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Full Length Research Paper

Adoption and willingness to pay for the push-pull technology among smallholder maize farmers in Rwanda

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The adoption and willingness to pay for a new technology by farmers is a sign of confidence on its effective performance and a motivation for the researchers and extension agents. This study comprised an assessment of the factors that influence the adoption and willingness to adopt and pay for push-pull technology (PPT) at over a 10% premium price by smallholder maize growers in selected districts of Rwanda. The survey was conducted in multiple villages of Nyagatare and Gatsibo districts in the Eastern province during the last quarter of 2018 on a sample of 587 farmers. Data were analyzed using descriptive statistics and the logit model. The results showed that farmers with better education levels and adequate land, and the ability to use yield-enhancing inputs e.g. DAP were more likely to adopt PPT. The study shows that household heads with spouses who belong to farmer groups or receive extension support for crop production were likely to adopt PPT. With regard to willingness to pay for PPT, the study finds that farmers who were resource constrained, for instance those needing credit for crop production and living relatively far away from input stockists, were less likely to pay for PPT. Whereas, farmers with livestock or who were receiving extension support for crop production were more likely to pay for PPT. The study concludes that farmers' decisions to adopt and pay for PPT depend on their socio-economic circumstances and performance of the technology.

Key words: Willingness to pay, adoption, push-pull technology, maize, Rwanda.

INTRODUCTION

Maize as a staple cereal crop is vital in terms of providing food, nutrition and improving the livelihood of the farmers and the general economic growth in Rwanda. The maize crop is produced in all the 5 provinces of the country, with the Eastern province having the largest area under maize cultivation, at about 113,000 ha, compared with Kigali city at 5000 ha, the Southern at 28,000 ha, the Western at 30,000 ha and the Northern at 32,000 ha. Through the Crop Intensification Program (CIP), maize production has been prioritized by the Rwandan government, under which farmers are provided with subsidized inputs and support such as seed and fertilizer, extension services, and land use consolidation (MINAGRI, 2013).This has resulted in maize production improving to a national average yield of 1540 kg/ha, the area under cultivation increasing from 115,000 to 230,000 ha, and export earnings improving between 0 and 2 million USD during the 2004–2017 periods (National Institute of Rwanda, 2017).

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Despite the CIP investment and strategic importance, the maize crop production is still below the potential of five (5) t/ha (Smale et al., 2013). The low cereal yields are attributed to socio-economic challenges, and the biotic and abiotic constraints such as *Striga* weeds, stemborers and low soil fertility (Oswald, 2005; Odendo et al., 2009; Vanlauwe et al., 2008). For example, stemborer infestation has been shown to cause maize grain yield losses up to 88% (Kfir et al., 2002) and when combined with *Striga,* this can result in the destruction of an entire crop (Kanampiu et al., 2002). Similarly, the recent invasion in the year 2016 and the fast spread of fall army worm (FAW) on maize crops in most of African countries has worsened the maize crop pest burden experienced by the farmers, especially smallholders (Baudron et al., 2019; Mantel & Van Engelen, 1999; Midega et al., 2018; FAO, 2017). The effects of the pests are further exacerbated by climate change. In order to manage the pests and weeds problem, it requires cost-effective and multifunctional control approaches within reach of the smallholder farmers and which are tailored to the diversity of their farming systems. For this reason, research has generated a number of productivity-enhancing technologies.

Researchers at the International Centre of Insect Physiology and Ecology (ICIPE) and at Rothamsted Research in the UK in the early 1990s commenced studies on the ecology of stemborer pests and *Striga* weed in order to develop an integrated pest management (IPM) approach. Their efforts, together with those of farmers and national research and extension partners, eventually led to the development of Push-Pull Technology (PPT) as an ecological approach for pest management, based on a combined use of inter- and trap-cropping systems where stemborers are driven away from maize crops by intercropped plants (push) and attracted by trap plants (pull). In this strategy, maize is intercropped with a stemborer moth repellent fodder legume, Desmodium, together with an attractant trap plant, Napier/Brachiaria grass, which is planted around the maize-legume intercrop. The chemical volatiles produced by Desmodium repel stemborer moths, while those produced by the trap grasses attract them (Chamberlain et al., 2006). The trap grasses, i.e. Napier grass or Brachiaria, do not allow all stemborer larvae to develop, and hence the majority of them die before reaching adulthood (Khan et al., 2007). Besides stemborer control, Desmodium also suppresses and eliminates *Striga,* leading to significantly improved maize grain yields (Khan et al., 2006). Desmodium suppresses *Striga* through allelopathic mechanisms (Tsanuo et al., 2003). Desmodium roots produce a blend of chemical compounds, some of which stimulate *Striga* seeds to germinate, while others inhibit lateral growth of *Striga* roots, thereby hindering their attachment to maize roots, i.e. suicidal germination (Khan et al., 2000;Tsanuo et al*.,* 2003). The *Striga* emergence is thus suppressed, with an *insitu* reduction of *Striga* seed bank in the soil (Khan et al., 2002). The deployment of PPT has also demonstrated effectiveness in the control of the FAW pest in maize (Hailu et al., 2018; Midega et al., 2018).

Besides pest control, the PPT supports the integration of other livelihood diversification enterprises, such as dairy farming through fodder provision, soil improvement and agro-ecosystems resilience, crop intensification, and income generation to meet food security and nutrition needs of smallholder farmers (Khanet al., 2008). Currently, based on the projected estimates by Khan et al. (2014), over 300,000 farmers are practicing PPT in eastern Africa. However, this number of farmers is still low, compared with the intensity and magnitude of the stemborer pest, *Striga* weed and, lately, the fall armyworm (FAW) infestation. Moreover, the potential population of smallholder farmers whose livelihoods could be improved with the implementation of PPT is enormous. This, therefore, requires proactive efforts to be made in the dissemination of PPT for adoption by as many farmers as possible.

The adoption and information sharing regarding new farming technologies such as PPT by farmers is crucial, and constitutes the ultimate objective of the researchers and the dissemination efforts by the extension agents (Kassie et al., 2018; Meijer et al., 2015; Tefera et al., 2016). However, in many African countries such as Rwanda, there are numerous promising research technologies in the agricultural sector that are not well taken up, with failed or abandoned attempts due to lack of local fit, or being inappropriate because of high input costs, or the specific nature of their intended outcomes (Simtowe, 2006). Moreover, this is associated with the risks and uncertainties linked with these technologies (Marra et al. (2003). Consequently, the adoption level of agricultural technologies is as low as less than 10% (NEPAD, 2002).

Farmers, who are the end users, are at the center of focus of the efforts made by researchers and other extension practitioners in the technology dissemination processes. That means that they have the final decision to make regarding the adoption of the new farming technologies, particularly with respect to resource allocation, adaptation and modification, or even rejection. Technology adoption is the process through which a farmer is exposed to knowledge about the technology, considers its usefulness, and finally accepts to start using it (Pierpaoli et al., 2013). This means that the adoption decision is dependent either on the attributes of the technology itself or on the motivation to use and willingness of the farmer to pay for the technology at an acceptable price, or sometimes, the farmer simply takes the risk or uncertainty that may be associated with its uptake (Kassie et al. 2018; Marraet al., 2003; Rogers, 2003).

There are numerous explanations for the adoption and willingness to pay for new technologies by smallholder farmers (Govindasamy et al., 2001; Lang et al., 2012). For example, farmers conduct their farming enterprises with limited resources, such as land, labor and capital. When new technologies are introduced, these are assessed based on their socio-economic implications. Where technologies require new investments or changes to existing cultural practices, farmers take time to assess them before making decisions on whether to start using, and even to pay for them (Gall-Ely, 2009; Govindasamy et al., 2001). Push-Pull Technology is an example of a research technology promoted as an alternative to the use of synthetic pesticides for the control of cereal stemborers, FAW and *Striga* weed. Because of this, numerous socio-economic studies have been undertaken on PPT, focusing on its dissemination pathways (Amudavi et al., 2008; 2009; Murage et al., 2012), on farmer perceptions (Khan et al., 2007), on economic performance (De Groote et al., 2010; Khan et al., 2008; 2011; 2014), on welfare benefits (Kassie et al., 2018), and on gender and adoption (Murage et al., 2015a; 2015b; Muriithi et al., 2018). This paper contributes further to the existing literature on PPT by exploring the adoption and willingness to pay for the PPT in Rwanda. The assessment of the adoption and willingness to pay for PPT by the farmers provides crucial information for the promoters of the technology that will assist them to undertake effective measures in the dissemination campaigns. The case of PPT implementation in Rwanda is used to assess whether farmers' socio-economic and other contextual factors have influence on adoption and willingness to pay for the inputs and extension services that are linked with the technology.

METHODOLOGY

The introduction and implementation of PPT in Rwanda was based on the request made through the Ministry of Agriculture of Rwanda to *icipe* researchers in year 2015. This was aimed to address the challenge faced by farmers in the management of stemborers, *Striga* weed, FAW and low soil fertility in Rwanda. The PPT was launched in Rwanda in December 2017 with the identification of partners, training of farmer trainers and setting up of demonstration sites. By end of 2018, there were over 4700 farmers trained and 220 farmers adopting the technology. In order to improve further on the dissemination of the PPT in the country, *icipe* initiated this baseline study to understand the adoption process and farmers willing to continue with PPT and more so their willing to pay for the inputs and extension services linked with the technology.

Study area

The survey was conducted in multiple villages of Nyagatare and Gatsibo districts in the Eastern province of Rwanda (Figure 1) during the last quarter of 2018, covering a total of 95 villages in Gatunda and Nyagihanga sectors, and reached 587 farmers (PPT adopters and non-adopters) operating on 1,561 maize plots. The sectors comprised the study areas where PPT was implemented.

In the study areas, the agriculture sector provides the main economic activity, and maize production is leading in terms of acreage and percentage crop share. This is followed by bananas, beans and cassava. According to the Nyagatare district development plan (2013), the agriculture sector employs more than 80% of the labor force of people aged above 16 years and contributes 25% to the GDP, whereas the mining and public sectors contribute 0.1% and 6.5%, respectively. Nyagatare district covers an area of about 2000 km² and borders Uganda to the north, Tanzania to the east, Gatsibo District to the south, and Gicumbi District on the west. Based on the 2012 national population census, Nyagatare district has a population of about 470,000 people, with 51% female and 41% male, whereas Gatsibo district has a population of about 440,000 people, representing 48% male and 52% female. In terms of population density, Gatsibo and Nyagatare districts have about 274 and 242 inhabitants per square kilometer, respectively (National Institute of Statistics of Rwanda (NISR), 2012). The vegetation cover in Nyagatare district is characterized by eucalyptus forest cover with savanna, while Gatsibo district is covered by steppe woodlands. Gatsibo district is known to experience low rainfall between 700 and 1000 mm and high temperatures between 20 and 21 °C, which limit the availability of water (Gatsibo District Development Plan, 2013; NISR, 2016).

The survey

The survey data were collected from respondents who were randomly selected from household lists of PPT adopters and non-adopters, through using a pre-tested structured questionnaire that was administered by trained enumerators. One household was dropped from the selected sample due to missing data and apparent enumerator errors. Similarly, key variables that had missing values were dropped, and the interquartile range was used to drop outlier observations. Respondents' participation in the survey was voluntary. The questionnaire captured detailed data at the household, plot, and village levels, including details regarding human capital, input and output data, farming practices such as PPT adoption (using and willing to continue using in next cropping season), and willingness to pay (WTP) for the technology.

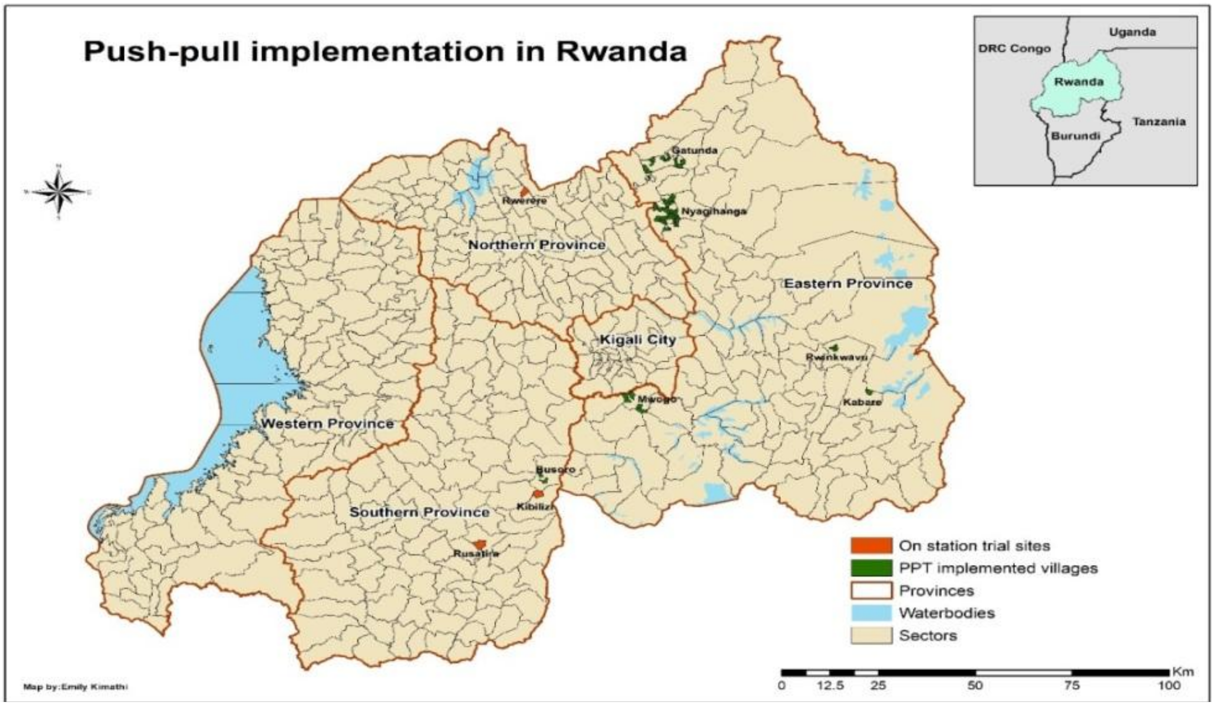

Figure 1. The PPT implementation and study area.

Data analysis

Data were analyzed using descriptive statistics, and a farmer's willingness to adopt and pay was estimated using a logit model. The descriptive statistics included frequencies, means and proportions. The analyses of variance (ANOVA) using t-tests were used for the ratio/interval variables (age, household size, and plot size) to investigate whether significant differences existed among the PPT adopters and non-adopters. A chi-square test was used for the categorical data (the age bracket of household head, education level, maize acreages, sources of livelihood and gender). A logit model, as a binomial regression analysis, was used based on its good asymptotic properties of predicting probabilities between 0 and 1. The logit model is commonly used in settings where the dependent variable is binary (Salasya et al., 2007). The model was estimated using a maximum likelihood method based on individual observations provided by data, and resultant parameter estimates are consistent and efficient, asymptotically (Horowitz & Savin, 2001). The empirical model assumes that the probability of adopting or willingness to pay at a premium for PPT, P_i, is dependent on a vector of independent variables (X_{ij}) associated with farmer I and variable j, and a vector of unknown parametersβ. The likelihood of observing the dependent variables (willingness to adopt and willingness to pay) was estimated as a function of variables that included socio-economic and demographic characteristics: $P_i = F(Z_i) = F(\alpha + \beta X_i) = 1/[1 + \exp(-Z_i)]$

where:

$F(Z_i)$ =Represents the value of the logistic Cumulative Density Function (CDF) associated with each possible value of the underlying index

$Z_i P_i$= The probability that an individual will be willing to pay a premium price of over 10% or continue using PPT given the independent variables X_is.

Z_i = The underlying index number of $\alpha + \beta X_i$

α = The intercept and βX_i is the linear combination of independent variables so that:

$$Z_i = log\left[\left({P_i}/{1 - P_i}\right)\right] = \alpha_i + \beta_{i1} X_{i1} + \beta_{i2} X_{i2} + \cdots + \beta_{in} X_{in} + \varepsilon_i$$

where:

i = 1, 2, …, n are observations

X_n= The nth explanatory variable for the ith observation

β= The parameters to be estimated

ε = The error or disturbance term.

To obtain the estimators for the explanatory variables, the changes in the probability P_i given that Y_i =1 brought about by the independent variable X_{ij} is given by:

$$(\Delta P_i / \Delta X_{ij}) = P_i(Y_i : X_{ij} = 1) - P_i(Y_i : X_{ij} = 0)$$

The change in probability for each explanatory variable was measured at the mean of all other independent variables. The following two models were developed to predict the likelihood of adopting or paying at a premium price of over 10% for PPT. The models were tested under the specification:

WTA/WTP _PPT= β_0 + β_1Primary level education
+ β_2 Tertiary education
+ β_3H size
+ β_4Gender of HH
+ β_5Land owned
+ β_6DAP
+ β_7Age1
+ β_8Age2
+ β_9 Altitude
+ β_{10}Credit
+ β_{11}Sector
+ β_{12} Hybrid Maize
+ β_{13}Market
+ β_{14} Stockist
+ β_{15}Water
+ β_{16}Hh_group
+ β_{17}Time_village
+ β_{18}TLU
+ β_{19}Extension
+ β_{20}Insecticides

where:

TA_PPT =1 if the respondent indicated willingness to continue using PPT during the next cropping season and 0 otherwise

WTP_PPT =1 if the respondent indicated willingness to pay for at least 10% premium to implement PPT and 0 otherwise

Hsize = Household size

Education 2 =1 if the highest level of education attained is secondary level and 0 otherwise (the base category being below secondary education level)

Education 3 =1 if the highest level of education attained is tertiary level and above, and 0 otherwise

Gender of Household head=1 if the individual is male and 0 otherwise

Ln (Land owned) = Natural log of total land owned by the Household

DAP = 1 if household applied Diammonium Phosphate fertilizer (DAP) and 0 otherwise

Age 2 =1 if the household head is between 35 and 60 years of age and 0 otherwise (base category being less than 35 years of age)

Age 3 =1 if the household head is above 60 years of age and 0 otherwise

Altitude = altitude of the location of the household to control for location differences

Credit = 1 if the household needed credit for crop production and 0 otherwise during the previous production season

Sector = 1 is Nyagihanga and 0 is Gatunda to control for location differences

Hybrid = 1 if the household used Hybrid maize and 0 otherwise

Market = Distance in time (minutes) farmer spends to reach the nearest market

Stockist = Distance in time (minutes) the farmer spends to reach the nearest input stockist

Water = Distance in time (minutes) farmer spends to reach nearest water source

Hhgroup = 1 if household head is a member of a farmer group and 0 otherwise

Spouse group = 1 if spouse is a member of a farmer group and 0 otherwise

Time village = Number of years the household head has stayed in the village as a measure of farmer's agricultural experience

TLU = Total livestock units as a measure of number of animals owned

Extension = 1 if the household head received extension support for crop production in the previous cropping season and 0 otherwise

Insecticides = 1 if the household used insecticides and 0 otherwise

RESULTS AND DISCUSSIONS

The socio-economic characteristics of the respondents

The average age of the household heads is about 47 years, and the majority (65.9%) of the respondents were over 40 years. There were more (81.5%) of the PPT adopters aged 40 years and above, compared with the non-adopters (58.7%) (Table 1). This shows that the PPT adopters are slightly older than the non-adopters, with an implication that few youthful farmers have interest in farming activities and taking up new technologies such as PPT. The finding could also imply that youthful farmers are more risk averse and thus less likely to experiment with new farming technologies. This is contrary to what Amudavi et al. (2008) and Speelman et al. (2008) reported, where they found that younger farmers are technically more progressive as compared with the older ones, since the former have a tendency towards adopting recent innovations. The contrary finding in this study, however, could be associated with the experience and knowledge that the older Rwandan farmers have gained in farming activities, especially in maize and other cereal

Table 1. The socio-economic characteristics of the respondents.

Variable	PPT Adoption			Statistics	
	Adopters (n=194)	Non-adopters(n=392)	Total (N=586)	χ^2	t-value
Age of Household Head(HH)	49.84(11.00)	45.19(12.49)	46.73(12.21)		4.399***
Age groups (%)					
<30	3.6	12.8	9.7		
31-40	14.9	28.6	24.1	31.404***	
41-50	36.6	26.5	29.9		
51-60	28.9	20.2	23.0		
>60	16.0	12.0	13.3		
Size of household (Mean)	5.22 (2.08)	4.84 (1.83)	4.97 (1.92)		2.215**
Size of household (%)					
1-3 members	21.1	24.7	23.5	7.105ns	
4-6 members	53.6	58.7	57.0		
7-10 members	24.2	16.3	18.9		
>10 members	1.0	0.3	0.5		
Average plot size (acres)	4.41 (10.04)	2.74 (6.31)	3.29 (7.78)		
Maize plot size (acres)	3.62 (8.68)	2.71 (9.11)	3.01 (8.98)		1.159ns
Education level of HH (%)					
Primary	55.7	68.6	64.3	15.780***	
Junior	20.1	14.0	16.0		
A level	5.7	1.8	3.1		
Tertiary	1.5	0.8	1.0		
Postgraduate	0.5	0.0	0.2		
Never in school	16.5	14.8	15.4		
HH source of Livelihood					
Farming (crop and livestock)	95.4	95.9	95.7		
Employment (informal and formal)	3.6	3.1	3.2	0.124ns	
Other sources	1.0	1.0	1.0		
Gender					
Female	54.6	40.3	45.1	10.770***	
Male	45.4	59.7	54.9		
Gender of the Household Head					
Female	20.6	14.5	16.6		
Male	79.4	85.5	83.4		

Standard deviation in parentheses.

crops, and thus they have an interesting learning about recent innovations to address their production constraints. This could also be attributable to the fact that young adults have migrated to urban areas to study or to look for employment, thus contributing to the high population (34%) of youths aged 20–24 years in urban areas, compared with their lower population (24%) in rural areas (NISR, 2012).

In terms of family sizes, both PPT adopting and non-adopting farmers have an average family size of 5 individuals, with the majority (57.0%) of households ranging from 4 to 6 members. Large family sizes are usually associated with the provision of farm labor among the smallholder farmers who may not afford to pay for hired labor.

The adopters have slightly bigger farm sizes, of about 4 acres, compared with non-adopters, with about 3 acres. In their farms, the adopters have allocated 3.6 acres of land for maize production, compared with 2.7 acres for non-adopters. This maybe due to the fact that land holding in Rwanda does not allow for expansion (Bosco, 2016). With this in mind, farmers need to apply PPT and rotate with other crops in subsequent seasons. Thus,they may not be willing to practice PPT that has perennial cropping arrangements. There is a need to investigate the possibility of having other seasonal crops introduced between the rows of Desmodium.

There were more numbers of non-adopter farmers (68.6%) than adopters (55.7%) who had primary levels of education. This implies that the higher the number of farmers with primary level of education, the lower the likelihood of them adopting PPT. This happens when compared with those with above primary and higher education levels who are likely to have access to more numerous pathways of information sourcing and open opportunities for exploring new opportunities offered by technologies such as PPT.

The households are mainly male headed in both adopter (79.4%) and non-adopter (85.5%) households. Overall, there were more males (54.9%) than females (45.1%). However, there were more female adopters (54.6%) than female non-adopters (40.3%), and more male non-adopters (59.7%) than male adopters (45.4%). According to the NISR (2012) report, 52% of the Rwandan population is represented by women. Moreover, the Crop Intensification Program (CIP), spearheaded by the government of Rwanda, is more focused on women farmers with regard to improving maize productivity through extension support and providing input subsidies. This is seen as means of empowerment and ensuring household food security and reducing poverty among women (Bundervoet, 2015). This observation is similar to what (Doss, 2001) found in Ghana, in a study on the gender differences on the adoption of maize varieties. The study shows that, within households and in smallholder farming, women play an important role in decision making on food security. Thus, in order for the women farmers to benefit directly, deliberate efforts need to be made to increase their access to resources and new farming technologies that promote food security, such as PPT.

The awareness and benefits of Push-Pull Technology

Majority of the PPT farmers interviewed (96.6%) were interested in continuing with the use of PPT during the subsequent maize cropping seasons (Table 2). This could be associated with the biophysical constraints addressed by PPT, including the ability to control pests and *Striga* (Table 3) and improving soil fertility (Table 4). Furthermore, this could be linked to the extensive awareness and dissemination campaigns that have been promoted through using several information sources (Table 2). Over 80% of the respondents indicated that they had received information from Food for the Hungry (FH) Rwanda, with the majority (98%) of them having started using PPT during the 2017–2018 period. Access to information about PPT enhances awareness and forms the basis for farmers' decisions to start using the technology and to even continue using it. Such information is useful for understanding the potential of PPT not only regarding pest control and the improvement of cereal crop productivity, but also as a platform to learn other new technologies related to farming and non-farming enterprises.

The uses of mass media, such as radio and Television, government and farmer-to-farmer extension systems resulted in the dissemination of information about PPT in Rwanda during the time of the study. The awareness levels among the adopters were higher than among the non-adopters. However, the general awareness is bound to improve further as time goes by, and as the need for using PPT intensifies as a result of crop pest challenges and as the demand for use of non-synthetic pesticides increases (Govindasamy et al., 2001) on one hand, and the need to adapt farming activities to the challenges of climate change and population increase. In Rwanda, the introduction and implementation of PPT have been undertaken for less than 3 years, but there is a signs of strong willingness among the adopters and non-adopters to continue or start using PPT in the future. Currently, some farmers may not be interested in cereal crop farming, either due to low prices for the harvested crop in the market or interested in other farming enterprises such as horticulture. To this group of farmers, it may not be urgent to engage in PPT, as it is for the farmers growing cereals. In other cases, the FAW, *Striga* and stemborers may not be a serious problem, while other farmers may be interested in integrating edible beans instead of the non-food Desmodium intercrop.

About 22.4% of the respondents expressed unwillingness to continue using PPT in future. This difference could be attributed to the lack of experience of the benefits of PPT, or to the fact that these respondents were not directly affected by the constraints addressed by PPT, or due to lack of interest. Influencing the adoption decision is a challenging task for the developers and the promoters of new technologies such as PPT. This is because the farmer's decision to adopt or not adopt is either dependent on the characteristics of the technology itself or on other factors, such as their socio-economic and bio-physical environmental conditions (Doss, 2006; Pierpaoli et al., 2013; Meijer et al., 2015).

The results in Table 2 show that the number of farmers known to be using PPT by fellow farmers is about six (6). This number is low when compared with other studies, e.g. Amudavi et al. (2009), where one(1) PPT farmer knew or was linked to more than 17 other PPT farmers for information sharing on matters linked to PPT and related activities. However, this observation could be due to the implementation of PPT in Rwanda being relatively new (less than three years), as compared with Kenya where the process has taken over 20 years. The results regarding the effectiveness and benefits of PPT (Tables 3 and 4) in addressing the farmers' pest problems are promising in terms of showing the attributes and incentives for enhancing information and knowledge dissemination, not only to foster the current level of adoption in Rwanda, but also in the future and elsewhere. The results in Table 3 show that over 75% of the biotic constraints in maize production were addressed following the adoption of PPT. Indeed, the technology has the potential to address a myriad of other farming challenges and to be integrated in programs that align with the current realities that the majority of Rwandese farmers are confronted with. These include small sizes of farmland, adopting the zero-grazing policy, and the one

Table 2. Awareness and use of Push-Pull Technology.

Variable	PPT Adoption			Statistics
	Adopters (n=194)	Non-adopters (n=392)	Total (N=586)	χ^2
Household awareness of PPT	100.0	14.8	43.0	384.379***
Sources of information about the PPT				
FH Rwanda/NGO	87.0	75.9	84.3	
Research Centers during demonstrations (*icipe* and National research centers)	7.6	5.2	7.0	12.811 ns
Government extension system	1.1	1.7	1.2	
Farmer to Farmer(FFS/Groups/Cooperatives)	3.8	17.2	7.0	
Mass media (TV and Radio)	0.5	-	0.4	
To continue using PPT in future	96.9	22.4	47.6	284.310***
Fellow PPT farmers the respondent knows	6.04(6.34)	-	-	

Table 3. The perceived effectiveness of PPT by the adopter farmers.

Level of effectiveness	Maize crop biotic production constraints		
	Stemborers	FAW	Striga
Very effective	81.3	75.7	79.7
Somehow effective	17.2	22.8	18.8
Not effective	1.5	1.5	1.6

Table 4.PPT benefits by the PPT adopters.

	Effects due to PPT (%)		
PPT attributes and benefits	Increased	Reduced	No change
Labor during ploughing	66.8	14.6	18.5
Laborfor harvesting maize	66.8	14.6	18.5
Weeding labor	58.9	18.8	22.4
Maize production	58.4	24.0	17.5
Stability of maize production	74.0	20.7	5.3
Maize production (Kg/acre)	40.81(45.33)	-	-
PPT labor effects on:	*Benefits*	*Deficits*	
Male	3.6	18.0	-
Female	10.7	20.3	-
Both male and female	85.7	61.7	-
Months of PPT fodder availability	1.80 (7.43)	-	-
Livestock production with PPT fodder			
Milk production(liters/cow/day)	4.57 (9.37)	-	-
Calving interval of cows	47.25	32.97	19.78
Lactation length of cows	57.14	16.88	25.97
Household milk production	58.97	17.95	23.08
Soil fertility improvement during the last 5 years	48.0	20.2	31.9

family one cow arrangement that promotes higher breed of livestock.

Although the demand for labor required for ploughing, harvesting and weeding increased as a result of adopting PPT, the stability of maize production increased by 74% (Table 4). The majority of the farmers (66.8%) experienced an increase in labor requirements for planting in their PPT plot, while others felt it reduced (14.6%), and others had experienced no change (18.5%). This was similar in the case of harvesting maize in the PPT plots. The initial establishment and planting of PPT required ploughing and harrowing the land to a fine tilth for the sowing of Desmodium seeds and the general layout of the plot. The PPT activities are labor demanding during the initial stages of establishment and may lead to increased expenditure arising from hiring labor and purchasing of inputs such as seeds and fertilizers. This finding is consistent with what was found by Kassie et al. (2018) and Muriithi et al. (2018), where their results show that labor use per acre on maize plots under PPT was significantly higher among PPT farmers than among the non-adopters. Nevertheless, they found that this reduces substantially once the PPT cropping is fully established and may also potentially lead to reduced expenditure due to a reduced need for pesticides and other inputs such as fertilizers.

The PPT is knowledge intensive (Khan et al., 2007). That means, it requires step by step application and learning about how the mechanism works from plant-to-plant and plant-to-insect pest interactions, the biology of insect pests, soil fertility improvement to the physical labor requirements in plot measurements, layout, crop spacing during planting, weeding, and the harvesting of PPT products. The increased knowledge and labor demands for the PPT farmers are linked with the additional PPT crops and their management requirements. For example, the weeding of the associated Desmodium by using hands to avoid uprooting the newly sprouted crop is labor intensive for the farmers who prefer to weed their plots by using implements such as hoes, knives or pangas. Nonetheless, the labor demand is reduced when the PPT plot is fully established, when most crop-management activities including weeding are reduced. This implies that, increased benefits are expected after the initial investment and during the subsequent cropping seasons (De Groote et al., 2010; Muriithi et al., 2018). In some cases where farmers indicated experiencing no change in labor demands, it was because they were already using a crop intensification approach of farming, e.g. intercropping of cereal crops with other legumes crops such as beans.

In terms of benefits, the results in Table 4 show that for a period of about 2 months of the year, there were sufficient quantities of available livestock fodder derived from PPT farms. The fodder abundance could be associated with an increase of about 5 liters of milk per day from lactating dairy cows and a 59% increase in their milk production among the households using PPT. The on-farm availability of fodder could also be linked to reduced calving intervals, an increased lactation length for the cows (57%), and reduced costs of fodder. However, for about 10 months of the year, there is a likelihood of fodder shortage. To fill this gap, the PPT farmers should be encouraged to expand their plot sizes beyond their initial sizes or to increase the number of plots in order to increase the amount of fodder produced.

In terms of soil fertility improvement, 48% of the respondents had experienced an increase during the preceding 5 years. This could be partly attributed to the PPT effects from nitrogen fixation by the Desmodium intercrop and general improvement of soil cover preventing soil erosion and mineral leaching. Such benefits contribute to improved human and environmental health through the reduced use of pesticides and providing quality livestock fodder (Pickett et al., 2014).

Factors influencing the willingness to adopt and pay for Push-Pull Technology

The maximum likelihood estimates of the willingness-to-adopt and pay a 10% premium price are presented in Table 5. The models exhibited McFadden's R^2 statistics of 0.1 and 0.145, respectively. These are generally consistent with R^2 values observed with cross-section models. However, the calculated chi-square statistics for both models rejected the global null hypothesis that all coefficients of explanatory variables were zero and at the 0.0001 level. The regression results (Table 5) are consistent with the results in previous sections and indicate that the level of education has a significant effect on the probability of adopting PPT in Rwanda. This implies that farmers with higher education levels are more likely to adopt and then continue using PPT during the subsequent maize cropping seasons. This is because such farmers are able to acquire and effectively make use of the information disseminated about PPT, most of it through the mass media and interpersonal communication. Learning about the PPT is knowledge intensive, as shown by Khan et al. (2007). The print materials, for example, require reading either as a reminder or to follow the step-by-step information content therein. That means that farmers who are able to read and understand the content of the material, and at the same time interact effectively with other information sources such as fellow farmers, researchers, extension agents, radio and television programs, have a higher probability of learning and acquiring more detailed knowledge on the PPT.

The results also show that the farmers with larger land pieces are more likely to adopt PPT than those with smaller sizes are. This is contrary to what Khan et al. (2008) and Murage et al. (2012) found in Kenya, where land size had no effect on the adoption of PPT and was inversely related with land sizes respectively. The small sizes of land in Rwanda and the need for crop rotation could account for this discrepancy in study findings. Farmers with larger land sizes have more space to expand and possibly continue using the PPT subsequently, and they could be motivated to invest more in their land to maximize productivity with the new technology that has the potential of addressing both biotic and abiotic maize production constrains. Furthermore,

Table 5. Estimation of factors influencing farmers' willingness to adopt and pay for PPT.

	Models	
Independent variables	Willingness to Adopt	Willingness to Pay
Secondary level education	0.466* (0.261)	0.188 (0.268)
Tertiary education and above	0.354(0.280)	-0.130(0.284)
Household size	-0.138**(0.0607)	0.0164(0.0612)
Sex of household head	-0.112(0.301)	0.390(0.295)
Ln(land owned)	0.166**(0.0707)	0.107(0.0669)
Used DAP	0.401*(0.225)	-0.264(0.228)
Household head between 35 and 61 years	0.429(0.272)	-0.210(0.265)
Household head above 60 years	0.311(0.355)	-0.416(0.372)
Altitude	-0.000912(0.000846)	0.000932(0.000754)
Need credit for crop production	-0.373*(0.207)	-0.798***(0.213)
Sector	-0.580**(0.231)	-0.621***(0.236)
Used Hybrid Maize	-0.155(0.262)	0.0217(0.250)
Distance to trading center	0.0148***(0.00404)	0.00101(0.00397)
Distance to input stockist	0.00263(0.00242)	-0.00737***(0.00280)
Distance to drinking water	0.00185(0.00441)	-0.0000303(0.00435)
Household is a member of a farmer group	0.266(0.254)	0.424*(0.254)
Spouse is a member of a farmer group	0.602***(0.228)	0.0326(0.221)
No. of years household head stayed in the village	-0.00401(0.00642)	-0.00783(0.00670)
Total Livestock Unit (TLU)	-0.0381(0.0332)	0.115**(0.0474)
Received extension support for crop production	0.483**(0.203)	1.198***(0.210)
Used insecticide	0.191(0.215)	0.371*(0.214)
Constant	0.961(1.332)	-1.123(1.233)
N	553	553
Wald chi2(21)	60.89	92.82
Prob > chi2	0.0000	0.0000
adj. R-sq	0.1005	0.1436

Standard errors in parentheses
* p<0.1
** p<0.05
*** p<0.01

due to land scarcity, farmers would want to reduce the risk of crop failure by allocating land to their most preferred food-security crops before experimenting with a new technology.

The results in Table 5 show that farmers currently using DAP fertilizer are more likely to adopt PPT. The use of DAP fertilizer is meant to boost production in a similar way that PPT does for their cereal crops. This means that the farmers currently using DAP would prefer to replace it with a cheap and alternative, but effective, approach (Pypers et al., 2007) by using PPT. The results also show that distance to a trading center has a positive and significant effect on PPT adoption. This implies that the farmers who cover greater distances to reach their trading centers are more likely to adopt PPT. Such a finding is contrary to expectation, where in most cases, nearness to market is associated with tendency to adopt new technologies as a result of access to input and output market needs and reduced transaction costs (Abdulai & Huffman, 2005). Moreover, this could also point to the fact that since PPT is a substitute for inorganic fertilizers and pesticides, it would then be a more convenient alternative for those farmers that are located far away from access to farm inputs stocked in distant market places.

Membership of a farmer group by a spouse in a household and receiving extension support had a significant and positive effect on PPT adoption. Belonging to groups in the community environment is not only used as means for social networking, but also as a channel for accessing information and knowledge on new technologies such as PPT. Farmer-based extension support approaches, such as Farmer Field Schools (FFS) or farmers field days, are modeled on group learning approaches where social capital forms the basis for interaction and information exchange among the members and also with other extension agencies. The positive and significant effect derived from receiving extension support for crop production was expected, based on the fact that having access to information and receiving advice from the extension agents have influences on farmers' decisions to start and even continue using new farming technologies (Wossen et al., 2017). Such support is useful in providing technical advice and access to farm inputs, and also in expanding the farmers' knowledge base on the practical benefits of the new technology (Doss, 2001). The long-term

Table 6. Willing to pay at high premium/discounted prices.

Willing to purchase at:	The PPT Adoption of the total respondents (%)			
Premium pricesin (RwandanFranc)USD	Adopters	Non-adopters	Total	Chi square
+10% (36,164.55)39.2	31.9	31.9	63.8	7.091***
+15% (39,455.24)42.8	44.0	36.0	76.0	0.361ns
+20%(42,743.16)46.4	61.3	25.8	87.1	0.662ns
Discounted prices				
-10%(23,014.75)24.9	6.8	10.2	17.0	2.591ns
-15% (26,302.53)28.5	0.0	29.4	29.4	3.864ns
-20% (29,589.54)32.1	7.0	18.9	26.0	0.801ns
Reasons not willing to willing to pay				
Expensive	9.9	31.6	41.5	15.99***
Lack of funds	6.0	20.3	26.3	10.160***
Stemborer is not a serious problem	0.3	1.0	1.4	0.241ns

Table 7. Willingness to pay for the PPT.

	Gender		Total	Chi-square
	Male	Female		
Willingness to adopt PPT (%)	98.0	96.9	97.8	0.410ns
Acres of land willingness to adopt PPT during:				
2018/19	10.64(23.11)	11.46(23.98)	10.77 (23.24)	
2020/21	10.95(23.19)	12.09(25.14)	11.13(23.50)	
2024/23	12.10(25.01)	12.88(26.55)	12.23(25.25)	
Willing to continue using PPT(%)	PPT adopter	Non-adopter		
	99.0	97.2		1.885 ns

Standard deviation in parentheses.

implementation of PPT over several maize cropping seasons attracts more benefits other than what is experienced during the first cropping season. During the subsequent seasons, farmer-to-farmer and research-extension agent interactions increase the likelihood that the farmers will learn additional and integrative elements associated with to the use of PPT (Khan et al., 2014).

The average size of the household of the respondents was about 5 members (Table 1). The regression results show that the size of the household had a significant and negative effect on the adoption of the PPT. This shows that the greater the size of a household is, the more the probability of willingness to adopt decreases. This finding is contrary to what is expected, that a large family is a measure of the abundant and supplementing labor demands required for PPT activities during the initial stages of establishment (Kassie et al., 2018; Khan et al., 2007). This kind of result implies that large household sizes place pressure on available resources such as land through subdivisions, especially in the context of Rwanda, where land is scarce for large household uses such as housing, grazing and crop farming. This implies that less land is available for investing in new technologies such as PPT, which require perennial cropping arrangements and investments. In such cases, farmers complement their small land sizes by renting additional land areas, and have no incentives to invest in perennial cropping arrangement such as PPT. This finding is consistent with the above-mentioned result on the adoption and land sizes, where it is shown that those farmers with large land sizes are likely to adopt PPT. The need for credit for crop production had a negative and significant effect on the respondents' willingness to adopt PPT. That means farmers who may need additional financial resources to plant crops are less likely to adopt PPT. This could be attributed to the fact that PPT was newly introduced in Rwanda and the inputs for its establishment, such as Brachiaria and Desmodium seeds, were initially not locally available. It could also mean that, given the risks associated with newer technologies such PPT, farmers were not willing to invest in them through using credit, which has high collateral requirements or interest rates (Abdallah, 2016). This result is consistent with the result regarding the need for credit in crop production, which had a significant and negative effect on the willingness to pay for PPT input requirements for implementation. This indicates that the costs associated with such credit are high and that there are no incentives to pay for it in order to plant PPT.

The distance to the nearest input stockist had a negative and significant effect on the respondents' willingness to pay for PPT. This means that the willingness to pay for PPT inputs at over a 10% premium price decreases as the distance to the input market increases. This is associated with increased costs arising from the long distances covered to reach market. This implies that the PPT inputs, e.g. Desmodium and Brachiaria, become less expensive when stocked by local-level agro-dealers. The total Livestock Unit (TLU) has a positive and significant impact on willingness to pay. This is associated with the fact that the provision of fodder is an incentive for farmers to invest in PPT. The farmers with livestock and who receive extension support for crop production are more likely to pay for PPT so that they can produce fodder to supplement other feeds for their livestock. The descriptive results in Tables 6 and 7, when interpreted together with regression results in Table 5, show that, with the benefits experienced or anticipated, the respondents had an increased willingness to invest in PPT for the increased maize yields, environmental safety derived from the reduced use of pesticides and increase fodder production. The results in Table 7 show that the respondents had shown willingness to expand the acreage under PPT by allocating more of their land for the PPT expansion and continued use. That means they are willing to invest in PPT technology during the subsequent cropping seasons, from the years 2018–2023. Regarding those who were not willing to pay (Table 6), this was mainly due to the cost of purchasing the inputs, which were either expensive, or to the fact that the farmers did not have the money required to pay for the inputs. The Desmodium and Brachiaria seeds required during the establishment of the technology were at the time of the survey not available locally. They were sourced from the neighboring countries, which made them expensive because of the transport and handling costs that were incurred.

CONCLUSION

The adoption of the PPT is expected to empower farmers through increased knowledge on pest management, and increased incomes from improved cereal yields derived from effectively controlling crop pests and livestock production. There has been remarkable success in terms of awareness creation and adoption of PPT by the farmers in Rwanda, but the rate and intensity of adoption are still slow and below the potential. This performance is partly attributed to some farmers not being able to adopt the technology, whether due to the associated costs or socio-economic constraints such as small land sizes, low education levels, and poor infrastructure. The non-adoption could also be directly or indirectly linked to the technology itself, e.g. in not seeing the immediate need for the technology or in having a low perception of its performance, effectiveness and even sustainability over several subsequent cropping seasons. To overcome this requires investments to be made in cutting the costs associated with distances travelled in search for information and inputs by establishing locally based and easily accessible agro-dealers on PPT inputs, e.g. Brachiaria and Desmodium. This can be done through the promotion and introducing of other integrative elements, such as livestock keeping, seed bulking and fodder production, as incentives.

The dissemination process when targeted to the farmers who have higher levels of education has the added benefit that these farmerscan effectively understand the PPT information and put it into use, and then share their experiences with their fellow farmers. Thus, there is a need to strengthen farmer-based dissemination by using other channels, in addition totraditional mass media and printed materials, to improve farmer communication and information uptake. Follow-up studies, which focus on some of the cases of non-adoption, risk aversion and unwillingness to continue with PPT, might point out the exact weakness of the technology in terms of dissemination and practical suitability for further research and refinement. The findings of this study have policy implicationsfor reducing the PPT input costs through providing subsidies, and establishing local agro-shops and farmers' seed bulking plots. Measures should also be taken to provide farmers with easy credit to invest in the expansion and to integrate additional commercial enterprises and marketing components into the PPT implementation. Furthermore, increased airtime for radio and TV call-in and listenership programs should be allocated toPPT and related activities.

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