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Impact of adoption lag of soil and water conservation practices on crop productivity in Sio-Malaba Malakisi Basin of Kenya-Uganda border

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The increasing need to feed a fast-growing population has significantly led to land degradation and a substantial reduction of soil and crop productivity globally, due to soil overexploitation. Adoption of Soil and Water Conservation Practices (SWCPs) improves crop productivity and reduces soil erosion rates. However, the adoption of SWCPs is still low in many countries, especially in Sub-Saharan Africa. Moreover, even farmers who adopt these practices do not adopt them on time. There are limited studies about adoption lag of SWCPs and its impact on crop productivity. This study used Generalized Propensity Score Matching to determine the impact of adoption lag of SWCPs on crop productivity in the Sio-Malaba-Malakisi Basin of Uganda and Kenya borders and 506 households were selected in five districts. Results indicate that the longer farmers take to adopt, the less the crop productivity they get from their land and this worsens with time lag. In Kenya, the adoption lag of SWCPs is associated with an increasing impact on crop productivity in the short run and a decreasing impact on crop productivity in the long run while the reverse is true in Uganda. Programs supporting SWCPs need to emphasize the importance of early adoption and proper maintenance of soil and water conservation structures, for optimum efficiency.

Key words: Adoption lag, crop productivity, duration model, generalized propensity score matching, Sio-Malaba-Malakisi River Basin, soil and water conservation practices.

INTRODUCTION

Soils are precious resources, producing more than 80% of food consumed by humans (Pimentel, 2006; Brevik et

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al., 2015; Poore and Nemecek, 2018). However, pressure to meet food demand for the growing population has resulted in overexploitation and unsustainable use of soil and hence poor soil productivity (Williams et al., 2004; Hardian et al., 2021). Human activities like deforestation, clearing of grasslands for agricultural extensification, reclamation of swamps, and nonstop cultivation of existing cropland pose a serious threat to future land productivity (FAO, 2011; Tully et al., 2015; Vanwalleghem et al., 2017; Davari et al., 2020). Approximately, 10 million hectares of cropland are lost to soil erosion per year (UNCCD, 2015; Pimentel, 2006). In 2007, the global cost of land degradation, as defined by Tully et al. (2015), was 0.42% of the global GDP (56.49 trillion USD), and 26% of these costs were attributed to Sub-Saharan Africa (SSA) (Nkonya et al., 2016). The resulting decline in crop yield reduced the ability of global food productivity to feed the growing population (Foley et al., 2011; Ray et al., 2013; Turinawe et al., 2014; Willett et al., 2019). Additionally, the productivity growth rate of some major crops on the globe (maize, rice, wheat, and soybean) is far less than what is required to meet the 2050 food demand (Ray et al., 2013) and predictions show that food demand continue to increase while surply diminishes (Tian et al., 2021).

In SSA, hunger and poverty are exacerbated by high population growth yet the dependence on degrading land compromises crop productivity (Tukahirwa, 2003; Pender et al., 2004; Oduol et al., 2011; Batjes, 2014; NEMA, 2014; Tully et al., 2015; Baloch et al., 2020). In Kenya, several counties are frequently affected by floods and severe drought stress. Also, land degradation due to erosion and landslides led to increased malnutrition in Kenya, especially for children (Harding and Tahia, 2009). The cost of land degradation was estimated at 11$ billion in Kenya between 2001-2009 (Kirui and Mirzabaev, 2015). In Uganda, four to twelve percent of GDP has been lost to environmental degradation annually for the last decade leading to soil erosion, compaction, and nutrient loss (MWE, 2016; World Bank, 2018).

Measures to rehabilitate and restore land or slow down the deterioration of land and water resources are of urgent concern if the future population is to be sustained. From traditional society till now, farmers have practiced different agricultural technologies to improve and sustain productivity. Indigenous and modern knowledge about soil and water conservation practices (SWCPs)[1] has been transmitted from one generation to the other (Tella, 2007; Kumar, 2016).

With time and as science evolves, indigenous/ traditional agricultural technologies have been upgraded results (AnimalSmart, 2007). Traditional SWCPs being used in SSA include compost, mulching, trashlines, terraces, crop rotation, intercropping, minimum tillage, fallowing, cover crops, alley cropping, and contour ploughing. While modern/improved practices include *fanyachini* terraces, *fanyajuu* terraces, trenches/diversion channels, grass trips, agro-forestry, improved trash lines, and bench-terraces (Reij, 1991; Ellis-Jone and Tengberg, 2000; Miiro, 2001; Turinawe et al., 2014; Karuku, 2018).

Timely adoption of soil and water conservation practices (SWCPs) is an option to improve crop productivity and sustainably conserve land. SWCPs increase productivity through reduced soil erosion rates (Nearing et al., 2017).

These practices have been advanced as a potential solution to soil degradation, water shortage, and crop productivity reduction in Africa (Mango et al., 2017). Unfortunately, timely adoption of SWCPs is still unachieved in many SSA countries. SWCPs need to be adopted on time and at a reasonable rate to control the decline in the quality of soils and improve the productivity of agricultural land in developing countries. Agriculture is still the core for economic growth in these countries, where more than 70% of the working population is engaged in agriculture (Duivenbooden, 1999; Tukahirwa, 2003; UBOS, 2012; MAAIF, 2010; World Bank, 2015). Research has given limited attention to the adoption lag[2] of SWCPs and its role in the eventual effectiveness of sustainable land management programs, despite its importance in explaining implications of low technology adoption. However, some previous related studies have focused on adoption, technical efficiency, intensity, and effect of SWCPs on productivity/household welfare (Ellis-Jones and Tengberg, 2000; Mugonola et al., 2013; Turinawe et al., 2014, 2015), giving limited attention to adoption lag of SWCP and it simplications on crop productivity. This study provides empirical evidence on the adoption lag of SWCP and its impact on crop productivity in the Sio-Malaba Malakisi basin of the Kenya-Uganda border. The study contributes to efforts geared towards increasing early adoption of SWCPs in Uganda and Kenya through soil and water conservation initiatives and policies for better adoption and productivity.

MATERIALS AND METHODS

The study was conducted in the Sio-Malaba-Malakisi River Basin (SMMRB) area located on the Kenya and Uganda border (Figure 1). SMMRB is endowed with abundant natural resources, including fertile soils, relatively high rainfall, and natural deposits of

[1]Soil and water conservation (SWC) refers to an activity or combination of activities that enhance or maintain the productivity of land in areas prone to soil erosion or affected by soil erosion (Mati, 2012).

[2]Adoption lag is the time between initial technology awareness and the actual adoption of the technology (Ainembabazi et al., 2015 ; Lindner et al., 1982).

Figure 1. Sio-Malaba-Malakisi River Basin in Kenya and Uganda (Manafwa District was split into Manafwa and Namisindwa Districts in 2014)
Source: Herrnegger, 2017.

phosphorus and limestone that present tremendous potential for social economic development. The basin covers about 4,000 km^2 whereby 2,880 km^2 are located in Kenya and 1,220 km^2 in Uganda (Roussel, 2012).

Administrative units covered in this study were Bungoma and Busia counties in Kenya and Busia, Namisindwa, and Tororo districts in Uganda. These districts/counties are characterized by land shortages and exponential population growth, causing significant changes in land cover (Mugagga et al., 2012). In addition, Bungoma, Namisindwa, and Tororo have partly steep slopes and high vulnerability to landslides and erosion (Knapen et al., 2006; NEMA, 2010).

Subsistence agriculture is the major socio-economic activity in the SMMRB catchment, employing about 85% of the people (Nile Basin Initiative, 2015; Muli, 2011). Within the basin, poor agricultural practices, intensive land cultivation, indiscriminate sand harvesting, and climate change hazards exacerbated by inadequate extension services have resulted in extensive catchment degradation and soil erosion (IUCN, 2017; Nile Basin Initiative, 2012).

The main research question of this study is; what is the impact of adoption lag of soil and water conservation practices on crop productivity?

Sampling and data collection

The multi-stage purposive random sampling technique was used to select the sample for this study. Kenya and Uganda were purposively selected due to their high population and economic growth which are leading to tremendous pressure on natural resources, reduced land cover, and subsequent land degradation. Yet, the two countries are the major producers and suppliers of food to other countries within the region that are not able to produce enough food for their populations (Nyirahabimana et al., 2021). The sampling and analysis unit was the household. Different administrative units were selected with a multi-stage sampling technique, starting with the highest unit (district for Uganda and county for Kenya) and ending with the lowest (village). While districts and counties within the SMMRB, close to the border and within high-risk part of soil degradation in the catchment were selected purposively, the rest of the sampling was stratified random sampling. A household survey was conducted with 506 households using semi-structured questionnaires in 2018. In addition, one focus group discussion, and two key informants were conducted in Kwaapa and Merikit sub-counties in Tororo District. The respondents were asked about socio-economic features of the household; SWCPs' awareness, and adoption time; land use, crop production; and livestock ownership among others. Further details on the sampling strategy for this study can be found in Nyirahabimana et al. (2021).

Analytical models

Duration model

Duration model determines the time elapsed till a certain event occurs (Wooldridge, 2010). When studying the time difference between two mutually exclusive events, in this case, non-adoption and adoption of SWCPs, the difference between the two time points is made (Lancaster, 1990). The Adoption lag of a particular SWCP j was determined by taking the difference between the year when the practice j was adopted (exit time) by the household h and the year when it was made available to the household h. However, for cases of non-adopters who were aware of a SWCP at the time of the survey, their exit time is unknown, but the adoption may take place soon or later in the future. For such cases (non adopters), the statistical procedure was right-censored to establish the year of the exit whereby the year when data was collected

(2018). Nyirahabimana et al. (2021) explains the proceduce taken in detail, to determine adoption that influence adoption that influence adoption lag of SWCP in SMMRB.

Generalized propensity score matching for determination of the impact of adoption lag on crop productivity

Crop productivity determination: Crop productivity was measured as the value (in USD) of all crops grown on an acre of land using rates from https://www.poundsterlinglive.com/on 13/03/2019 (1UGX=0.000274363 USD while 1KES=0.0100706963 UDS). The study used crop production data from the two seasons of 2017. Crop harvest in kg and the market price of each of the grown crops were reported by farmers and their local values were converted to USD. These crops included maize, sorghum, millet, rice, cassava, sweet potato yam, beans, groundnuts, soybeans, pigeon peas, green grams, cowpeas, cabbage, amaranth, onions, green peppers, leafy vegetables, eggplants, sweet banana, banana, tomatoes, avocado, pumpkin, watermelon, black peppers, coffee cotton, fodder, and sugarcane. The value of all crops' yield was determined by multiplying the yield by their market price for each crop to get the seasonal crop productivity at the plot level for each of the crops grown. Plot level productivity was then brought to the household level productivity and the household level productivities for the two seasons of 2017 were added to get the annual household level productivity used for analysis in this study.

Determinations of the impact of adoption lag on crop productivity: The most common methods for determining the impact of a binary treatment include, but are not limited to, Treatment Effect, Treatment Effect on the Treated, Difference in Difference, Instrumental Variable, and Propensity Score Matching (Asfaw et al., 2012; Khandker et al., 2009; Oduol et al., 2011; Verkaart et al., 2017; Wossen et al., 2017). These methods are used in impact evaluation for binary treatments, such as in technology adoption studies where the adoption status is "yes" or "no," with all treated individuals receiving the same level of a random dosage of treatment. In the case of adoption lag, individual farmers have different levels of adoption lag because they learned about and adopted specific Soil and Water Conservation Practices (SWCPs) at different times. Thus, conventional binary treatment methods would classify adopters of SWCPs identically, even though they have different adoption lags for each specific SWCP and thus different household-level adoption lags (average lag). This necessitates a continuous treatment method. We used the Generalized Propensity Score Matching (GPSM) method developed by Hirano and Imbens (2004). GPSM focuses on assessing the effect of different levels of adoption lag (treatment) on crop productivity (dependent variable). The method relies on the unconfoundedness assumption, meaning that selection into various levels of adoption lag is random and conditional on observables found to be determinants of adoption lag (Hirano and Imbens, 2004).

In their work, Hirano and Imbens (2004) proposed a partial mean approach to estimate the entire dose-response function for a continuous treatment as follows: Consider a random sample of size n and individuals' index l where $l = 1, ...n$. Also, let $Y_l(t)$ represent the potential outcome (crop productivity) for an individual l under treatment t (adoption lag), where $t \in T$ and T is an interval (t_0, t_1) . t represents the dosage/treatment (in this case dosage is the level of the adoption lag). There is a set of potential outcomes for each individual l represented by the individual-level dose-response function (Y_{tl}) , $t \in T$. However, because of the inherent missing data problem in impact evaluation, the research focus is the identification of the curve of average potential outcome which is the parameter of interest and represented by the entire dose-response function, $u(t) = E\left[Y_l(t)\right]$. This is the average potential impact of adoption lag (AL) of SWCPs on crop productivity over all possible levels of adoption lag. When the focus is the estimation of the average dose-response function and marginal treatment functions for households that adopted innovations, the untreated households (non-adopters and who were not aware of SWCPs in this case) are excluded from the analysis (Kassie et al., 2014).

The unconfoundedness assumption means that the assignment of treatment is independent of each potential outcome conditional on observables, $Y_l(t) \perp T_l / X_l$ for every $t \in T$. Let the conditional density of treatment given covariates be denoted by $r(t, x) = f_{T/X}(t / x)$. According to Hirano and Imbens (2004), there is a Generalized Propensity Score (GPS) defined by $R_l = r(T_l, X_l)$ that has a balancing property whereby within the strata of the same value of $r(T, X)$, the probability that $T = t$ for a given individual does not depend on the X value, that is $X \perp 1(T = t) / r(t, X)$.

Hirano and Imbens (2004) also note that if treatment assignment is weakly unconfounded given covariates, it is also weakly unconfounded given GPS that is, $Y_l(t) \perp T_l / r(t, X_l)$ for all $t \in T$. Thus, GPS can be used to remove biases caused by a difference in observables. In addition, Hirano and Imbens (2004) mention that if the assignment of treatment is weakly unconfounded given pre-treatment variables X , then $\beta(r,t) = E\left[Y(t) / r(t, X_l)_l\right] = E(Y_l / T1 = t, R_l = r)$ and $u(t) = E\left[\beta(t, r)(t, X_l)\right]$. Thus, the entire dose-response function at a specific level of adoption lag t was estimated in three steps by the use of a partial mean approach as follows: First, lognormal distribution was used to model the level of adoption lag (T_l) given covariates:

$$LnT_l / X_l \approx N(\beta_0 + \beta_1^{'} X_l, \delta^2) \qquad (1)$$

where β_0 , β_1 and δ^2 are estimated by maximum likelihood. Second, to make sure that covariates are balanced across individuals, GPS were estimated based on the parameters in

$$LnT_l / X_l \approx N(\beta_0 + \beta_1^{'} X_l, \delta^2) \qquad (2)$$

$$\hat{R} = \frac{1}{\sqrt{2\Pi \hat{\sigma}^2}} \exp\left(-\frac{1}{2\hat{\sigma}^2}(T_l - \hat{\beta}_0 - \hat{\beta}_1{}' X_l)^2\right) \qquad (3)$$

As indicated by Hirano and Imbens (2004), the conditional expectation of outcome (crop productivity) was estimated as a function of observed treatment level (Ti) (Al) and estimated GPS (Ri) by quadratic approximation as follows:

Table 1. Socio-economic and demographic characteristics of households by country.

Characteristic	Kenya (n=253)	Uganda (n=253)	t-statistics
	Mean (SD)	Mean (SD)	
Education level of household head(years)	7.37 (3.73)	6.20 (3.94)	3.43***
Farming experience of household head (years)	37.79 (15.74)	33.29 (15.29)	3.26***
Farmland owned (acres)	1.55 (1.76)	2.59 (3.87)	-3.89***
Household size	5.81 (2.40)	6.57 (2.63)	-3.39***
Age of household head	51.79 (14.99)	46.85 (14.93)	3.71***
Number of accessible markets	2.08 (0.99)	1.90 (1.12)	1.93*
Tropical Livestock Units (TLU)	1.73 (3.18)	1.70 (2.14)	0.15
Dependency ratio	1.31 (0.95)	1.60 (1.10)	-3.13***
Number of plots operated	5.13 (2.70)	6.42 (3.27)	-4.82***
Number of parcels operated	1.56 (0.80)	1.89 (1.03)	-4.05***
Male headed household (1/0)	0.79 (0.14)	0.82 (0.39)	-0.80
Participation in natural resource management training (1/0)	0.32 (0.47)	0.15 (0.35)	4.81***
Participation in extension services (1/0)	0.16 (0.37)	0.09 (0.29)	2.14**
Participating in social groups (1/0)	0.46 (0.50)	0.50 (0.50)	-0.98
Access to off-farm income (1/0)	0.73 (0.45)	0.70 (0.46)	0.59
Households with access to credit (1/0)	0.28 (0.45)	0.35 (0.48)	-1.72*
Household owning livestock (1/0)	0.92 (0.26)	0.86 (0.35)	2.31**

SD means standard deviation and the figures in parentheses are standard deviations. ***, ** and * indicate significance level at 1, 5 and 10% respectively.
Source: Own computation form the data.

$$\beta(t,r) = E\left[Y_l / T_l, R_i\right] = \alpha_0 + \alpha_1 T_l + \alpha_2 T_l^2 + \alpha_3 R_l + \alpha_4 R_l^2 + \alpha_5 T_l R_l \quad (4)$$

The coefficients in equation 4 do not have a causal interpretation (Hirano and Imbens, 2004). Thus, in the final (third) step the dose-response function at a specific level of treatment was estimated. This was done by averaging the estimated conditional expectation $\beta(t,r)$ over GPS at that very specific level of treatment as follows:

$$u(t) = E\left[\widehat{Y(t)}\right] = \frac{1}{N}\sum_{l=1}^{N}\left(\hat{\alpha} + \hat{\alpha}_1 t + \hat{\alpha}_2 t^2 + \hat{\alpha}_3 \hat{r}(t, X_l) + \hat{\alpha}_4 \hat{r}(t, X_l)^2 + \hat{\alpha}_5 t\hat{r}(t, X_l)\right) \quad (5)$$

The α is a vector of parameters estimated in the second stage, $\hat{r}(t, X_l)$ is the predicted value of $r(t, X_l)$ at t level of the treatment. To estimate entire Dose-Response Function (DRF), it is important to estimate the average potential outcome for each level of treatment. The results of both GPS and those of DRF can be presented graphically (see for example Kassie et al., 2014).

RESULTS AND DISCUSSION

Characteristics of the respondents and reported soil and water conservation practices

Table 1 reports the socio-economic characteristics of the respondents. The results reveal statistically significant differences in socio-economic characteristics of respondents by country. Kenyan household heads were significantly more educated; had more farming experience; had access to more markets and participated more in extension services than their Ugandan counterparts. On the other hand, Ugandan households significantly owned more farmland; had larger household sizes, had a higher dependency ratio, and more households accessed credit than Kenyan households.

Further summary for pooled statistics and comparison between male and female-headed households are discussed in Nyirahabimana et al. (2021).

Adoption lag of soil and water conservation practices

We analyse seventeen Soil and Water Conservation Practices (SWCPs) that were reported by farmers as the most common in the study area. Table 2 summarises adoption levels of these SWCPs in Kenya and Uganda. Further information on overall adoption levels of SWCP in the study area are highlighted in Nyirahabimana et al. (2021), while deinitions of some SWCPs are presented in Appendix C. Intercropping was the most practiced SWCP, while alley cropping was the least practiced in both countries. The focus of this paper was to understand impact of adoption lag on crop productivity. Individual SWCPs was analysed to understand the adoption lag for each of the individual SWCPs and thus understand the average household-level adoption lag. We therefore focus on the synthesis of the impact of SWCPs but also

Table 2. Reported adoption of soil and water conservation practices in the study area.

Reported SWCPs	Number and percentage of adopters	
	Kenya (n=253)	Uganda (n=253)
Mulching	137 (54.15)	108 (42.69)
Trenches/Diversion channels	168 (66.40)	136 (53.75)
Trash lines	114 (45.06)	69 (27.27)
Fallow	121 (47.63)	112 (44.27)
Contour ploughing	110 (43.48)	53 (20.95)
Grass strips	123 (48.62)	66 (26.08)
Fanya chini	54 (21.34)	19 (7.5)
Fanya juu	59 (23.32)	16 (6.23)
Minimum tillage	32 (12.64)	31 (12.25)
Hedges	42 (16.60)	21 (8.300)
Alley cropping	16 (6.32)	10 (3.95)
covercrops	146 (57.70)	139 (54.94)
Stones/soil bands	47 (18.58)	25 (9.88)
Agro-forestry	100 (39.52)	80 (31.62)
Intercropping	216 (85.37)	240 (94.86)
Fresh and decomposed manure	187 (73.91)	143 (56.52)
Crop Rotation	208 (82.21)	212 (83.79)

The figures in parentheses are percentages of adoption while those outside parentheses are frequencies.
Source: Own computation from the data.

present results of adoption lag and comparison between Kenya and Uganda in Appendix A. Households in the study area had an average adoption lag of about 10years, meaning that an average household waits for at least 10 years to adopt any SWCP after they have become aware of it. There were no statistically significant differences in adoption lag of most of the individual SWCPs between Kenyan and Ugandan households except for minimum tillage at a 10% level of significance. The adoption lag of minimum tillage in Uganda wasabout 8 years while in Kenya it was around 11 years. In addition, the mean-lag (household lag) was 8.9 years in Uganda while in Kenya it was 9.7 years with no statistically significant difference in the mean household lag between the two countries (Appendix A). This implies that the timing of adoption of most of the SWCPs does not vary significantly between the two countries.

Impact of adoption lag of soil and water conservation practices

Households that did not report information about crop productivity were excluded from analysis reducing the number of households from 253 to 240 and 252 for Kenya and Uganda respectively. Results indicate that productivity was significantly higher for Kenyan (4072.30 USD) than for Ugandan households (231.68 USD) (at a 1% significance level) (Appendix B). This result agree with Smale and Jayne (2003) and Sserunkuuman (2005) who found that Kenya has one of the highest crop productivities in Africa. This could partly be because Kenyan farming households apply more inorganic fertilizers that usually boost crop yield than Ugandan households (Matsumoto and Yamano, 2011; Edwin and Dienya, 2015). Figures 2, 3A, and 3B indicate the Average Treatment Effect (ATE) (dose-response curve) and Treatment Effect (TE) of adoption lag on crop productivity in the entire study area, Kenya and Uganda, respectively.

Different tests of goodness-of-fit showed that the selected covariates give a good estimate of the conditional density of adoption lag. The treatment variable was transformed using Kolmogorov-Smirnov equality-of-distributions to test for the normal distribution of the disturbance. The assumption of normality of the treatment variable (adoption lag) was satisfied at the significance level of 5% in Kenya, Uganda, and in both countries combined. The test for the conditional mean of the pre-treatment variables given the generalized propensity score is not different between units that belong to a particular adoption lag interval and units that belong to all other adoption lag intervals was carried out. The balancing property was satisfied at $p<0.01$ in Kenya, Uganda, and in both countries combined. Information about the distribution of GPS is in Appendix D.

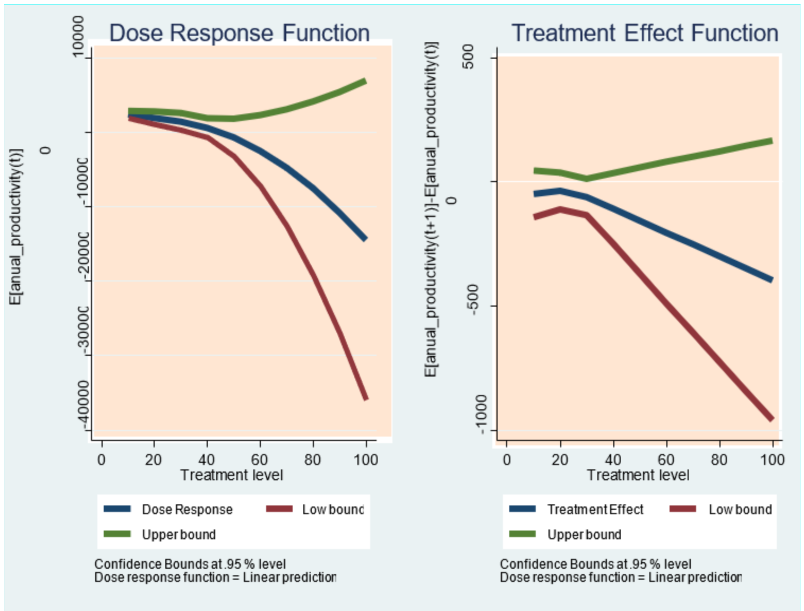

Figure 2. Impact of adoption lag of SWCPs (X-axis, in years) on crop productivity (in USD/acre, Y-axis) in Sio-Malaba Malakisi River Basin.

The results in Figure 2 shows that the adoption lag of SWCPs is significantly (dose-response function and marginal effect/treatment effect functions lie in the middle of 95% confidence interval) associated with a reducing impact on crop productivity. That is to say that crop productivity becomes less and less (indicated by the downward direction of dose response and treatment effect functions) as adoption lag increases. This could be because when farmers delay adopting SWCPs, over time they may forget the correct information that they gotfrom the extension services or any other source that introduced the practices and their establishment protocols. In addition, when farmers delay adopting, the initial source of extension support could no longer be there to help them properly establish and maintain those SWCPs. This together with land degradation reduce the crop productivity over time due to the delayed adoption of SWCPs.

Eventually, when soils are so bad, the adoption of conservation measures is not a rewarding option, at least in the short run.

On the other hand, in Kenya and Uganda, the impact of adoption lag on crop productivity shows mixed trends. Two terms that are used in this paper, to help interprete the results in Kenyan and Ugandan sides are defined. The two terms are short-run and long-run to mean: lagging for at most 20 years for the short-run and lagging for more than 20 years for the long-run.Twenty years is taken as a reference to distinguish the two time periods because it marks the turning points (changing direction) of the dose-response and the treatment effect graphs that show the impact of adoption lag on crop productivity (Figures 2 and 3).

In Kenya, Figure 3A shows that a short-run adoption lag is associated with an increasing impact on crop productivity compared to a long-run adoption lag. That is to say, Kenyan farmers who delay adopting SWCPs for at most 20 years after learning about SWCPs are better off (have higher crop productivity per acre of land) than those who delay adoption for more than 20 years after learning about SWCPs. In other words, farmers who have taken so long to adopt SWCPs (for more than 20 years) since they learned about SWCPs may have less and less crop productivity overtime than those who delayed for fewer years. This could be explained by the prevalence of high levels of inorganic fertilizer use in Kenya (Matsumoto and Yamano, 2009; Edwin and Dienya, 2015). Fertilisers can facilitate farmers to realise good productivity despite short-term lags for SWCPs. In addition, research has pointed to long-term crop yield decline in plots that experienced a high intensity of inorganic fertilizers than in plots with long-term organic amendments (Yadav et al., 1998; Zhang et al., 2008). Thus, the negative impact of adoption lag of SWCPs on crop productivity in Kenya, in the long run, could be associated with other factors such as high and long-term inorganic fertilizer applications which are not accounted for by the model herein. This is in line with a study that analysed impact of long term (from 1992 to 2013) fertiliser use in maize production and found that slight increase in quantity of fertiliser applied resulted in yield decline in maize growing regions of Kenya (Jena, 2020).

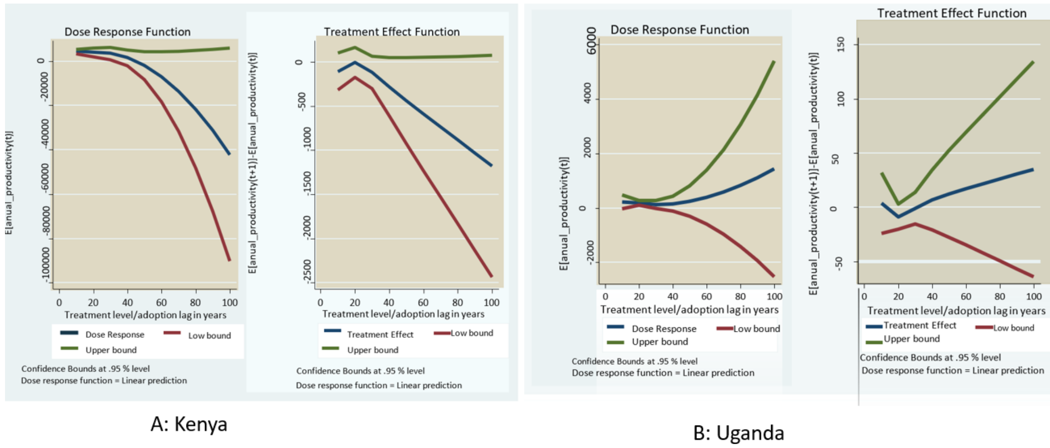

Figure 3. Impact of adoption lag of SWCPs (X-axis) on crop productivity (in USD/acre, Y-axis) in Kenya (A) and Uganda (B).

Another possible explanation is that the profitability of SWCPs is realized in the long run and yet soil degradation increases with time on land where no conservation and land management activities are undertaken (Adgo et al, 2013). This means that even though a farmer may adopt SWCPs after a long time of no adoption, it will take many more years for the degraded land to recover. Thus, the results imply that Kenyan late adopters of SWCPs will experience less and less crop productivity as opposed to early adopters.For Uganda, Figure 3B shows that short-run adoption lag is associated with a decreasing impact on crop productivity while the reverse is true for long-run adoption lag. This implies that Ugandan households that may take so long (approximately more than 20 years) to adopt SWCPs will have more and more crop productivity than those farmers who delay less. A possible explanation is that an initial reduction in productivity could be leading farmers to adopt other fertility-restoring (or yield-boosting) methods of production, other than the SWCPs that this study focused on. Another possible explanation is based on the time it takes for a specific SWCP to get old and ineffective. Thus, in long-run, for farmers who have lagged for so long (meaning that they have just adopted), their SWCPs structures may be still new and effective than those which were adopted long before. This implies that for SWCPs to be effective in terms of boosting crop productivity in Uganda, they have to be renewed continuously. For example, if a farmer is controlling erosion with trenches, the farmer should keep on renewing the trenches such that erosion is controlled effectively over the years. Although it is clear that adoption of SWCPs may not eradicate the problem of soil and water degradation with one-time establishment investment. It is undoubtable that they play an important proactive role in preventing the impact of the degradation by controlling erosion among other functions (Appendix C) and their continuous functionality is crucial.

The possible explanation of the reverse trends of the impact of adoption lag of SWCPs on crop productivity between Kenya and Uganda could be the possibility that the levels of soil degradation differ in the two countries. It is possible that the quality of soil in Eastern Uganda and Western Kenya varies, with Uganda having better soils. Therefore, productivity will still be higher in Ugandan than in Kenyan farmers even though they will both have delayed adopting SWCPs.

Another possible explanation could be that Kenya is a high economically growing country with the highest GDP growth, services contribution to GDP, and higher industrial products comparative advantage than Uganda (Chingarande et al., 2013; African Development Bank Group [ADBG], 2019). This means that, in long-run, Kenyan farmers may not be very much engaged in agriculture making their crop productivity decline. Contrary in Uganda, farmers would be more engaged in agricultural production and thus generating higher long-run crop productivity. The results thus imply that the impact of adoption lag of SWCPs on crop productivity is possibly not comparable between Kenya and Uganda.

Conclusions

The paper used a cross-sectional data collected from 506 randomly selected households in the Sio-Malaba-Malakisi River Basin of the Kenya-Uganda border. Duration model and generalized propensity score matching methods were used to determine adoption lag and its impact on crop productivity respectively. The results show that adoption lag is associated with a negative impact on crop productivity in the study area. The study shows that the importance of early adoption of SWCPs in improving crop productivity, necessitating the inclusion of timely adoption of SWCPs as a key component of any soil and water conservation intervention. It can be concluded that Kenyan and Ugandan households are not comparable in terms of the impact of adoption lag of SWCPs on crop productivity due to possible country-specific differences in economic indicators and or differences in soil degradation levels. To increase crop productivity in time, reduction of adoption lag of SWCPs should be a key area of focus for programs that promote sustainable land management practices. Development programs and interventions that intend to promote the adoption of SWCPs need to emphasize the importance of early adoption, sustainability, and proper maintenance of soil and water conservation structures, for optimum efficiency.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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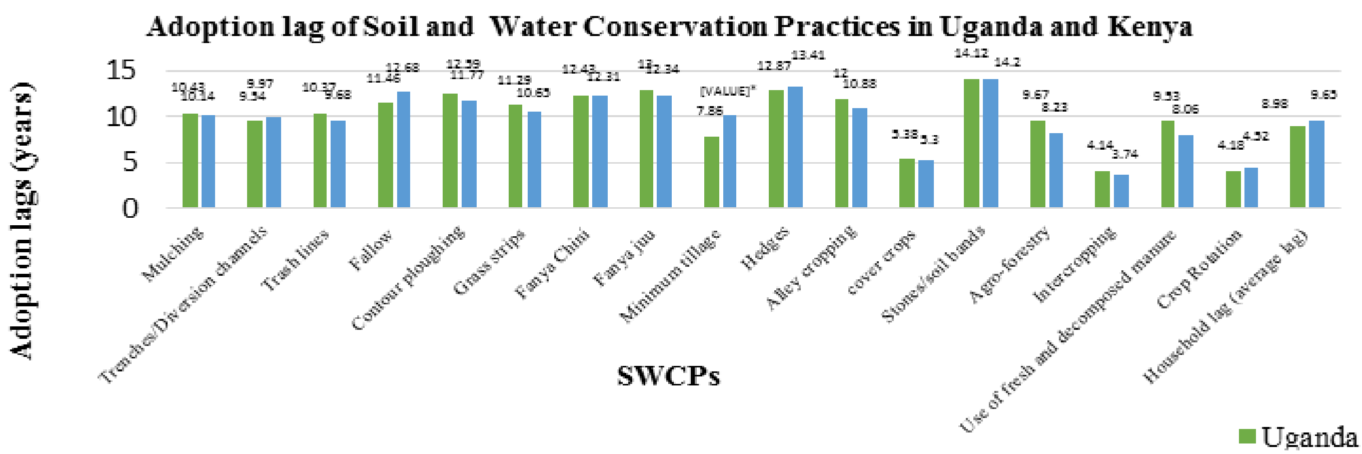
APPENDICES



Appendix A. Adoption lags (years) of SWCPs in Kenyan and Ugandan households. * denotes a 5% significance level.
Source: Own computation.

Appendix B. Crop productivity in Sio-Malaba Malakisi River Basin.

Productivity	Overall (n=492)	SE	Kenya(n=240)	SE	Uganda (n=252)	SE	t-test
Mean productivity (UDS/acre/year)	2105.153	170.85	4072.30	301.78	231.68	15.31	13.02***

SE represents Standard Errors.
Source: Own computation from the data.

Appendix C. Soil and water conservation practices definitions.

SWCPs	Definition
Soil and water conservation (SWC)	SWC is defined as a set of activities that maintain or enhance the productive capacity of land in areas affected by or prone to soil erosion
Compost	Refers to decomposed organic matter that includes one or more of the ingredients like crop residues, farmyard manure, grain husks, compost manure, kitchen wastes, slurry, hedge cuttings and other materials. Compost improves soil moisture Adds nutrients and beneficial microbes in the soil; reduce plant diseases; improves soil structure; balance and buffers soil HP; among other functions.
Conservation farming	This is also called conservation agriculture and it refers to the holistic application of approaches to enhance soil water, biodiversity to increase or maintain yields. It involves no-tillage alongside other agronomic practices (e.g. manuring, crop rotations, mulching, among others) to reduce labour and preserve the natural state of the soil.
Conservation tillage	This is a type of tillage trying to preserve the water, soil, crop residues and biological status of the soil with as little disturbance as necessary. It involves at least 30% of soil cover crop residues after planting. Conservation tillage reduces soil erosion; improves soil health and profitability; improves water conservation and improves crop yield.
Contour (line)	Contour lines are lines that run across a (hill) slope such that the line stays at the same height and does not run uphill or downhill. They are established so that the vertical distance between the lines does not vary. Contour lines increase crop production and decrease run-off volume.

Appendix C. Contd.

Cover crops	These are crops grown to cover the soil during the cropping season, fallow periods, or between harvest and planting of commercial crops. Cover crops help in soil protection, water retention, and improved nutrient cycling.
Crop rotation	This is the act of planting different crops on the same piece of land every successive season. Crop rotations are useful to improve soil conditions and fertility, minimizes pest pressures, and reduces risk.
Mulching	Mulching refers to the practice of covering cropped land with a layer of loose material (mulch) such as dry grass, straw, crop residues, leaves, compost inorganic covers. It reduces soil-water loss.
Terrace	Terrace refers to a piece of land whose slope steepness and/or length has been reduced by either construction works, or by creating barriers across the slope, so as to absorb and/or reduce surface runoff.
Water conservation	Water conservation refers to the act of control, protection, storage, management and utilization of water resources in such a way as to optimize productivity.
Trash lines	They are built by piling crop and plant residues along contour lines, they are also called mulch lines. They reduce water flow and increase organic matter in the soil.
Fallow	It involves putting agricultural fields to rest for some time between two cropping seasons.
Grass strips	These are deep-rooting perennial grasses planted along the contour lines; they develop terraces with time due to sediment trapping.
Fanya chini	These are built in parallel to contour line to discharge water in high rainfall areas; they are constructed by digging a ditch while putting the soil from the ditch at the downslope side of the ditch.
Fanya juu	These are built in parallel to contour line to discharge water in high rainfall areas; they are constructed by digging a ditch while putting the soil from the ditch at the upslope side of the ditch.
Minimum tillage	Reduces soil loss and agricultural energy requirement.
Intercropping	It increases crop yield, soil fertility, and household food security.
Hedges	Fodder shrubs and tree like Acacia and Atriplexspp planted along crop fields to reduce water loss and wind wind flow and increase organic matter in the soil.
Stones/Soil bands	They are obtained by piling stones or soils to form a barrier to water and soil flow.
Alley cropping	
Agro-forestry	Tree or shrubs are grown either together with crops, pastures or livestock or in a certain sequence.
covercrops	Growing crops such as beans that cover soils and keep its moisture.

Source: Kanwar (1989), Tengnas (1994), Ellis-Jones and Tengberg (2000), Gebreegziabher et al. (2008), Gebreegziabher et al. (2008), Mati (2012), Kebeney et al. (2015), Wolka et al. (2018), SERE (2020), Wolka et al. (2018), SERE (2020); Conservation Technology Information Center.

Appendix D. Summary statistics of the distribution of the generalized propensity score evaluated at the representative point of each treatment interval in Sio-Malaba Malakisi River Basin.

Variable	Mean	St. Dev.	Min	Max	Observation
Pooled					
Group1	0.482	0.243	3.79e-14	0.909	491
Group2	0.795	0.120	0.307	0.909	486
Group3	0.508	0.237	0.056	0.909	486
Kenya					
Group1	0.472	0.270	6.74e-17	0.958	240
Group2	0.815	0.155	0.218	0.958	237
Group3	0.541	0.261	0.051	0.958	237
Uganda					
Group1	0.479	0.223	1.21e-11	0.872	251
Group2	0.773	0.101	0.408	0.872	249
Group3	0.470	0.218	0.075	0.872	249

Source: From own computation, in GPSM.