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Ex-post economic analysis of push-pull technology in Eastern Uganda

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ABSTRACT

Push–pull technology (PPT) simultaneously reduces the impact of three major production constraints, pests, weeds and poor soil, to cereal–livestock farming in Africa. In order to ascertain the social value of the technology and to make decisions about the trade-offs in the allocation of scarce resources in research, gross margin analysis and the Dynamic Research for Evaluation Management economic surplus model were applied to calculate and analyze the benefits of PPT for 568 households located in four districts in eastern Uganda. The results showed that with PPT the economy of these districts would derive an overall net gain of 3.8 million USD. At a discount rate of 12% for a period of 20 years (2015–2035), Net Present Value was about 1.6 million USD, the internal rate of return 51%, and the Benefit to Cost Ratio 1.54. This implies that PPT is economically viable and profitable. Hence the technology should be further up-scaled and disseminated to other regions to reduce poverty and increase household food security.

1. Introduction

Low agricultural productivity is linked to human, technical and socio-economic factors, and in the dominant smallholder sector in sub-Saharan African (SSA), to a virtual absence of improved varieties of crops and breeds of livestock, agronomic and post-harvest technologies, and inputs of fertilizers, pesticides and irrigation (Nkamleu et al., 2003; Republic, 2011). In SSA, smallholder farmers are faced with three constraints that result in low maize yields, poor soils, stemborers and parasitic weeds (Menkir et al., 2012; Rubiales and Fernández-Aparicio, 2012). As part of addressing these issues, this paper evaluates the economic benefits that have emerged from the introduction of farm-based push-pull technology (PPT) systems into eastern Uganda.

Control methods for parasitic *Striga* weeds and stemborers in maize production have been widely researched in Africa (Berner et al., 1994; Mullen et al., 2003; Labrada, 2007; Rubiales and Fernández-Aparicio, 2012). Methods that embrace the application of herbicides, insecticides and inorganic fertilizers are environmentally unfriendly and unaffordable to most farmers, as is the use of Imazapyr Resistant (IR) maize-StrigAway, whereas crop rotation, uprooting *Striga* weeds, organic fertilizers and natural enemies, although affordable, often result in insufficient levels of control (Berner et al., 1994; Woomer, 2004). Additionally, control of stemborers using insecticides is often ineffective as the chemicals fail to reach deep inside the plant stems where the larvae reside; similarly use of herbicides against *Striga* can be ineffective (http://www.push-pull.net/2.shtml).

Push-pull technology (PPT) is a habitat strategy developed for the integrated management of stemborers, *Striga* weeds and poor soil fertility in SSA. It involves intercropping maize (and other cereal crops) and desmodium (e.g. *Desmodium uncinatum*), with Napier (*Pennisetum purpureum* Schumach) or Brachiaria (*Brachiaria cv mulato II*) grass planted as a border crop (Khan et al., 2008b; Midega et al., 2010). The desmodium repels stemborer moths ('push'), while the surrounding grass attracts them ('pull') (Khan et al., 2001). The desmodium also suppresses *Striga* weeds, mainly through allelopathy i.e. root-to-root interference (Khan et al., 2001). Farmers practising this technology have benefited from increased maize and fodder yields, as well as improved milk production and soil fertility (Khan et al., 2008a; Midega et al., 2015). To date, this technology has been adopted by > 155,000 smallholder farmers in Kenya, Uganda, Tanzania, and Ethiopia (http://www.push-pull.net/adoption.shtml).

The economic benefits of PPT for maize cropping have been demonstrated previously. Khan et al. (2001) evaluated the benefit-cost ratio of introducing PPT compared to maize monoculture with or without the use of pesticides, and Khan et al. (2008c) the returns on investment for the basic factors of production under PPT compared with other cropping methods. Both studies showed that PPT was more profitable. However, these studies only focused on incomes generated

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from increased maize yield; the other benefits of PPT, increased fodder from Napier or Brachiaria grasses and desmodium, and increased milk production, were not quantified. They were also conducted in selected districts in the western part of Kenya where PPT had been widely disseminated since 1998 (http://www.push-pull.net/Climate-smart_Push-Pull.pdf). In contrast, PPT technologies were first introduced into Uganda in 2001 into more diverse farm typologies and socio-economic conditions (Gatsby Charitable Foundation, 2005). The broader approach of this new study can potentially strengthen the relevance of PPT in other parts of SSA where the production of cereals is hugely constrained by the same suite of problems as in Uganda.

Around 30% of the total population in Africa live with chronic hunger and malnutrition; this number could probably increase given its projected rate of population growth (FAO, 2009). Hence there is a need to increase food security in the continent; one solution is through increased agricultural productivity that delivers increased food availability and rural income (Godfray et al., 2010; Asenso-Okyere and Jemaneh, 2012). Maize yield losses caused by stemborers can reach as high as 80% and by *Striga* weeds between 30 and 100%, and both are aggravated by low soil fertility (Khan et al., 2014a). Where both pests occur simultaneously, farmers often lose their entire crop (Khan et al., 2008b; Oerke, 2006). These losses, which amount to approximately USD 7000M annually in SSA, mostly affect subsistence farmers resulting in high levels of food insecurity, malnutrition and poverty (Kfir et al., 2002; Khan et al., 2014a; Ngesa et al., 2015; http://www.push-pull.net/2.shtml).

The objective of the current study was to evaluate the economic benefits of push-pull technology (PPT) in the context of maize cropping and the associated production of fodder and milk in eastern Uganda. This was done by assessing the social gains, and calculating gross margins with and without PPT and three investment parameters: present value (NPV), internal rate of return (IRR) and benefit cost ratio (BCR). The relevance of the results for accountability and planning purposes, and the further adoption of PPT in Uganda are discussed.

2. Methodology

2.1. Study area

The study covered four districts in eastern Uganda, namely Bugiri, Busia, Pallisa and Tororo (Fig. 1). In these districts, *Striga* weed, stemborers, poor soil fertility, and unreliable rainfall are the major constraints to maize production (Odendo et al., 2001; Khan et al., 2006). The districts are subject to the same tropical climatic conditions and land use, which is mainly arable. All are rain fed with annual rainfall between 1000 and 2000 mm, with short rains in April to May and long rains in September to November (http://psipse.org/about-uganda/). Agriculture is a core sector of Uganda's economy and the largest employer, and maize one of four major subsistence crops; the others are cassava, plantain and sweet potato (Karyeija et al., 1998; Mukwaya et al., 2011).

2.2. Sampling procedure and data types

Primary and secondary data were collected, the latter obtained from *icipe* offices in Mbita, Kenya and Mbale, Uganda. Data collected were both quantitative and qualitative. Quantitative data were collected during the November to December 2014 growing season and growing seasons between January and October 2015 from smallholder households, the sampling unit, through one-on-one interviewing with the household head, or if absent, their spouse. Qualitative data were collected from farmer groups and key informants and based on focus group discussion (FGD) and key informant interview (KII) guidelines respectively.

The sampling frame comprised smallholder farmers participating in PPT and those not participating. A multi-stage sampling procedure was applied. In the first stage, purposive sampling was used to select the region, Eastern Uganda and four districts with a predominant use of PPT relative to other districts. To obtain a sample of households from the four districts in the second stage, systematic random sampling was employed to identify sub-counties, parishes and villages. To ensure that different units in the population had equal probabilities of being chosen, selection of the sample was based on probability proportionate to size sampling, and sample size, *n* was computed from Kothari's (2004) formula:

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

where p = population proportion with the characteristic of interest, q = (1-p), N = size of the population, e = margin of error, Z = critical value at the desired confidence interval. Given a population of approximately 1300 farmers in the study area who had the characteristics of interest, and assuming that the sample mean should be ± 3% of the population mean at 95% level of confidence, the sample size was calculated as follows:

$$n = \frac{(1.96)^2 * (0.5) * (0.5) * 1300}{(0.03)^2(1300-1) + (1.96)^2 * (0.5) * (0.5)} = 586 \tag{2}$$

Thus a sample of approximately 586 respondents was required in which, for every district, smallholders both with and without PPT were sampled equally. Because of incomplete and/or poor responses, the final sample size of 568 households was achieved, 148 in Tororo and 140 each in Bugiri, Busia, and Pallisa. Of these, approximately half the households in each district had adopted PPT. This study was done simultaneously with an impact assessment of push-pull pest management in the same districts (Chepchirchir et al., 2017) which targeted early adopters of the technology. The earlier dissemination of PPT in Tororo than the other districts may explain the higher number of useable questionnaires from Tororo.

Experienced enumerators were trained to collect household data. The interview schedule focused on farmers' socio-economic characteristics, farm and institutional factors, household incomes, food and non-food expenditure, and consumption. FGDs were held with groups of farmers and KII's with founder farmers, opinion leaders, agronomists and agribusiness officers in the Ministry of Agriculture Animal Industry and Fisheries (MAAIF), and PPT project officers. Information collected from FGD's and KII's were quantities and prices per unit of maize, fodder and milk. A data validation exercise was conducted after the survey in Busia and Tororo from January to October 2015 whereby 30% of the previously interviewed farmers (both PPT and non-PPT participants) were interviewed.

2.3. Theoretical framework

Performance was evaluated using the DREAM economic surplus model (Alston et al., 2000). This model is based on the assumption that technology adoption leads to an outward shift in the product's supply curve which triggers a process of market-clearing adjustments in one or multiple markets, thereby affecting the flow of final benefits to producers and consumers. Through appropriate parameterization, the model was used to assess annual changes in producer and consumer economic surpluses as a consequence of the adoption of PPT. Thus:

$$\Delta PS_{it} = (K_{it} + PP_{it}^{R} - PP_{it})[Q_{it} + 0.5(Q_{it}^{R} - Q_{it})] \tag{3}$$

$$\Delta CS_{it} = (PC_{it} - PC_{it}^{R})[C_{it} + 0.5(C_{it}^{R} - C_{it})] \tag{4}$$

where, holding back the subscripts for region i in time t, ΔPS and ΔCS are the producer and consumer benefits, K is the realized supply curve shift or reduction in the per unit cost of production, and PP_{it}^{R} and PP_{it} are the producer prices with and without PPT, Q^R and Q the annual production totals with and without PPT, PC^R and PC the consumer prices with and without PPT, and C^R and C the market costs with and

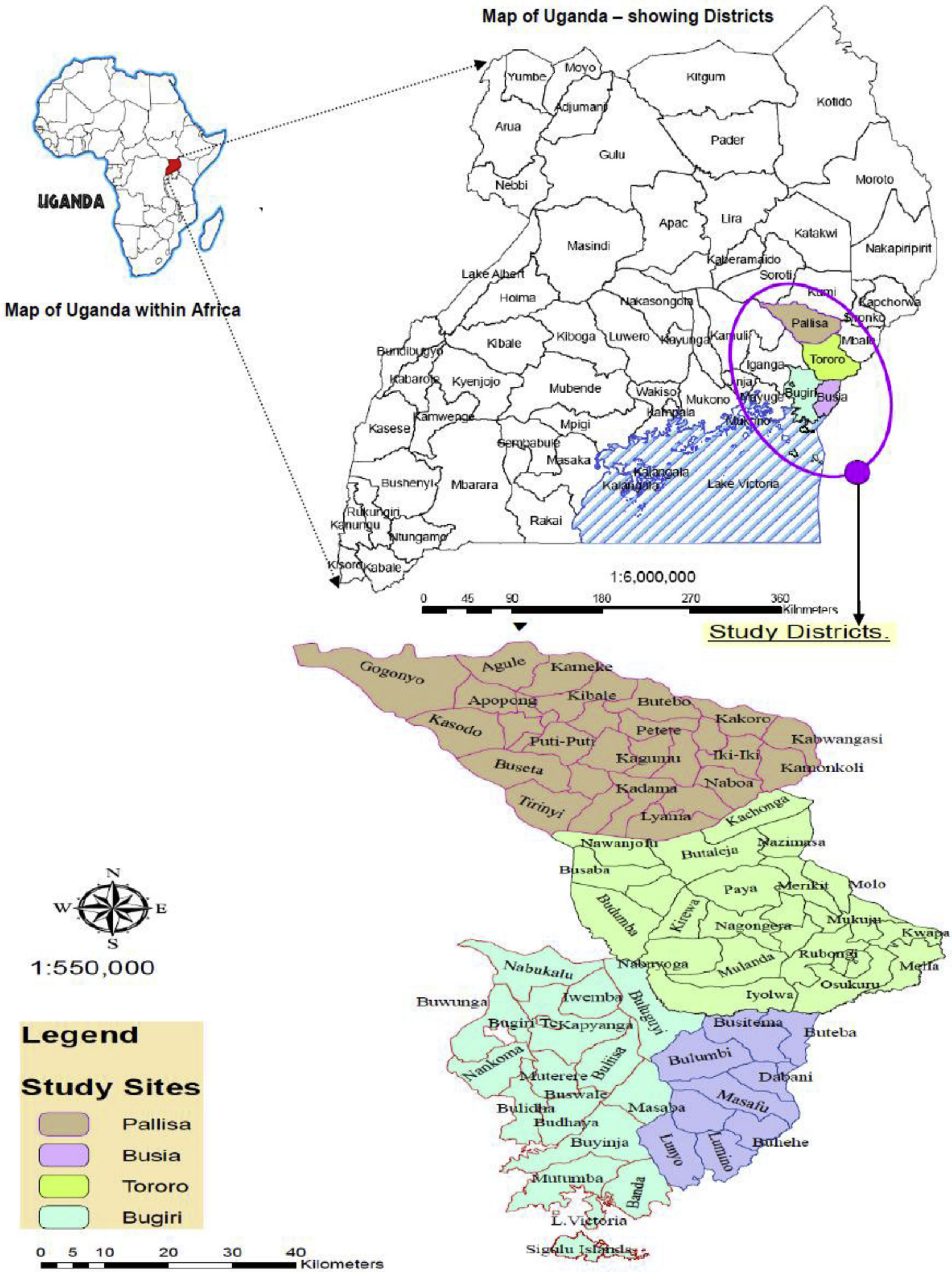

Fig. 1. Map of the study sites within Uganda.

without the PPT technology, respectively. Thus, the producer experiences a change in income due to a lower production cost per unit while the consumer experiences a gain in income by buying at lower prices. These series of benefits were converted into present value totals by conventional discounting techniques for a twenty-year stream of benefits as follows:

$$VPS_i = \sum_{t=0}^{20} \Delta PS_{i,t}/(1+r)^t = \Delta PS_{i,0} + \Delta PS_{i,1}/(i+r) + \Delta PS_{i,2}/(1+r)^2 + ... + \Delta PS_{i,20}/(1+r)^{20} \quad (5)$$

$$VCS_i = \sum_{t=20}^{20} \Delta CS_{i,t}/(1+r)^t = \Delta CS_{i,0} + \Delta CS_{i,1}/(1+r) + \Delta CS_{i,2}/(1+r)^2 + ... + \Delta CS_{i,20(1+r)^{20}} \quad (6)$$

where VPS_i and VCS_i are the present values for producer and consumer surplus, respectively for region *i*, and *r* is the discount rate. For both estimation and model sensitivity, $K_{i,t,}$ is the downward measure of the supply curve shift attributable to technical change in region *i* and time *t* and defined as:

$$K_{i,t} = E(c_i).\ a_{i,t}.PP_{i,0} \quad (7)$$

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

The net present value (*NPV*) was defined as the sum of the present values of the cumulative cash flow induced by an investment generated over a defined time period. Costs and benefits of the technology that occur in future periods were discounted. Thus:

$$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t} \quad (8)$$

where, B_t is the benefit of PPT, C_t represents the technology costs, *r* is the discount rate, and *t* is time period for which the technology will be there. A technology project is profitable and acceptable if the $NPV > 0$.

The *IRR* is the discount rate, r^* at which the PPT project's *NPV* equals zero. Thus the *IRR* is a measure of the actual investment efficiency regardless of the discount rate.

$$IRR = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r^*)^t} = 0 \quad (9)$$

The third investment criterion, benefit-cost ratio was expressed as a ratio of the sum of a project's discounted benefits to the sum of the project's discounted costs.

$$BCR = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+r)^t}} \quad (10)$$

A project is deemed to be suitable if the *BCR* is greater than or equal to one.

2.4. Analytical framework

2.4.1. Gross margin (GM) analysis

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

$$GM = TR - TVC \quad (11)$$

where

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

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

hence,

$$GM = \sum_{i=1}^{n} P_i Q_i - \sum_{j=1}^{n} P_j X_j \quad (12)$$

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

2.4.2. Statistical analysis of gross margin results

To compare maize performance from with PPT and without PPT smallholders, *GM* from maize only for the latter was also calculated. A statistical test was then conducted using one-way ANOVA for the gross margins and an F test was statistically significant when $p < 0.05$; a Bonferroni post hoc procedure was employed to examine differences between means.

2.4.3. Description of model variables, data and assumptions

Both market- and technology-related variables were included in the model. Market-related data were obtained from the survey and secondary sources, and technology-related data from project officers and key informants. Market-related data were the quantity of maize supplied and the consumed price, and the elasticity of supply and demand; technology-related data were the rate of adoption of PPT, the discount rate, research costs, and expected change in yields.

For the purposes of this study, it was assumed that production was equal to consumption; this was also necessary for the market clearing condition of the model. The average prevailing market price was obtained from farmers during the survey. All price data were specified in Ugandan shillings and converted into US dollars (USD) using the average exchange rate during the survey (2015) of 1 USD = 3300 UGX.

Estimates of the price elasticity of demand vary between −0.3 for basic commodities to −2.0 for non-basic commodities (Mills, 1997); the elasticity of supply ranges from 0 to 1.2 for agricultural commodities (Mwanaumo et al., 1997). The elasticities for supply and demand used for maize in this study were, respectively, −0.77 and 0.80, and based on earlier studies (Delgado et al., 2004; Karugia et al., 2009; Omamo et al., 2006).

An adoption rate of 30% was used (Khan et al., 2014b; Murage et al., 2015). This rate refers to the number of farmers adopting PPT per year as a proportion of the number of farmers trained in this technology. The research costs, which were the extension costs used for PPT dissemination, were obtained from the project office. The expected change in yield or growth in productivity is a function of technical progress and efficiency improvements; therefore the uncertainty associated with achieving benefits from investing in research requires estimation of the probability of research success and the expected benefits.

Primary data were acreages, yields of maize and fodder for farmers participating in PPT and those not participating PPT, unit prices for maize and fodder, the number of cows owned and milked, the quantity of milk yielded per cow per day, milk prices, and labour costs. Secondary data were maize yields from previous years, and research costs. The year 2015 was chosen as the base year, as this was the final year when data were collected from the farmers.

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

- Seventy three per cent (73%) of the farmers with cows keep and feed

their dairy cows with fodder from PPT;
- Farmers who do not have dairy cows (27% of all farmers) sell fodder from PPT;
- Project budget (costs) will increase by 1% per annum from 2017 onwards up to the year 2035;
- The number of farmers adopting PPT will increase 5% per annum from 2016 onwards (based on past trends);
- PPT gross margins will increase by 0.38% per annum (based on the past trends);
- PPT cropped areas will increase by 10% per annum up to 2025 and thereafter by 5% per annum up to 2035;
- The discount rate is 12% based on Uganda's Central Bank Rate, a rate conventionally assumed for economic analysis (https://www.bou.or.ug/bou/media/statement);
- The project life is 20 years.

2.4.4. Sensitivity analysis

Sensitivity analysis was performed by varying key assumptions: increasing projected costs by 20%, reducing projected benefits by 20%, decreasing the number of farmers adopting PPT from 5% to 2% per annum, and decreasing the increase in annual PPT cropped areas so that 5% per annum throughout the 20-year period.

3. Results

3.1. Gross margin analysis of PPT components

The gross margin (GM) per hectare from maize with fodder with PPT was 725 USD[1] and the GM of maize without fodder with PPT was 405 USD, but there was no significant difference (Table 1). There was a statistically significant difference between groups as determined by one-way ANOVA (F (2,403) = 325.67, p = .001). A Bonferroni post hoc test revealed that the GM of maize without PPT was 239 USD and this was significantly different from the GM of maize without fodder with PPT (p = 0.003), and maize with fodder with PPT, (p = 0.001). The GM of milk per cow was 26 USD.

3.2. Revenues and costs with PPT and without PPT

Total revenues arising from sale of farm produce, TVC and material input costs were significantly higher with than without PPT ($p < 0.05$) (Table 2). Conversely, labour cost was significantly higher without than with PPT ($p < 0.05$), although the difference was small, about 6000 Ugx/ha. With PPT material input costs accounted for 29% of the TVC and labour costs 71%; without PPT, these costs were 11% and 89%, respectively. The main contributing factor to this difference in material costs was the requirement for fertilizer with PPT. For costs related to labour, that for land preparation was higher without PPT whereas that for weeding, trimming of desmodium and cutting back Napier grass was higher with PPT.

3.3. Economic surpluses

When summed for a 20-year period of the simulation of the economic model, households with PPT in the study region would derive an overall net gain of 3.8 million USD. The total benefits from adoption of PPT had a net present value (NPV) of 1.61 million USD; the internal rate of return (IRR) was 51% and the benefit cost ratio (BCR) was 1.54.

3.4. Sensitivity analysis

If the projected costs were increased by 20%, or the projected benefits reduced by 20%, the NPV remained > 580,000 USD, the IRR > 20% and BCR > 1.2; however if both occurred in combination, NPV was < 300,000 USD, and the IRR and BCR only 13% and 1.03, respectively (Table 3). The effects on projected benefits of reducing the increase in the number of farmers adopting PPT to 2% per annum and PPT cropped areas increasing by 5% throughout, and both in combination were less; NPV, IRR and BCR remained > 570,000 USD, ≥39% and ≥1.23, respectively (Table 3).

[1] The average exchange rate during the survey (2015) was 1 USD = 3300 UGX.

Table 1
Gross margins with PPT and without PPT.

Variable	Gross margins#	
	UGX	USD
With PPT		
PPT gross margin for maize with fodder (per ha)	2,019,786a	725a
PPT gross margin of maize without fodder (per ha)	1,111,794a	405a
Without PPT		
Gross margin for maize	656,222b	239b
Other		
Milk gross margin (per cow)	70,460	26

#Means marked by different letters within a column are significantly different ($p < 0.05$).

Table 2
Revenues and costs with and without PPT.

Variable	Revenues and costs (Ugx/ha)#	
	With PPT	Without PPT
Total Revenue (TR)	3,769,853a	2,072,280b
Total Variable Costs (TVC)	1,750,067a	1,416,058b
Material input costs	500,459a	160,355b
Labour costs	1,249,607b	1,255,703a
% of TVC		
Material input costs	29%	11%
Labour costs	71%	89%
% of Material input cost		
Seed cost/ha	18%	54%
Fertilizer (DAP)/ha	67%	0%
Bagging/ha	15%	46%
% of Labour cost		
Land preparation/ha	18%	35%
Planting/ha	13%	15%
Weeding, trimming desmodium and cutting Napier/ha[a]	35%	16%
Harvesting/ha	23%	22%
Postharvest/ha	12%	12%

#Means marked by different letters within a row are significantly different ($p < 0.05$).
[a] Weeding applies to with and without PPT; trimming desmodium and cutting back Napier applies to with PPT only.

Table 3
Sensitivity analysis based on costs, benefits, number of farmers adopting PPT and cropped areas.

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

3.5. Qualitative results

The focus group discussions (FGDs) and key informant interviews (KIIs) indicated that farmers without PPT spent more hours weeding than those with PPT because of the need to uproot *Striga*. Farmers with PPT used a lot more planting fertilizer and labour was required to manage desmodium and Napier grasses. Farmers with PPT owned more cows and produced more milk than farmers without PPT.

4. Discussion

Using the common indicators that assess economic viability, this study has shown that the introduction of push-pull technology (PPT) into Eastern Uganda has the potential to deliver monetary benefits to households reliant on maize farming to generate income. The results also provide further support to the view that by adopting low cost approaches, the three major problems confronted by maize growers, *Striga* weeds, stem borers and low fertility, can be addressed through using this technology. How these benefits are realized in an economic context is now discussed below.

Whether farmers had maize with fodder or maize without fodder, their gross margins (GMs) were enhanced by the application of PPT. An earlier study in six districts in Western Kenya also showed that use of a similar maize PPT system consistently resulted in significantly greater gross revenues than from a maize monoculture (Khan et al., 2008c). In the current study, the benefits of using PPT were enhanced if maize was grown with fodder. This provided on-farm feed for livestock and tripled the GM compared to that from maize without PPT; milk production further enhanced the benefit. And even without fodder, the GM with PPT delivered a significant benefit compared to maize without PPT. It is therefore evident that farmers in Eastern Uganda working in maize-based cropping systems where yields are constrained by stemborer moths and *Striga* weed infestations will financially benefit from investing in PPT.

Total revenues (TR) and Total variable costs (TVC) were greater with than without PPT. In the Siaya and Vihiga districts of Western Kenya, compared to other cropping systems those with PPT had the highest average revenue of which more than half came from the fodder crops (De Groote et al., 2010); in the current study, TR was increased by > 80%. De Groote et al. (2010) also found that PPT was associated with higher costs attributed to the purchase of desmodium seeds and Napier grass cuttings and the labour for their establishment and maintenance. In this study total labour costs were similar with and without PPT, although the distribution of the costs clearly indicated that a greater proportion of labour was required for maintenance of the desmodium and Napier grass; however planting costs remained unchanged because once established at the start of the 20-year cycle, planting costs were associated with the maize only (Khan et al., 2008c; ICIPE, 2015). By contrast, material input costs with PPT were tripled compared to without PPT because of the application of DAP fertilizer. However, yields and therefore revenues may also have been enhanced by the desmodium which fixes nitrogen and conserves soil moisture (Gatsby Charitable Foundation, 2005; Kifuko-Koech et al., 2012; ICIPE, 2015). These findings concurred with the statements made through the FGDs and KIIs that planting fertilizer and labour for managing desmodium and Napier grass were the main factors that distinguished PPT from without PPT. However, as the practice of PPT in Eastern Uganda was essentially cost neutral for labour, there may be opportunities for reducing the high costs of inorganic fertilizer inputs and enhancing inherent soil fertility with better management of the desmodium.

The investment parameters NPV, IRR and BCR indicated that PPT is economically viable and socially beneficial. The study by Khan et al. (2008c) in Western Kenya showed that PPT produced a positive and substantially higher NPV from land at a similar discount rate (10% *vs.* 12% in this study) in two of the six districts examined than from maize monoculture which was associated with a negative NPV in the district severely affected by *Striga* weed. A parallel project in two other districts in Western Kenya and also over a six-year period also demonstrated high economic returns with positive and greater than one benefit-to-cost ratio (BCR) when compared to farmers' own practice of maize mono-cropping (De Groote et al., 2010; ICIPE, 2015). While these findings from detailed field studies strongly support an expected economic viability for PPT in East Africa, De Groote et al. (2010) note that investments in fertilizer as well as green manure and IR-maize are not always justified by their increased revenue. Nevertheless, that the IRR in this study was 51% and substantially greater than the discount rate and that there is expected to be an economic gain of 3.8M USD to households in the study region in the next 20 years, equivalent to 9500 USD per household, suggest that the economic returns from investing in PPT are significantly different from zero and justify the research needed to enhance the returns from inputs that can potentially increase yield.

Changes to all the investment parameters pointed to continued viability of PPT when four key variables, costs, benefits, numbers of farmers adopting PPT and per cent increase in PPT cropped areas were subjected to nominal change during a sensitivity analysis. Of these, the most sensitive was project benefits, a 20% decrease leading a reductions of NPV, IRR and BCR by 64%, 28% and from 1.54 to 1.23, respectively. However, the viability of PPT was compromised if this decrease in benefits was accompanied by a 20% increase in costs as the IRR was close to the discount rate and the BCR very close to unity. Nevertheless, the economic model adopted appears to provide a strong indication that PPT should be profitable and economically viable at farm level for the next 20 years.

PPT was initially developed to control cereal stemborer pests and *striga* weeds attacking cereal crops in sub-Saharan Africa (Khan et al., 2010). Its adaptation and extension to drier agro-ecologies has expanded its pest management functionality, including effective management of fall armyworm in the region (Midega et al., 2018). Hence PPT has further potential for wider use in SSA to control key pests affecting cereal production and this recent study done in 2014 and 2015, illustrates that it is providing positive outcomes in eastern Uganda. Given that all the components of the technology were evaluated, the results indicate an economic viability for PPT and hence an economic justification for further investment and dissemination to other regions.

5. Conclusions and implications

This study has shown that the proper implementation of PPT offers the prospect of monetary benefits to households who depend on maize farming to generate their income. Gross margin analysis indicated that income from PPT with or without fodder was higher than for maize without PPT and that farmers also financially benefited from fodder as dairy feed as this generated income from milk production. However material input costs were greater with PPT due to application of DAP fertilizer. This suggests that farmers may benefit from training on the better management of desmodium to improve soil fertility in order to reduce the high costs of inorganic fertilizer inputs. While the investment parameters NPV, IRR and BCR and gains to households supported the economic viability and social benefits of PPT, marked increases in costs in combination with reductions in benefits were the greatest threat. Nevertheless the results suggest further up-scaling and dissemination of the technology where farmers are facing the problem of *Striga* weed infestation, stemborer pests and low soil fertility.

Conflicts of interest

The authors declare that we have no conflict of interest with the organization that sponsored the research work.

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