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Does gender matter in the adoption of sustainable agricultural technologies? A case of push-pull technology in Kenya

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Abstract

This paper examines if there is difference in the adoption of push-pull technology and other sustainable agricultural practices on plots managed by males, females and plots that are jointly-managed by males and females using plot level and gender disaggregated data. The econometric results suggest that there is no gender heterogeneity in the adoption of push-pull technology when the plot manager and plot characteristics are controlled for, suggesting that the technology is gender neutral. However, gender differences in the adoption pattern of other practices are evident. Jointly managed plots are more likely to adopt animal manure and soil and water conservation compared to male and female-managed plots. We do not, however, find any gender differences in the adoption of the rest of the practices. The analysis further shows that there is a significant correlation between push-pull and other sustainable agricultural practices, suggesting that the adoption of agricultural technologies is interrelated. The gender neutrality suggests that a program that considers women in the promotion and dissemination of push-pull technology can enhance the food security status of women and their households.

Keywords: push-pull technology, sustainable agricultural practices, gender, Kenya, Africa

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I. Introduction

Agriculture remains the driver of economic growth, poverty reduction and food security in many developing economies. In sub-Saharan Africa, the sector generates 33% of the Gross Domestic Product (GDP) on average and employs 60% of the labour force (World Bank, 2011). Women supply over 65% of the agriculture labour force in the region (World Bank, 2011). However, low productivity remains a challenge especially among women farmers who tend to have access to fewer resources, including land, market information, extension services, and credit compared to male farmers (Doss & Morris, 2000; Quisumbing & Pandolfelli, 2010). The challenge of low agricultural productivity of female managed farms has been mainly attributed to low rates of adoption of agricultural technology among women, compared to men (Doss & Morris, 2000; Doss, 2001; Quisumbing & Pandolfelli, 2010; Peterman, Behram & Quisumbing, 2014). Addressing gender inequality in agricultural production systems can transform livelihoods of farming communities, enhance economic growth and provide enabling institutional cultures (Kristjanson Waters-Bayer, Johnson, Tipilda, Njuki, Baltenweck, Delia & MacMillan, 2014).

In Sub-Saharan Africa, cereal stemborer and the parasitic *Striga* weed have been a serious threat to sustainable maize production (Khan & Pickett, 2004; Khan, Midega, Amudayi, Hassanali & Pickett, 2008). Stemborer pest and *Striga* weed can cause yield losses up to 88% and 100%, respectively (Midega, Bruce, Pickett, Pittchar, Murage & Khan., 2015). To address these challenges, push-pull technology (PPT) has been developed by icipe and its partners over the past 20 years. Push-pull technology is a cropping system in which maize is intercropped with perennial fodder legumes (Desmodium) that repel stemborers and suppress *Striga* weed, and surrounded by a border perennial fodder grass (Napier or Brachiaria) that attracts (pulls) stemborers away from the cereal crop (Khan, Midega, Pittchar, Murage, Birkett, Bruce & Pickett, 2014). The fodder crops provide added benefits that include: enhancing soil fertility through nitrogen-fixation and organic matter addition; nearly eliminating soil erosion; and providing high quality livestock forage that increases milk production, contributing to improved income and nutritional security in smallholder households.

There are clear indications of success of this technology, with farmers reporting doubled and tripled cereal yields and more fodder for the livestock (Khan, Pickett, Wadhams & Muyekho, 2001; Cook, Khan & Pickett, 2006; Khan, Amudayi, Midega, Wanyama, & Pickett, 2008; Murage, Midega, Pittchar & Khan, 2015). Over 122,000 households have been reached by the programme in Kenya, Uganda, Tanzania, Ethiopia, Zambia, Malawi, Somalia, and Nigeria.

The determinants of the PPT adoption have been evaluated in past studies (Murage, Obare, Chianu, Amudavi, Pickett, & Khan, 2011; Murage et al., 2015), with less attention given to understanding how gender affects technology adoption including resource management and adoption decisions. Murage et al. (2015) attempt to analyze the gender perceptions in the adoption of the technology, but looked at the gender of the household head rather than the specific plot or farm manager within the household. Similarly, most studies on agricultural technology adoption have mostly focused either on identifying factors associated with the adoption of individual technologies (e.g, Ade Freeman & Omiti, 2003; Chirwa, 2005; Doss & Morris, 2000; Erbaugh, Donnermeyer, Amujal & Kidoido, 2010), or multiple technologies (e.g. Marenya & Barrett, 2007; Teklewold, Kassie & Shiferaw, 2013; Kassie, Teklewold, Jaleta, Marenya & Erenstein, 2015; Diiro, Ker & Sam, 2015; Wainaina, Tongruksawattana & Qaim, 2016). While these studies provide useful insights on the adoption of sustainable agricultural practices (SAPs), the majority of them assume a patriarchal theory of the household; that every member of the household has similar preferences and hence a common utility, yet studies have shown that the adoption of new agricultural technologies depends on who in the household makes the investment and managerial decisions on those plots (Udry, 1996; Ndiritu, Kassie & Shiferaw, 2014).

Analyzing the adoption of SAPs based on the patriarchal perspective could potentially lead to biased conclusions and policy recommendations. The proposed study seeks to contribute to the limited literature on gender and technology adoption by analyzing the adoption of the push-pull technology across different cereal plots, differentiating plots managed by men, women and both together. Specifically, the objective of this study is to establish whether there are systematic gender differences in the adoption of PPT. The insights of this study will provide a better understanding of gender adoption gaps and causes of these gaps which will offer relevant information for designing promising agricultural policy options to boost cereal productivity that can enhance income growth, food security and poverty reduction for male and female farmers in sub-Saharan Africa. The study hypothesizes that there are no systematic differences in the adoption of push-pull technology between male- and female-managed cereal plots.

Push-pull technology is one form of agricultural technology that aims at fostering agricultural development among small-scale farmers. Other strategies, including low-external-input strategies, such as the use of organic manure and soil and water conservation, as well as input intensification strategies, for instance, the use of inorganic fertilizer, have also been highlighted in existing literature as technologies that can help increase productivity and thus improve access to food and reduce poverty (De Janvry & Sadoulet, 2001; Pingali, 2007; Minten & Barrett, 2008). Against this background, while focusing on the adoption of push-pull technology alone would still be useful for our research question, we recognize that integrating other SAPs in our analysis, would provide a broader picture and can compare, and identify complementarities and substitutes, that may enhance or hinder push-pull adoption. Consequently, we jointly explore technology adoption gender differences of PPT and other SAPs including maize-grain legume intercropping, crop rotation, inorganic fertilizer, improved maize seeds, manure and soil and water conservation.

Push-pull technology has triggered other farm enterprises including poultry and dairy farming crops thus providing important input for organic farming through preparation and use of animal manure (Khan et al., 2014; Murage et al., 2015). Organic manure can, therefore, be viewed as a complementary practice, that cannot be overlooked when assessing PPT adoption. From a different view, the use of organic manure is cited as an alternative method for reducing *Striga* infestation (Ogborn, 1984; Reda, Ransom, Bayu, Woldewahid & Zemichael, 2000), hence, could also be a substitute of the PPT. Farmers in the study area use physical soil and water conservation (SWC) practices to protect their plots from soil erosion. However, there is a trade-off, as this practice takes productive land away from production. In such circumstances, farmers may switch to multifunctional technology, PPT, that protects the soil and enhances soil quality through nitrogen fixation. On the other hand, with the current incidences of flooding and drought, farmers may integrate SWC with yield enhancing practices such as PPT to increase their resilience further. Soil and water conservation can, therefore, be considered a complementarity, and, or substitute practice to push-pull technology.

Although the use of chemical inorganic fertilizer is not considered as one of the sustainable agricultural practices (Lee, 2005), other nutrients, in addition to nitrogen, that are provided by the PPT, may not be readily available and thus must be supplemented through fertilizer application. For instance, in their study in western Kenya, Gacheru and Rao (2001) noted the need to correct for phosphorus (P) deficiency in addition to suppressing *Striga* infestation through nitrogen fixation in order to achieve increased maize yield. While intercropping maize with fodder legume (PPT) has been found to significantly reduce the *Striga* weed (Khan, Hassanali, Overholt, Khamis, Hooper, Pickett, Wadhams & Woodcock, 2002), some farmers may prefer maize-grain legume intercropping as immediate subsistence food, and cash needs surpass production for livestock because of imperfect grain markets. In addition, grain-legume intercropping can also fix nitrogen and help to suppress pest diseases and weeds. On the other hand, crop rotation has been cited as one of the traditional methods of *Striga hermonthica* control (Robson & Broad, 1989), thus crop rotation may be perceived as a tradeoff to the PPT. High-yielding varieties can provide high yields under favorable, high-input conditions compared to the traditional or local farmer varieties. Support and promotion of improved maize seeds in the PPT platform, therefore, would lead to positive interactions in enhancing productivity and resilience of cereal production systems.

Some of the above synergies and tradeoffs among different sustainable agricultural practices (SAPs) have been demonstrated in recent empirical studies including (Kassie, Zikhali, Manjur & Edwards, 2009; Teklewold et al., 2013; Ndiritu, et al. 2014; Kassie et al. 2015; Wainaina et al. 2016). Similar studies are, however, needed for the PPT. Understanding the synergies that exist between the technology and SAPs, and integrating gender, is crucial for technology dissemination and adoption processes. We apply a multivariate probit model that accounts for the fact that the adoption of one practice is not mutually exclusive of another, using plot and household-level data obtained from maize-growing farms in the western region of Kenya.

The rest of the paper is organized as follows: the next section highlights the relationship between gender and technology adoption. Section 3 describes the materials and methods including the study area, data sources, descriptive statistics and conceptual and empirical model. Section 4 presents the empirical results, and section 5 concludes by summarizing and outlining the policy recommendations obtained from this study.

II. Gender and technology adoption

In sub-Saharan, effective application of agricultural technologies in production has strategic gender implications. Men and women often have unequal access to, and use of new technologies. Although most of the technologies may be gender neutral, project design and implementation may be biased towards one sex, often toward male farmers, thus hindering women's participation (Njuki et al., 2011). New technologies may also reduce the role of women even if they were the main contributors of farm production before the technology shift (Dolan, 2001; Shiundu & Oniang'o, 2007). Gender differences, therefore, cannot be overlooked while developing sustainable agricultural technologies for alleviating poverty and food insecurity in sub-Saharan Africa.

In Kenya, women provide 60% to 80% of labour in the household and reproductive activities, and in agricultural production (Government of Kenya (GoK), 2010), but have limited access to productive resources. For instance, although existing land laws provide rights and privileges for both men and women, land ownership in Kenya, especially in rural settings, is governed by customs and social conventions, that compromise the equality enshrined in the legal laws, often excluding women (Heyer, 2006; GoK, 2010). Land inheritance is the most common way of acquiring land in Kenya, and is mainly biased to male heirs. Women often lack legal knowledge or are limited by social traditions to exercise their land-use rights (Quisumbing & Pandolfelli, 2010). Lack of secure land use rights, as well as limited access to other agriculture-related resources, therefore, have gender implications on technology adoption.

Major contributions to the literature on gender-related issues in agriculture technology adoption in developing countries include reviews by Doss (2001), Quisumbing and Pandolfelli (2010), Croppenstedt, Goldstein and Rosas (2013), and Peterman et al. (2014). These reviews focus on existing microeconomic studies on gender differences in use, access, and adoption of land and non-land agricultural inputs including the use of improved crop varieties, labour, fertilizer, credit and extension services. The studies demonstrate the complexity of gender norms and roles that are heterogeneous within different cultures and contexts, and thus may affect the way a technology is perceived and consequently adopted. Emphasis is given to the need to focus on a wide range of gender indicators to provide a rigorous evaluation of different agricultural interventions, and to design culture and context specific policies that allow equitable access to resources among men and women farmers. These studies underscore the need to collect and analyze plot-level gender-disaggregated data, which is limited in previous studies. The current study contributes to bridging this gap. In general, the studies reviewed observe unequal access and use of complementary inputs, including land, labour, fertilizer, financial resources, and extension services between men and women, with women being the most disadvantaged group.

Similarly, as the majority of the reviewed studies, Murage et al. (2015) compared female-headed households and male-headed households while evaluating the adoption of PPT. This may not be a perfect gender indicator as the performance of farm plots depends on the decision maker of those plots (Udry, 1996; Peterman et al., 2014). Murage et al. (2015) observed that women's lack of access to productive resources compelled them to adopt the PPT, and therefore they were likely to reap higher benefits from the technology compared to male farmers. Disaggregating the analysis further by the gender of the plot manager, as aimed at in the current study, would identify gender inequalities that may affect access and adoption of the technology, and suggest policies needed to address those inequalities.

There are a few studies that look at how the gender of the plot manager affects the adoption of agricultural innovations and practices. For instance, Udry (1996) who considered the gender of the plot manager in Burkina Faso, found that plots controlled by women had less output per unit land than similar ones managed by men, attributing the difference to inadequate access to inputs by female farmers. Similarly, Doss and Morris (2000), in their study on the adoption of improved maize and chemical fertilizer in Ghana, linked the differences in adoption between men and woman to gender-related differences in access to complementary inputs. Chirwa (2005), in his study on the adoption of fertilizer and hybrid maize in Malawi, found no significant association between gender of plot manager and adoption rates, but did find that female-headed households had lower adoption rates than their male counterparts. Likewise, in the same country, Gilbert, Sakala and Benson (2002) found a significant difference in fertilizer use based on the gender of the plot manager. However, once provided with seed and fertilizer inputs for trial, the efficiency was comparable between male- and female-managed plots.

A recent study by Ndiritu et al. (2014) on the adoption of multiple sustainable agricultural practices, based on the gender of plot manager in Kenya, also did not find gender differences in the adoption of improved seed varieties and chemical fertilizer. However, the study by Marenya, Kassie and Tostao (2015) in Mozambique identified joint management of plots to be associated with higher fertilizer use on maize plots, but lower fertilizer use on other non-food cash plots. The above studies provide mixed evidence on agricultural innovations and practices, making it difficult to design policies to address gender-related inequalities in agricultural systems. Further studies, in particular, utilizing plot-level gender-desegregated data, are therefore paramount in addressing these gaps.

While most of the above studies have paid attention to the core pillars of Asia's green revolution in wheat and rice; that is, extensive adoption of improved varieties and fertilizers, there is limited evidence on gender differences in the adoption of natural resource management practices, such as maize-legume intercropping, manure use, crop rotation and soil and water conservation. The majority of the previous studies on sustainable agricultural intensification practices (e.g. Marenya & Barrett, 2007; Teklewold et al., 2013; Kassie et al., 2015, 2009; Wainaina et al., 2016), analyzed the adoption of these practices at household level without considering the gender of the plot manager who makes the investment decisions of those practices. An exception is Ndiritu et al. (2014) who found that compared to male plot managers, female managers were less likely to adopt minimum tillage and animal manure in crop production. The authors, however, did not find gender heterogeneity in regard to maize-grain legume intercropping, maize-legume rotations and soil and water conservation measures. The current study will contribute to the limited studies on the link between gender and the adoption of new agricultural innovations for enhanced food security and poverty reduction among rural farming communities in sub-Saharan Africa.

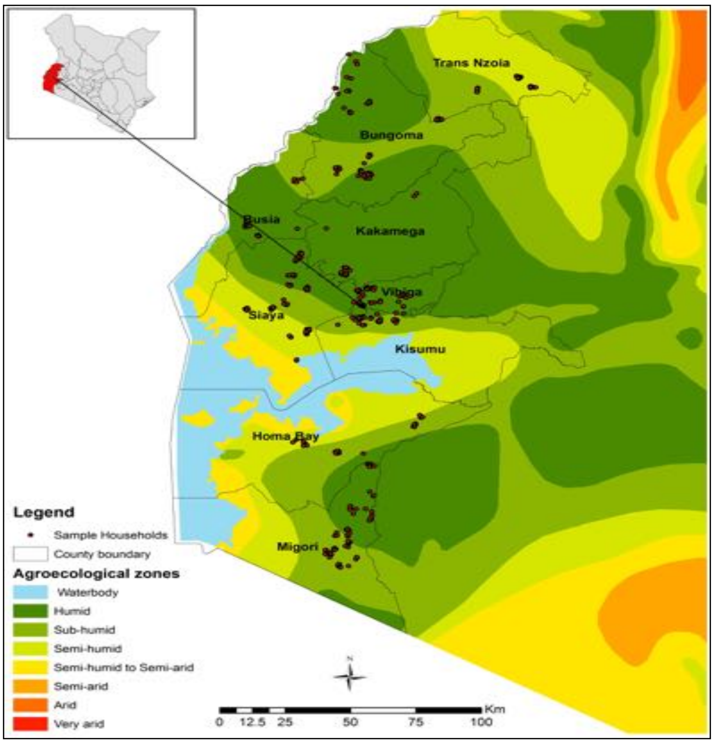
III. Study area and data collection

The study employed comprehensive household and plot level data collected from maize farming households in Western Kenya in 2016 by the International Centre of Insect Physiology and Ecology (*icipe*). The study area falls between the humid and semi-humid agroecological zones characterized by severe infestation of the *Striga* weed and stemborer pests (Khan et al., 2014). A multi-stage sampling procedure was used to select counties, villages and respondent households. In the first stage, nine counties were deliberately selected in Western Kenya where push-pull technology has been promoted and disseminated (namely Migori, Homa Bay, Kisumu, Siaya, Busia, Vihiga, Kakamega, Bungoma, and Trans-Nzoia), as shown in Figure 1. In the second stage, PPT adopters and non-adopters were identified from the population census obtained from each village within the counties. We obtained lists of total farmers from village chiefs and lists of PPT adopters from extension workers and icipe field staff. In the final step, we randomly selected a total sample of 711 rural farming households operating on 4,863 plots for the interviews from 60 villages using a probability proportional to size sampling technique. After removing plots with missing data and apparent enumerator errors, we were left with a sample of 4,472 plots from 710 households.

Data collection took place between July and August 2016. The data were collected by trained enumerators supervised by a researcher from *icipe* using a semi-structured questionnaire that had been programmed in CSPro software. The survey covered detailed information including gender-disaggregated data on plot and plot management, socio-economic and plot characteristics, access to services including credit constrained[1], social capital, input use and crop and livestock production, participation in off-activities. The survey also captured information on technology and practices adoption: push-pull technology, maize-grain legume intercropping, crop rotation, use of inorganic and organic fertilizer, improved maize seeds and soil and water conservation.

1 Household needs credit but unable to get it.

Figure 1: Study area



3.1. Data description and summary statistics

Table 1 provides the description and statistics of the dependent variables used in the regression models. These consist of different SAPs including push-pull technology, presented for the full sample, and by gender of the plot manager (female, male and joint). A plot manager is assumed to be the one who makes most decisions about plot management and other production decisions. Joint decisions are perceived as made equally between male and female members or between head and spouse, in the same household. Male- and female-managed plots make up 25% and 52% of the total plots, respectively, while the rest are managed jointly by both males and females. The large share of plots managed by female farmers is expected for the Kenyan rural context, where most of the farming is managed and practiced by women (Moock, 1976; Ellis, 2007). In addition, while 68% of the households had a male head, and the rest were female-headed, heads of households managed about half of the plots (54%), while the rest were managed either jointly between the head and other household members (22%), or exclusively by other household members (24%). The noteworthy proportion of plot managers that were not heads of households elucidates the need to model technology adoption decisions at plot level and not at household level.

The tests for the equality of proportions for the binary variances are based on unpaired data with unequal variances on plots managed by gender-differentiated managers. About 17% and 23% of all the plots were covered with a push-pull technology (maize-forage legume intercrop) and maize-grain legume intercropping, respectively. Beans were found to be the most dominant grain intercropped with maize. With respect to gender of the plot manager, 26% and 21% of plots managed by males and females, respectively, were covered with maize-grain legume intercropping, and the difference was significant. Fewer plots were covered with push-pull technology, 18% and 16% for male- and female-managed plots, respectively. The bigger proportion of plots practicing maize-grain legume intercropping compared with those adopting PPT is plausible for small-scale farmers, as home consumption needs may increase pressure on available land, thus reducing the volume of livestock feed produced, as food security needs become a priority over commercial livestock production.

Table 1: Gender-disaggregated plot level adoption of sustainable agricultural practices

	Full sample (n=4472)	Male (n=1133)	Female (n=2337)	Joint (n=1002)	Difference	Difference	Difference
	[1]	[2]	[3]	[4]	[2]-[3]	[2]-[4]	[3]-[4]
Push-pull technology (1=Yes, 0=No)	0.168 (0.374)	0.183 -0.387	0.167 (0.373)	0.155 (0.362)	0.016	0.028*	0.012
Maize-grain legume intercropping (1=Yes, 0=No)	0.231 (0.422)	0.266 (0.442)	0.214 (0.410)	0.231 (0.421)	.051***	0.035*	-0.016
Crop rotation (1=Yes, 0=No)	0.148 (0.356)	0.121 (0.326)	0.153 (0.360)	0.169 (0.375)	-0.032***	-0.048***	-0.015
Fertilizer (1=Yes, 0=No)	0.502 (0.500)	0.539 (0.499)	0.493 (0.500)	0.480 (0.500)	0.046***	0.059***	0.013
Manure (1=Yes, 0=No)	0.567 (0.496)	0.519 (0.500)	0.562 (0.496)	0.632 (0.483)	-0.043**	-0.113***	0.018***
Improved maize seeds (1=Yes, 0=No)	0.356 (0.479)	0.402 (0.490)	0.327 (0.469)	0.373 (0.484)	0.074***	0.028	-0.046**
Soil and water conservatior (1=Yes, 0=No)	0.623 (0.485)	0.560 (0.497)	0.631 (0.483)	0.679 (0.467)	-0.071***	-0.119***	-0.048***

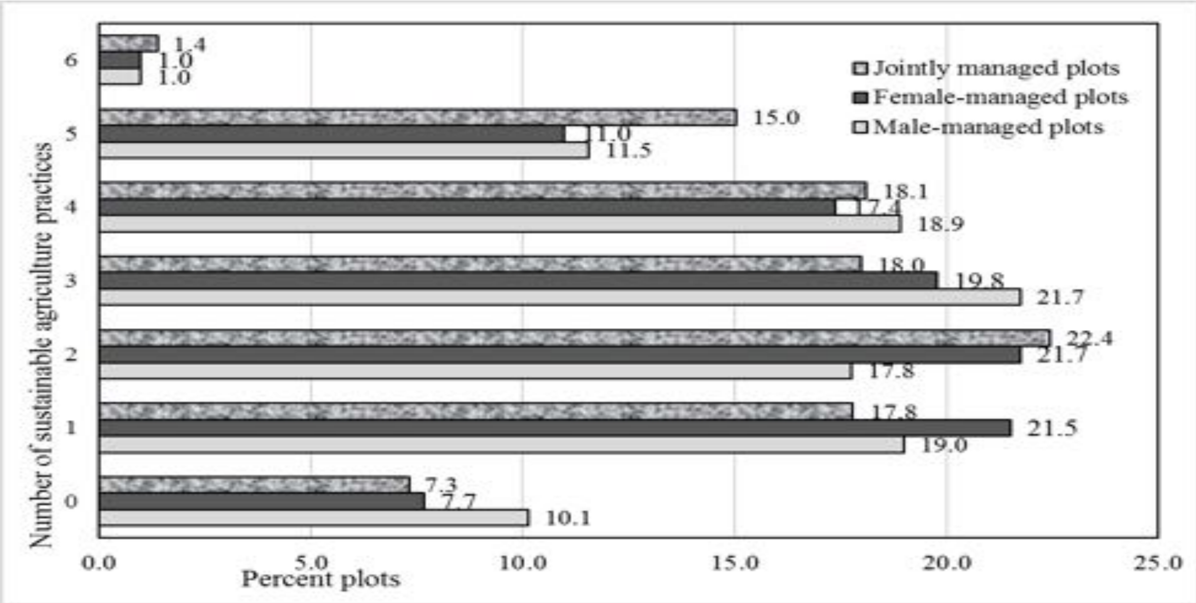
Statistical significance at *P<0.1, **p<0.05, ***0<0.001
Source: Author's computation using survey data

More female-managed plots (15%) practiced crop rotation compared to those managed by males (12%), which is statistically significant. As noted by Glazebrook (2011) in his study on gender and climate change in Ghana, women farmers may adopt crop rotation to improve soil quality and maximize production as they lack resources to buy fertilizer or invest on other productivity improvement strategies. Similarly, more jointly managed plots practice crop rotation compared to those managed by males. Over half of the plots received inorganic fertilizer, with significantly more male-managed plots (54%) compared to those managed by females (49%) and those managed jointly (48%) applying this practice. This corroborates with Udry (1996) who observed that women-controlled plots were less likely to use fertilizer in comparison with plots planted with the same crop but controlled by men in Burkina Faso. Manure (or livestock waste), utilization was comparable between male and female-managed plots. However, more female (56%) and jointly-managed (63%) plots received manure compared to male-managed plots (52%). Contrasting with male farmers, female managers often use low cost soil improvement practices such as manure, while their counterparts prefer to purchase inorganic fertilizer.

Improved maize seed is another sustainable agricultural practice considered in this study. High yielding maize provides for efficient utilization of plots, does also where PPT technology has been invested. A significantly higher proportion of male-managed plots (40%) utilized improved maize seeds compared to female plot managers (33%), perhaps because they demand high cash outlays that may be a constraint to the majority of the women farm managers. Soil and water conservation was practiced in over half of the plots (62%), and of these, significantly more female-managed plots (63%) than male-managed plots (56%) used these practices.

Figure 2 shows the extent of sustainable agricultural practices ownership by gender of the plot manager. About 20% of all plots managed either by males, females or jointly-managed plots did not receive any of the practices. Over 60% of plots managed by either gender received at least two or more practices. The majority of the male-managed plots received over three practices (54%) compared to female-managed plots that received similar practices (49%).

Figure 2: Number of sustainable agricultural practices owned by gender of plot manager



Source: Author's computation using survey data

Table 2 presents plot attributes considered important for the adoption of PPT and other sustainable agricultural technologies by gender of the plot manager following previous studies (Marenya & Barrett, 2007; Kassie et al., 2015, 2009; Teklewold et al., 2013; Ndiritu et al., 2014; Murage et al., 2015; Wainaina et al., 2016). Plots managed by males were bigger in size (0.265 hectares) than those managed by females (0.175 ha), and were located further from the residence. Farmers' perception of soil fertility, where they ranked their plots as good, medium and poor, showed that males dominate in the management of good quality plots (*good fertile plots*) while females manage the less fertile plots. Fewer of the plots managed by females (36%) had good soil fertility compared to 49% of plots under male management.

Table 2: Plot characteristics by gender of plot manager

	Full sample (n=4472)	Male (n=1133)	Female (n=2337)	Joint (n=1002)	Difference
	[1]	[2]	[3]	[4]	[2]-[3]
Plot size in hectares	0.211	0.265	0.175	0.232	0.0125***
	(0.297)	(0.387)	(0.241)	(0.286)	
Plot distance to residence in walking minutes	4.108	4.656	3.699	4.444	0.969*
	(17.283)	(11.644)	(17.262)	(22.013)	
Plot ownership (1= owned, 0=Otherwise)	0.994	0.998	0.997	0.982	0.001
	(0.077)	(0.042)	(0.055)	(0.133)	
Good fertile plot (1=Yes; 0=No)	0.380	0.420	0.359	0.384	0.061***
	(0.486)	(0.494)	(0.480)	(0.487)	
Medium fertile plot (1=Yes; 0=No)	0.545	0.522	0.565	0.527	-0.044**
	(0.498)	(0.500)	(0.496)	(0.500)	
Poor fertile plot (1=Yes; 0=No)	0.074	0.058	0.075	0.089	-0.017**

	(0.262)	(0.234)	(0.264)	(0.285)	
Gentle slope plot (1=Yes; 0=No)	0.488 (0.500)	0.515 (0.500)	0.472 (0.499)	0.497 (0.500)	0.044**
Moderate sloped plot (1=Yes; 0=No)	0.493 (0.500)	0.471 (0.499)	0.511 (0.500)	0.477 (0.500)	-0.040**
Steep sloped plot (1=Yes; 0=No)	0.018 (0.134)	0.013 (0.114)	0.018 (0.131)	0.026 (0.159)	-0.004
Shallow depth plot (1=Yes; 0=No)	0.066 (0.249)	0.062 (0.241)	0.059 (0.235)	0.090 (0.286)	0.002
Moderate depth plot (1=Yes; 0=No)	0.439 (0.496)	0.440 (0.497)	0.455 (0.498)	0.402 (0.491)	-0.014
Deep depth plot (1=Yes; 0=No)	0.494 (0.500)	0.498 (0.500)	0.487 (0.500)	0.508 (0.500)	0.013
Soil loss (1=Yes; 0=No)	0.273 (0.445)	0.266 (0.442)	0.288 (0.453)	0.245 (0.430)	-0.0246
Irrigated plot (1=Yes; 0=No)	0.014 (0.118)	0.013 (0.114)	0.009 (0.097)	0.026 (0.159)	0.004

[a]Note: Statistical significance at *P<0.1, **p<0.05, ***0<0.001; plots with poor fertile soil are reference category in the regression model; [b]plots with steep slope are reference category in the regression model; [c]plots with deep depth soil used as reference category in the regression model
Source: Author's computation using survey data

Of the total cultivated plots by female managers, 57% and 8% were classified as medium and poor in terms of soil fertility, compared to 52% and 6% of male-managed plots, respectively. This may reflect gender bias when plots were originally allocated or lack of resources to invest in soil improvement. Similarly, a significantly higher number of male-managed plots (52%) fall in the gentle slope category, relative to 47% of plots under female management.

Tables 3 and 4 present definitions of independent variables used in the empirical model. We begin with demographic characteristics of male and female plot managers presented in Table 3. On average, male plot managers were older and more educated than female plot managers. A farmer older in age is often related to risk aversion or less flexibility in adopting new techniques, and hence may be negatively associated with the adoption of sustainable agricultural practices (Braun & Kennedy, 1994). Education enhances the allocative ability of decision makers as it enables them to process and use information efficiently, and subsequently adopt new technologies (Heltberg & Tarp, 2002). Subsequently, we expect education to be positively associated with the adoption of sustainable agricultural technologies. Recall education of the plot manager is presented since it is important specifically for the PPT dating back when farmers started adopting the technology. About 62% of the male plot managers had some off-farm income compared to 58% among the female plot managers. Household resource literature treats off-farm income as an exogenous income earning opportunity that could provide capital for technology investment, but may also be a substitute for farm income, thus may deter the adoption of agricultural technology adoption (Braun & Kennedy, 1994; Heltberg & Tarp, 2002).

In addition to the demographic and endowment characteristics of the plot manager, we collected information in relation to social capital and networks that can influence technology adoption decisions. Specific for plot managers, we asked about the number of village institutions or associations of which a manager is a member, such as production and marketing groups. Such social networks are viewed as means to access information, obtain capital, exchange market information and enforce contracts (Fafchamps, 2004). Female plot managers were members in more village groups compared to male managers. Women's participation in village groups is critical for technology dissemination through access to information and capital that may be required for technology investment.

Table 3: Household characteristics by gender of plot manager

	Male plot manager (N=1133)		Female plot manager (n=2337)		Difference
	Mean	SD	Mean	SD	
Current age (years)	51.606	12.478	50.231	11.754	1.375***
Current education (years of schooling)	9.279	3.661	7.403	3.683	1.875***
Education 5 years ago (years of schooling)	9.139	3.642	7.273	3.674	1.866***
Off-farm income (1=Yes,0=No)	0.652	0.476	0.581	0.493	0.071***
Number of village membership groups	3.173	1.839	4.361	2.017	-1.188***

Statistical significance at *P<0.1, **p<0.05, ***0<0.001
Source: Author's computation using survey data

Table 4 presents common household-level variables that are expected to influence technology adoption based on a review of economic theory and empirical literature on the adoption of agricultural technologies.

Table 4: Household, social capital and village level characteristics of sample households

	Full sample (N=711)	
	Mean	SD
Household characteristics		
Current household size (adult equivalent)	3.107	1.110
Household size (5yrs ago, adult equivalent)	6.706	3.259
Credit constrained (1=Yes, 0=No)	0.610	0.488
Household resources		
Current livestock owned (TLU)	1.520	1.832
Livestock (5yrs ago,)	3.169	2.861
Ownership of exotic cow bread (1=Yes, 0=No)	0.183	0.387
Own a cow (1=Yes, 0=No)	0.376	0.485

Current farm size (hectare)	1.145	5.769
Owned farm size 5 years ago (hectares)	2.693	3.054
Per capita expenditure	21,109.41	14,432.30
Major farm assets and furniture ('000 KES)	73.267	166.469
Off-farm income (1=Yes, 0=No)	0.865	0.342
Hired labor (1=Yes, 0=No)	0.632	0.483
Household access to services		
Distance to main input market (walking minutes)	52.270	43.009
Distance to nearest main market (walking minutes)	60.596	40.862
Social capital		
Confidence on government extension services (1=Yes, 0=No)	0.806	0.396
Number of reliable relatives (count)	7.502	24.799
Relatives in official position	.454	.498
Location dummy		
Migori county (1=Yes, 0=No)	0.180	0.384
Kisumu county (1=Yes, 0=No)	0.104	0.306
Siaya county (1=Yes, 0=No)	0.174	0.380
Busia county (1=Yes, 0=No)	0.042	0.201
Vihiga county (1=Yes, 0=No)	0.122	0.328
Kakamega county (1=Yes, 0=No)	0.060	0.239
Bungoma county (1=Yes, 0=No)	0.103	0.304
Tranzoia county (1=Yes, 0=No)	0.097	0.296
HomaBay county (1=Yes, 0=No)	0.117	0.321
PPT related variables (n=357)	***n=357***	
Age at PPT adoption	51.331	11.419
Number of PPT adopters in the village	5.031	3.318
Number of training attended	2.563	4.175
Number of field days attended	2.451	2.338
Farmer's perception on the PPT usefulness (1=effective, 0=otherwise)	0.404	0.491

Source: Author's computation using survey data; TLU abbreviated for Tropical Livestock Unit

On average, household size was higher five years ago (6.7), above the national average of 4.6 (GoK, 2010) than its current size (3.1). With respect to household resources, on average, livestock owned five years ago was more than the current herd. This was in contrast to our expectation, since push-pull technology allows the integration of livestock husbandry, as the companion plants provide valuable and nutritious fodder (Khan et al., 2014). Subsequently, the technology is expected to enhance livestock production among smallholder farmers. Similarly, the current farm size is lower than the size of land owned five years ago. Access to, control over and ownership of assets are critical for stable and productive lives, especially among rural dwellers. Assets can act as collateral and facilitate access to credit and financial services that may be required for adoption of a new technology.

With respect to household-level social capital variables, about 80% of the reported farmers had confidence in services derived by government extension workers. Acces to extension services for both male and female farmers is decisive for agricultural technology adoption (Quisumbing & Pandolfelli, 2010). The number of people within and outside the village that the households can rely on in times of critical needs, and those in offical positions are also considered as important determinants of technology adoption. Such social networks and collective action are widely promoted as they improve access to information and capital for technology adoption, resulting from imperfections in the rural markets (Shiferaw, Kebede, Kassie, & Fisher, 2015).

A few additional variables were considered for PPT adopters, as shown in Table 4. In addition to the recall demographic characteritics (age and education) presented in Table 3, the number of PPT adopters in a village, training attended, the number of field days attended and farmer's perception of the PPT effectiveness are also considered as drivers for PPT technology.

IV. Econometric framework and estimation strategy

This study analyzes the gender dimensions of adoption of sustainable agricultural practices (SAPs) by examining adoption patterns of multiple practices adopted by female and male plot managers in a maize producing system in Western Kenya. These SAPs include push-pull technology, maize-grain legume intercropping, crop rotation, improved maize seed varieties, fertilizer, manure and water and soil conservation. We follow recent studies (Marenya & Barrett, 2007; Kassie et al., 2009; Teklewold, et al., 2013; Ndiritu et al., 2014; Kassie et al., 2015; Wainaina et al., 2016) that recognize that farmers adopt technologies at plot or household level as complementarities and substitutes in multiple ways to address their production constraints, for instance, weeds, pests, and diseases (see, for instance, the unconditional analysis in Figure 1). That is, the adoption of one practice may trigger or hinder the adoption of other practices.

Estimating multivariate decisions as separate adoption equations; for instance, using a univariate technique such as probit analysis for discrete choice dependent variables to model each of the agriculture practices individually, would provide biased results as the estimations ignore interdependence or correlation among the unobserved disturbances in the adoption equations (Cappellari & Jenkins, 2003). Complementarities and substitutabilities between different practices may be a source of correlations between error terms (Belderbos, Carree, Diederen, Lokshin & Veugelers, 2004). Unobservable household-specific factors that affect the choice of different practices that cannot be measured, for instance, indigenous skills, may also be a source of correlation. Multivariate probit model (MVP) accounts for these correlations. The MVP simultaneously models the effect of a set of covariates on each of the different SAPs while allowing the unobserved factors (error terms) to be correlated (Greene, 2012). The MVP model for multivariate choice decision problems can be represented in two levels. First, a set of equations with latent dependent variables are described as a linear function of a set of observed household (*i*) and plot (*p*) characteristics (X_{ipm}) and a multivariate normally distributed error terms ($_{ipm}$) such that each equation is given as follows:

$$y^*_{ipm} = \boldsymbol{X_{ipm}\beta} + \ _pG + \ _{ipm} \quad m = 1,2,.......,7 \qquad (1)$$

where y^*_{ipm} represents latent dependent variables that can represent the level of expected utility derived from adoption, *m* (1,2,……,7) denotes the different SAPs including push-pull technology, and $\boldsymbol{\beta}$, is a vector of parameters to be estimated. The gender of the plot manager is represented by *G (*given as male, female or joint) while $_p$ is the parameter of interest that shows the effect of the gender of the plot manager on technology adoption. Each of the error terms $_{ipm}$, *m*=1,2,….,*7,* has a mean of zero, and variance-covariance matrix *V,* where *V* has values of 1 on the leading diagonal and correlations $_{jk} = \ _{kj}$ as off-diagonal elements. Household *i,* may decide to adopt a certain combination of the practices (*m*=1,2….,*7),* if the expected utility from adopting the specific practices is greater than not adopting. The set of equations that describes the observable decision of households is given as:

$$y_{ipm} = 1 \quad if \quad y^*_{ipm} > \boldsymbol{0} \text{ and } 0 \text{ otherwise} \qquad (2)$$

where y_{ipm} represents the adoption of the *m*th technology by the *i*th household on plot *p.* The error terms are assumed to be jointly distributed multivariate random variables. Key explanatory variables X_{ipm} that are likely to affect adoption of push-pull technology and other SAPs, as highlighted in the previous section, are selected based on reviewed theoretical and empirical literature on gender differences and technology adoption. These include the socio-economic factors, broadly classified as household characteristics (age and education level of plot manager, household size, and credit availability), household resources and assets (per capita expenditure, asset ownership including livestock and other productive farm assets, furniture, farm size, off-farm income and hired labour), access to services (input and output market access), social capital (farmer's confidence on government extension services, farmer groups' membership, availability of rural institutions, relatives in official positions, relatives who can be relied on during periods of critical need), plot characteristics and location dummies.

V. Empirical results and discussions

This section presents the correlation complementarity and tradeoffs between push-pull technology and other SAPs and factors influencing the adoption of these practices. The estimation of determinants of the adoption has two parts: first, farmers' choice of interrelated SAPs is modelled using a multivariate probit (MVP) model; second, we analyze the determinants of the extent of combinations of SAPs adopted (number of practices) using ordered probit.

5.1. Complementarity and tradeoffs among SAPs

Results on the complementarities and substitutabilities of the practices are presented in Table 5. The likelihood ratio test [chi2 (21) = 2725.14; Prob > chi2 = 0.0000] rejects the null hypothesis of zero correlation between the covariance of the error terms across equations, suggesting that the multivariate probit model is preferred over single-equation probit models. This is supported by the correlation between error terms of the adoption equations reported in Table 5.

The negative correlation between push-pull and maize-grain legume intercropping supports our earlier argument that immediate food security and cash needs may surpass the production of livestock feed. Crop rotation is also a substitute of push-pull technology. This is because push-pull is a long-term investment which affects farmers farm planning such as crop rotation. The rest of the technologies and, or practices (fertilizer, manure, and improved maize varieties) were positively correlated with push-pull technology, indicating technological complementarities. Although desmodium can fix nitrogen, farmers still need to apply other types of fertilizer (e.g. DAP). These synergies are plausible because under push-pull, two crops are grown at the same time with a different demand for fertilizer and intercropping can also serve as a risk mitigation strategy so that a push-pull farmer can apply more fertilizer. Besides, as noted by Gacheru and Rao (2001), phosphorus (P) deficiency is common in western Kenya, so reduction of *Striga* alone through PPT may not increase yields unless P deficiency is corrected. Push-pull technology promotes livestock and poultry production, thus increasing the availability and utilization of manure.

There were also complementarities and substitutability among other sustainable agricultural technologies (see Table 5).

Table 5: Complementarities and substitutability of SAPs: Correlation coefficient of error terms

	Push-pull technology	Maize-grain legume intercropping	Crop rotation	Fertilizer	Manure	Improved maize seeds	Soil and water conservation
Push-pull technology	1						
Maize-grain legume intercropping	-0.155*** (0.027)	1					
Crop rotation	-0.093*** (0.031)	-0.151*** (0.031)	1				
Fertilizer	0.507*** (0.025)	0.319*** (0.026)	-0.100*** (0.027)	1			
Manure	0.297*** (0.026)	0.180*** (0.025)	-0.030 (0.026)	0.359*** (0.021)	1		
Improved maize seeds	0.624*** (0.023)	0.324*** (0.025)	-0.213*** (0.028)	0.761*** (0.013)	0.404*** (0.022)	1	
Soil and water conservation	0.053* (0.027)	0.035 (0.026)	-0.012 (0.027)	0.026 (0.024)	0.086*** (0.024)	0.064*** (0.024)	1

Robust standard errors in parenthesis
The likelihood ratio test of overall error terms correlation is rejected (chi2(21) = 2725.14; Prob > chi2 = 0.0000). *N*=4,472
Statistical significance at *P<0.1, **p<0.05, ***0<0.001

5.2. Determinants of sustainable agricultural practices: MVP model results

Table 6 reports on the MVP model regression results. The key variables of interest are those related to the gender of plot manager, where male-managed plots were used as the reference category. The results indicate there was no gender difference in the adoption of push-pull technology. This implies that push-pull technology is gender neutral, probably because it does not demand a high cash outlay once it is established, compared to other technologies. This supports the inclusive promotion and dissemination of the technology to increase the food security status of women and their households.

Similarly, there was no gender difference in the adoption of maize-grain legume intercropping, fertilizer, and improved maize seeds. Compared with male managed plots, jointly managed plots were more likely to adopt crop rotation, manure, and soil and water conservation. The positive association between adoption of manure and soil and water conservation and jointly managed plots was expected since both practices are labour intensive, and thus may require joint effort of household members. Further comparison between female and jointly managed plots[2] revealed that jointly-managed plots were more likely to apply manure and soil and water conservation, again suggesting the importance of joint effort in undertaking labour intensive farming activities.

Other drivers of technology adoption included social capital, information, socio-economic and plot characteristics (Table 6). Among the social capital and network variables, the number of village groups associated with the plot manager had a significant and positive impact on the adoption of PPT, improved maize seeds and soil and water conservation. Likewise, the adoption of maize-grain legume intercropping, fertilizer, manure and improved maize seeds, increased with the number of relatives that can be relied on for support during times of need. Having a relative in an official position also increased the probability of adopting maize-grain legume intercropping. The significant role of social capital suggests the need to strengthen farmer associations to enhance and sustain technology adoption. Such local institutions play a critical role in providing farmers with information, input access and technical support and insurance, especially in rural settings where input and output

[2] The analysis was repeated using jointly managed plots as the reference group. The results are not shown here but available on request from the authors

markets are missing or incomplete. Confidence in government extension, another form of social capital, had a positive and significant influence on adoption of maize-grain legume intercropping, crop rotation, fertilizer, manure and soil and water conservation, suggesting that improving the quality of extension services can facilitate the adoption of agricultural technologies and practices. Kassie et al. (2015) found similar results in Kenya, Tanzania, Malawi and Ethiopia.

The number of PPT training and field days attended had a significant and positive effect on the adoption of push-pull technology, suggesting that certain skills and knowledge are required at the intial establishment of the tehcnology and for continued management.

As expected, credit constrained households were likely to adopt crop rotation and manure, which would be considered less capital-intensive compared with most of the other practices. Regarding farmer characteristics, the age of the plot manager at the time of PPT adoption was positively associated with the adoption of push-pull technology. A plausible explanation is that older farmers with longer farming experience have experienced prolonged maize losses due to the *Striga* weed and stemborer, and are thus more willing to try the technology. However, there was a negative association between plot managers' age and the adoption of maize-grain legume intercropping and crop rotation, but a positive association with manure. Education of the plot manager was positively related to the adoption of push-pull technology and improved maize seeds. On the other hand, it was negatively associated with maize-grain legume intercropping, which is consistent with findings by Ndiritu et al., (2014). Finally, farm households with a large family size were less likely to adopt crop rotation; perhaps due to land shortage and also that subsistence farmers may focus more on producing stable crops using the available land at their disposal.

With respect to plot characteristics, plot size was negatively associated with adoption of PPT while it was positively associated with maize-grain legume intercropping inorganic fertilizer, manure, and improved maize seeds, which is consistent with the findings of Ndiritu et al., (2014). A possible reason for the negative association between plot size and PPT is that the technology reduces the area for maize production due to disodium and border forage crops intercropping. The negative relationship between plot distance and PPT is possible since the fodder crops should be protected from livestock grazing and probably to avoid theft of fodder crops. The results further show that perceived plot characteristics were important for the choice of push-pull technology. For instance, plots perceived to have good and medium soil fertility were likely to adopt the technology, perhaps to maximize the expected higher returns, while those plots with high potential soil-loss were less likely to receive the technology.

Table 6: Multivariate probit model results

	Push-pull technology	Maize-grain legume intercropping	Crop Rotation	Fertilizer	Manure	Improved maize seeds	Soil and water conservation
Plot managers							
Female-managed plots	-0.015	-0.065	0.095	0.079	0.071	0.017	-0.073
	-0.068	(0.064)	(0.069)	(0.057)	(0.055)	(0.056)	(0.056)
Jointly managed plots	-0.022	-0.036	0.160**	-0.001	0.238***	0.100	0.139**
	(0.079)	(0.071)	(0.078)	(0.064)	(0.064)	(0.065)	(0.065)
Plot characteristics							
Ln(plot area)	-0.269***	0.715***	-0.147***	0.434***	0.043**	0.365***	-0.071***
	(0.025)	(0.034)	(0.024)	(0.026)	(0.022)	(0.022)	(0.022)
Plot distance to residence	-0.011**	-0.002	-0.005	0.000	-0.016***	-0.001	-0.005***
	(0.005)	(0.001)	(0.004)	(0.001)	(0.004)	(0.002)	(0.002)
Plot ownership (1=Yes; 0=No)	0.015	0.180	-0.165	-0.443	0.059	-0.424	-0.365
	(0.352)	(0.281)	(0.295)	(0.287)	(0.303)	(0.261)	(0.261)
Good fertile plot (1=Yes; 0=No)	0.730***	-0.320***	-0.298***	0.292***	0.447***	0.565**	-0.029
	(0.127)	(0.091)	(0.097)	(0.088)	(0.085)	(0.088)	(0.088)
Medium fertile plot (1=Yes; 0=No)	0.223*	-0.250***	-0.055	0.166**	0.333***	0.259***	-0.006
	(0.125)	(0.088)	(0.090)	(0.085)	(0.082)	(0.085)	(0.085)
Gentle slope plot (1=Yes; 0=No)	-0.032	0.303	0.000	-0.035	0.053	0.210	-0.831***
	(0.226)	(0.187)	(0.184)	(0.161)	(0.150)	(0.190)	(0.190)
Moderately slope plot (1=Yes; 0=No)	-0.163	0.260	0.037	-0.148	-0.043	0.102	-0.568***
	(0.225)	(0.185)	(0.182)	(0.160)	(0.148)	(0.190)	(0.190)
Shallow depth plot (1=Yes; 0=No)	0.015	-0.012	0.047	0.028	-0.235***	0.017	-0.652***
	(0.110)	(0.096)	(0.101)	(0.090)	(0.086)	(0.085)	(0.085)
Medium depth plot (1=Yes; 0=No)	-0.034	0.099*	-0.029	0.020	0.152***	0.089**	-0.025
	(0.053)	(0.051)	(0.054)	(0.045)	(0.044)	(0.045)	(0.045)
Soil loss (1=Yes; 0=No)	-0.122*	0.138**	0.063	0.093*	0.254***	0.089*	0.639***
	(0.064)	(0.058)	(0.062)	(0.052)	(0.051)	(0.055)	(0.055)
Farmer characteristics							
Plot manager age 5 years ago	0.009***						
	(0.002)						
Current plot manager age		-0.008***	-0.004*	0.003	0.004***	-0.001	0.003*
		(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Plot manager education 5 years ago	0.025***						
	(0.008)						
Current plot manager education		-0.022***	0.012	0.010	0.010	0.022***	0.006
		(0.008)	(0.008)	(0.007)	(0.007)	(0.007)	(0.007)
Household size 5 years ago	-0.010						
	(0.015)						
Current household size		-0.031	-0.080***	-0.028	-0.034	0.025	0.011
		(0.026)	(0.026)	(0.022)	(0.022)	(0.022)	(0.022)
Credit constrained	0.019	0.003	0.175***	0.048	0.096**	-0.037	-0.086*
	(0.055)	(0.052)	(0.053)	(0.046)	(0.045)	(0.046)	(0.046)
Household resources							
Livestock owned 5 years ago	-0.022**						
	(0.009)						
Current livestock owned		-0.003	-0.023	0.017	0.072***	0.018	-0.021
		(0.016)	(0.016)	(0.013)	(0.014)	(0.014)	(0.014)
Ownership of a cow	0.032	0.078	0.121*	0.065	0.019	0.034	-0.139***
	(0.056)	(0.060)	(0.062)	(0.052)	(0.052)	(0.053)	(0.053)
Ln (owned farm size 5 years ago)	0.081						
	(0.087)						
Ln(current owned farm size)		-0.444***	0.213***	-0.322***	-0.130***	-0.286***	0.024
		(0.048)	(0.035)	(0.036)	(0.032)	(0.030)	(0.030)

Ln(per capita expenditure)	-0.013	-0.103**	-0.080	0.021	0.188***	0.083***	-0.027
	(0.047)	(0.047)	(0.049)	(0.042)	(0.041)	(0.041)	(0.041)
Ln(major farm assets and furniture)	-0.024	0.002	0.021	0.010	0.049*	0.021	0.079***
	(0.032)	(0.029)	(0.031)	(0.026)	(0.026)	(0.027)	(0.027)
Off-farm income	-0.097*	0.000	0.220***	0.026	-0.097**	-0.007	0.024
	(0.054)	(0.051)	(0.055)	(0.046)	(0.045)	(0.046)	(0.046)
Hired labour	-0.077	0.010	-0.055	0.061	-0.076*	-0.023	0.062
	(0.057)	(0.054)	(0.055)	(0.047)	(0.045)	(0.046)	(0.046)
Household access to services							
	(0.080)	(0.071)	(0.074)	(0.058)	(0.058)	(0.060)	(0.060)
Distance to the nearest main output market	0.000	0.001*	0.001	-0.002***	-0.001	-0.001	-0.001**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Distance to the nearest main input market	0.002**	-0.002***	0.000	0.000	0.002***	0.000	-0.002***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Farmer's perception of the PPT usefulness	0.364***						
	(0.052)						
Number of PPT training attended	0.002***						
	(0.000)						
Number of PPT field days attended	0.022***						
	(0.005)						
Number of PPT farmers in the village	0.001						
	(0.001)						
Social capital							
Confidence on government extension	0.046	0.299***	0.228***	0.136**	0.104*	0.027	0.347***
Number of plot manager village membership groups	0.035**	-0.055***	0.012	0.010	0.067***	0.008	0.100***
	(0.014)	(0.014)	(0.014)	(0.012)	(0.012)	(0.012)	(0.012)
Reliable relatives (count)	0.001	0.002***	-0.002	0.005***	0.003***	0.002*	-0.002
	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Relatives in official position (dummy)	-0.071	0.153***	0.057	0.020	-0.058	0.013	-0.161***
	(0.052)	(0.049)	(0.052)	(0.044)	(0.043)	(0.044)	(0.044)
Location fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-2.398***	1.743***	-0.444	-0.046	-3.173***	-1.307**	0.690
	(0.660)	(0.618)	(0.666)	(0.574)	(0.584)	(0.564)	(0.564)
Model chi-square (263)		3320.89***					
Log pseudo-likelihood		-14784.12					
Number of observations (plots)		4472					

Robust standard errors in parenthesis
Statistical significance at *p<0.1, **p<0.05, ***p<0.01

Application of fertilizer, manure, and improved maize were likely on good fertile plots, obviously due to higher expected returns. As expected, soil and water conservation was unlikely in gentle and medium sloped plots, as well as in shallow plots, but more likely to be adopted in plots susceptible to soil-loss. Plots perceived to suffer soil loss were also likely to receive manure. This was expected as manure enhances the formation of soil aggregates which improves infiltration, porosity, and water-holding capacity and subsequently reduces soil loss (Gilley Risse, & Eghball, 2002). The distance to the main output market negatively affected inorganic fertilizer use. This result could be explained by potential transaction costs involved in acquiring the purchased inputs hindering the adoption of fertilizer. There was a positive association between push-pull adoption and the distance to the main input market, suggesting that households further away from the input market were less likely to adopt the technology. Likewise, the farmer's perceived importance of the PPT technology positively influenced the adoption of PPT.

5.3. Intensity of adoption: Ordered probit model results

As evident in Figure 2, the combinations of technologies differed substantially across female, male and jointly-managed plots, indicating the appropriateness of evaluating the differences in number of technologies adopted, based on whether plots were managed individually or jointly. To formally test this, we estimated an ordered probit model with the number of practices as dependent variables, but using the same independent variables as in the MVP model. The results presented in Tables A.1 and A.2 (see the Appendix) show that jointly managed plots adopted more technologies in comparison to individually managed plots. This is in line with the descriptive statistics results (Figure 2). This indicates that joint effort enhances the intensity of adoption, especially where combined resources such as labor are required.[3] However, the ordered probit model results show that there was no difference in the intensity of adoption between female- and male- managed plots.

VI. Conclusion and policy implications

We have utilized data from a survey of Western Kenya cereal farmers to assess whether there were systematic gender differences in the adoption of push-pull technology. Existing studies on push-pull adoption either do not consider gender dimensions of the adopters, or consider the gender of the household head rather than the specific plot or farm manager within the household, so that performance of the farm plot cannot be attributed to a specific gender of the household member. Nevertheless, empirical evidence clearly shows that the performance of different African farm plots depends on who in the household makes investment and managerial decisions on those plots. We used plot level data to address this shortcoming. While most existing adoption studies focus on individual technologies, we integrate, in our analysis, other sustainable agricultural practices that could be complementarities or substitutes of push-pull technology, using a multivariate probit modeling approach. The other practices considered in this study are maize-grain legume

[3] We would wish to thank the anonymous reviewer for this suggestion.

intercropping, crop rotation, use of inorganic fertilizer, manure, improved maize seeds and soil and water conservation.

The correlation results obtained from the MVP regression reveal that there were stong complementarities and tradeoffs between push-pull and other substainable agricultural practices, reflecting the interdependence of agricultural practice adoption that should not be ignored while analysing the adoption of such practices. The results show a negative association between push-pull technology and maize-grain legume intercropping and crop rotation, but a positive correlation with the use of fertilizer, manure, and improved maize seeds. While crop rotation could partially serve a similar purpose to push-pull technology, maize-grain legume intercropping seems to be a substitute, where beans are preferred for desmodium, obviously for food security and cash needs. These complementarities and tradeoffs imply important policy implications. For instance, policy changes that promote push-pull technology adoption can have positive spillover effects on adoption rates of organic and inorganic nutrient sources as well as high yielding seeds. Promoting these technologies together can have positive effects on productivity, food security, and livelihoods.

The multivariate probit results suggest that there is no heterogeneity with regard to gender dimensions in the adoption of push-pull technology, implying that technology is gender neutral, perhaps due to the low cash outlay requirements once it is established, compared to other technologies. Promotion and dissemination of the technology can thus be supported for enhanced food and nutritional security status of women and their households. In particular, efforts should be made to promote awareness and offer training through field days. Promotion efforts should first be focused on plots that have medium to good fertility, as farmers are more likely to take a preventive approach than attempt to cure degraded plots. Social capital and networks through village group membership should also be encouraged and supported, as they provide key avenues for access to information and enable smallholders to acquire inputs and technical assistance that accelerate and sustain the adoption of technologies.

Gender differences in the adoption of some of the other sustainable agricultural practices were evident. Jointly-managed plots were more likely to adopt animal manure and soil and water conservation practices, compared to male and female-managed plot managers, probably because the practices are labour-intensive and thus require joint effort from the household members. In the same way as the push-pull technology, we found no gender differences in the adoption of maize-grain legume intercropping, inorganic fertilizer and improved maize seed. Jointly-managed plots were also likely to adopt crop rotation.

While this study provides useful insights regarding the importance of recognizing the gender differences within the heterogenous farming households, our findings are only limited to the study area and broad generalization should be carefully interpreted as gender roles and technology adoption are dynamic. Moreover, heterogeneity between regions in terms of socio-economic conditions and culture may differ considerably from one situation to another. We recommend further studies to explore gender differences in the adoption of push-pull technology utilizing panel data sets and focusing on different cultures where the technology is being promoted, in order to enhance food and nutritional security and reduce poverty. Further analyses on productivity and welfare implications of adoption of different combinations of push-pull technology and other sustainable agricultural practices, differentiated by gender of the plot manager, are worth exploring for future policy design.

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Appendix

Table A.1: Coefficient estimates of the ordered probit model comparing jointly and individually managed plots

	Coefficients	Robust SE	Prob (Y=0/X)	Prob (Y=1/X)	Prob (Y=2/X)	Prob (Y=3/X)	Prob (Y=4/X)	Prob (Y=5/X)	Prob (Y=6/X)
Plot manager (1=Joint,0=Individual)	0.101***	(0.040)	-0.013***	-0.020***	-0.008**	0.0047***	0.015***	0.018**	0.002**
Plot characteristics									
Ln(plot area)	0.224***	(0.017)	-0.030***	-0.044***	-0.016***	0.0118***	0.034***	0.039***	0.004***
Plot distance to residence (walking minutes)	-0.005***	(0.001)	0.001***	0.001***	0.000	-0.0002***	-0.001***	-0.001***	0.000
Plot ownership (1=Yes; 0=No)	-0.278	(0.265)	0.030	0.053	0.026	-0.0068***	-0.040	-0.055	-0.008
Good fertile plot (1=Yes; 0=No)	0.202***	(0.061)	-0.026***	-0.040***	-0.015***	0.0096***	0.031***	0.036***	0.004***
Medium fertile plot (1=Yes; 0=No)	0.068	(0.058)	-0.009	-0.013	-0.005	0.0036	0.010	0.012	0.001
Gentle slope plot (1=Yes; 0=No)	-0.055	(0.096)	0.007	0.011	0.004	-0.0029	-0.008	-0.009	-0.001
Moderately slope plot (1=Yes; 0=No)	-0.073	(0.095)	0.010	0.014	0.005	-0.0038	-0.011	-0.013	-0.001
Shallow depth plot (1=Yes; 0=No)	-0.238***	(0.071)	0.036***	0.046***	0.012***	-0.0169***	-0.037***	-0.037***	-0.004***
Medium depth plot (1=Yes; 0=No)	0.070**	(0.035)	-0.009**	-0.014**	-0.005	0.0036**	0.011**	0.012**	0.001*
Soil loss (1=Yes; 0=No)	0.314***	(0.042)	-0.037***	-0.061***	-0.026***	0.0119***	0.046***	0.058***	0.007***
Farmer characteristics	Yes								
Household resources	Yes								
Household access to services	Yes								
Social capital	Yes								
Location fixed effects	Yes								
Number of observations (plots)	4472.0								
Model wald [X²(40)]	588.8***								

Notes: *Dependent variable=number of technologies adopted;* Statistical significance at *p<0.1, **p<0.05, ***p<0.01

Table A.2: Coefficient estimates of the ordered probit model comparing gender of plot managers

	Coefficients	Robust SE	Prob (Y=0/X)	Prob (Y=1/X)	Prob (Y=2/X)	Prob (Y=3/X)	Prob (Y=4/X)	Prob (Y=5/X)	Prob (Y=6/X)
Female managers (1=Yes; 0=No)	0.034	(0.044)	-0.004	-0.007	-0.002	0.002	0.005	0.006	0.001
Joint managers (1=Yes; 0=No)	0.125**	(0.050)	-0.016***	-0.025**	-0.009**	0.006***	0.019**	0.022**	0.003**
Ln(plot area)	0.225***	(0.017)	-0.030***	-0.044***	-0.016***	0.012***	0.035***	0.039***	0.004***
Plot distance to residence	-0.005***	(0.001)	0.001***	0.001***	0.000***	0.000***	-0.001***	-0.001***	0.000***
Plot ownership (1=Yes; 0=No)	-0.271	(0.266)	0.029	0.052	0.025	-0.007***	-0.039	-0.054	-0.007
Good fertile plot (1=Yes; 0=No)	0.200***	(0.061)	-0.026***	-0.039***	-0.015***	0.010***	0.030***	0.036***	0.004***
Medium fertile plot (1=Yes; 0=No)	0.067	(0.058)	-0.009	-0.013	-0.005	0.004	0.010	0.012	0.001
Gentle slope plot (1=Yes; 0=No)	-0.053	(0.096)	0.007	0.010	0.004	-0.003	-0.008	-0.009	-0.001
Moderately slope plot (1=Yes; 0=No)	-0.072	(0.095)	0.009	0.014	0.005	-0.004	-0.011	-0.012	-0.001
Shallow depth plot (1=Yes; 0=No)	-0.239***	(0.071)	0.037***	0.047***	0.012***	-0.017***	-0.037***	-0.037***	-0.004***
Medium depth plot (1=Yes; 0=No)	0.070**	(0.035)	-0.009**	-0.014**	-0.005**	0.004**	0.011**	0.012**	0.001*
Soil loss (1=Yes; 0=No)	0.313***	(0.042)	-0.037***	-0.061***	-0.026**	0.012***	0.046***	0.058***	0.007***
Farmer characteristics	Yes								
Household resources	Yes								
Household access to services	Yes								
Social capital	Yes								
Location fixed effects	Yes								
Number of observations (plots)	4472.0								
Joint significance of mean of plot varying covariates[X²(40)]	588.8								

Notes: *Dependent variable=number of technologies adopted;* Statistical significance at *p<0.1, **p<0.05, ***p<0.01