despite its importance as food and cash crop, yields particularly from smallholder farms are often very low; this is attributable to numerous major production constraints faced by farmers. Ribaut *et al.,* (2009) reported that production of cereals is constrained by negative abiotic factors, such as water stress and the degraded soils, and biotic constraints, such as pests and parasitic weeds, resulting in extreme degrees of food insecurity, malnutrition and poverty. Field pests along with stored grain insect pests are amongst the aspects that cut down yields and food accessibility in Sub-Saharan Africa (SSA).

There are several storage and field crop pest species, major maize pest species include the following; the moth group (cutworms, earworms, stemborers, and grain moths), the beetles (rootworms, wireworms, grubs, grain borers, and weevils), and disease vectors (leafhoppers and aphids) (Abate *et al.*, 2000; Mugisha-Kamatenesi *et al.,* 2008). The most important weed in maize production that is seriously causing threats to food security in SSA is the *Striga* weed (Witchweed). It causes yield losses which can get to a high-level of about 80% in various regions and a mean of about 15-40% in other regions depending on the soil fertility and climatic conditions (Khan *et al.*, 2014). Other significant unwanted plants in maize production comprise spear grass (*Imperata cylindrica*), couch grass (*Digitaria* *scalarum*), and nut grass (*Cyperus rotundus*) among others (Bouagnimbeck & Ssebunya 2011; http://www.push-pull.net/2.shtml).

Increased occurrence of the cereal stemborer pests (mainly *Chilo partellus* Swinhoe and *Busseola fusca* Füller) and parasitic *Striga* weeds, (mainly *Striga hermonthica* (Del.) Benth and *Striga asiatica* (L. Kuntze) results to about 20% to 80% and intermittently up to 100% losses on maize produce, respectively (Kfir *et al.,* 2002; Andersson & Halvarsson, 2011; Atera *et al.,* 2013). Attachment of *Striga* roots to the host roots (cereal crops, in this case maize) draws moisture and nutrient requirements hence hinders natural growth of maize plant resulting in a decline in grain output or even total loss. Among the many field crop insect pests, stemborers are tremendously detrimental in SSA. They can cause crop losses varying between 30 and 100% in most areas, and are mainly intensified by poor soils which are predominant in the region (Khan *et al.,* 2014).

Striga and stemborer control methods have been widely researched in Africa. Appendix 1 summarizes the various control methods used which include uprooting, use of herbicides, heavy application of fertilizer and manure, Imazapyr Resistant (IR) maize-StrigAway (an herbicide-coated maize seed which kills *Striga* before it damages the crop), application of insecticides, use of natural enemies, crop rotation and use of push-pull technology. Appendix 1 also outlines advantages and disadvantages of each control method. However, all the mentioned techniques, together with the commonly used hoe weeding method, are intensely confined by the unwillingness of farmers to take up and practise, for either biological or socio-economic motives (Khan *et al.,* 2003; Mbwika *et al.,* 2011).

Further, research findings have shown that the control methods mentioned including use of herbicides, pesticides, organic fertilizers, and IR maize are expensive, unfriendly to the environment and may be unaffordable to some farmers whereas crop rotation, use of natural preparations, use of natural enemies, and uprooting are insufficient (Woomer *et al.,* 2004; Mbwika *et al.,* 2011). As a reaction to these production constraints, the International Centre of Insect Physiology and Ecology (*icipe*) in partnership with some other research institutes came up with a conservation agricultural approach to simultaneously curb the three major challenges of cereal production in Africa which are stemborers, *Striga* weeds and poor soil fertility. The novel strategy is termed as the 'push-pull' technology (PPT).

Push-pull technology is a habitat strategy developed for the integrated management of stemborers, *Striga* weeds and poor soil fertility in SSA. It involves intercropping maize (and other cereal crops) and desmodium (e.g. *Desmodium uncinatum*), with Napier (*Pennisetum purpureum* Schumach) or Brachiaria (*Brachiaria cv mulato II*) grass planted as a border crop (Khan *et al.,* 2008b; Midega *et al.,* 2010). The desmodium repels stemborer moths ('push'), while the surrounding grass attracts them ('pull') (Khan *et al.*, 2001). The desmodium also suppresses *Striga* weeds, mainly through allelopathy i.e. root-to-root interference (Khan *et al.,* 2001).

The strategy is suitable and efficient to smallholder farmers in the region who are not well endowed with resources due to its important features- utilizes locally accessible plants, affordable inputs, and corresponds perfectly to the classical assorted cropping systems commonly practised in Africa. The method has been taught to thousands of farmers and by end of 2017, this technology had been adopted by > 155,000 smallholder farmers in Kenya, Uganda, Tanzania, and Ethiopia where farmers are facing serious constraints of *Striga* and stemborer pests (http://www.push-pull.net/adoption.shtml).

Push-pull technology is of two types; the conventional and the climate smart push-pull. In conventional PPT, a multiple cropping practice involving maize and a legume is done whereby, silverleaf desmodium (*Desmodium uncinatum*) is planted amid the rows of maize whereas Napier grass (*Pennisetum purpureum*) is planted around the intercrop. Gravid stemborer females are driven away from the core crop (in this case maize) but are drawn to the crop acting as bait (Napier grass) by a concentration of alluring evaporative substance- green leaf volatiles. Besides being a 'push' plant, desmodium accelerates the development of *Striga* seeds but then hinders their growth after the germination process. With this strategy as well, there is a provision of high quality fodder (Napier grass, desmodium, and maize stalks). Besides, given that both companion plants are perennial, the technology therefore conserves soil moisture and boosts soil fertility (Khan *et al.*, 2001; Tsanuo *et al.*, 2003; Khan *et al.*, 2007).

On the other hand, climate smart PPT involves use of two species which are resistant to drought: Greenleaf desmodium (*Desmodium intortum*) and Brachiaria grass (*Brachiaria cv mulato II*). Climate smart technology is adapted to drier conditions but both technologies serve the same purpose of *Striga* and stemborer control (http://push-pull.net/Climate-smart_Push-Pull.pdf). The new climate-smart PPT which has been adopted and presently carried out by > 61,000 farmers in Kenya, Tanzania and Ethiopia was adapted for drier agro ecological zones and focused to get rid of the two major crop production problems; stemborer pests and the parasitic weed *Striga* on the key cereal crops including sorghum, millet and maize (http://www.push-pull.net/adoption.shtml). Notably, the brachiaria cv mulato II grass is not only tolerant to drought as compared to the Napier grass but also resistant to the stunting disease which has continuously affected the Napier grass (Khan *et al.*, 2014). This initiative is a biological control strategy, a crop management technique for smallholder cereal-livestock farming in drought stricken areas whose major aim is to boost food security and intensify poor smallholder farmers' wellbeing in Africa who are susceptible to uncertainties associated to climate change (http://push-pull.net/adaptation/).

Efforts have been made to evaluate the economics of the technology by Khan *et al.*, (2008b) and De Groote *et al.*, (2010). However, the two studies did not factor in other indirect benefits accrued as a result of adoption of PPT including an increase in livestock feed, and further increase in milk production. More importantly, the economics of PPT had not been evaluated in other East African countries particularly in Uganda where the technology has been expanded; this general paucity of information and data in the region constraints policy interventions. This study therefore aimed to contribute to a comprehensive economic analysis of PPT by characterizing smallholder maize-dairy farmers, evaluating economic benefits associated with the technology and further, its impact on households' welfare.

1.2 The Statement of the Problem

In East Africa, a broad range of insects and weeds have been identified as the main causes of low yield leading to food and nutritional insecurity among many households living in the rural areas. Stemborer pests, *Striga* weeds, and low soil fertility have been ranked as the most destructive to smallholder farmers in maize production. To address this, the novel Push-pull technology was introduced, first in Kenya and further efforts have been made to expand it to other East African countries including Uganda, Ethiopia, and Tanzania with much success. Over 150,000 farmers in East Africa have been practising the technology as an alternative to conventional *Striga* and stemborer control measures. While a study on economics of the conventional PPT was done in Western Kenya, the study only used maize yield as the major target output. All other components of the technology including fodder and milk were not evaluated. This is likely to understate the overall profitability of the enterprise by farmers who had adopted it. In Uganda, economic evaluation of PPT has not been done. Given that farmers' interest in a new innovation is about its profitability, there is a growing demand for and stronger emphasis on impact assessment in order to respond to stakeholders' requirements including research institutes, academic institutions and policy-makers, and increase the accountability and effectiveness of research. There is also need to understand the wholistic economic benefits accrued as a result of adopting the technology in Eastern Uganda and the impact of the technology on the welfare of the smallholder farmers. The study therefore, aimed to provide this missing information.

1.3 Justification

Economic evaluation of PPT and its impact on smallholders' livelihoods in the context of maize cropping and the associated production of fodder and milk in Eastern Uganda is of the essence. Besides, the relevance of the results is vital for accountability, planning purposes and further adoption of PPT in Uganda and other regions.

The economic benefits of PPT for maize cropping have been demonstrated previously. Khan *et al.,* (2001) evaluated the benefit-cost ratio of introducing PPT compared to maize monoculture with or without the use of pesticides, and Khan *et al.,* (2008b) evaluated the returns on investment for the basic factors of production under PPT compared with other cropping methods. Both studies showed that PPT was more profitable. However, these studies only focused on incomes generated from increased maize yield; the other benefits of PPT, increased fodder from Napier or Brachiaria grasses and desmodium, and increased milk production, were not quantified. They were also conducted in selected districts in the western part of Kenya where PPT had been widely disseminated since 1998 (http://www.push-pull.net/Climate-smart_Push-Pull.pdf). In contrast, PPT technologies were first introduced into Uganda in 2001 into more diverse farm typologies and socio-economic conditions (Gatsby, 2005). The broader approach of this new study can potentially strengthen the relevance of PPT in other parts of SSA where the production of cereals is hugely constrained by the same suite of problems as in Uganda.

This research study was therefore, reasonably relevant since the results contributed to the framework for *icipe* and other collaborating research and academic institutions in examining the economics of integrating agricultural technologies in various farming systems and the impact on smallholder farmers' welfare and hence, provide a recommendation domain to research institutes and other stakeholders on the course of action to be taken regarding uptake of agricultural technologies.

1.4 Objectives of the Study

The key purpose of this study was to perform a comprehensive economic analysis of integrating PPT in maize-dairy farming systems in Eastern Uganda, while evaluating its impact on the welfare of the smallholder farmers.

The specific objectives of the research study were to:

i. Characterize maize-dairy farming systems and assess factors influencing choice of farming system;
ii. Evaluate the economic performance of PPT when integrated in maize-dairy farming systems; and
iii. Determine the impact of PPT integrated in maize-dairy farming systems on smallholder farmers' welfare.

1.5 Hypotheses

This research study was guided by the following hypotheses:

i. Household and farm characteristics do not influence the choice of farming system;

ii. Push-pull technology integrated in maize-dairy farming systems is not profitable ; and

iii. Adoption of PPT has no positive and significant impact on the welfare of smallholder farmers.

1.6 Definition of Terms

i. **Push-pull Technology:** A biological pest control approach established to curb agricultural pests and weeds by use of repulsive "push" plants and "pull" plants which act as bait in various cereal crops which are usually attacked by stemborer pests and *Striga* weeds. In this technology, grasses are grown as a perimeter to the core plant to attract and trap stemborers whereas legume (desmodium) is sown amid the rows of the cereal crop to repel the stemborer pests and control parasitic plant (*Striga*) (Khan *et al*., 2001)

ii. **Smallholder farmers:** People who rely upon farming in small-scale as their main source of income and with limited resources compared to some other farmers in the region (Dixon *et al*., 2003). For the purposes of this study, it referred to farmers who owned small plots of land averaging 5 acres on which they grew maize, kept livestock and relied on family labour.

iii. **Farming Systems:** A decision making unit which is composed of a family farm, crop and livestock entity that convert major factors of production into valuable outputs that can be utilized or disposed of (Fresco & Westphal, 1988).

iv. **Adoption:** Describes the degree to which a new strategy/technology has been utilized over a long duration when a farmer has obtained complete and valid knowledge with reference to it and its ability (Feder & Zilberman, 1985). In this study, it refers to the proportion of land allocated to PPT.

v. **Adopters:** Within the context of this research, they are farmers who have decided exploit full potential of the push-pull technology for management of *Striga* weeds and stemborer pests, and also to boost soil fertility.

vi. **Household:** Comprises one or more persons who reside in the same house, sharing meals and accommodation and may consist of a single family unit or other group of people (Haviland, 2003).

1.7 Theoretical Framework

Like any other decision-maker who wants to maximize satisfaction, farmers are also expected to make their choices by settling on the best possible option that capitalizes on their anticipated utility (Sadoulet & de Janvry, 1995). A conceptual model based for the farmers' adoption decisions was presented by Rogers (1995) and Adesina & Zinnah (1993). According to the mentioned authors, the adoption choice greatly depends on the postulation of utility optimization which remains to be unobserved.

This study assumes that farmers, from their day-to-day practice, are aware of the most important agricultural constraints facing them and therefore, can point out with ease their most preferred choice for management of major agricultural pests and diseases. Underlying this postulation is that the specified choice is dependent on farmers' implied cost and benefit that are anticipated from the alternative intervention, given their capability. They are anticipated to logically state their choice in consonance with the purpose of improving their welfare or incomes.

This most preferred choice can be expressed by a utility function and the decision problem can thus, be model as a utility optimization problem. The conclusion whether to take up a new know-how is dependent on the association of marginal/additional net benefits/utility of new technology with practice without a technology. In this study, without technology and with new technologies scenarios are defined using the denotation 'w' along with 'n'.

The choice of the i^{th} farmer (y_i) for the technology adoption is indicated by the change amid the marginal net benefits of adopting 'n' technology with that of practice without technology 'w' which is unobserved. $y_i > 0$ is equivalent to the net benefit (gains) of the 'n' technology (NB_{net}) surpassing that of the 'w' without technology while NB_w refers to the net benefits (gains) of without technology 'w' being less compared to that of the 'n' technology. This can be presented in the following equation:

$$NB_{NetBen} = NB_n - NB_w \quad \text{……………………………………………………………….. (1)}$$

In modeling, the satisfaction that farmers acquire from PPT adoption, the proceeds from maize production under conventional ways including maize monocrop, maize intercrop with other crops and maize production under PPT; and milk production by farmers practising PPT and those not practicing PPT were given due consideration. A typical smallholder-farming household aims to optimize a multi-dimensional objective function, as well as a reduction in food security, and a boost in incomes. When a variation is experienced in any of the parameter that is correlated with PPT adoption, the most important issue that arises is on the total benefits that the household acquires. Therefore, a variation in the gains related to this adoption was employed for the purpose of economic analysis procedure. When a farmer encounters a quantifiable change, for instance more gains from PPT adoption (G), then G changes in quantity from G_0 to G_1 (with $G_1 > G_0$). The indirect satisfaction (utility) function S following the change becomes more than the existing condition. Now the existing condition can be expressed econometrically as below (Equations 2 to 4):

$$S_{PPT} = S_{PPT}(M_i, N_i, Q_i, \varepsilon_I) \quad \text{.........} \quad (2)$$

$$S_{NonPPT} = S_{NonPPT}(M_i, N_i, Q_i, \varepsilon_I) \quad \text{.........} \quad (3)$$

$$S_{Net} = S_{PPT} - S_{NonPPT} > 0 \quad \text{.........} \quad (4)$$

Where, S_{Net} signifies the farmer's net satisfaction/utility accrued as a result of PPT, whereby S_{PPT} indicates the satisfaction from PPT adoption, while S_{NonPPT} indicates satisfaction related to farming without PPT adoption. Additionally, M_i is a vector of the farmer's socio-economic characteristics, N_i represent farm characteristics and Q_i are institutional characteristics, and ε_i is the stochastic error term describing other unobserved utility factors not included in the model. The farmers will only single out adoption on condition that the following situation holds (equation 5):

$$S_{PPT}(M_i, N_i, Q_i, \varepsilon_I) > S_{NonPPT}(M_i, N_i, Q_i, \varepsilon_I) \quad \text{.........} \quad (5)$$

Considering that random factors of the preferred choices are certainly unknown, it is only likely to come up with probabilistic declaration on the anticipated outcomes from PPT adoption. Therefore, adoption of PPT as the better choice by the farmer is the likelihood that he/she will be better off than before. This is illustrated in equation 6:

$$\Pr ob(PPT) = \Pr ob\left[S_{PPT}(M_i, N_i, Q_i, \varepsilon_i) > S_{NonPPT}(M_i, N_i, Q_i, \varepsilon_i) \right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

The underlying factors influencing the farmers to decide on whether to maximize the utility by adopting a technology (PPT) can be affected by various factors. For instance, the preference of the i^{th} farmer to choose PPT or not to choose the technology can be determined by a number of attributes including socio-economic, farm and institutional factors.

1.8 Conceptual Framework

Every research institutions' (both private and public) aspiration is to have an influence on farmers' livelihood through innovations that increase production by disbursing resources in development and up-scaling of improved innovations with the aim to maximize output given the available inputs (Rogers, 1995). Once contemporary agricultural technologies are introduced and disseminated to farmers who will accept and use it (adoption), it is then advisable to conduct an *ex-post* evaluation to assess its net benefits.

Push-pull technology, an integrated pest control approach requires an in-depth understanding that involves several steps along an economic impact pathway or results chain. In Figure 1.1, the economic impact pathway is shown as a staircase model, first conceptualized by Bennett (1975) then recently used by Rockwell & Bennett, (2004) and modified for this study. The commencement of a new technology comprises inputs in terms of planning, organization, material, monetary and personnel. The mentioned inputs will aid introduction, training and dissemination of PPT activities from its source (research institution, in this case *icipe*) to the farmers who are the end users. This is done using various dissemination avenues which comprise print media, field-days, farmer teachers, radio, participatory video and farmer field schools (step 2). This leads to step 3, a stage of being aware and well-informed of the new technology and consequently triggers formation of attitudes or perceptions towards it (step 4).

Step 5 (technology testing/trial) is done by farmers as a means to guarantee that the technology is pertinent to their problems and priorities which include stemborers and *Striga* control and eventually increased yields. After several trials/attempts, farmers eventually choose to accept and use the technology hence adoption (step 6). It is assumed in this case that an individual farmer depending on his/her own personal attributes chooses to adopt the technology or otherwise. This is influenced by several variables which are classified into demographic or socio-economic, farm, and institutional characteristics. The adoption of PPT then leads to various economic benefits (direct and indirect) including; a decrease in *Striga* dormant seeds, control of stemborer pests, soil fertility improvement hence increased maize yields and provision of livestock feed (Napier grass, Brachiaria and Desmodium) leading to increased milk production and consequently increase in farmers' incomes (step 7). In the long run, farmers who adopted the technology will be made better off than before and also a beneficial to the entire society (step 8).

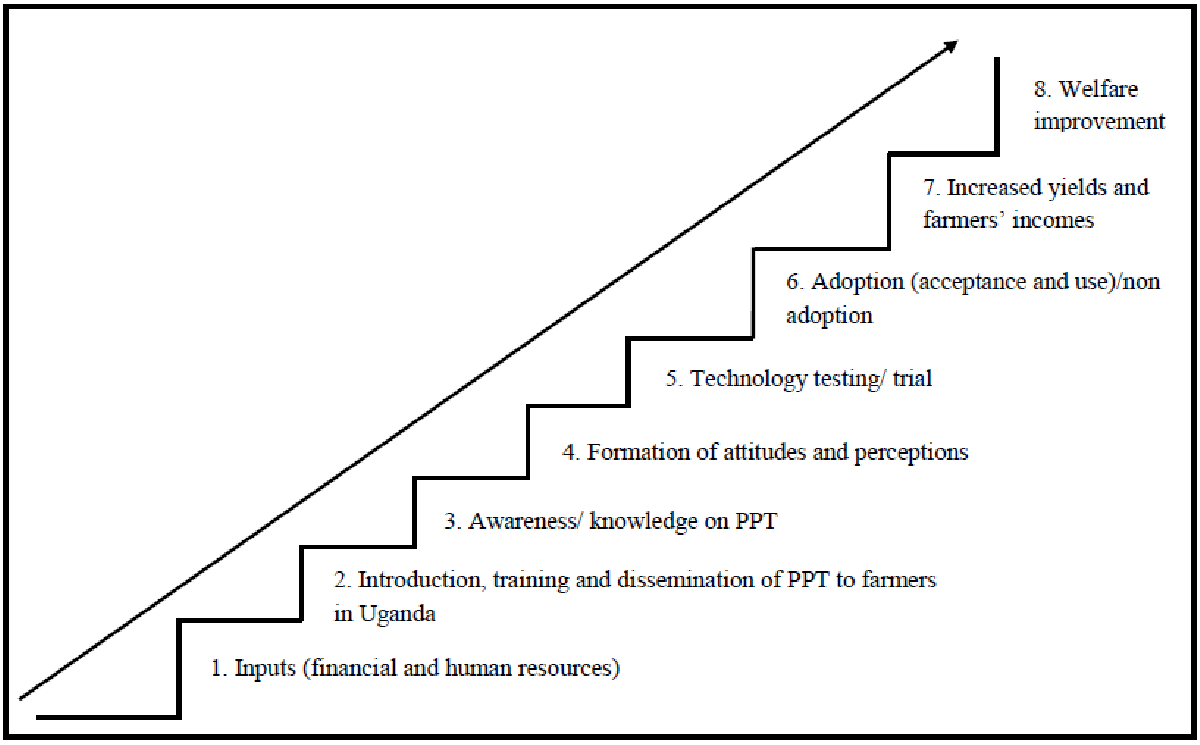


Figure 1.1: Conceptual Framework

Source: Modified from Rockwell & Bennett, (2004).

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter reviews studies that have evaluated the economic benefits emerging from the introduction of agricultural technologies. The chapter starts by introducing major insect pest and parasitic weed which are the most important constraints in maize production in East Africa; it is followed by the importance of economic analysis in agricultural technologies, and the commonly used approaches in economic assessments including their strengths and weaknesses. The chapter winds up by providing a review of past studies that have evaluated economic performance of agricultural technologies and clearly points out the research gap that the current study will address.

2.2 Major Pest and Weed Problems in Maize Production in East Africa

The main insect pest and parasitic weed problems causing significant crop losses to farmers who rely on maize production for survival in East Africa are the *lepidopteran* stemborers and parasitic *Striga* weeds. Among the twenty-one *lepidopteran* stemborers which have an economic impact in Africa, the native *Busseola fusca* Fuller (Noctuidae) and the intrusive *Chilo partellus* Swinhoe (Crambidae) are most destructive in SSA. (Kfir *et al*., 2002; Gressel, *et al*., 2004; Gethi *et al*., 2005). Whereas amongst the twenty three varieties of *Striga* in Africa, *Striga hermonthica* (Del.) Benth and *Striga asiatica* (L.) O. Kuntz, are of economic important (Khan *et al*., 2014). The stemborer moths feed on the leaves while the larvae cause the main damage by boring through the stalk thereby preventing full development of the crop whereas *Striga* attaches itself to maize roots, stunting its growth and causing severe under development by depriving its host plant of nutrients (Gatsby, 2005; Khan *et al*., 2007).

Consequently, in East Africa region, maize growing farmers are conquering a number of the most destructive plant and insect pests in an eco-friendly justifiable way using the novel ‘push-pull system’ which was first brought up by the International Centre of Insect Physiology and Ecology (*icipe*), in partnership with the Kenya Agricultural Research Institute (KARI)- currently known as the Kenya Agricultural and Livestock Research Organization (KALRO), Rothamsted Research (UK) amongst other collaborators in Eastern Africa to concurrently tackle the devastating biotic and abiotic constraints leading to improved yields (Khan *et al*., 2001).

2.3 Economics of Agricultural Technology

Currently, many agricultural researchers deliberate on how projected agricultural technologies and the risks linked to them may have some implications to the effectiveness of technologies. Therefore, the need to include economic analysis in decisions regarding various agricultural technologies suggested to farmers to boost their incomes is of great importance. This is necessary in interpreting the social value of technical facts and expertise so as to come up with valid opinions about the concession based on apportionment of limited assets in research (Alston *et al.*, 1998).

The three main common groups of economic assessments are econometric, programming and consumer surplus methods (Masters & William 1996). The main objective of econometric models is to approximate an extra output gained for the study over a longer interval by utilizing a cost or a relation between physical outputs of a production process to physical inputs or either an assessment of overall efficiency of factors so as to evaluate a variation in output as a result of investment in research. Programming approaches on the other hand attempt to determine at least one or more from a number of best possible technologies or research activities from given alternatives. Therefore, the mentioned approaches aim to maximize one goal which is; farmers' output subjected to major constraint for example accessibility to the factors of production which include; land, labour, as well as other inputs (Masters & William 1996; Maredia *et al.*, 2000).

Further, the foremost aim of the total welfare approach is to compute the cumulative social benefits associated with agricultural technologies. Applying economic surplus approach facilitates estimation of the return on investment by computing a difference of end user and supplier welfare by way of a change in the amount of output produced rising from adoption of agricultural technology (Maredia *et al.,* 2000). Major benefit of applying the welfare approach is the requirement of lesser data compared to other methods. In addition to that, it can generate informative and valuable outputs that show benefits achieved through agricultural research. Besides, the approach allows computation of the economic benefits generated from uptake and use of technological novelty, in contrast to the condition prior to or with no adoption, where only the habitual or other conventional means were available.

Economic surplus approaches are commonly utilized to evaluate agricultural technologies on certain crops, regions, and countries; the approach is suitable for both after the event (*ex-ante)* and actual (*ex-post)* assessment. Before adoption of agricultural technologies, an *ex-ante* technique is normally utilized in the prediction of the future effects of taking up and implementing various agricultural skills. (Alston *et al.,* 1995). *Ex-post* studies alternatively, evaluate the economic performance of technologies already adopted. Although *ex-ante* approaches are frequently used, *ex-post* studies where real information is collected are likely to be trustworthy (Masters & William 1996).

Softwares /spreadsheets developed specifically for economic surplus computation comprise MODEXC (*Modelo de Análisis de Excedentes Económicos)* initially established by International Center for Tropical Agriculture (CIAT), RE4 instituted by the Australian Centre for International Agricultural Research (ACIAR), and Dynamic Research Evaluation for Management (DREAM) set up at International Service for National Agricultural Research (NAR) and International Food Policy Research Institute- IFPRI- (Lynam & Jones, 1984; and Alston *et al.*,1995). Because of its simplicity, DREAM is preferred for this assessment. The DREAM model is applied in the evaluation of economic proceeds from investment in agricultural technologies along with positioning priorities for crop-based activities. The strong point about the DREAM model is within its capability to include all the conceptual concerns that originate from the implementation of a prioritized research activity. These take account of how research in agriculture influence agricultural know-how, the act of invention and markets and to what degree these outcomes are converted to expenses and profits from various studies by way of accessible software programmes installed in computers whereby their intricate calculations are included in the software package to permit the handler to target information-collection along with the clarification of guiding principle. In addition, its foundation is on the economic surplus methodology which brings about the cost-effective justification for the establishment of supplies that benefit the public which include agricultural research.

Nevertheless, this approach has its disadvantages; the attributes and the measure of degree of research brought about by supply shift greatly rely on the assumptions made in the model. However, poor quality data are a major challenge (Alston *et al.*, 1998). The DREAM model has been utilized repeatedly in similar research studies for example: (Pachico *et al.*, 2001), Lusty & Smale (2003), and Macharia *et al.*, (2005).

A review of literature as summarized in Table 2.1 reveals efforts to evaluate economic performance of agricultural technologies. The Table illustrates names of authors, objectives of their research studies, methods or models used for analysis, key findings/conclusions and the research gap the current study will address.

Table 2.1: Summary of past studies

Authors	Objectives	Method/model used	Key findings/conclusions	Research gap
Khan *et al.*,(2008b)	- Evaluated economic performance of push-pull technology versus farmer's common practices of either planting maize as a monocrop or maize intercropped with beans in Western part of Kenya	-Gross margins -Net present Values (NPVs) -Cost benefit analysis	- Compared to other methods under realistic production assumptions, PPT is more profitable -To boost production and diversification in smallholder farming, PPT is a feasible alternative	-Economic performance of climate smart PPT has not been evaluated -Milk yield as a push-pull component was not evaluated -Site specific study has not been done in Uganda
De Groote *et al.*, (2010)	- Estimated and compared the profitability of diverse pests and soil fertility management practices over time	-Gross margins -Net present Values (NPVs) -Marginal rate of return(MRR)	- Newly introduced cropping arrangements with fodder intercrop (push-pull) or rotations of soybean were greatly profitable -PPT was more beneficial compared to other farming systems though it requires comparatively high establishment cost	-Options compared were under researcher-managed conditions and could lead to overestimation of benefits hence biased results, there is therefore need for research under farmer managed conditions
Midega *et al.*, (2013)	Estimated cumulative impact and established economic benefits of intercropping maize with regularly grown food legumes on *Striga* invasion	-Gross margins	- Desmodium is effective in smothering *Striga*, boosting crop yields and economic proceeds to small-scale farmers -Intensifying cropping systems by incorporating leguminous food plants and edible grains may possibly offer a feasible and cost-effective system	-Data utilized was from *icipe* campus under research managed conditions, there is need for evaluation on farmers own fields

Authors	Objectives	Method/model used	Key findings/conclusions	Research gap
			compared to maize in sole stands	
Macharia *et al.*, (2013)	Evaluated possible economic and poverty impact of enhanced chickpea varieties in Ethiopia	Economic surplus model (based on DREAM model)	- Consumers are anticipated to acquire 39% of the benefits - Producers are estimated to get 61% of the benefits - The investment is profitable	The study used an ex-ante approach to predict future benefits. The current study utilized ex-post approach to evaluate economic gains of the adopted PPT
Macharia *et al.*, (2005)	Assessed the possible impact of effect of biological control of diamondback moth (*Plutella xylostella*) in cabbage production in Kenya	Economic surplus model	- Crop losses was valued at US$ 452.9/ha which is equivalent to US$ 7.9 million per year countrywide -Consumers were approximated to acquire 58% of the benefit whereas 42% to producers	The study assessed economic impact of PPT in cereal-livestock farming systems in Uganda
Amare *et al.*, (2012)	Estimated the impact of technology uptake on household well-being	-Propensity score matching -Switching regression techniques.	- Adoption of maize and pigeon peas had a positive and significant impact on household incomes and consumption expenditure	- Heterogeneous effects of adoption were not accounted for (binary treatment effect approach does not account for it)
Simtowe *et al.*, (2012)	Evaluated the role that improved groundnut technology adoption on consumption expenditure along with poverty position determined by headcount index, poverty gap and poverty severity indices.	-Propensity score matching	-Improved groundnut variety adoption had strong, positive and significant effect on per capita consumption expenditure and poverty reduction	-The extent to which the adoption benefits differ with the intensity of adoption was not considered, (that is the impact of level of adoption). This is due to the fact that PSM assumes that the effects among treatment groups receiving different treatment levels are similar

Authors	Objectives	Method/model used	Key findings/conclusions	Research gap
Midingoyi *et al.*, (2016).	Assessed the long-term welfare effects of the biological control of cereal Stemborer pests in East and Southern Africa- Kenya, Mozambique and Zambia.	-Economic surplus model	-Greater returns and higher efficiency of investment in biological control programme as confirmed by net present value, the internal rate of return and the benefit-cost ratio estimates. - The programme contributes to lifting a large number of people out of poverty.	-The study evaluated the impact of the biological control program on cereal crops production in Kenya, Mozambique and Zambia. Whereas the current study evaluated the economic effects of integrating the push-pull technology in maize-dairy farming systems in Eastern Uganda

2.4 Impact Evaluation of Agricultural Technologies on Households Welfare

Agricultural technologies are outlined to attain particular target and recipient. Therefore, approaches to get to know whether such technologies absolutely work, and also the intensity and type of impacts on anticipated recipient are exceptionally necessary. Agricultural technologies may seem to show potential prior to putting it into practice yet not succeed in generating anticipated impacts or payback. The apparent need for impact assessment is to guide various institutions including; help research institutions, academic institutions and policy makers in understanding whether agricultural technologies achieve anticipated outcome; to boost liability in the apportionment of resources; to fill up gaps in considering what works or fits well, what doesn't, and how deliberated transformation in wellbeing are inferable to a specific agricultural technology adoption or strategy intervention (Ravallion, 2008).

Adequate impact assessment on agricultural technologies is recommended to be satisfactory and absolute in evaluating ways by which recipients are reacting to the intervention. In addition, an impact evaluation that helps research institutions, academic institutions together with policy-makers value the outcomes of one innovation can direct allied and expected impact assessments of similar innovations. The advantages of a coherent impact assessment are for that reason enduring and can have significant spillover effects (Khandker, 2011). Summary of past studies is presented in Table 2.1.

Notably, most research institutions including *icipe* have invested in agricultural technologies but not much has been done on the impact assessment of implementation of these agricultural skills regarding farm operations along with household welfare that could validate the investments made. This research study intends at providing more information to fill the gap in the literature by estimating if the intensity of adoption of PPT has a beneficial outcome on poverty decline, increment in incomes and productivity, and to what extent these benefits change with the intensity of adoption.

To reach the objective of increased yields and incomes for every one along with poverty reduction, the obligation to boost and sustain agricultural output in Africa is vital. One of the approaches of increasing agricultural productivity is to push for the usage of up-to-date and modernized agricultural technologies. Particularly, since the prospects of increasing production by intensifying cropped areas are narrow, increasing agricultural productivity vitally relies upon the development and distribution of productivity- boosting technologies that are economical. Aforementioned technologies have been set up to facilitate improving food security promptly by increasing output intensities and also obliquely by for instance lowering poverty levels through increasing farm households incomes, and employment as well as reducing the prices of food items (De janvry & Sadoulet, 2001).

A number of studies on economic analysis of agricultural technologies have been done for example Macharia *et al.*, (2005), Khan *et al.*, (2008b), De Groote *et al.*, (2010), Midega *et al.*, (2013), Macharia *et al.*, (2013) and Midingoyi *et al.*, (2016). Additionally, impact assessment of agricultural technologies on household welfare have been done by various researchers including Amare *et al.*, (2012), and Simtowe *et al.*, (2012) amid others. Unlike the above mentioned studies, the current research study with the aim of filling the knowledge gap and as an *ex-post* study, assessed the economic performance of both conventional and climate smart Push-pull (ADOPT) technologies, by evaluating increased maize and milk yields, and fodder which are the components of PPT, as a site specific study in Eastern Uganda.

In addition, a critical question at present concerns the extent to which adoption of PPT has brought about a decrease in poverty and affected income distribution in Eastern Uganda. To respond to these, and also to conquer the shortcomings of the mentioned approaches, this study adopted a generalized propensity score (GPS) technique, a recommended approach for covariate adjustment under continuous treatment regimes. The GPS for continuous treatments is a clear-cut expansion of the well-recognized and extensively utilized propensity score methodology for binary treatments and multi-valued treatments (Rosenbaum & Rubin, 1983; Imbens, 2009).

The GPS approach which was established by Hirano & Imbens (2004) differs from the binary method which considers that the effects are comparable among treatment sets in receipt of different intensities of treatment, and also due to the difficulty of identifying the control group (non-adopters), the GPS methodology allows for estimation of treatment effects for every level of treatment in this case intensity of adoption.

Similarly, this research study aim at making a contribution towards the limited knowledge on the association involving increased productivity and incomes, reduction in poverty levels, and the level of adoption of PPT in Eastern Uganda. The output produced will as well be a contribution in policy making by guaranteeing that enabling policies are executed to reinforce integrated smallholder cereal-livestock enterprises in target areas and beyond, thus contribute in solving serious problems of poverty, food insecurity, and nutrition related health risks currently experienced in Africa.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter presents the procedure used in eliciting the data from the study sites. The chapter first describes the study sites, followed by sampling procedure and data types; this included secondary data, data from focus group discussions, key informant interviews and households' survey. Lastly the chapter specifies model specification and data analysis techniques.

3.2 Overview of Study Sites

After PPT was initially pioneered and rolled out in Kenya in 1997, *icipe* team linked up with other experts to launch the technical knowledge in other East Africa counties including Uganda. The process of out scaling PPT was initiated in the *Striga*-infested districts of Eastern Uganda in 2001. The districts included; Kapchorwa, Budaka, Busia, Bugiri, Iganga,Tororo, and Pallisa (Gatsby, 2011). The study was done in four districts in Eastern Uganda, namely; Bugiri, Busia, Pallisa, and Tororo. In these regions, *Striga* weed, stemborers, decline in soil quality, and unreliable rainfall are the key challenges to maize production. Furthermore, PPT has been widely disseminated among farmers in these regions (http://www.push-pull.net/). The districts are subject to the same tropical climatic conditions and land use, which is mainly arable. All are rain fed with annual rainfall between 1,000 and 2,000 mm, with short rains in April to May and long rains in September to November (http://psipse.org/about-uganda/).

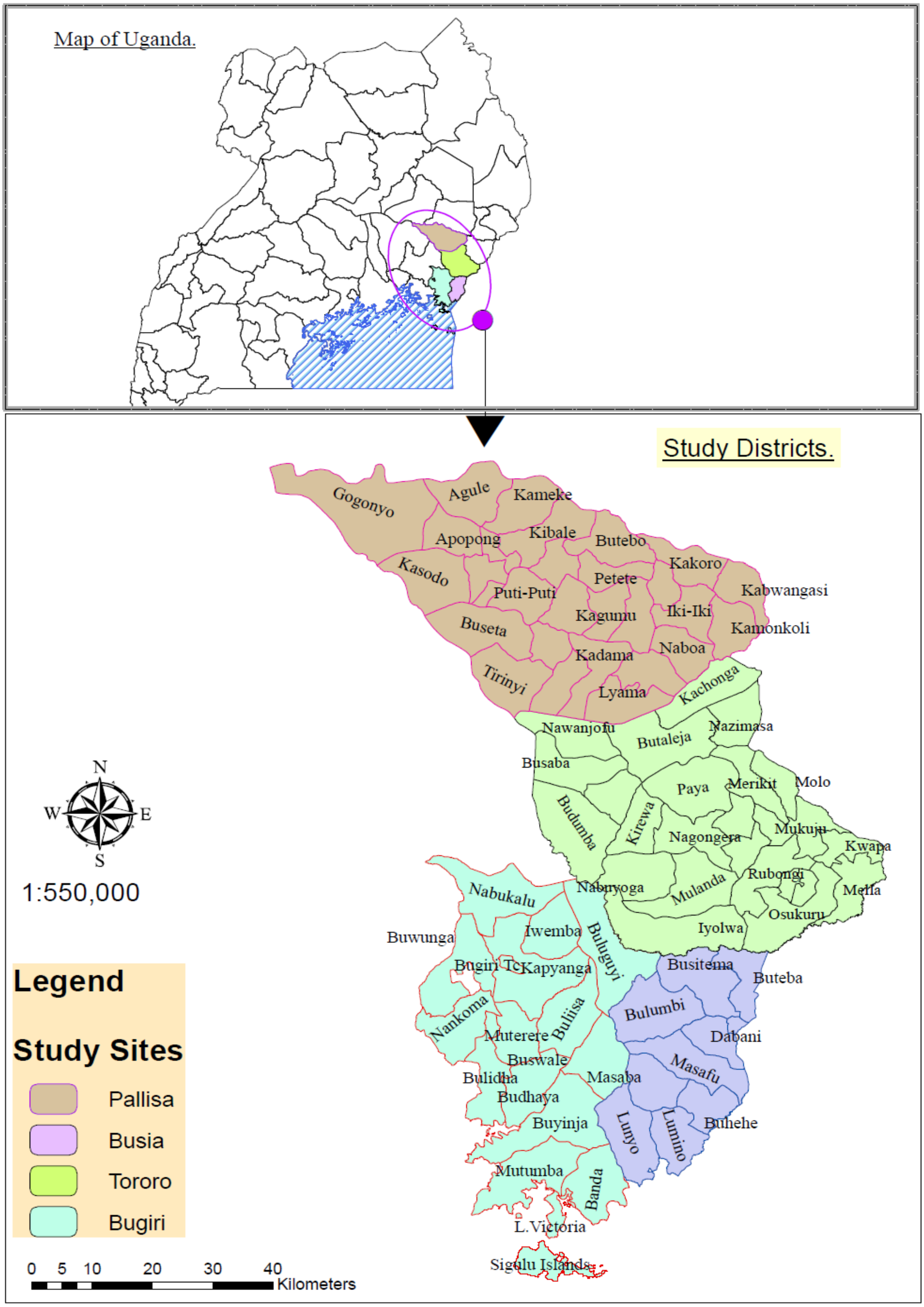


Figure 3.1: Map of study Districts within Uganda, 2017

Agriculture is a core sector of Uganda's economy and the largest employer, and maize is one of the four major subsistence crops; the others are cassava, plantain and sweet potato (Karyeija, *et al.,* 1998; Mukwaya *et al.,* 2011). Additionally, the country's ordinary habitat supports livestock keeping including; cattle, sheep, and goats, with a monopoly of native varieties. A map of the study area is represented in Figure 3.1.

3.3 Sampling Procedure and Data Types

Purposive sampling was used to select four districts with a predominant use of PPT relative to other districts. A sampling frame which included both adopters and non-adopters of the technology was prepared. Random sampling was then utilized to arrive at the sampling size which was computed based on Kothari’s (2005) formula:

$$n = \frac{Z.^2 \, p.q.N}{e^2(N-1) + Z^2.p.q} \quad \text{.......................} \quad (7)$$

Where n = sample size, p= Population proportion with the characteristic of interest, q = (1-p), N = The estimated population comprising the number of both adopters and non-adopters from the selected districts (approximately 8,500 farmers), e = 4% acceptable margin of error, Z = 1.96, the estimated standard variation at 95% confidence interval which is considered the point of the normal distribution corresponding to the level of significance. The sample size was calculated as follows:

$$n = \frac{(1.96)^2 * (0.5) * (0.5) * 8500}{(0.04)^2(8500-1) + (1.96)^2 * (0.5) * (0.5)} = 560$$

.... (8)

Thus a total of 560 households in four districts that is; Bugiri, Busia, Tororo and Pallisa were considered for the study. In every district, both users and non-users of PPT were sampled equally.

Primary and secondary data were collected; the latter was obtained from *icipe* offices in Mbita, Kenya and Mbale, Uganda. These included; average cropped areas, number of farmers practicing PPT, average number of farmers with dairy cows, maize yields, and research costs from previous years. These data were mainly utilized to address the second objective using the DREAM model. Data collected were both quantitative and qualitative. Quantitative data were collected during the November to December 2014 growing season and growing seasons between January and October 2015 from smallholder households, through one-on-one interviewing with the household head, or if absent, their spouse. Qualitative data were collected from farmer groups and key informants based on focus group discussion (FGD) and key informant interview (KII) guidelines respectively.

For primary data, experienced enumerators were trained to collect household data through a household survey which entailed personal interviews. An interview schedule was structured to gather data on farmers' socio-economic attributes, farm and institutional factors, household incomes, food and non-food expenditure and consumption. Focus group discussions were held with farmers who were organized into groups while KII's were held with key informants including founder farmers, opinion leaders, agronomists and agribusiness officers in the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF), icipe partners (including spotlight international and send a cow), and push-pull project officers in Uganda.

In addition to the initial data collected, a data validation exercise was conducted after the survey in two districts: Busia and Tororo from January to October 2015. The exercise comprised farmers training, monitoring and evaluation from land preparation to final stage of maize harvesting whereby 30% of the previously interviewed farmers (both PPT and non-PPT participants) were targeted. An aggregate of 145 farmers were interviewed. The data collected during this exercise was important for the second objective using the DREAM model.

3.4 Model Specification and Data Analysis Techniques

To achieve the objectives of the study, several statistical techniques and methodologies were utilized. These are outlined in the sub-sections below.

3.4.1 Characterization of Maize-Dairy Farming Systems

Previous studies have used cluster analysis to define comparable collections of farms based on data sampling or data collection through surveys, and combining cluster analysis with other techniques to improve the results (Hardiman *et al.*, 1990; Köbrich *et al.,* 2003; Milan *et al.,* 2003; Usai *et al.,* 2006). However, using such techniques to classify farms into groups can be problematic because of multicollinearity among variables (Iraizoz *et al.*, 2007). To overcome such problems, Ketchen & Shook (1996) proposed combining Principal Component Analysis (PCA) with orthogonal rotation, and the consequential factor scores for each observation used as the origin for clustering.

The current study employed a multivariate analysis that comprised PCA and Cluster Analysis (CA) to classify and characterise farming systems in Eastern Uganda. The PCA approach compresses the data from the interdependent variables to a reduced group of uncorrelated variables that correspond to most of the info in the authentic group called components (Jolliffe, 2002).

The CA is a data-driven technique, aimed at identifying natural groupings among the sampling units so that similar units are grouped within each group (cluster) while dissimilar units are grouped in a different group (Everitt *et al.,* 2001). Usually, the groups or clusters that will arise in a sample are unknown. Since the best solution is required, a two-stage series of analysis is conducted. Stage one involves a hierarchical cluster analysis that is the main analytical technique for realising comparatively harmonized clusters of cases on the basis of considered features done by using Ward's method of utilizing squared Euclidean Distance as the distance or similarity measure. This facilitates determination of the best possible number of clusters to work with. The subsequent stage is to repeat the hierarchical cluster analysis with the chosen number of clusters, which facilitates allocation of every case to a specific cluster in the sample (Everitt, *et al.*, 2011).

Principal component analysis was employed to condense the variables to smaller components to develop a distinct set of variables or scores to correspond to farming systems from the variables indicative of household, farm, and institutional characteristics. Cluster analysis on the other hand was used to sort cases or variables into homogeneous groups (farming systems in this case) that differ from each other. A combined approach of PCA and CA was first employed to determine homogenous groups of farmers carrying out different farming practices, followed by binomial logit. Initial investigations identified multicollinearity among the variables as hampering the formation of clusters. To deal with this, PCA was utilized first and the consequential factor scores for every observation employed as the foundation for clustering, as recommended by Ketchen and Shook (1996).

Additionally, chi-square and t- statistical tests were applied to respectively test the existence of the relationship between variables and check if the means differed in values between clusters. Binomial logit was then applied to evaluate factors that influence the choice of farming systems. The PCA was employed for reducing data to recognize a small number of essential factors or variables that clarify the pattern of correlations within variables related to performance of agricultural farming for both PPT and non-PPT participants. The variables were grouped into three sets comprising household, farm and institutional attributes. The most important initiative is to put together a new variable Y^* (factor score), which is the linear arrangement of the inventive indicators, such that it explains the highest of the total variance in the initial indicators. Thus, Y^* is worked out as:

$$Y^* = V_1 Z_1 + V_2 Z_2 + V_3 Z_3 \cdots V_p Z_P \quad \text{.......} \quad (9)$$

where the weights are indicated such that Y^* explains the upper limit variance in Z_1, Z_2,..,Z_P which are the original set of p variables. This index has a zero mean and a standard deviation equal to one (Basilevsky, 1994; Sharma, 1996). For the objective of this study, six new components/factor scores representing household, farm, and institutional characteristics were formed, hence:

$$Y^* = a_1 x_1 + a_2 x_2 + a_3 x_3 + \cdots a_6 x_6 \quad \text{.......} \quad (10)$$

where, Y represents the component scores and a_i (i=1,2,..,6) are weights, that is, the principal component coefficients.

Gockowski, *et al.*, (2004) suggested that a common rule of thumb for selecting significant principal components is to consider the components with Eigenvalues equivalent or greater than one (i.e E ≥1). Consequently, all factors more than Eigenvalue of one were reserved, which indicated the number of components for extracting the variables.

The cluster analysis yielded two clusters that formed relatively homogeneous groups based on typical farming systems practised by smallholder farmers, and their attributes. Binomial Logit model was then used to assess factors that determine the choice of a particular farming system. From the PCA and CA results, two farming systems were identified, namely; mixed crop–livestock farming and crop farming systems. Since the logistic model is the benchmark method of analysis when the outcome variable is dichotomous (Hosmer, *et al.,* 2013), the logistic regression model specified in Equation 11 below was utilized to find out factors influencing choice of farming system.

To identify key determinants of farming system, a computed dichotomous variable indicating the type of mixed farming system practised by a household was utilized. The dependent variable, FMNGSYM, was assigned the value of 1 if the respondent chooses to practise mixed farming and 0 if crop farming is chosen. On the basis of Pearson's Chi-square statistic, a determination of whether the predictors (including marital status, household size, age, gender, education level, farm size, farming experience, access to extension services, attendance and/or participation in field days, access to credit, membership to organisations and participation in PPT), were associated with farming system (FMNGSYM) was made.

A logistic regression model was stipulated as follows:

$$\log it(p) = \ln\left[\frac{p}{1-p}\right] = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_{12} X_{12} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Where $X_1 \ldots X_{12}$ were the predictor variables and p denoted the probability that the household practised mixed farming system. Marginal effects were then computed from logit output to facilitate interpretation of results. Table 3.1 below gives definitions of variables utilized in the PCA and CA.

Table 3.1: Variables utilized in Principal Component and Cluster Analysis

Variables **Farmer characteristics**	Variable type	Measurement
Age	Continuous	Years
Gender	Dummy	1=Male,0=Female
Average years of schooling	Continuous	Years
Source of labour	Categorical	1=Family,2= Hired, 3 =Permanent, 4=Casual
Farm characteristics		
Total farm area owned	Continuous	Acres
Area under cultivation	Continuous	Acres
Livestock numbers	Continuous	Numbers
Livestock breeds kept	Categorical	1=Cross, 2=Pure, 3=Local breed
Main livestock systems	Categorical	1=Open,2=Zero grazing,3= Semi-zero grazing
Type of animal feed	Categorical	1=Napier grass,2=Maize stover, 3=Desmodium,4=Brachiaria
Source of animal feed	Categorical	1=Own fodder, 2=Purchase
Major farming systems	Categorical	1=Mixed, 2=Livestock only, 3= Crops only
Major crop enterprise	Categorical	1=Food crops, 2= Cash crops
Institutional characteristics		0=No;1=Yes
Membership to farmer group		
Access to extension services	Dummy	0=No;1=Yes
Access to credit services	Dummy	0=No;1=Yes
Participation in PPT	Dummy	0=No;1=Yes

Test for Collinearity

Possible multicollinearity among predictor variables was tested in a preliminary analysis using Variance Inflation Factor (VIF). Variance inflation factor quantifies how much the variance is inflated. As a criterion, variables whose VIF value exceeds 10 are said to be highly collinear (Greene, 2003; O'brien, 2007).

3.4.2 Economic Performance of PPT Integrated in Maize-Dairy Farming Systems

Economic performance was evaluated using the DREAM model for the purpose of determining the real value of the technology benefits to the society. This model is established on the postulation that uptake of the scientific knowledge gives rise to an outer move in the product's supply curve that prompts a procedure of equilibrium modifications in one or various markets affective on the flow of eventual payback to the participants (Alston *et al.*, 1995). Through suitable parameterization, the model was employed to evaluate yearly adjustments in producer and purchaser economic surpluses in consequence of the adoption of latest technologies in this case PPT. Thus,

$$\Delta PS_{it} = \left(K_{it} + PP_{it}^{R} - PP_{it}\right)\left[Q_{it} + 0.5\left(Q_{it}^{R} - Q_{it}\right)\right] \quad \ldots\ldots (12)$$

$$\Delta CS_{it} = \left(PS_{it} - PC_{it}^{R}\right)\left[C_{it} + 0.5\left(C_{it}^{R} - C_{it}\right)\right] \quad \ldots\ldots (13)$$

Where, when the subscripts for region i in time t are suppressed, ΔPS and ΔCS are the producer and end-user gains, k is the realized supply curve shift which is the decline in the per unit cost of production. PP_{it}^{R} and PP_{it} are producer prices with and without technology, Q^R and Q are the yearly production summations with and without technology and PC^R and PC are consumer prices with and without the technology. Thus, the producer undergoes an adjustment in income attributable to a reduction in production cost per unit whereas the consumer will be subjected to an increase in income by buying at reduced prices. These sequences of profits were transformed into present value totals by conventional discounting approaches for a twenty-year stream of benefits.

$$VPS_i = \sum_{t=0}^{20} \Delta PS_{i,t} / (1+r)^t \quad \text{......} (14)$$

$$= \Delta PS_{i,0} + \Delta PS_{i,1} / (i+r) + \Delta PS_{i,2} / (1+r)^2 + ... + \Delta PS_{i,20} / (1+r)^{20}$$

$$VCS_i = \sum_{t=0}^{20} \Delta CS_{i,t} / (1+r)^t$$

$$= \Delta CS_{i,0} + \Delta CS_{i,1} / (1+r) + \Delta CS_{i,2} / (1+r)^2 + ... + \Delta CS_{i,20} / (1+r)^{20}$$

Where, VPS_i is the present value for producer surplus and VCS_i is the present value for end-users surplus meant for section i, whereas r is the discount rate. For both estimation and model sensitivity, $k_{i,t,}$ is the downward measure of the supply curve shift, this is associated to technical change, in region *i* and time *t.* It can be defined as;

$$K_{i,t} = E(c_i).\, a_{i,t.} PP_{i,0} \quad \text{......} (15)$$

Where, $E(c_i)$ for region *i*, is the anticipated percentage cost saving per unit of output associated to PPT, whereas $a_{i,t}$ is the expected uptake level of that technology in time *t*, and $PP_{i,0}$ is the initial producer price.

Typically, the three investment parameters used as indicators of social gains were; net present value (*NPV*), internal rate of return (*IRR*), and benefit cost ratio (*BCR*). The *NPV* is interpreted as the summation of the present values of the aggregate cash flow brought about by a venture incepted across a well-defined duration. Costs and benefits of the technology that crop up in prospective duration are discounted (Belli, 2001).

$$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t} \quad \text{......} (16)$$

Where, B_t is benefits of PPT, C_t signifies the know-how costs, r is the discount rate, and t is duration in which the technology will exist. A technology project is beneficial and satisfactory if the *NPV* is more than zero (Graham *et al.,* 2005).

The *IRR* is the discount rate, r^*, upon which the PPT project's *NPV* is zero. Thus the *IRR* is an assessment of the real venture effectiveness despite the discount rate (Kelleher & MacCormack, 2004).

$$IRR = \sum_{t=0}^{n} \frac{B_t - C_t}{\left(1 + r^*\right)^t} = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

The third approach used to compute the effectiveness of venture is the benefit-cost ratio (*BCR*). Its estimation is comparable to that of the *NPV* except that it is articulated as a proportion of the summation of a project's discounted benefits to the summation of the project's discounted costs.

$$BCR = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+r)^t}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (18)$$

A project is considered to be appropriate if the *BCR* is bigger than or equal to one (Boardman & Greenberg, 2006).

Gross Margin (GM) Analysis

The gross margin (*GM*) is the difference between total variable costs (*TVC*) and total revenues (*TR*). That is:

$GM = TR – TVC;$

where, *TR* = Quantity of output (Q_i) × Price (P_i) and

TVC = Quantity of Input (X_j) × Price (P_j)

hence,

$$GM = \sum_{i=1}^{n} P_i Q_i - \sum_{j=1}^{n} P_j X_j \quad \ldots\ldots (19)$$

In this study, three sets of gross margins were calculated from PPT project components which included; total *GM* of maize with fodder, *GM* of maize without fodder and *GM* of milk. This lead to calculation of two types of revenues: Revenue 1 was from PPT farmers with dairy cows (milk) whereas revenue 2 was from PPT farmers without cows. The total project revenues were then arrived at by summing up the two sets of revenues. Revenue 1 had two revenue streams, from maize and milk. The revenue from maize was calculated as the product of the *GM* of maize/ha, the average area cropped per farmer and the number of farmers with cows; revenue from milk was arrived at as the product of *GM* per cow, the average number of cows per farmer and the number of farmers with cows. For this revenue stream, it was assumed that fodder from PPT was used to feed the dairy cows. Revenue 2 also had two revenue streams, from maize and fodder. It was assumed that farmers without cows sold their fodder to earn some income. Each was computed as the product of *GM* of either maize or fodder/ha, the respective average cropped area per farmer, and the number of farmers without cows.

Description of Model Variables, Data and Assumptions

Both market and technology related variables were included in the model. Whereas market related data were acquired from the survey and secondary sources, technology related data were obtained from project officers and key informants opinion. The study used panel data gathered during a household surveys in 2014, a validation survey in 2015 and secondary data including data based on expert opinion elicited from key informants. The year 2015 was chosen as a base year; this is the final year when data were collected from the farmers. Market related data included quantity of maize supplied and consumed, price, and elasticity of supply and demand whereas technology related data comprised adoption rate (number of farmers adopting PPT), discount rate, research costs, and expected change in yields.

For the aim of this research, it was postulated that production was similar to spending; this as well was essential for the market clearance situation of the model. The average dominating market price was obtained from farmers during the survey. All price data were specified in Ugandan shillings.

Whereas estimations of price elasticity of demand from numerous researches have revealed the demand elasticity to range between -0.3 for essential commodities to -2 for non-essential commodities (Mills, 1996), the elasticity of supply varies from 0 to 1.2 for agricultural commodities (Mwanaumo, 1994). The supply and demand elasticity estimations utilized in this study were adapted from previous studies carried out in the region. The adopted price elasticity of demand for maize was -0.77 whereas price elasticity of supply of maize was 0.8 (Wood & You 2001: Delgado *et al.,* 2002: Karugia *et al.,* 2009).

On technology related variables, adoption rate of 30% was adopted for the study (Khan *et al.*, 2014: Murage *et al.,* 2015). Among the farmers trained on PPT in a year, the number of farmers (from the trained) adopting the technology is equivalent to the adoption rate. A discount rate of 12% which was Uganda's central bank rate (CBR) during the data gathering period was used while values for research costs were obtained from the project office. These were extension costs used for PPT dissemination in Uganda. On expected change in yield, the growth in productivity is a function of technical progress and efficiency improvements; from investing in research is that it needs evaluation of the likelihood in which the intended research will succeed and the anticipated benefits from investing in research calls for assessment of the prospect of research achievement and the anticipated benefits.

For gross margin analysis, primary data including acreages, yields from PPT components (maize, fodder) and control maize plots, unit prices, number of cows owned and milked quantity of milk per cow per day, milk prices, and labour cost were used. Secondary data on maize yields from previous years, and research cost were obtained from *icipe* office, Uganda and in Mbita point, Kenya.

At the base case scenario, the following assumptions were made:

- Seventy three per cent (73%) of the farmers with cows, keep and feed their dairy cows with fodder from their PPT plots;
- Farmers who do not have dairy cows (27% of all farmers) sell fodder from their PPT plots;
- Project budget (costs) will increase by 1% from 2017 onwards up to the year 2035;
- Farmers adopting PPT will increase at rate of 5% annually from 2016 onwards (based on previous trends);
- Push pull plot gross margins increase by 0.38% annually (based on the past trends)
- Push pull cropped areas will increase by 10% up to 2025; after which they will increase at 5% up to 2035;
- The discount rate is 12% conventionally assumed for economic analysis and
- The project life is 20 years (up to 2035).

Sensitivity analysis

Sensitivity analysis was performed at both results level by varying the projected benefits and project costs and at inputs levels by varying some of the key assumptions; including number of farmers adopting PPT and annual PPT areas cropped.

Statistical tests

Statistical test was conducted using one-way ANOVA for gross margins and F test was statistically significant (*p* value < 0.05), therefore pos hoc procedure in this case Bonferroni was employed to know where the difference in means was. Furthermore, an independent t-test was used to compare gross margins from PPT and control plots.

3.4.3 Impact of PPT Adoption on Household Welfare

Data collected for the above objective were grouped into farm and farmer attributes, maize yields, household incomes (both farm and non-farm), household expenditures (both food and non-food) as well as institutional attributes. Key household characteristics comprised gender, age, household size, education level, farm size, farming experience and livestock numbers. Total household expenditure data were adjusted for each household to arrive at per capita consumption expenditure which facilitated the determination of poverty indices. The treatment variable for the study was the area under PPT whereas outcome variables comprise incomes, maize yield, and poverty.

Explanatory variables used in the adoption estimation were grouped into household, farm, and institutional characteristics. Definitions of variables utilized in the analyses are as elaborated in Table 3.2.

Table 3.2: Description of variables

Description	Variable type	Measurement
Outcome variables		
Intensity of PPT adoption	Continuous	Acres
Productivity	Continuous	Kgs/acre
Yield	Continuous	Kgs/unit area
Average incomes per annum	Continuous	Ugx
Dependent variables		
Household poverty status	Dummy	0=Non-poor; 1=Poor
Per capita expenditure	Continuous	Ugx
Independent variables		
Gender of household head	Dummy	0=Women; 1=Men
Age of household head	Continuous	Years
Marital status	Categorical	1=Married;2=Single;3=Widowed;4=Divorced
Highest level of education of household head	Categorical	1= No formal education;2=Adult education;3=Primary school;4=Secondary school;5=Post-secondary
Family size	Continuous	Number of persons
Family members above 18 years that offer farm labour	Continuous	Number of persons
Farm size owned per household	Continuous	Acres
Kind of farming system practiced	Categorical	1=Livestock farming;2=Crop farming;3=Mixed farming
Farming experience	Continuous	Years
Major source of income	Categorical	1=Farm incomes;2=Off-farm casual work;3=Off-farm permanent employment;4=Remittances
Total crop area	Continuous	Acres
Tropical Livestock Units	Continuous	Units
Access to agricultural extension services	Dummy	0=No;1=Yes
Field days/ demonstration Participation	Dummy	0=No;1=Yes
Access to credit	Dummy	0=No;1=Yes
Group membership	Dummy	0=No;1=Yes
Distance to nearest extension service provider	Continuous	Kilometers
Busia district	Dummy	0=No;1=Yes
Tororo district	Dummy	0=No;1=Yes
Bugiri district	Dummy	0=No;1=Yes
Pallisa district	Dummy	0=No;1=Yes

In this study, household welfare was assessed in terms of incomes, yield, and poverty status. Expenditure approach appertaining to per capita food consumption was used to determine poverty indices. The dependent variable was area under PPT and the first step was to determine the GPS, i.e. the conditional likelihood of getting an appropriate quantity of treatment (intensity of adoption of PPT) given the observed covariates. This was estimated using maximum likelihood (ML) estimator using gpscore which is a Stata routine known as 'dose response'.

In comparison with other econometric approaches, GPS technique has some merits. The GPS technique permits for continuous treatment, i.e., varied quantities of the adoption intensities, proxied by land allocated for PPT. In this way, the study was capable of establishing the causal relationship between the outcome and the size of land allocated for PPT (level of adoption/adoption intensity). Thus, it enables for identification of the whole function of the outcome by every attainable values of the continuous treatment variable. Despite these advantages, GPS methods do not control for unobserved heterogeneity in estimating for adoption process. Major postulation in the STATA actualized edition of the GPS techniques is the routine of the treatment variable conditional on the pre-treatment covariates. For the rationale of this study, it was assumed that the log transformation of the treatment (acreage under PPT) has a normal distribution, given the covariates.

Ensuing Hirano and Imbens (2004), we describe dose–response functions (DRF) in the potential outcomes framework (Rubin, 2005) as elaborated below. Suppose there are random sample of units, indexed by $i = 1,...,N$. The continuous treatment of interest can take values in $t \in \tau$, where τ is an interval (t_0, t_1). For each unit, $Y_i(t)$ is the potential outcome for individual i under treatment level $t, t \in \tau$ where τ is an interval (t_0, t_1), and t denotes the dosage which in the case of this study was the area under PPT. For each i there is a group of potential welfare outcomes $\{Y(t)i\}t \in \tau$ which is the individual level DRF.

The key point of concern is the estimation of the average possible outcomes curvature which is the entire average DRF, $\mu(t) = \mathrm{E}[Y_i(t)]$, that signifies the average potential function of the welfare indicator for PPT farmers. The pragmatic indicators for every unit i are a vector of covariates X_i (independent variables), the intensity of treatment acquired (land under PPT in acres), $T_i \in (t_0, t_1)$, and the probable outcome equivalent to the quantity of treatment acquired, $Y_i = (T_i)$.

Notably, the GPS approaches are considered for evaluating the cause of a treatment level which is specified as the sub-population of treated units (Bia & Mattei, 2008). This means that including the non-adopters may generate ambiguous outcome (Guardabascio & Ventura, 2013). For that reason, the GPS results for this study only focused on average DRF and marginal treatment functions for households who have adopted PPT whereas farmers who did not invest in the technology (untreated households) are not incorporated in the GPS analysis.

The most remarkable assumption in estimating the DRF is the weak unconfoundedness; this postulation necessitates that for any level of treatment, the likelihood of acquiring this level is independent of the potential outcomes, conditional on covariates, where the treatment obligation is autonomous of every probable result conditional on the covariates: $Y_i(t) \perp T_i \mid X_i$ for all $t \in \Gamma$ under unconfoundedness. The average DRF can be attained by approximation of average outcomes in sub-populations distinct by covariates and diverse intensity of treatment. Hirano and Imbens (2004) proved that GPS can be employed to remove biases related to variations in the observed covariates and that the DRF at a specific treatment level *t* can be estimated by means of a partial mean methodology in three equations below:

The first equation utilizes the lognormal distribution to model the level of adoption of PPT (Ti) given the covariates:

$$\ln(\mathrm{T}_i) \mid \mathrm{X} \sim \mathrm{N}\left(\beta_0 + \beta_i^{'} \mathrm{X}_i, \delta^2\right) \quad \ldots\ldots (20)$$

The parameters β_0, β_1 and δ^2 are estimated using maximum likelihood. The GPS ascertains that differences in covariates do not exist across treatment groups based on different areas allocated to PPT. Accordingly; the observed difference in welfare outcomes is attributable to different areas allocated to the technology. The GPS was evaluated contingent on the parameter estimates in equation 21 as follows:

$$\hat{R} = \frac{1}{\sqrt{2\pi \hat{\delta} 2}} \exp - \left(\frac{1}{\sqrt{2\pi \hat{\delta} 2}} \left(\ln(\mathrm{T}_i) - \hat{\beta}_0 - \hat{\beta}_i \mathrm{X}_i \right)^2 \right) \quad \ldots\ldots (21)$$

The second equation involves estimating the conditional expectation of the outcome (household welfare) as a function of the intensity of the PPT (T_i) and estimated GPS ($\hat{R}_i$). As indicated by Hirano and Imbens (2004), the conditional prospect of the outcome can be anticipated as a flexible function of treatment level and probable GPS, which might also entail some relations among the two. This study employed quadratic estimation as follows:

$$\beta(t,r) = g\left(\left[\mathrm{Y}_i \mid \mathrm{T}_i, \hat{R}_i\right]\right) = \alpha_0 + \alpha_1 \mathrm{T}_i + \alpha_2 \hat{R}_i + \alpha_3 \mathrm{T}_i^2 + \alpha_4 \hat{R}_i^{2} + \alpha_5 \mathrm{T}_i \hat{R}_i \quad \ldots\ldots (22)$$

Where, *g* is a relation function which is dependent on the household welfare outcome. Linear regression models were used, where welfare outcomes (household incomes, yield and poverty indices) were measured as continuous variables.

The final pace of the Hirano and Imbens' GPS methodology is the evaluation of the DRF estimates that is the average expected conditional welfare outcomes in terms of yield, household incomes and poverty contingent upon the intensity of the uptake and the anticipated GPS. Therefore, the average DRF at a specific level of the treatment *t* was predictable by calibrating the (projected) conditional probability *β(t,r*) over the GPS at that intensity of treatment as follows:

$$\mu(t) = E(Y_i(t)) = \frac{1}{N}\sum_{I=1}^{N} g^{-1}\left(\hat{\alpha}_0 + \hat{\alpha}_i . t + \hat{\alpha}_2 \cdot t^2 + \hat{\alpha}_3 . \hat{r}(t, x_i) + \alpha_4 . \hat{r}(t, x_i) 2 \alpha_5 x \hat{r}(t, x_i)\right) \ldots \text{(23)}$$

Where $\hat{\alpha}$ the vector of parameters anticipated in the second stage and $\hat{r}(t, x_i)$ is the projected value of $r(t, x_i)$ at level t of the treatment. The entire DRF can then be attained by evaluating this average potential outcome for every level of area under PPT. Findings are shown by plotting the average DRF and marginal treatment effect functions, described as derivatives of the equivalent DRF's. The average DRF indicates how the extent and the kind of the underlying correlation between the area allocated to PPT and the welfare outcomes, which vary as per the values of the treatment variable, following the control of covariate biases. Marginal treatment effect function on the other hand shows the marginal effects of varying the area under PPT by a given unit on the welfare outcomes.

Poverty Decomposition model

The Foster, Greer and Thorbeecke (FGT) poverty index was utilized in determining poverty levels amongst the interviewed households (Foster & Thorbecke, 1984). Relative poverty approach which is attributed to cost of basic needs (CBN) approach whereby certain minimal nutritional necessity is described and converted into minimum food expenses (Ravallion & Chen. 2005) was considered while constructing the poverty line. A household was defined as poor if its consumption level was less than this minimum. The relative approach that was preferred for this study uses a fraction of mean consumption expenditure as the poverty line.

To come up with a cumulative poverty outline for Uganda, Appleton's study (2009) utilized a huge household survey dataset to approximate a consumption poverty line in Uganda shillings as UGX 15,446 (USD 12.94) and UGX, 15,189 (USD 12.71) per adult equivalent per month for Eastern and rural Uganda respectively. Appleton (2009) also employed a national average poverty line of UGX 16,643 (USD 13.93) per capita per month. The FGT poverty index is generally given as:

$$P_\alpha = \frac{1}{N}\sum_{i=1}^{q}\left(\frac{Z - Y_i}{Z}\right)^{\alpha} \quad \text{..........} (24)$$

Where, P is Foster, Greer and Thorbecke index ($0 \leq P \leq 1$), N is the entire respondents, q is the number of respondents below the poverty line Z is the poverty line, and Y_i is per capita household expenditure of the i^{th} respondent. The determination of the poverty status of the households were broken down into the three indicators whereby when α=0, P_0 gives the Incidence of Poverty (Headcount Index,); when α=1, P_1 gives the Depth of Poverty (Poverty Gap,) and when α=2, P_2 gives the Poverty Severity (Squared Poverty Gap). This study adopted Appleton’s (2009) rural poverty line of 12.71 USD. The average exchange rate during the survey (2014) was that 1 USD was equivalent to 2,748 UGX.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

This Chapter discusses the results and findings from the study. First, summary statistics of independent variables are presented. Subsequently, the first objective results from multivariate analysis (PCA and CA) and binomial logit model are reported followed by the second objective results from the DREAM model. Finally, the third objective results from the generalized propensity score model (GPS) are reported

4.1 Summary Statistics

This sub-section provides descriptive statistics on major variables which include; household and farm characteristics and evaluation of farmers' activities before and after participating in the push pull technology.

4.1.1 Household and Farm Characteristics

Out of the 560 respondents interviewed in the four districts 51% of the respondents were male-headed, and 85% were married. The mean age of household heads was 43 years and half of the interviewed household heads had attained primary education as their highest level of education indicating a fairly low literacy levels in the study region. Further, a majority had adopted PPT whereas most of the interviewed respondents practised mixed farming (i.e kept livestock and practised crop farming) as a result, farm incomes (crop and livestock sales) was the key source of household's income for a greater number of the farmers in the study area. Results further show that, the standard household size was six persons whereas the average number of family members who were 18 years and above (and therefore able to offer farm labour), was approximately three persons.

The mean total area of land owned by respondents was 4.5 acres whereas the average size of land under crop farming was 3.3 acres. This is an indication that more than half of the land (73%), is allocated for crop farming. The average farming experience in years of the interviewed farmers was 20.5 years, this shows that interviewed farmers had better technical knowledge in both livestock keeping and crop farming. There was no statistical difference in age of the interviewed respondents in years and total land owned in acres among the interviewed farmers (Table 4.1).

Table 4.1: Household and farm characteristics per district

Variable	**Sample N=560**	**Busia N=140**	**Tororo N=140**	**Bugiri N=140**	**Pallisa N=140**	χ^2
Gender of household head (%)						34.18***
Men	51	31	52	61	61	
Women	49	69	48	39	39	
Highest level of education (%)						28.31*
No formal education	10	5	10	6	8	
Primary school	55	19	48	50	24	
Secondary school	28	8	32	36	6	
Post-secondary school	7	67	10	6	63	
Main source of income (%)						59.48
Farm incomes	83	76	95	78	81	
Off-farm incomes	18	25	6	22	18	
						F-statistic
Household size in number (persons)	6.4 (0.1)	7.0 (0.2)	6.6 (0.2)	5.5 (0.2)	6.7 (0.2)	8.22***
Age of household head (years)	43.0 (0.6)	44.5 (1.3)	44.2 (1.2)	41.9 (1.1)	41.4 (1.1)	1.83
Number of family members offering labour (18 and above years)	2.7 (0.1)	2.6 (0.1)	2.4 (0.1)	2.9 (0.1)	3.0 (0.1)	4.00**
Total land owned (acres)	4.5 (0.2)	4.5 (0.4)	4.6 (0.5)	4.5 (0.3)	4.55 (0.2)	0.04
Land under crop farming (acres)	3.3 (0.1)	2.8 (0.3)	3.2 (0.2)	3.3 (0.2)	3.8 (0.1)	22.19***
Farming experience (years)	20.5 (0.5)	22.0 (1.1)	20.2 (1.0)	18.9 (1.1)	21.1 (.86)	1.82*

NOTE: ***, **, * significant at 1%, 5% and 10% level respectively:

Source: Author’s survey, 2014

4.1.2 Before and After PPT Adoption Scenarios

Farmers’ activities before adoption and after adoption of PPT were evaluated. Before PPT adoption, the average number of weeding per season was four times compared to twice after adoption of PPT; implying a reduction in labour requirements and therefore, costs. The average number of hours per day per season spent uprooting *Striga* before PPT adoption was approximately five compared to two hours spent after PPT adoption. This is a clear indication that with PPT adoption, the number of weeding and uprooting *Striga* reduces greatly hence farmers can have more time to attend to other daily activities. The test results on differences between crop scenarios before and after practising PPT showed that average number of weeding per season, average hours spent uprooting *Striga* per day per season, cows owned and the average quantity of milk produced per cow per day in litres significantly differed between the two groups ($p<0.05$).

Majority of the farmers used fertilizers before PPT adoption compared to those who still used fertilizers after adoption. On the contrary, a small number of farmers used manure before PPT adoption whereas majority used manure after. On agro-chemicals use, there was a reduction in the application of pesticides and herbicides for the management of *Striga* and stemborers respectively from 76.2% to 10.6%. There was statistical significant difference between crop scenarios before and after practising PPT in terms of fertilizer use, chemical use for stemborer control and source of fodder (Table 4.2).

This is attributable to the technology, which has allowed farmers to set up organic farming by preparing and applying animal manure on their farms, hence allowing nutrient cycling along with decline in the use of chemical fertilizers (Fischler, 2010). Moreover, apart from sparing some cash for other intension, a decline in the application of pesticides and organic fertilizers is of great advantage on human and environmental health (http://www.push-pull.net/planting_for_prosperity.pdf).

Table 4.2: Farming activities before and after PPT adoption

Activity		Before PPT	After PPT	t-value	χ^2
Crop scenario		**Input use by farmers**			
		Number per ha			
Average number of weeding/season		4.00	2.00	9.18***	
Average hours spent uprooting *Striga*/day/season		5.00	2.50	17.07**	
		Percentage (%) per ha			
Fertilizer use		76.44	36.31		36.50***
Manure use		46.22	78.74		48.67
Chemical use for *Striga* control		76.23	10.62		26.25
Chemical use for stemborer control		72.92	11.53		49.23*
Livestock scenario					
Number					
Cows owned		2	4	11.56*	
Quantity of milk produced per cow/day (litres)		1.8	3.5	7.10***	
		Percentage (%)			
Source of fodder:	Own	13.13	97.91		47.35**
	Bought	16.90	3.63		16.57*
	Free grazing fields(road side)	70.00	10.10		38.25***

NOTE: ***, **, * significant at 1%, 5% and 10% level respectively

Source: Author's survey results, 2014

4.1.3 Livestock and Fodder Utilization Before and After PPT Adoption

Although majority of the interviewed farmers (84%) were already keeping livestock before adoption of PPT, it is notable that they had doubled the number of cows kept after adoption of the technology from 2 to 4 cows per household. Additionally, quantity of milk produced per cow per day also doubled; before PPT adoption, a cow would produce approximately 1.8 litres of milk per day and on average 3.5 litres of milk per day after adoption of the technology (Table 4.2).

On fodder utilization, majority of the interviewed farmers who were using the technology practised extensive farming systems by grazing their cows freely on grazing fields or on the road side before PPT adoption compared to the majority who switched to semi-intensive systems with increased use of their own fodder to feed livestock after PPT adoption (Table 4.2). Companion plants from PPT (Napier and desmodium) produce enough good quality fodder to let farmers prepare hay to be used to feed cows at the time of dry season. Mainly for dairy breeds, a diet which includes fodder from PPT gives rise to an increase in milk production. A good number of farmers have also reported positive transformation in the healthiness and productivity of their livestock, specifically with the nutritional features of desmodium legume; which is rich in proteins and regularly boosting existing milk production by doubling or even tripling (http://www.push-pull.net/Climate-smart_Push-Pull.pdf).

4.2 Multivariate and Binomial Logit Analysis Results

This section (4.2) elaborates results and discussions for the first objective by first providing findings from the application of PCA then results from cluster analysis. This was followed by results on classification and characterization of identified farming systems and eventually, binomial logit results are discussed.

Principal component analysis was initially carried out on nine variables, but after considering Kaiser–Meyer–Olkin index (KMO) measure of sampling adequacy, Bartlett's test of sphericity, Eigenvalues, and communalities, only four variables (which included age of household head, household size, years of farming, and number of household members above 18 years that offer farm labour), were selected for further analysis as essential measures of household characteristics. The variables yielded two factors with Eigenvalues greater than 1, which explained 80% of the total variation in the chosen variables. Referring to the principles for choosing significant principal components, the outputs indicated that there were two components for extracting from these variables named as years of experience in farming and labour availability. Rotated correlation coefficients of these factors on the original variables are summarised in Table 4.3.

Table 4.3: Rotated factor pattern for household characteristics

	Components	
Variables	**Factor 1**	**Factor 2**
Age of respondent in years	0.92	0.10
Years of farming	0.91	0.15
Number of household members	0.06	0.87
Number of family members above 18 years that offer farm labour	0.18	0.84

Source: Author's e survey (2014)

4.2.1 Principal Component Analysis by Farm Characteristics

On the category of farm characteristics, PCA was primarily applied on ten variables, but on considering KMO measure of sampling adequacy, Bartlett's test of sphericity, Eigenvalues and communalities, only six representative principal components (main source of income for the household, size of land under crop farming, incomes from crop sales, incomes from livestock and livestock product sales, off-farm incomes, and total livestock units) were chosen as important measures of farm characteristics as shown in Table 4.4. These variables yielded two factors with Eigenvalues greater than 1 that contributed 61% of the total variation. From the analysis, each variable had two components (factors 1 and 2) and signs of the factor loadings (plus or minus) do not invalidate the findings because it is only the size that is interpreted and not the sign of the loadings. Therefore, these factors were named as crop and farm incomes for factor 1 and livestock incomes and numbers for factor 2.

Table 4.4: Rotated factor pattern for farm characteristics

	Components	
Variables	**Factor 1**	**Factor 2**
Household main source of income	0.90	0.05
Off farm incomes	0.82	-0.02
Crop incomes	0.26	0.79
Size of land in acres under crop farming	0.53	0.65
Income from livestock sales	0.03	0.61
Total livestock unit	-0.18	0.61

Source: Source: Author's survey (2014)

4.2.2 Principal Component Analysis by Level of Institutional Characteristics

In Table 4.5, Principal component analysis was first applied on ten variables and five principal components were selected as important measures of institutional characteristics for further analysis (access to agricultural extension services, involvement in field days and/or demonstrations, access to farm use credit, membership to community organisations, and participation in PPT). The variables yielded two factors with Eigenvalues greater than 1, which explained 62% of the total variation in selected variables and were named as PPT participation for factor 1 and credit access and community organisation membership for factor 2.

Table 4.5: Institutional characteristics

	Components	
Variables	**Factor 1**	**Factor 2**
Practising push–pull technology	0.81	0.02
Participation in field days/demonstrations	0.80	0.08
Access to extension services/contact	0.78	0.22
Access to farm use credit	0.21	0.80
Membership to community organisation/association	0.16	0.70

Source: Author's survey (2014)

As shown in Table 4.6, depending on the level of weighting, factors formed from PCA were used to define six new variables which comprised years of experience in farming (PCA 1), labour availability (PCA 2), incomes from crops and off-farm work/employment

(PCA 3), livestock numbers and incomes from livestock sales (including livestock product sales) (PCA 4), participation in PPT and access to agricultural extension services (PCA 5), and access to farm use credit and membership to community organisation (PCA 6).

Table 4.6: Final cluster centres identified through K-means clustering

	Cluster		F	Sig
Principal components	**1**	**2**		
PCA 1 (Years of experience in farming)	-0.31	**0.35**	6.00	0.02
PCA 2 (Labour availability)	**0.01**	-0.01	0.01	0.94
PCA 3 (Crop incomes and off-farm incomes)	-0.51	**1.16**	818.91	0.00
PCA 4 (Livestock incomes and livestock numbers)	**0.14**	-0.31	25.07	0.00
PCA 5 (Push-pull participation and access to extension services)	**0.03**	-0.07	1.08	0.30
PCA 6 (Credit access and membership in community organisation)	-0.06	**0.14**	4.26	0.04

Note: Figures in bold shows identification of clusters from each principal component
Source: Author's survey, 2014

4.2.3 Cluster Analysis Results

As shown in Table 4.6, six factors from the PCA were applied for hierarchical clustering by means of Euclidean as distance measure and Ward's technique as agglomerative clustering. The agglomeration schedule culminating from this analysis demonstrated the series of analysis and generated coefficients. A check of the agglomeration schedule and scree diagram suggested that the number of clusters should be two.

Cluster 1 comprised 390 farmers while Cluster 2 comprised 170 farmers. The study then ensured that the number of reserved clusters was sensible with regard to the field observations acknowledged as a meaningful classification. Thus, two clusters were found suitable, as these seemed most representatives of the farming systems within the study districts. The K-means clustering method was then utilized on the two clusters and the analysis produced final cluster centres that deduce what is representative for an appropriate cluster.

4.2.4 Classification of Identified Farming Systems

As shown in Table 4.6, relatively high incomes from livestock sales (including from sales of livestock products), participation in PPT, access to extension services, and labour availability characterised Cluster 1. This implies that in this cluster, majority of the interviewed farmers kept various types of livestock and were practising PPT. This is consistent with the technology components, which is ideally developed for small-scale mixed farming systems whereby farmers benefit from increased cereal yields, improved soil fertility, and availability of fodder throughout the year. Additionally, PPT farmers use their fodder crops to feed livestock and/or generate income from sale of cereals, milk and fodder (http://push-pull.net/Climate-smart_Push-Pull.pdf). Results are also consistent with regard to labour requirements and extension services. PPT is a labour-intensive technology especially during establishment period that requires proper crop-livestock management practices; hence, the vital prerequisite of agricultural extension services. Research output also showed consistency in terms of mixed farming system. The mode of livestock kept was 6 (this included 3 cattle, 2 goats, 1 pig, and 5 chicken).

Compared to Cluster 1, Cluster 2 was characterised by high incomes from crops and off-farm incomes, many years of farming experience, and access to farm use credit (including membership to community organisations). This shows that most of the farmers in Cluster 2 relied on crop farming with both food and cash crops being the most common farming enterprises. Notably, some of the interviewed farmers practised PPT without keeping livestock: a total of 43% of farmers sold fodder to their neighbours and/or other farmers, 26%

gave out the fodder for free to neighbours and/ or other farmers, while 32% used it as mulch. Additionally, results show that farmers produced maize (91%), cassava (70%), beans (41%), groundnuts (38%), millet (29%), sorghum (26%), and sesame (20%) for both food and income generation.

Apart from crop incomes, farmers in Cluster 2 obtained the portion of household incomes from non-farm incomes, including salaries, pensions, renting out land or houses, and remittances. Given that farmers (33%) in this cluster acquired farm use credit from various sources comprising banks, cooperative societies, informal money lenders or micro-finance institutions (MFIs), it is possible that farmers used non-farm incomes and benefits from various organisations/institutions as collateral for agricultural credit; hence, a diversification strategy. As noted by Mbwika *et al.*, (2011) the most common approaches to reduce *Striga* infestation and stemborer pests comprise excessive application of nitrogen fertilizers or manure, rotational cropping, use of trap crops, hoeing and hand pulling, and application of chemicals (herbicides and pesticides).

Based on the final output from the cluster analysis, this study classified Cluster 1 as mixed (crop-livestock) farming system and Cluster 2 as pure crop farming system; as a result, the number of clusters retained was practical, matched up with the actual condition, and was a significant categorization of the major farming systems in Eastern Uganda. This further implies that there is more room and potential to integrate PPT in the existing farming systems, since farmers keep various livestock and can use available land to benefit fully from PPT.

4.2.5 Characterisation of Identified Farming Systems

To deeply understand distinct characteristics of each of the two clusters, descriptive statistics, which involved cross tabulations and t-test analyses, were further employed on the three major groups of attributes prior to application in PCA and CA (including household characteristics, farm attributes, and institutional characteristics). Findings summarised in Table 4.7 show descriptive statistics of the major indicators in every reserved cluster.

Table 4.7: Characteristics of selected clusters and test statistics of t-test and Chi-square

		Cluster 1	**Cluster 2**	
Variable	**N**	**Mean/ Percent**	**Mean/ Percent**	**Test statistic**
				t-value
Age of respondent (years)	560	36.60 (.5)	57.63(.70)	-23.04^{***}
Number of household members	560	6.66 (.1)	5.87(.19)	3.31^{***}
Number of family members above 18 years that offer farm labour	560	2.73 (.1)	2.64(.10)	.75
Farming experience (years)	560	15.33 (.4)	32.39 (.78)	-19.22^{***}
Total livestock income (Ushs)	410	235,464 (16,625.8)	206,527 (20,486)	1.10
Off farm income (Ushs)	390	1,493,805 (160.366)	181,533 (260,184)	-1.05
Crop income (Ushs)	488	410,804 (22,776.6)	496,622 (37,817)	-1.94^{**}
Total livestock unit	508	3.4303(.1)	2.58(.19)	-.67
Size of land under crop farming (acres)	557	3.22(.1)	3.33(.24)	-.50
				Chi-square
Gender of respondent	560	68	32	0.96
(%)		71	29	
Name of district (%):				
Busia		65	35	
Tororo		67.10	32.90	
Bugiri		72.90	27.11	
Pallisa		73.41	26.60	
Whether practising push–pull (%):	560	80	20	13.17^{***}
Household main source of income (%):				
Off-farm casual work		69	31	
Off-farm permanent employment		77	23	
Remittance		13	87	
Whether accessed extension service	544	69	31	0.12

		Cluster 1	Cluster 2	
Variable	**N**	**Mean/ Percent**	**Mean/ Percent**	**Test statistic**
Whether participated in field days/demonstrations (%)	519	70	30	0.84
				Chi-square
Whether accessed farm use credit:		71	29	0.80
Whether a member of community organization	560	70	30	0.65

NOTE: ***, **, *Significant at 1%, 5% and 10% level respectively

Source: Author's survey, 2014

Cluster 1: Mixed Farming System

Cluster 1, which is characterised by mixed farming system, accounts for 70% of the interviewed farm households. They are spread out over the four study districts—65% in Busia, 67.1% in Tororo, 72.9% in Pallisa and 73.4% in Bugiri districts compared to Cluster 2 farmers (crop farmers). Compared with the farmers in Cluster 2, majority of the farmers in Cluster 1 (crop-livestock farmers), practise PPT, and are thus benefiting from increased maize yield, supply of cattle feed (from Napier grass, bracharia grass and desmodium legume, leading to increased milk yield); and therefore, increased incomes.

Notable from the results is that majority of the farmers in Cluster 1 (mixed-farming system) are female whereas a few are male. On the other hand, Cluster 2 (crop farmers) farmers comprise a greater number of men and a few women. This implies that women form the majority adopters of PPT. Because they are the main farmers who provide majority of the agricultural labour and thus face the major challenges, women adopt new innovations with the aim of providing enough food to ensure household food security. This endorses the findings of Murage *et al.*, (2015), who acknowledged that compared to men, majority of the interviewed women understood PPT as an efficient approach, a reality which is inferable to the characteristics of technology that seemed to be in favour of women's preferences

Majority of the farmers in Cluster 1 acknowledged farm incomes as their main source of household income compared to farmers in Cluster 2 whose major source of income is remittances. This is likely because majority of farmers in Cluster 1 practise PPT, and are therefore, able to sell surplus produce (including maize, milk or fodder) from PPT plots. These findings are consistent with those of Khan *et al.,* (2003, 2008a) who revealed that since PPT has a variety components of Napier grass, brachiaria, desmodium herbage and desmodium seeds and maize, the technology contributes to improved livestock in terms of milk and meat by supplying additional fodder and various crop residues particularly on small-scale farms where land is scare and hence its competition is high.

Furthermore, Cluster 1 comprises relatively young farmers (mean age of 37 years) compared to Cluster 2 where the mean age of farmers was 58 years. As a result of their relatively young age, farmers in Cluster 1 had a lower number of years of farming experience (averaging 15 years) compared to farmers in Cluster 2 with an average of 32 years of farming experience. This would imply that PPT is attractive to young farmers who are likely to be more educated and therefore, more aware of benefits that accrue from agricultural technologies. At any other rate, young farmers are less reluctant to take risks and they have a longer planning horizon compared to farmers with advanced age. These results are, however, divergent to Murage *et al.,* (2011), who observed that older farmers, who had gained enough expertise from many years of farming in comparison to young farmers, were more likely to take up new farming methods without seeking advisory assistance from various information sources. The findings are however corresponding to research findings by Chi & Yamada

(2002); Nsabimana & Masabo (2005), and Brooks *et al.*, (2013), who stated that young farmers are more receptive to new agricultural technologies than the old conservative farmers. Therefore, given that most farmers integrating PPT in their farms are young, there is future for the expansion of PPT; and thus sustainability of the programme.

Farmers within Cluster 1 had a higher number of livestock units (mean Total Livestock Units (TLU) of 3.22) and more incomes from livestock (including incomes from livestock sales and sale of livestock products, such as milk, eggs, and manure) compared to farmers in Cluster 2. Further, the analysis showed that majority of the interviewed respondents (84%) started keeping livestock, particularly cattle, before adopting the technology compared to a few (16%) who started keeping cows after adopting PPT. This implies that farmers who had livestock before adopting the technology targeted benefits from PPT fodder, whereas those who started livestock keeping after adopting the technology expected to fully use the benefits from PPT. This corroborates the research results by Khan *et al.*, (2008b) and Fischer *et al.*, (2010), who report that PPT has turn out to be a starting-point for expanding the farming system, particularly for integrating dairy farming activities using Napier, desmodium and brachiaria as fodder. In addition, the availability of fodder specifically for the period of dry season motivates a number of farmers to commence dairy operations, which is an acknowledge benefit of PPT. It is, therefore, evident that more income from livestock enterprise (which corresponds to a higher number of livestock) is a clear indication of benefits acquired from crop-livestock integration.

Apart from livestock playing multiple key roles in the functioning of the farm by providing livestock products and easily getting converted into ready cash during times of need, some livestock (such as oxen) are a good source of draught power for ploughing, weeding and transportation. Farm animals as well supply manure and various types of useful animal by-products, including biogas. In an incorporated system, crops and livestock form an interaction whereby crop residues are used as animal feed whereas livestock and livestock side-product production and dispensation boost agricultural productivity by increasing nutrients that advance soil fertility, thus lowers the need for chemical fertilizers (https://www.ifad.org/documents).

In terms of institutional characteristics, most of the farmers in Cluster 1 attended and participated in field days and or demonstrations; they accessed credit for farm use and were members of community organisations. Since farmers in Cluster 1 were benefiting from PPT, there is a high likelihood that they had benefited from field days that *icipe* organised; which are important pathways of dissemination. These results confirm the results of Amudavi *et al.,* (2009) and Murage *et al.,* (2011; 2012), who established that majority of farmers would have a preference on field days as the approach in which they would successfully get information regarding a new agricultural technology. In addition, the farmers' tendency to look for new agricultural knowledge encouraged them to go to field days, because they are effective in disseminating information.

Cluster 2: Crop Farming System

Farmers within Cluster 2 were fewer compared to those in Cluster 1, as they comprised only 30% of the total interviewed farmers. However, they were represented in all the four study districts of Busia, Tororo, Bugiri, and Pallisa. The mean age of farmers in this cluster was 58 years, which is higher compared to farmers in Cluster 1. Additionally, with a smaller household size and a few family members over 18 years that offer farm labour, farmers in this cluster are limited by labour availability and may lack enough education to adopt PPT; which is knowledge-intensive and associated with additional work force for planting and maintenance of the desmodium, brachiaria and Napier grass, especially during the initial stages of establishment (Khan *et al.,* 2008b; De Groote *et al.,* 2010). These findings agree with research output by Prokopy *et al.*, (2008) and Howley & Dillon (2012), that older farmers are less educated compared to young farmers, hence, tend to preserve their status quo as concerns adoption of new management procedures, not adjustable with ease, and more doubtful about benefits of utilising a new agricultural technology.

The major food crops grown in this cluster included maize (90%), cassava (72%), beans (38%), groundnuts (20%), and millet (19%), whereas the major cash crops included maize (37%), groundnuts (29%), millet (26%), cassava (25%) and sorghum (19%). Additionally, majority of farmers (87%) practised intercropping. The most common cereal-legume intercrops were maize-beans, maize-groundnuts, cassava-beans, maize-sesame, maize-soya beans, cassava-soya beans, cassava-groundnuts, and sorghum-beans. The principal reasons for smallholder farmers to intercrop were gaining higher yields per unit area as opposed to having PPT plots; which limited integration with other crops. This agrees with research output by Fischer *et al.*, (2010), who stated that PPT restricts the incorporation of edible legumes for example beans and the practice of crop rotations, by the reason that desmodium legume is perennial in nature.

The average years of farming experience of farmers in Cluster 2 was 32 years. This indicates that these farmers have acquired more years of experience in farming by trying out and scrutinizing the outcome and therefore, may find it quite challenging to depart from such skills for new technologies. Caswell *et al.,* (2001) and Khanna (2001) observed that farmers view advancement in technology and the succeeding rewards as requiring a lot of time to realise. Furthermore, these farmers also thought that they would not have an extensive live enough to benefit from the expected repayment.

Statistical output from t-test analysis showed that age of household head, household size, years of farming experience, and incomes from crops were significantly different between the two clusters, whereas chi-square test confirmed a statistically significant difference between Cluster 1 and Cluster 2 in terms of whether farmers practised PPT and the main source of income for the household.

4.2.6 Factors Influencing Choice of Farming System: Binomial Logit Results

Pair-wise correlation among regressors revealed there was no problem of collinearity between age and farming experience since the highest correlation was 0.2 whereas collinearity is a serious problem if pair-wise correlation among regressors exceeds of 0.5. From binomial logit results as shown in Table 4.8 with farming system as dependent variable; household size had a positive and significant marginal effect, as it is assumed that many members in a household can provide enough labour. Large household size is related to more labour requirement, which would allow a household to achieve diverse agricultural errands. Croppenstedt *et al.*, (2003) attest that households with enough labour sources are expected to take up agricultural technologies and exploit them exclusively; this is because they might not experience a shortage of labour.

Table 4.8: Factors influencing choice of farming system: Binomial logit

Variable	Marginal effects	Std.Err
Marital status	0.00	0.01
Household size	0.02	0.01**
Gender	-0.01	0.01
Age	-0.01	0.00***
Education level	-0.00	0.01
Main occupation	-0.01	0.01
Farm size	0.00	0.00*
Farming experience	-0.01	0.00***
Extension service	-0.01	0.01
Field day attendance	0.03	0.03
Credit access	0.00	0.01
Membership to community organisation	0.13	0.08*
Practising push–pull	0.03	0.01**
LR chi2(13)	572.08	
Prob > chi2	0.00	
Log likelihood	-63.11	
Number of observations	560	

NOTE 1: ***, **, *Significant at 1%, 5% and 10% level respectively.

2: The dependent variable in this analysis was farming system coded so that 0 = practised crop farming and 1 = practised mixed farming.

Source: Author's survey, 2014

From the results, age of the household head had a negative and significant influence on the choice of farming system. This implies that young household heads are more interested in new practices, more responsive in their conclusion to adopt new innovative ideas and skills, and more ready and prepared to tolerate the risks associated to extended planning timelines. This is unlike older household heads that are more conservative, sceptical and less flexible, and fear the risk associated with new technologies. The relationship between age of household head (often used as farmer's experience) and technology adoption has been correlated either positively or negatively with farmer's choice or not significant in farmer's alternative decision (Ogutu & Obare, 2015; Abay *et al.*, 2016).

Land size was positively significant in influencing choice of farming system. Land size can be used to stand in for other socio-economic indicators; for example greater wealth, which is a resource that enables a farmer to diversify in farming or access farm use credit, since large farms have more collateral value. This can be used to suggest that those farmers who practice cropping also practice crop rotation, an organized procedure where farmers decide which crop to plant, and where to plant it in their farms successively. Crop rotation is essential to organic farmers who would require more land for various crops; and therefore, can lessen reliance on the use of external inputs which arises by way of internal nutrient recycling, maintaining the continuous land productivity, and disturbing weed and disease cycles, which leads to increased yield and profitability (Gebremedhin & Schwab, 1998).

Farming experience had significant marginal effect on the choice of farming system. The negative relationship between farming experience and choice of farming system implies that farmers with few years in farming are expected to adopt a new technology in comparison to farmers with more farming experience. This is also because such farmers expect to increase their productivity and make a profit. However, this may depend on the kind of technology. This is contrary to the results of Teklewold *et al.,* (2006), who reported that as farmers acquire a lot of info about a technology, the scale of adoption increases.

Membership to community organisation was important in influencing the choice of farming system, which could be due to pooling of resources, accessing extension services through groups, and reducing information asymmetry. Most farmers who participate in groups have access to research and extension services, produce and input markets, and financial services since various organisations and institutions offer these services using group-based approaches. Various studies give an account for a strongly positive association among access to information and adoption conduct of farmers (Tizale, 2007). Participation in PPT had a positive and significant marginal effect that implies that farmers practising the technology benefited from increased crop yields and fodder; and therefore, increased milk production and incomes. Indeed, higher yields and incomes have been reported from PPT plots (Khan *et al.,* 2008a, b; De Groote *et al.,* 2010). It was, however, noted that some factors (including marital status, gender, educational level, main occupation, access to extension services and credit) did not statistically influence the choice of farming system.

4.3 Economic Analysis

This section (4.3) illustrates findings and discussion for the second objective from gross margin analysis and the Dynamic Research for Evaluation Management economic surplus model. The sub-sections provides results and discussions from gross margin analysis of push-pull and non push-pull plots, the PPT project revenues, the economic indicators including net gain, net present value, benefit cost ratio, and internal rate of return. The section finally provides the sensitivity analysis results and a discussion of the interpretation of the findings.

4.3.1 Gross Margin Analysis of PPT Components

The study has shown that gross margins per hectare from both maize and fodder from PPT plots was 725 USD (The average exchange rate during the survey in 2015 was 1 USD =UGX. 3,300), gross margin of maize without fodder was 405 USD where as gross margin of milk per cow was 26 USD (Table 4.9). There was a significant difference in gross margins between maize without fodder (from PPT plots) and maize from control plots (non PPT) (p= 0.003), and between both maize and fodder (from PPT plots) and maize from control plots

(p=0.001), but no significant difference between both maize and fodder (from PPT plots) and maize from PPT plots (p=0.138).

Table 4.9: Gross margin analysis of PPT components

Variable **maize and fodder**	**UGX**	**USD**
PPT gross margin for both maize and fodder (Per ha)	2,019,786.19	725
PPT gross margin of maize without fodder (Per ha)	1,111,794.93	405
Milk gross margin (Per cow)	70,460.00	26

Source: Author's survey (2014 and 2015)

4.3.2 Gross Margin Analysis of PPT and Control Plots

Gross margin per hectare from PPT plots was more than the gross margin from control plots (Table 4.10). In PPT plots, input cost accounted for 29% of the total variable cost whereas labour cost accounted for 71%. This is attributed to the fact that most of the PPT components, that is, grass (Napier grass) and legume (desmodium) are perennial therefore farmers plant them only once during establishment period hence reducing the cost of inputs. These fodders also improve soil fertility and thus a justification that farmers do not use organic fertilizers; thus, in subsequent seasons after establishment, farmer only bought maize seed. Labour cost contributes a higher percentage of total variable cost because PPT plots require extra labour for weeding, trimming desmodium, cutting Napier and harvesting maize compared to maize monocrop. Push pull technology is labour-intensive nature of the technology, especially during the first season of land preparation, planting, weeding, trimming and cutting back of desmodium and Napier grass (De Groote, 2002; Khan *et al.*, 2014). This is significantly reduced in subsequent seasons. Farmers practising PPT and those not practising the technology (control) differed significantly on total revenues, total variable cost and gross margins (p<0.05).

Table 4.10: Comparison of gross margins from PPT and control plots (Ugx/ha)

VARIABLE	PPT	CONTROL	t-value
Total Revenue (TR)	3,769,853.63	2,072,280.00	400.16***
Total Variable Costs (TVC)	1,750,067.44	1,416,058.00	73.80***
Material inputs cost	500,459.53	160,355.00	103.60***
Labour cost	1,249,607.91	1,255,703.00	11.38*
TVC			
Material input cost	500,459.53	160,355.00	
Labour cost	892,262.72	1,113,506.67	
Material input cost			
Seed cost/ha	92,374.42	86,345.00	
Fertilizer (DAP) Cost/ha	834,159.16	0	
Bagging/Ha	74,010.00	74,010.00	
Labour cost			
Land preparation/ha	223,963.10	444,060.00	
Planting/ha	161,341.80	185,025.00	
Total. Weeding/trimming.des/cutting. Napier/ha	435,456.18	197,360.00	
Harvesting/ha	281,293.23	281,238.00	
Postharvest/ha	147,553.60	148,020.00	
Gross margin (Ugx/ha)	**2,019,786.19**	**656,222.00**	**21.33*** **

NOTE: ***, **, *Significant at 1%, 5% and 10% level respectively

Source: Author's survey data (2014 and 2015)

4.3.3 Economic Surpluses

The total benefits from adoption of PPT had an economic net present value (ENPV) of USD 1.61 million when summed for 20-year period of the simulation, the economic internal rate of return (EIRR) was 51% and the economic benefit cost ratio (EBCR) was 1.54. Given that ENPV was positive, EIRR was greater than the discount rate of 12% which is based on Uganda's CBR and EBCR was greater than 1 implying that PPT is economically viable for the next 20 years, and therefore, plans should be made to further up-scale and disseminate the technology to other regions where farmers are facing the problem of *Striga* weed infestation, stemborer pests and low soil fertility.

4.3.4 Sensitivity Analysis

Sensitivity analysis was done for the NPV, IRR, and BCR in relation to project benefits, project costs, number of farmers adopting PPT and PPT cropped areas (Table 4.11). The results clearly demonstrate that even if the project cost is increased by 20%, project benefits reduced by 20%, the number of farmers adopting PPT increases by 2% (and not 5% as the base case assumed) and PPT cropped areas increase by 5% (not 10% as the base case assumed) throughout, the NPV will still be positive, the IRR will exceed the discount rate of 12% and the benefit cost ratio (BCR) will still be greater than 1. This indicates that under the circumstances, the project is still robust enough to withstand all the shocks and that PPT will still be profitable and economically viable.

Table 4.11: Sensitivity analysis at high and lower levels

Scenario	Description	NPV ($ Million)	IRR (%)	BCR
1	20% increase in project costs	853,859	26	1.28
2	20% reduction in project benefits	582,454	23	1.23
3	Both 1and 2	297,418	13	1.03
4	No. of farmers adopting PPT increases by 2% and not 5%	632,586	50	1.52
5	PPT cropped areas increase by 5% throughout and not 10%	797,864	40	1.25
6	Both 4 and 5	574,481	39	1.23

Source: Author's survey (2014 and 2015)

4.4 Generalized Propensity Score (GPS) Results

This section (4.4) provides results and discussions for the last objective from the generalized propensity score model. This include descriptive statistics on the relationship between the intensity of PPT adoption in terms of portion of land allocated to the technology and household welfare measures (incomes, per capita food expenditure and yield) and econometric analysis results together with interpretations on the impact of adoption intensity on household welfare.

4.4.1 Relationship Between Level of PPT Adoption and Household Welfare Measures

The relationship between the level of PPT adoption and household incomes, per capita expenditure and maize yield is presented in Table 4.12. Households were sub-divided into quintiles according to the area of land allocated to PPT. Results show that average household incomes, per capita food consumption, and yields increased with the expansion of land allocated to PPT.

Table 4.12: Level of PPT adoption, incomes, per capita food expenditure and yield

Quintiles of area under PPT (acres)	Mean annual household incomes ('000 Ugx)	Per capita food consumption ('000 Ugx)	Yield (kgs)
1	1,092.94	51.21	60
2	1,368.21	52.92	165
3	2,181.50	60.46	186
4	2,384.44	62.18	350
Productivity status for both adopters and non-adopters			
Productivity(kgs/acre)	**Minimum**	**Maximum**	**Mean**
PPT plots for adopters	800	1,433	988
Non-PPT plots for adopters	31	900	382
Non-PPT plots for non-adopters	88	909	338

1:<=0.125, 2:>0.125<=0.25, 3:>0.25<=0.5, 4:>0.5
Source: Author’s survey, 2014

Average maize productivity for adopters was higher in PPT plots (988kgs/acre) compared to non-PPT plots for the same farmers (adopters) with an average of 382kgs/acre. Statistical test showed that there was a significant difference in productivity for PPT plots and non-PPT plots for adopters (p=001). It was also noted that maize productivity from non-PPT plots amongst PPT adopters was higher than that from non-adopters (in non-PPT plots), which averaged 338 kgs/acre. This scenario is attributable to adopters having more information from the extension services, coupled with quality and reliable information offered through various dissemination pathways including field days, public meetings (*barazas*), farmer field schools, farmer teachers, and mass media (radio and print materials) used by *Icipe* and extension partners at different stages of dissemination and adoption process of PPT, and hence, they (adopters) were able to give proper management to even the areas where PPT is not being applied and get a better crop yields than the complete non-adopters (Amudavi *et al.*, 2009; Murage *et al.*, 2011; 2012).

Table 4.13 presents gender disaggregated mean difference of the impact of PPT adoption on household incomes as well as per capita consumption expenditure and productivity between adopters and non-adopters. Whereas household income signifies the capability of the household to buy its essential requirements, per capita expenditure indicates the effectual utilization of households and for that reason gives information regarding the food security status of households (Nguezet, 2011).

Table 4.13: Gender disaggregated analysis of PPT adoption on welfare indicators

Variable	Adopters	Non adopters	Difference Test
Incomes (USD)	505.11	381.39	123.71*
	(43.89)	(49.60)	(66.23)
Male	533.36	326.54	-206.82*
	(62.63)	(59.89)	(86.66)
Female	478.00	445.52	-32.48
	-62.50	-81.50	-102.17
Per capita expenditure (USD)	22.49	19.11	3.38
	(2.95)	(1.19)	(3.18)
Male	16.74	27.84	11.10*
	(1.19)	(5.23)	(5.37)
Female	21.47	16.37	-5.10*
	(2.08)	(1.86)	(2.77)
Productivity (Kgs/acre)	987.95	382.34	0.24***
	(6.94)	(13.05)	(0.01)
Male	969.22	326.48	-0.23***
	(9.2)	(16.58)	(0.01)
Female	1,006.49	351.88	-0.24***
	(10.29)	(20.58)	(0.01)

NOTE: ***, **, *Significant at 1%, 5% and 10% level respectively
Source: Author's survey, 2014

Results indicate that PPT adopters were better-off than non-adopters with regard to incomes and productivity; female adopters had higher per capita consumption expenditure at 21.47 USD and maize productivity (1,006 kgs per acre) compared to their male counterparts who had a per capita consumption of 16.74 USD and productivity of 969 kgs per acre. This concurs with results by Murage *et al.,* (2015) which revealed the motivation to increase PPT plots and continue using it was higher for women and this was attributed to its ability to reduce key limitations under cereal production, and this is an action for increased food security. Notably, there was a significant disparity involving incomes and productivity of adopters and non-adopters, but with no significant difference in per capita consumption between the two groups. Nevertheless, the disparity in observed mean outcomes among adopters and non-adopters may not be accredited exclusively to PPT adoption because of the problem of self-selection and non-compliance (Imbens & Angrist, 1994; Heckman & Vytlacil, 2005).

4.4.2 Econometric Results

Results on covariate balancing which provides balance statistics as mean differences (*t*-statistics) before and after adjustment with the GPS are shown in Table 4.14. Comparing the last four columns (raw or unadjusted data) in Table 4.14 with the first four columns of the same Table (adjusted data); results suggest that the covariate balance has evidently been enhanced after GPS balancing. For example, the initial interval has 27 variables with a t-statistics > 1.90 in absolute value, exclusive of conditioning on the GPS; while, following adjustment with the GPS, this is lowered to 11 variables. Generally, the covariate imbalance decreased by 65% following adjustment.

Table 4.14: Covariate balancing for generalized propensity score matching: t statistics

Covariates	Data after adjustment by GPS				Data before adjustment by GPS			
	[.025,.028]	**[.03,.05]**	**[.056,.125]**	**[.126,1]**	**[.025,.028]**	**[.03,.05]**	**[.056,.125]**	**[.126,1]**
Marital status	-1.198	0.102	0.956	-0.448	-1.728	0.408	0.483	0.072
Household size	0.443	-1.829	1.491	**-2.147**	1.273	**-3.286**	**3.359**	-1.467
Gender	-1.204	-1.885	**2.416**	-0.742	**-2.841**	-1.361	**3.265**	0.673
Age	0.073	-1.604	**2.714**	-0.939	0.660	**-2.651**	**1.943**	-0.974
Education level	1.038	0.783	-0.400	-1.045	0.796	0.707	-0.656	-0.568
Farm labour	0.677	1.134	-0.906	-0.866	0.731	0.530	0.122	**-1.930**
Farm size	0.321	-1.079	0.809	-0.568	1.252	0.357	0.526	**-2.151**
Farming system	-1.088	-1.672	1.630	-0.871	-1.119	0.146	**2.065**	**-2.242**
TLU	0.198	-0.264	0.146	-0.896	0.468	-0.794	-0.389	1.178
Extension service	-1.057	1.427	-1.091	0.352	0.074	0.914	-0.948	0.109
Field day	0.234	0.035	-0.168	1.378	**-1.905**	-0.122	1.247	-0.162
Credit access	-1.832	1.048	0.394	-0.347	**-2.619**	1.013	1.133	-0.935
Group membership	0.321	0.613	-0.007	0.556	0.028	0.969	0.184	-1.509
Distance to main road	0.911	0.616	-1.171	0.658	1.102	1.311	**-2.131**	0.483
Distance to extension service	0.878	1.049	-1.716	0.535	1.271	**1.930**	**-2.541**	0.140
Busia	-1.114	**-2.658**	**5.027**	**-3.551**	**-2.105**	-1.267	**4.172**	**-2.555**
Tororo	1.427	**-2.073**	**2.013**	0.205	**2.951**	**-3.563**	**2.017**	-0.535
Bugiri	1.825	**4.622**	**-7.942**	**2.507**	**3.291**	**6.147**	**-8.218**	0.752
Pallisa	-1.091	-0.164	1.026	1.387	**-4.508**	-1.429	**2.000**	**2.313**

Source: Author's survey, 2014

4.4.3 Impact of Intensity of Adoption: Generalized Propensity Score

The GPS results in Table 4.15 show that gender, farm size, participation and/or attendance of field days, and membership to community organizations had a significant effect on the intensity of adoption. If a farmer was a member to a community organization and/ or attended field days, he/she was more likely to gather information about the technology from other farmers, farmer teachers, and agricultural extension officers and hence intensified adoption of PPT. Additionally, extension service providers availed technical advice as well as farm inputs. This agrees with Kassie *et al.*, (2012), who observed that with limited and insufficient information sources coupled with inadequate markets and transaction expenses, social networks for example farmers organizations or groups simplify the swap of info.

Table 4.15: Estimation of propensity score: Generalized Propensity Score

Explanatory variables	Average marginal effects	Std. Err
Marital status	0.01	0.07
Household size	0.02	0.02
Gender	-0.18*	0.10
Age	-0.00	0.01
Education level	0.06	0.04
Farm labour	0.04	0.03
Farm size	-0.03***	0.01
Farming system	0.00	0.01
TLU	-0.02	0.02
Extension service	-0.06	0.21
Field day	0.31**	0.13
Credit access	0.02	0.09
Group membership	0.23*	0.12
Distance to main road	0.00	0.01
Distance to extension service	0.00	0.00
Busia	0.04*	0.13
Tororo	0.11**	0.14
Bugiri	0.61***	0.18

NOTE: ***, **, *Significant at 1%, 5% and 10% level respectively

Source: Author's survey, 2014

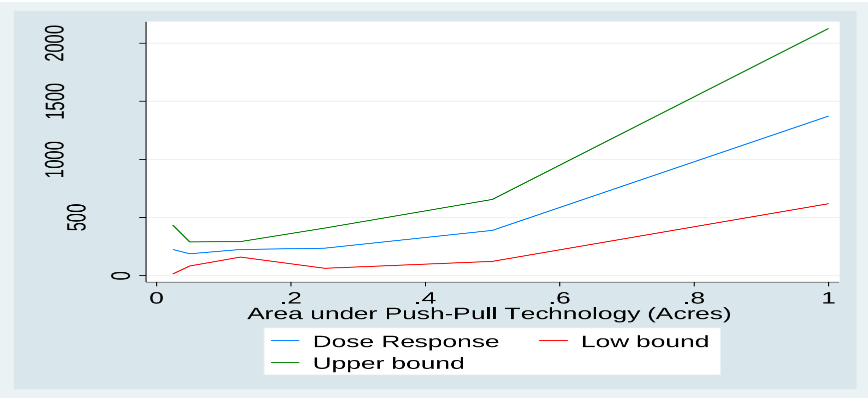
A negative significant relationship of gender means that being a woman increased the intensity of PPT adoption. This validates the outcomes of Murage *et al.,* (2015), who established that more women recognize PPT as an incredibly useful strategy in comparison to men, an experience which is inferable to the qualities of the technology that appeared to support women's preferences, and hence a higher percentage of women are likely to intensify adoption than men.

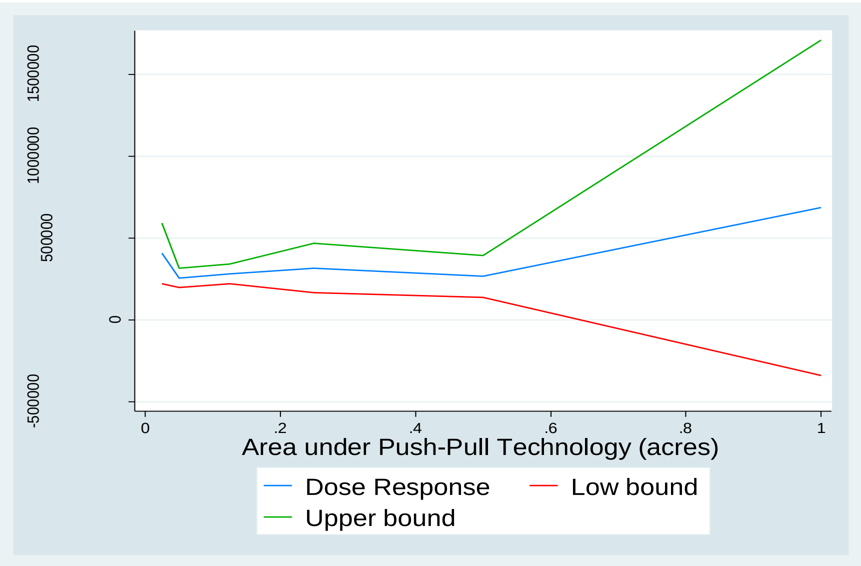
4.4.4 Impact of Adoption Intensity on Welfare Outcomes: Dose-Response Function (DRF) Estimates

Figures 4.1 to 4.4 show the DRF estimates and their derivatives, that is, the Marginal Treatment Function (MTF) of the impact of intensity of adoption on maize yield, household incomes, per capita consumption and poverty. The findings clearly depict that a significant and positive average effect of the intensity of adoption of PPT exists on maize yield, household incomes and per capita consumption expenditure, whereas poverty levels decline significantly. It is evident from the results that the average maize yield increases from 27 kgs at 0.025 acre to 1,400 kgs at 1 acre PPT adoption level. The average household income increases from 135 USD at 0.025 acre to 273 USD at 1 acre PPT adoption point whereas per capita food consumption increases from 15 USD at 0.025 area share to 27 USD at 1 acre. Additionally, there is a clear indication that the extent of poverty drops significantly with the intensity of adoption whereby the DRF estimate of the impact of intensity of PPT adoption on poverty as shown in Figure 4.5 confirms that likelihood of being poor drops from 48% at 0.025 acre to 28% at 1 acre PPT adoption level. The marginal treatment effects corresponding to maize yield, household incomes, and per capita consumption expenditure was positive and increased with a unit increase in area under PPT.

Nabasirye (2012) using binary PSM methodology found similar results where uptake of improved maize technology had a positive significant effect on yields. Outcomes confirmed that on average, the rise in maize yields after adoption of enhanced seed was about 371 kgs per acre using the Epanechnikov kernel matching algorithm and about 359 kgs per acre using the radius matching algorithm hence positive effect for food security and poverty mitigation in Uganda. In addition, Kassie *et al.*, (2014) results from GPS analysis indicated that on average, as households expand land area under improved maize technology, from one acre, the possibilities of chronic and transitory food insecurity reduced between 0.7 and 1.2% and between 1.1 and 1.7%, in that order while the extent of poverty declined in rural Tanzania.

DRF


0
500
1000
1500
2000
0
.2
.4
.6
.8
1
Area under Push-Pull Technology (Acres)
Dose Response
Low bound
Upper bound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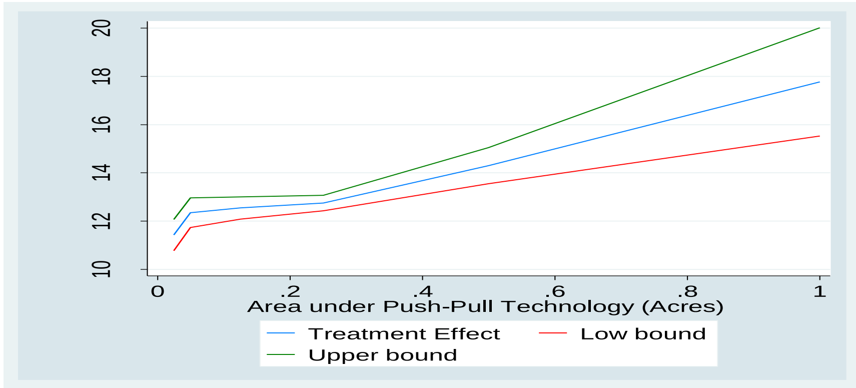
1
Area under Push-Pull Technology (acres)
Dose Response
Low bound
Upper bound

MTE


10
12
14
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18
20
0
.2
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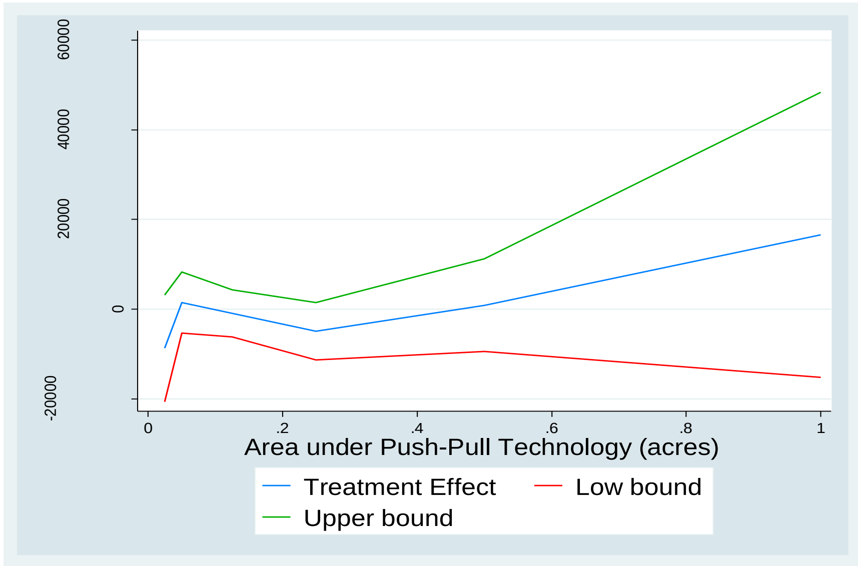
.6
.8
1
Area under Push-Pull Technology (Acres)
Treatment Effect
Low bound
Upper bound


-20000
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1
Area under Push-Pull Technology (acres)
Treatment Effect
Low bound
Upper bound

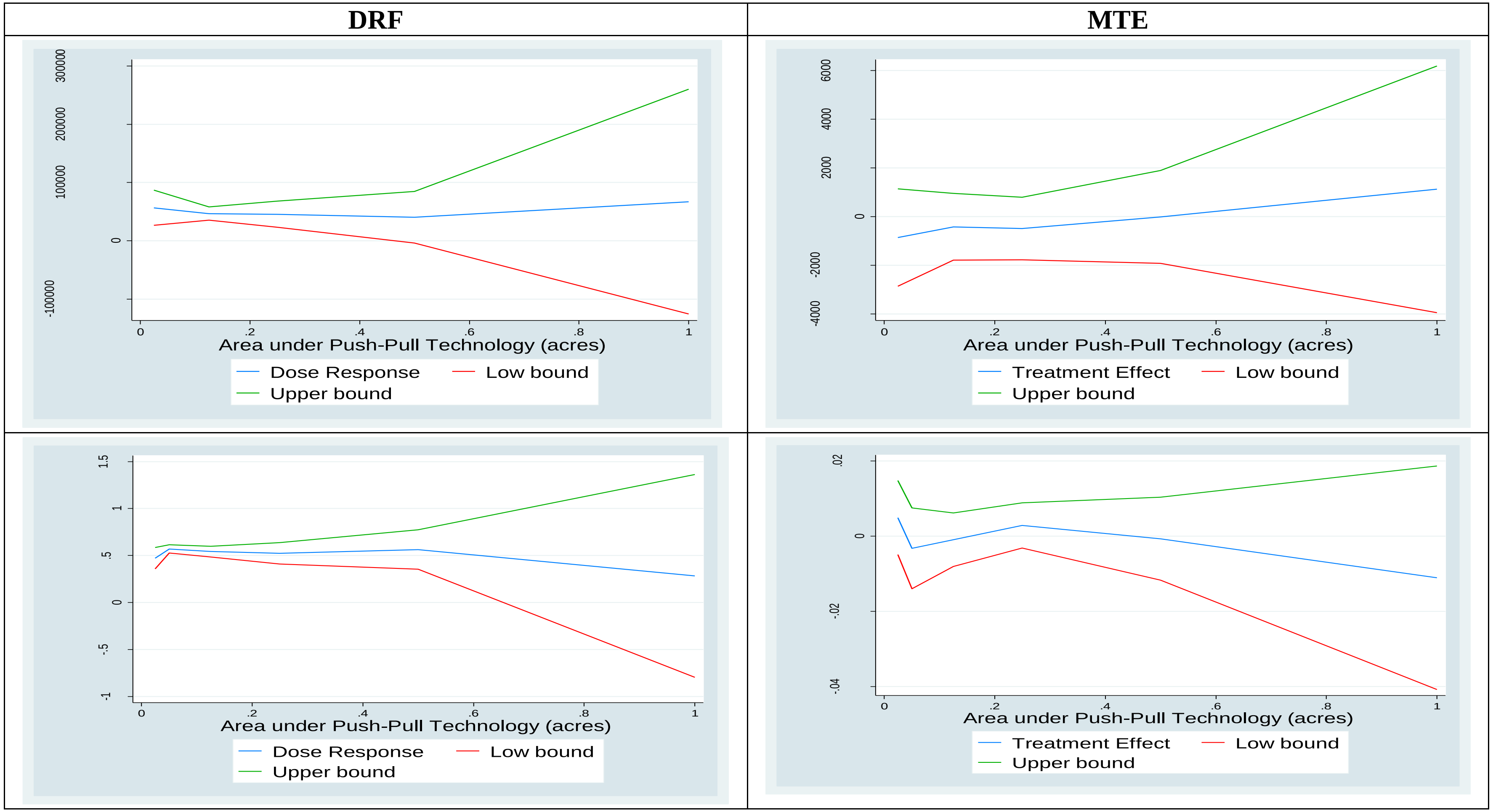

Figure 4.1-4.4: Dose Response Function (DRF) and Marginal Treatment Effect (MTE) of maize yields, household income, per capita consumption expenditure and poverty

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

The study characterized the farming systems and assessed factors that determine the choice of farming system; it evaluated the economic performance of PPT and also determined the impact of adoption of the technology on household welfare. This was done to ascertain the social value of the technology with the purpose of extending the technology to other regions.

Using multivariate analysis approach, two distinct clusters that represented two typical farming systems namely, mixed crop-livestock farming system (Cluster 1) and crop farming system (Cluster 2) were identified. Cluster 1 consisted of relatively young farmers who practised PPT, majority of whom were female whose income sources were mainly on-farm. These farmers also kept livestock, accessed credit, and participated in field days and demonstrations. On the other hand, Cluster 2 comprised relatively older farmers who mainly practised crop farming, by intercropping food and cash crops. Further, the study identified determinants that positively have an effect the choice of farming system for instance household size, age of household head, farm size, farming experience, and group membership. The study provides evidence that there is more room and potential for integrating PPT in the existing farming systems.

The DREAM model results from this study has shown that the proper implementation of PPT offers the prospect of monetary benefits to households who depend on maize farming to generate their income. Gross margin analysis indicated that income from PPT farmers with or without fodder was higher than for maize without PPT from non-PPT farmers, and that farmers also financially benefited from fodder as dairy feed as this generated income from milk production. While the investment parameters NPV, IRR and BCR and gains to households supported the economic viability and social benefits of PPT, marked increases in costs in combination with reductions in benefits from the sensitivity analysis were the greatest threat. Nevertheless the results conclude that PPT would remain economically viable for the next 20 years.

On the impact evaluation of PPT, outcome of the study showed that the average yield, average household incomes, and average per capita food consumption improved with the expansion of land set aside for PPT. Additionally, PPT adopters were at an advantage compared to non-adopters with regard to incomes and productivity. Gender, education level, access to family labor, small land sizes, attendance and participation in field days and availability of extension services all increased the intensity of adoption, which further increased productivity and incomes but reduced poverty levels. Further, results from GPS dose-response function estimates revealed a positive and significant average effect of the intensity of PPT adoption on yield, incomes, and per capita consumption and a negative average effect of the level of adoption on poverty.

5.2 Policy Implications and Recommendations

There has been a growing demand for and stronger emphasis on impact assessment of agricultural technologies over the years to respond to various stakeholders' requirements, and increase the accountability and effectiveness of agricultural technology adoption. Without economic analysis, it would be difficult to understand and appreciate the societal and financial worth of scientific know-how and expertise and to come up with strong decisions regarding the decision in the distribution of limited reserves in research. Study findings on the first objective recommends integrating PPT in cereal cropping and livestock rearing in

Eastern Uganda, as it is a low input technology that is suitable with mixed farming and because farmers benefit from provision of high value fodder that they can sell or feed to livestock to increase milk production. It is also a recommendation that *Icipe* and its development partners consider the dynamics that positively determine the choice of farming system (such as household size, age of household head, farm size, farming experience, and group membership) to further disseminate PPT.

Findings from the DREAM model on the second objective provide consistent evidence to confirm study's working hypothesis that push pull integrated in maize-dairy farming systems is a profitable technology. This technology has proved to be profitable for the next 20 years even at its worst case scenario. Hence the study recommends further up-scaling and dissemination of the technology where farmers are facing the problem of *Striga* weed infestation, stemborer pests and low soil fertility.

The GPS outcomes on the last objective present a robust confirmation on the impact of PPT on rural poverty in Uganda, with opportunities to enhance this impact by encouraging allocation of more land to the technology. This study therefore recommends that agricultural policies targeting farm household food security and poverty reduction in maize-based systems in Uganda and elsewhere should explicitly encourage push-pull technology adoption.

5.3 Suggestions for Further Research

For impact assessment of PPT on household welfare, (incomes, productivity, and poverty), the study focused only on the use of cross sectional data. But to establish whether results persist over time, further analysis using panel data should be planned. This would be of great importance to control for unobserved heterogeneity and to observe the relationship between PPT adoption and poverty status. There is also need to establish the contribution of

PPT to food security by use of subjective assessments. Further on economic analysis, since there is a change during every season on the number of farmers adopting PPT, the cropped areas, and the number of cows kept, and also given the key intent of the project which is to reach a target number of 10 million farmers in SSA, it is therefore, advisable to repeat the economic analysis in Eastern Uganda and also to extend the analysis to the countries in which the technology has been disseminated so as to understand the optimum use of PPT for further accountability and dissemination.

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APPENDIX 1: Approaches of *Striga* and Stemborer Control

	Control method	Advantage	Disadvantage
***Striga* control** Watson, (1992)	Uprooting *Striga* plants before they flower and burning them	• Reduces number of *Striga* seeds	• Labour intensive • Must be done before flowering • *Striga* will regenerate/redevelop from the dormant seeds in the ground
Hassan & Ojiem, 1995; Kayeke *et al.*,2007	Use of herbicides	• Can only be useful during the current season of application • Not labour intensive compared to hand weeding	• Costly • Manual or motorized sprayers are a requirement • May not be successful with the dormant *Striga* seeds in the soil • Can be toxic to human beings • Can destroy other important plants in close proximity • May pollute water and soil hence detrimental to ecosystem
Woomer & Savala, (2007)	Excessive application of manure or fertilizer	• Increases crop yields and enhances crop resistance to *Striga*	• Labour intensive • Manure may not be accessible at the time of need • Fertilizer is costly and may not be within farmers means • Application of excessive manure or fertilizer is not economical
	Imazapyr Resistant (IR) maize-	• Successful in *Striga* control • Improves maize yield	• Imazapyr herbicide may perhaps hinder growth of other crops

	Control method	Advantage	Disadvantage
	StrigAway. Herbicide seed coating		• *Striga* will germinate again from dormant seeds in the soil • It might be difficult to access herbicide resistant maize seeds of which may be more costly than the ordinary maize seeds
Stemborer control Van den Berg & Nur, 1998	Application of insecticides	• Successful in destroying caterpillar stemborers which derive regular nourishment from crop leaves • Not labour intensive	• Most commonly used insecticides are selective-they eliminate stemborer caterpillars only on leaves and not on the stems • Costly • It could be harmful to human beings • Can destroy other useful insects such as bees • Can possibly pollute the environment- water and soil
	Use of homemade natural extracts: Ash, neem extract, pyrethrum, chili	• Easy to access, cheap and harmless	• Not powerful and effective compared to other options
Kfir *et al.*, 2002; DeBach &	Biological control method: small wasps that kill young stemborers	• Useful • Requires minimal labour	• Biological control agents may not be readily accessible • Requires assistance of a professional

	Control method	Advantage	Disadvantage
Rosen,1991 Shelton & Badenes-Perez, 2006	Cultural control strategy-crop rotation	• Not a rigid strategy • Makes soil more fertile through nitrogen fixation • Minimizes stemborers by breaking their lifecycles	• During the rotation, farmers may miss out on maize which is an essential food crop
'Push-pull' technology for both *Striga* and stemborer control http://www.push-pull.net/	Maize and legume (desmodium) intercrop and grass (Napier or Bracharia grass) as a border crop	• Simultaneously controls stemborer and *Striga* • In a situation where both stemborers and *Striga* weeds are a crisis, application of PPT can double maize yields. • Biological control strategy which does not need any chemical • Boosts soil fertility through nitrogen fixation Lowers cost of production • Controls soil erosion through desmodium which act as cover crop • Legumes and grass are perennial plants • More incomes from desmodium seeds ,increased milk production and sales from both Napier grass and desmodium fodder	• Desmodium seeds are quite costly and hard to find • Demands high establishment cost of desmodium seeds and labour

APPENDIX 2: Interview Schedule

This study is collaborative between International Centre of Insect Physiology and Ecology (*Icipe*) and Kenyatta University. As a respondent you are kindly requested to participate in answering this interview schedule and you are guaranteed that any information offered will be strictly not to be disclosed. Your assistance in responding to these questions will be much cherished. Information collected will contribute to the understanding of economic benefits accrued as a result of adopting push-pull technology in Uganda.

A: BACKGROUND INFORMATION

Date (day/month/year) __/__ __/2014

Enumerator's name: ________________________________

District: ______________________Sub-county: ________________________

Parish: _______________________Village: ________________________

Start time: ________ End time: _________

GPS location of the household____

B: HOUSEHOLD CHARACTERISTICS

1. Name of the respondent____

2. Telephone number of respondent ____

3. What is your position in the household 1=Household head [ ], 2=Spouse [ ], 3=Child [ ], 4=Worker [ ]

4. What is your marital status? 1=Married [ ], 2=Single [ ], 3= Widowed [ ], 4= Divorced [ ]

5. What is the number of household members (including household head) living permanently in the compound_______

(***Please fill in the Table below for the household members***)

6. Name of HH member **(start with respondent)**	**7**.Gender (**Codes**) **(1=Male, 2=Female)**	**8.**Age (years)	**9.**Highest Level of Education (**Codes**) 1= No formal education 2= Adult education 3= Primary school 4= Secondary school 5= Non school child 6= post secondary school 7= Other (specify)____	**10**.Relation to HH (**Codes**) 1=Household head 2= Spouse 3= Son/daughter 4= Parent 5=sister/brother 6= Grandchild 7= Other relative 8= Non-relative(including employees who live in the house) 9= Other, specify______	**11**.Main occupation (**Codes**) 1= Farming (crop + livestock) 2= Salaried employment 3= Self-employed off-farm 4= Casual labourer on-farm 5= School/college child 6= Herds boy/girl 7= Household chores 8= Non-school child 9= Other, specify_____
1					
2.					
3.					
4.					
5.					
6.					
7.					
8.					

12. What is the source of farm labour for the household? (**Multiple response**)
1=Family [ ], 2=Casual [ ], 3=Permanent [ ]
13. How many members of your family who are 18 years and above offer farm labour? ________
14. How many members of your family below 18 years of age offer farm labour? ________

C. FARM CHARACTERISTICS

1. What is the household land ownership? (**Multiple response**) 1=Title deed [ ], 2=Own but not titled [ ] 3=Family/clan [ ], 4=Communal/public [ ], 5=Rented/leased [ ], 6=Others (**specify**) _________

2. How did you acquire your land?
1=Inheritance [ ], 2=Purchase [ ], 3=Others (**specify**) ____

3. What is the total area of land owned? ____________________ (Acres)

4. What kind of farming system do you practice? **(Please tick only one)** 1= Livestock farming [ ], 2=Crop farming [ ], 3=Mixed farming (both crops and livestock) [ ]

5. For how many years have you been farming…………………………Years

6. What is the household's main source of income? **(Please tick only one)**
1=Farm incomes (crop and livestock sales)[ ], 2= Off-farm casual work [ ], 3=Off-farm permanent employment [ ], 4=Remittance [ ], 5=Food aid [ ], 6= other (**specify**) ________________

D: INFORMATION ON PUSH-PULL TECHNOLOGY (PPT)

1.(a) Are you aware of Push-Pull technology? 1=Yes [ ], 2=No [ ]

(b) If yes above (1a), which year did you first hear about it? ------------------------------

(c) Which was your **very first source** of information about PPT? ***(Tick only one source)***
1=Friends/Neighbors [ ], 2=Radio [ ], 3=ICIPE project officers [ ], 4=Field day [ ], 5=Farmer teachers [ ], 6=Print media (Pamphlet, brochures, posters) [ ], 7=Others specify………………

2. **(a)** Are you currently practicing Push-Pull technology? 1=Yes [ ], 2=No [ ] ***(If NO go to Qstn.9)***

(b) If yes above (2a), for how long have you been practicing it? ------------------years

(c) What was the initial type of PPT Planted 1=Conventional PPT [ ], 2=Climate smart [ ], 3 =Both [ ]

(Conventional PPT is a combination of silver leaf desmodium, Napier grass and maize whereas climate smart is a combination of green leaf desmodium, Bracharia/Mulato and maize)

(d) What was your initial land area planted under PPT? ***(Fill in for each PPT)***
(i) Conventional---------------------m^2 (ii) Climate smart-----------------------------m^2

3. **(a)** Have you expanded your PPT plot? 1=Yes [ ], 2=No [ ] ***(If NO go to 3c)***

(b). If yes above (3a) **kindly fill in the Table below**

PPT Type	**Size of new plot (m^2)**	**When planted**	
		Season	**Year**
Conventional PPT			
Climate PPT			

(c) If you **have NOT** expanded the PPT plot **(3a),** please give reasons **(multiple responses)**
1=Scarcity of land [ ], 2=Too risky to adopt [ ], 3=Insufficient labour [ ], 4=Still gathering more information about it [ ], 5=Cash constraint to buy seeds and other farm inputs [ ], 6=others (specify)…………….

4. (a) Do you have access to desmodium seeds for planting ? 1=Yes [ ], 2=No [ ]

(b) If Yes above **(4a),** where do you get them from? 1= Purchase from seed companies [ ] 2 = From own farm [ ], 3=From neighbor/friend [ ], 4=ICIPE project [ ] ,5=Others **(specify)…………**

(c). Do you have access to Brachiaria/Mulato seeds? 1=Yes [ ], 2=No [ ]

(d) If Yes above **(4c),** where do you get them from? 1=Purchase from seed companies [ ], 2=From own farm [ ], 3=From neighbor/friend [ ], 4=ICIPE project [ ], 5=Other **(specify)……………**

5 (a). Has the adoption of push-pull technology affected the situation of women in this area? 1=Yes [ ], 2=No [ ]

(b). If yes, in which ways?

i.--

ii. --

iii. --

iv --

6 (a). Has the adoption of push-pull technology affected the situation of children? 1=Yes [ ], 2=No [ ]

(b). If yes, in which ways?

i.--

ii. --

Iii. --

iv. --

7(a). Are there some crops mainly managed by women? 1.=Yes [ ], 2=No [ ]

(b). If yes, which ones?..

8 (a). Do women have control over the household resources? 1=Yes [ ], 2=No [ ]

(b). If yes, which ones? **(Multiple response)** 1=Land [ ], 2= Crop produce [ ], 3=Livestock [ ], 4=Livestock produce [ ], 5= Others (specify)……………..

9. (***For non PPT adopters***) If you do not practice Push-Pull technology, are you willing to adopt it (PPT) in future? 1=Yes [ ], 2=No [ ]

10. If NO please give reasons

i.--

ii. --

iii. --

iv. --

E: <u>FARM BUDGET ANALYSIS</u>

1. Please fill in the table below farm budget for CONVENTIONAL PPT in your farm

		Long rain season (Feb-August 2014) Plot size …………………			
Annual Operation costs	**Unit**	**Number of persons**	**Number of days**	**Unit Price (Ushs)**	**Total cost (Ushs)**
Labour costs (A)	**Man days (MD)**				
Land preparation	MD				
Planting	MD				
1st Weeding	MD				
2nd Weeding	MD				
3rd Weeding	MD				
4th Weeding	MD				
Fertilizer application(top dressing)-***if any***	MD				
Manure application-***if any***	MD				
Chemical application-***if any***	MD				
Harvesting	MD				
Shelling/threshing/winnowing	MD				
Bagging/loading	MD				
Others (specify)	MD				
Sub Total Labour cost (A)					
Non Labour costs (B)	**Unit**	**Quantity**		**Unit Price (Ushs)**	**Total cost(Ushs)**
Maize seeds-Type; 1.Hybrid [ ], 2.Local variety [ ]					
Maize seed quantity used					
Desmodium seeds quantity used					
Napier grass cuttings					
Planting fertilizer (DAP)					
Top dressing fertilizer (CAN)					
Gunny bags-***if any***					
Transport costs (To farm gate)	Ushs				
Sub-Total Non-labour costs (B					
Total variable costs (A+B) =C					
Total incomes (D)	**Unit**	**Quantity**		**Unit Price (Ushs)**	**Total cost(Ushs)**
Maize yield (threshed)	Kgs				
Napier grass herbage	bundles				
Desmodium herbage	bundles				
Total Income (D)					
Gross income (D-C)					

2. Please fill in the table below farm budget for CLIMATE-SMART (ADOPT) PPT in your farm

		Long rain season (Feb-August 2014) Plot area…………………			
Annual Operation costs	**Unit**	**Number of persons**	**Number of days**	**Unit Price (Ushs)**	**Total cost(Ushs)**
Labour costs (A)	**Man days (MD)**				
Land preparation	MD				
Planting	MD				
1st Weeding	MD				
2nd Weeding	MD				
3rd Weeding	MD				
4th Weeding	MD				
Fertilizer application(top dressing)-***if any***	MD				
Manure application-***if any***	MD				
Chemical application-***if any***	MD				
Harvesting	MD				
Shelling/threshing/winnowing	MD				
Bagging/loading	MD				
Sub Total Labour cost (A)					
Non Labour costs (B)	**Unit**	**Quantity**		**Unit Price (Ushs)**	**Total cost(Ushs)**
Maize seeds-Type; 1.Hybrid [ ] 2.Local variety []					
Maize seed quantity used					
Desmodium seeds					
Bracharia/Mulato seeds					
Planting fertilizer					
Top dressing fertilizer					
Gunny bags-***if any***					
Transport costs (To farm gate)	Ushs				
Sub-Total Non-labour costs (B					
Total variable costs (A+B)=C					
Total incomes (D)	**Unit**	**Quantity**		**Unit Price (Ushs)**	**Total cost(Ushs)**
Maize yield (threshed)	kgs				
Bracharia/Mulato herbage	bundles				
Desmodium herbage	bundles				
Total Income (D)					
Gross income (D-C)					

3. Please fill in the table below farm budget for NON Push-Pull plot

Crop:	**Long rain season (Feb-August 2014)** **Area under plot………………………**				
Annual Operation costs	**Unit**	**Number of persons**	**Number of days**	**Unit Price (Ushs)**	**Total cost(Ushs)**
Labour costs (A)	**Man days (MD)**				
Land preparation	MD				
Planting	MD				
1st Weeding	MD				
2nd Weeding	MD				
3rd weeding					
Fertilizer application (top dressing)	MD				
Manure application	MD				
Chemical application	MD				
Harvesting	MD				
Shelling/threshing/winnowing	MD				
Bagging/loading	MD				
Sub Total Labour cost (A)					
Non Labour costs (B)	**Unit**	**Quantity**		**Unit Price (Ushs)**	**Total cost(Ushs)**
Maize seeds-Type; 1. Hybrid [ ] 2.Local variety [ ]					
Maize seed quantity used					
Planting fertilizer					
Top dressing fertilizer					
Chemicals- **if any**					
Manure					
Gunny bags					
Transport costs (To farm gate)	Ushs				
Sub Total Non labour costs (B)					
Total variable costs (A+B)=C					
Total incomes (D)	**Unit**	**Quantity**		**Unit Price (Ushs)**	**Total cost(Ushs)**
Maize yields (threshed)					
Total Income (D)					
Gross income (D-C)					

E: BEFORE AND AFTER ANALYSIS-(*PUSH-PULL FARMERS ONLY)*

9. Please fill in the table below

Activity	Before Push-pull	After Push-pull
1a.Were you using fertilizer before and after push-pull?	1=Yes [ ]2=No [ ]	1=Yes [ ]2=No [ ]
b. If yes, which planting fertilizer?	1=DAP [ ] 2=SSP [ ] 3=TSP [ ]	1=DAP [ ] 2=SSP [ ] 3=TSP [ ]
c. If yes which topdressing fertilizer?	1=CAN[ ] 2=Urea [ ] 3=Manure [ ]	1=CAN[ ] 2=Urea [ ] 3=Manure [ ]
2a.Were you using manure before and after push-pull?	1=Yes [ ]2=No [ ]	1=Yes [ ]2=No [ ]
b. If yes what is/was the source of manure	1=own farm [ ] 2=Free from neighbor [ ] 3=Purchase [ ]	1=own farm [ ] 2=Free from neighbor [ ] 3=Purchase [ ]
3. What is/was the number of weeding before and after push-pull?		
4. What is/was time spent weeding *Striga* (hours per day)		
5. Were you using chemicals in *Striga* control before and after push-pull?	1=Yes [ ]2=No [ ]	1=Yes [ ]2=No [ ]
6. Were you using chemicals in stem-borer control before and after push-pull?	1=Yes [ ]2=No [ ]	1=Yes [ ]2=No [ ]
7. What time was spent in ash application (hours per day)		

F. CROP FARMING ***(BOTH PUSH-PULL AND NON PUSH-PULL FARMERS)***

1. What is the size of household land under crop farming? ____________________ (Acres)

2. Indicate **3 major crop** enterprises on farm in the last one year

Type of crop	Area allocated (acres)
Food crops	
1.	
2.	
3.	
Cash crops	
1.	
2.	
3.	

3(a). Do you practice intercropping in your farm? 1=Yes [ ] 2=No [ ]

(b). If Yes above (3a), which crops do you usually intercrop?

Intercrops	Crop 1	Crop 2
Intercrop 1		
Intercrop 2		
Intercrop 3		

4. What major challenges do you experience in crop farming? (**Multiple response**)

1=*Striga* weeds[ ], 2=Stemborer pests [ ], 3=Low soil fertility [ ], 4=Inadequate rainfall/drought [ ], 5=Poor quality seeds [ ], 6=Scarcity of land [ ],7=Mole rats [ ], 8 =Storage weevils [ ], 9 =Termites [ ], 10=Lack of markets [ ], 11=Low market prices [ ], 12=Others (specify)……………..

5. Constraints in crop farming

a) How is the threat of *Striga* weeds in your farm? **(Tick only one)**
1= Moderately severe [ ], 2=Severe [ ], 3=Very severe [ ]

Please fill in the table below

(b). Which method(s) are you using to control *Striga* weeds in your farm? (**Multiple response**)	**(c).** How effective is each method mentioned 1. Very effective 2. Effective 3.Not Effective
1=Planting early [ ]	
2=Manure application [ ]	
3=Uproot and burn [ ]	
4=Planting alternative crops/crop rotation [ ]	
5=Use of chemicals [ ]	
6=Weeding [ ]	
7=Use of Push-pull technology[ ]	
8=Others (specify)……….	

(d) How is the threat of Stemborer pests in your farm? **(Tick only one)**
1= Moderately severe [ ], 2=Severe [ ], 3=Very severe [ ]

Please fill in the table below

(e). Which method(s) are you using to control stemborer pests in your farm? (**Multiple response**)	**(f).** How effective is each method mentioned 1. Very effective 2. Effective 3. Not Effective
1=Use of chemicals [ ]	
2=Uproot affected plants [ ]	
3=Ash application [ ]	
4=Use of push-pull technology [ ]	
8=Others (specify)……….	

F. LIVESTOCK ENTERPRISE

1. Please indicate the number of livestock you currently own/have

Livestock Category/type			**Number owned**	**Livestock system**1=Zero grazing 2=Free range 3=Tethering 4=Semi zero grazing 5=Deep litter
Cattle	Local	Bull		
		Cows		
		Young bulls		
		Heifers		
		Calves		
	Pure/exotic	Bull		
		Cows		
		Young bulls		
		Heifers		

Livestock Category/type			**Number owned**	**Livestock system** 1=Zero grazing 2=Free range 3=Tethering 4=Semi zero grazing 5=Deep litter
		Calves		
	Crossbreed	Bull		
		Cows		
		Young bulls		
		Heifers		
		Calves		
Goats	Local			
	Pure/exotic			
	Crossbreed			
Sheep	Local			
	Pure/exotic			
	Crossbreed			
Chicken	Local			
	Pure/exotic			
	Crossbreed			
Turkeys				
Ducks				
Pigs				

2. What is the major type of feed for your livestock? (**Multiple response**)
1=Napier grass [ ], 2=Maize stover [ ], 3=Desmodium [ ], 4=Brachiaria (*Mulato*) grass [ ], 5=Natural cut grass [ ], 6=Banana stalks [ ], 7=Sweet potato vines [ ] ,8= Other (**specify**)_________________

3. What major challenges do you experience in livestock keeping? (**Multiple response**)
1= Insufficient fodder [ ], 2=Pests and diseases [ ], 3=Scarcity of land [ ],
4=Low market prices for livestock products [ ], 5=Lack of markets [ ],
6=Others (specify)…………………

Livestock and fodder utilization before and after push-pull adoption (*push-pull farmers only*)

4. When did you start keeping dairy cows? 1=Before adopting PPT [ ] 2=After adopting PPT [ ]

5. Please fill in the table below about farm situation before and after adopting push-pull

Activity	**Before**	**After**
1. How many cows did you have before and after push-pull?		
2. What is/was the quantity of milk produced per cow per day (Litres) before and after push-pull?		
3. How many dairy goats did you have before and after push-pull?		
4. What is/was the quantity of milk produced per dairy goat per day (litres) before and after push-pull?		
5. What was the source of fodder before and after push-pull?- (*1=Own fodder 2=Buy fodder 3=Free grazing fields(road side)*)		
6. If fodder is bought, what is/was cost of buying		

Activity	Before	After
fodder (Ush)		
7. Do you sell any fodder from your farm before and after push-pull? 1 = yes 2 = No		
8. If Napier grass is/was sold, what is/was the quantity?		
9. If Brachiaria is/was sold what is/was the quantity?		
10. If Desmodium is/was sold, what is/was the quantity?		
11.What time is/was spent herding livestock (hrs per day) before and after push-pull?		
12.What is/was the cost of herding livestock per month (herdsman) before and after push-pull?-		

6 (a). How do you utilize Napier grass from your push-pull plot? (**Multiple response**)

1=Feed livestock [ ], 2=Sell to neighbor/other farmers [ ], 3=Give to neighbor/other farmers for free [ ], 4=Use as mulch [ ], 5=Others (specify) ………………………..

(b). How do you utilize Brachiaria (*Mulato*) grassfrom your push-pull plot? (**Multiple response**)

1=Feed livestock [ ], 2=Sell to neighbor/other farmers [ ], 3=Give to neighbor/other farmers for free [ ], 4=Use as mulch [ ], 5=Others (specify) ………………………..

(c). How do you utilize desmodium from your push-pull plot? (**Multiple response**)

1=Feed livestock [ ] 2=Sell to neighbor/other farmers [ ] 3=Give to neighbor/other farmers for free [ ] 4=Use as mulch [ ] 5=Others (specify) ………………………..

7(a). Is fodder from your push-pull plot sufficient for your livestock?

1= Sufficient [ ] 2=Not sufficient [ ]

(b). If not sufficient, are you buying more fodder? 1=Yes [ ] 2=No [ ]

8. (***For farmers without livestock***) If you do not have livestock, where do you take your fodder?

1=Sell to neighbor/other farmers [ ] 2=Give to neighbor/other farmers for free [ ]
3=Use as mulch [ ] 4.=Others (specify) ………………………..

9. Has the push-pull technology changed your livelihood/ way of living? 1=Yes [ ] 2=No [ ]

10. How have you benefited from adopting PPT? (**Multiple response**)1=Reduced *Striga* weeds [ ] 2=Reduced stemborer pests [ ] 3=Improved soil fertility [ ] 4=Increased crop yields [ ] 5=Increase in fodder [ ] 6=Increase in milk [ ]7=Others (specify)…………

G. OTHER HOUSEHOLD INCOMES

1. Indicate sources of income in the last one year and amount

(***Note: Income sources should include income from all members of the household)*** **Did you sell any of the following items in the last one year?**	**Total household income in the last 12 months from this source (Ugsh)**	**Who mainly controls this source? Code: 1=Husband 2= Wife 3=Joint Husband and wife 4=Child**
Crop sales from the farm;		
Maize		
Sorghum		
Cassava		
Millet		
Groundnuts		
Other 1.(specify)		

(*Note: Income sources should include income from all members of the household)* **Did you sell any of the following items in the last one year?**	**Total household income in the last 12 months from this source (Ugsh)**	**Who mainly controls this source? Code: 1=Husband 2= Wife 3=Joint Husband and wife 4=Child**
Other 2.(specify)		
Sales from livestock:		
Bull		
Cows		
Young bulls		
Heifers		
Goats		
Sheep		
Chicken		
Turkeys		
Ducks		
Pigs		
Sales from livestock products		
Eggs		
Milk		
Manure		
Hides		
Skins		
Honey		
Employment as casual labour		
Formal employment		
Remittances from relatives		
Government pension		
Renting out land (Cash value of or rent)		
Renting out houses (cash value of rent)		
Other (specify)		

H. FOOD EXPENDITURE AND CONSUMPTION

1. Please fill in the table below on food consumed , the source and value

In the last 7 days have you consumed / used the following items?	**How many days did you consume in a week (7 days)**	**What was the main source in the last 7 days** ***Codes*** ***(1=own production, 2=hunting/gathering/fishing, 3=bought/purchased4=borrowed(friends/relatives), 6=gifts, 7=received as payment)***	**What was the value (Ug sh)?**
Maize			
Sorghum			
Cassava			
Millet			
Groundnuts			
Yams			
Matoke			
Vegetables			
Fruits/fruit juices			
Beans			

In the last 7 days have you consumed / used the following items?	How many days did you consume in a week (7 days)	What was the main source in the last 7 days *Codes* ***(1=own production, 2=hunting/gathering/fishing, 3=bought/purchased4=borrowed(friends/relatives), 6=gifts, 7=received as payment)***	What was the value (Ug sh)?
Green grams			
Peas			
Eggs			
Milk			
Red meat (beef,pork,goat,sheep,)			
Poultry meat (chicken, duck, turkey,)			
Fish			
Oil/fats (vegetable oil, ghee, butter)			
Sugar			
Tea leaves			
Coffee			
Salt			
Other 1.(specify)			
Other 2.(specify)			

I. NON-FOOD EXPENDITURES

2. (a). **How much has your household spent during the last 12 months (1 year) on the following?**

Expenditure	**Cost in Ushs**
School fees(including tuition fees, books and uniforms)	
Housing(construction and repairs)	
Household furnishing and appliances	
Health insurance	
Other health expenditures(e.g. medicine)	
Financial institutions(membership fees)	
Buying gifts	
Renting in land	
Renting agricultural equipment	
Purchasing land	
On-farm enterprise(bee keeping, processing crops)	
Investment in own business(non-agricultural)	
Buying livestock	
Other livestock expenses(feed, vaccination, veterinary)	
Electricity bill	
Water bill	
Other (specify)	

2 (b). How much did the household spend in the last 1 week on the following?

Expenditure	Cost in Ug shs
Transport	
Communication	
Clothing and personal belongings	
Leisure(going to bar, watching film, sports etc)	
kerosene	
Charcoal	
Other (specify)	
Other (specify)	

J. ASSET OWNERSHIP

Which assets do currently you have in your household?	Cost of one asset (Ugs)	Total number of assets currently owned	For how many years have you owned the asset?	Who owns the asset? (1=Husband 2=Wife 3=Both husband and wife)
Domestic				
Cooker/ Gas				
Stove				
Refrigerator				
Radio				
Television				
DVD Player				
Mobile phone				
Sofa set				
Sewing Machine				
Mosquito nets				
Transport				
Car/truck				
Tractor				
Motorcycle				
Bicycle				
Cart(animal drawn)				
Farm				
Hoes/jembes				
Spades/shovel				
Ploughs				
Ox-ploughs				
Sprayer pumps				
Water pumps				
Watering cans				
Wheelbarrows				
Poultry feeders				
Milking cans				
Bee hives				

K. HOUSING

Research assistant to ask where necessary and tick appropriately

What is your home ownership?	**Roofing material?**	**Wall material?**	**Floor material?**
1=Owned [ ]	1=Grass [ ]	1=Earth/mud [ ]	1=Earth/mud [ ]
2=Rented [ ]	2=Iron sheets [ ]	2=Wood/iron sheets [ ]	2=Cement [ ]
3=Borrowed [ ]	3=Tiles [ ]	3=Cement/bricks [ ]	3=Tiles/bricks [ ]
4=Other(specify)	5=Other (specify)	4=Other (specify)	4=Wood [ ]
			5=Other (specify)

L. ACCESS TO EXTENSION SERVICES AND CREDIT

1 (a). Did you have an agricultural extension service/contact in the last one year? 1=Yes [ ] 2=No [ ]

(b). If Yes above (1a), what is the frequency of contact? 1=Once a week [ ] 2= Once in two weeks [ ]
3=Once a month [ ] 4=Once in three months [ ] 5=Not regular [ ]

(**c**). Who provides the extension service/contact? 1=Government [ ] 2=NGO's [ ] 3=Private practitioners' [ ] 4=Cooperative/farmer group [ ] 5.=Other (specify)

2. Do you participate in /attend field days/demonstrations? 1.=Yes [ ]2=No [ ]

3(a). Have you accessed any type of credit for farm use in the last one year? 1=Yes [ ]2=No [ ]

(b). If Yes above (3a), which form of credit? 1= Cash [ ] 2=Kind [ ]

(c). Who is the provider? 1=Bank [ ] 2=Cooperative [ ] 3=Trader/shop [ ] 4=Informal money lenders [ ]
5= Micro-finance institution (MFI) [ ] 6=Mary-go-rounds [ ] 7=other (**specify**

M. COMMUNITY ORGANIZATION MEMBERSHIP

1(a). Are you a member of any community organization/association?1=Yes [ ] 2=No[ ]

(b). If yes above (1a), which group? 1=Women group [ ] 2=Farmers' organization. [ ]
3=Cooperative society [ ] 4=Other (**specify)**

(c). What services do you get from the organization you belong to?
1=Savings and Credit [ ] 2=Loans [ ]3=Labour [ ] 4=Farm inputs [ ] 5=Others (specify)

N. INFRUSTRUCTURE (DISTANCES IN KILOMETERS)

1. What is the **distance** from your home to the nearest **murram road?** _____________

2. What is the **distance** from your home to the nearest agricultural **public/private extension services** _________

3. What is the **distance** from your home to the nearest source **of water for domestic use** _____________

Farmers' signature__________________________ ***THANK YOU***

APPENDIX 3: Published Papers in Peer-Reviewed Journals

Chepchirchir, R. T., Macharia, I., Murage, A.W., Midega, C.A., & Khan, Z.R. (2018). Ex-post economic analysis of push-pull technology in Eastern Uganda. *Crop protection*, 112,356-362.

Chepchirchir, R. T., Macharia, I., Murage, A.W., Midega, C.A., & Khan, Z.R. (2017). Impact assessment of push–pull technology on incomes, productivity and poverty among smallholder households in Eastern Uganda. *Food Security*, 9 (6), 1359-1372.

APPENDIX 4: List of Conference Papers, Poster and Submitted Manuscripts

Chepchirchir, R. T., Macharia I, Murage A.W, Midega C.A.O., Khan Z. R. Impact assessment of push-pull technology on incomes, productivity and poverty among smallholder households in Eastern Uganda. Paper presented at the African Association of Agricultural Economists (AAAE) conference held in Addis Ababa, Ethiopia from 23rd to 26th September 2016

Chepchirchir, R. T., Macharia I, Murage A.W, Midega C.A.O., Khan Z. R. Impact of push-pull technology on smallholder farmers' welfare: A generalized propensity score approach. Poster presentation given at: Agriculture for Food Security Post 2015 – The Role of Science; 23- 24 September 2015, Uppsala, Sweden. http://www.siani.se/agri4d_booklet_final_web.pdf

Manuscript under review

Chepchirchir R., Macharia I., Murage A.W., Midega C.A.O. and Khan Z.R. Characterizing farming systems and understanding Push–pull technology integration in Eastern Uganda. *Crop protection journal*