Agroforestry for Improving Small-Scale Farm Yield in Volcanic Highlands in Rwanda

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Summary

This paper attempts to examine the role of agroforestry in improving crop yield of small-scale agriculture in the region of Volcanic Highlands of Rwanda. We conducted a survey to a random sample of 401 crop growers, including 305 agroforestry adopters and 95 non-adopters, selected from the study area. An econometric model that lowers the heterogeneity between the treatment and the control groups was specified and estimated. Results revealed a considerable difference in farm yields between agroforestry practitioners and non-practitioners. The adoption of agroforestry appears to have a good impact on small-scale agricultural yield, even though this effect is not statistically significant. Results also show that factors including farm investment cost, market accessibility, cooperative membership and return of plan leftovers to the soil have a significantly substantial effect on farm productivity. On the other hand, farm experience and cultivated land area have a detrimental but considerable impact on farm productivity. Based on the research findings, governmental institutions and development associates should promote and hasten the adoption of agroforestry structures, start increasing support for agroforestry adoption through proximity to extension services and accessibility of high-quality plant seedlings, support for the sustainability of farm cooperatives along with financial support for enhancing farm investments and guarantee a continuous and increased market access to crop farmers so as to ensure sustainable sources of farm investments.

Key words

agroforestry, yield, Coarsened Exact Matching, T-test, volcanic highlands, Rwanda

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Received: September 8, 2023 | Accepted: March 25, 2024 | Online first version published: May 1, 2024

Introduction

There will be about 11 billion people on the planet at the end of the 21st century (Adam, 2021), making it difficult to achieve food security without compromising environmental quality (Babu et al., 2022a). According to Yadav et al. (2021) and Babu et al. (2022b), the two main factors that influence farm output, financial achievement and human well-being are soil and climate. Climate hardships have a detrimental effect on farm yield, natural resources, and ultimately food security, as well as on environmental health (Ordevic et al., 2018; Das et al., 2022). A commensurate growth in food demand should be in line with a geometric increase in the human population due to a declining agricultural environment in Sub-Saharan Africa (Parwada et al., 2022).

Agroforestry is frequently regarded as a method of eco-friendly land management that supports the livelihood of farmers. Whereas there is ample indication that the agroforestry technologies are not being used as anticipated, many nations, like Rwanda, lack the knowledge regarding farmers' perspectives to intervene in developing extension approaches catered to farmers' requirements (Cyamweshi et al., 2023). Agroforestry is a structure that aims to consciously manage and integrate agriculture and forestry resources on a single area. For sustainable forestry and agriculture, this intermediary land use system is crucial (Kiyani et al., 2017). Agroforestry plays a crucial role in the enhancement of food security for the nation through diverse food production, conservation of natural resources, improvements in food and health status and an increase in the economic income of rural poor people (Alavalapati et al., 2004; Sarvade et al., 2014).

Agroforestry systems can boost agronomic production, sequestration of carbon, nitrogen cycling, soil biodiversity, pollination and water retention (Sollen-Norrlin et al., 2020). Along with providing advantages for pleasure and culture, they can help lessen the risk of fire and soil erosion. According to Sida et al. (2020), the agroforestry markedly increases nitrogen and phosphor utilisation efficiencies, which finally leads to greater grain yields in wheat. According to Gahutu Mbabarira and Nahayo (2020), agroforestry practitioners in Western Rwanda (Karongi District) rear more goats, calves, and chickens than non-agroforestry practitioners. Additionally, the average annual income of agroforestry practitioners and their uses (agricultural, food security, and house building) are much higher than those of non-agroforestry practitioners. As a result, agroforestry greatly improves the livelihood of those who exercise it.

In an intent to develop integrated, varied and productive land use systems, agroforestry combines agricultural and forestry technologies (FAO & ICRAF, 2019). Simply defined by den Herder et al. (2017), agroforestry system is considered the most widely used land use techniques in the world. According to Verma and Rao (2015), agroforestry is the land use scheme in which agricultural crops (annual or woody), animals, or both, are purposefully employed on the same plot along with the woody perennials (trees, shrubs, palms, and bamboos). According to Kiyani et al. (2017), agroforestry practices are enhancing soil fertility, preventing deforestation, as well as soil and water conservation. They are also helping agroforestry adopters earn more money than non-agroforestry adopters do. However, Kiani et al.'s (2017) findings also indicate that, due to a shortage of funding, professional skills and high-quality seeds, some crop growers are not ready to adopt the new agroforestry practices.

Given that there are numerous possibilities and opportunities available to farmers through its various forms, agroforestry has the ability to improve household livelihood. Ten varieties of woody plants have been seen to be growing on the farm, producing a variety of goods such as timber, firewood, food, feed, stakes for climbing beans, as well as farm income (Mukkobwa et al., 2023). Farmers may be able to adapt to local, regional, or global changes with the support of agroforestry (Kandji et al., 2006). According to Ekise et al. (2013), agroforestry actions on the farms generate 40% of the overall farm income per year. Agroforestry practices have a strong positive impact on the subjective well-being of households (Mutagoma, 2022).

A number of studies have reported that agroforestry farming practice is one of the most significant sustainable strategies of land administration in many African countries (Gudeta et al. 2009; Pretty et al. 2011; Pinho et al. 2012; Minang et al. 2014), and it significantly improves food security through higher productivity (Ereso, 2023). Small woodlots and agroforestry resources, which have not yet been quantified, are included in Rwanda's forest resources (Ndayambaje and Mohren, 2011; Ndayambaje et al., 2013). According to NISR (2010) and Ndayambaje et al. (2013), the presence of trees on the farms of around 70% of Rwanda's agricultural households encourages many of them to purchase wood furniture and plant trees to increase crop yields and safeguard the environment. Consequently, rural households that practise agroforestry produce significant amounts of wood while both improving crop yields and preserving the environment (Ndayambaje et al. 2013).

In agroforestry systems, growing both cash crops and medicinal plants significantly raises rural income. Although policymakers and politicians frequently disregard smallholder tree production, it can significantly provide early income to agroforestry adopters, improve rural livelihoods and build national economies (Sarvade et al., 2014). Despite improvements in food safety and nutrition security that could have been made possible by intensifying crop produces, significantly reducing periods of hunger, and in some cases, having a more differentiated asset inventory and income portfolio, there is still a noticeable delay in the welfare of families, their ability to subsume and handle shockwaves and their inclusive upgraded welfare (Eriksen et al. 2005; Quinion et al., 2010). Living on the edge of survival means that households' livelihood strategies are more concerned with meeting immediate needs and weathering shocks than they are with escaping poverty (Eriksen et al. 2005; Quinion et al., 2010).

By generating tree products like timber, firewood, food and construction materials, agroforestry also enhances the socioeconomic status of the farmers through the income generation (Irshad et al., 2011), and contributes to the environmental protection and conservation (reduces soil erosion, increases soil moisture and fertility, and maintains microclimate equilibrium) (Ereso, 2023).

Along with achieving other objectives for developmental sustainability, agroforestry can advance food security. Agroforestry increases crop as well as livelihood sustainability among farmers, specifically for the most deprived food producers (Waldron et al., 2017). In addition to directly producing food for humans, domesticating trees also improves soils (supporting the yields of staple crops) (Sileshi et al., 2008), meets energy requirements that are crucial for the correct processing and preparation of food (Haider et al., 2011), sustains the financial support for food purchases (Gyau et al., 2012; Jamnadass et al., 2013). Numerous agroforestry technologies are having a significant impact on the East and Central Africa (ECA) region, helping to alleviate resource depletion and elevate many people out of poverty (Jama et al., 2006).

Since the beginning of time, agroforestry, or the incorporation of woody perennials with farming structures, has been a traditional land use system in India because it provides farmers and rural communities with an economically and ecologically viable option for extensive agricultural diversification in order to obtain supplemental energy, fibers, fruit, and fodder on one side, and to improve the environment on the other (Sharma et al., 2017). In addition to lowering farm production risk significantly and increasing overall farm output, agroforestry systems enable long-term agricultural production from modest scales (Mercer & Pattanayak, 2003).

Most farm producers are converting from traditional subsistence farming to more economically focused practices due to fresh climate variation and soil squalor effects on crop productivity and poverty dynamics, specifically in Sub-Saharan Africa. These crop growers are more eager to investigate new technologies that aim to boost output and farmer incomes (Castle et al., 2016, Akudugu et al., 2012, Lavison, 2013). Integrating trees and woody plants into food crop systems can mitigate and considerably reduce agricultural system vulnerability (Bishaw et al., 2013), boost CO2 sequestration, and alleviate food insecurity (FAO, 2010).

With an average holding size of less than a half hectare, Rwanda's smallholder farmers provide 90% of the country's necessities and contribute for 70% of export revenues (Cantore, 2011). Since it primarily supports livelihoods and makes up the largest household enterprises, the agriculture sector is considered to be one of the first growing industries in terms of employment (NISR, 2016). However, ineffective agricultural land management and land degradation, which lead to poor soil health, impede efforts to boost crop output and food security (Murindangabo, 2021). One of the causes reducing productivity is soil degradation and losses, which result in overall national damage of between 110 and 89 million tonnes per year (Nambajimana et al., 2020).

This paper attempts to examine the contribution of agroforestry to smallholder farm productivity in the Volcanic Highlands in Rwanda.

Materials and Methods

Description of the Research Area

Our research area covers one of Rwanda's 12 agro-ecological zones – Volcanic Highlands, which also includes Buberuka Highlands, Central Plateau, Congo-Nile Crest, Eastern Plateau, Eastern Savannahs, Granitic Soils, Imbo, Impala, Kivu Borders, and Mayaga (Rushemuka et al., 2014). The black volcanic soils of the volcanic highlands are widely recognised for their fertility and good agricultural value, at altitudes of 1600 to 2500 m (NISR, 2014). In the area, common crops include beans, maize, potatoes, vegetables (such as red onions, white onions and carrots), and wheat (MINAGRI, 2018). The research area covers four districts (Burera, Musanze, Nyabihu and Rubavu), as per Fig. 1 depicting the map of Rwanda.

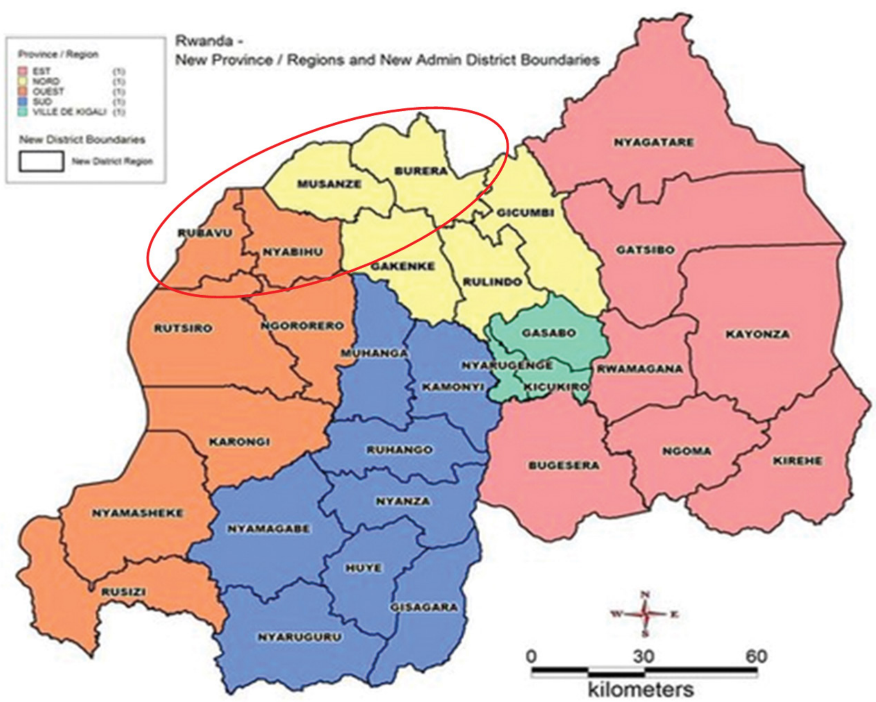

Figure 1. Location of the research area on the map of Rwanda

Sources of Data

The data for this study was collected through an anonymous survey of 401 smallholder farmers in the agro-ecological zone of the volcanic highlands of Rwanda. Each farmer that used a pure cropping method during the 2019 B growing season provided data on the prototypical farm. Three criteria were used to select the model farms surveyed: (1) the holding must be principal in terms of size, (2) or productivity, (3) or it must meet both criteria simultaneously. The questionnaire's sections on socioeconomic traits of farm owners, farm size, data on agricultural production, costs, prices, income, as well as details on farming practices (including the use of agroforestry), were all covered. It is important to mention that, within the designated research area, participation in agroforestry practices is voluntary across all sub-regions. This scenario creates a mosaic of adoption, where individuals implementing agroforestry (adopters) may reside in close proximity to those who do not (non-adopters).

Model Specification and Study Variables

Considering that the dependent variable is numeric, farm yield, a multiple linear regression model was specified as per equation 1.

$$Y = \alpha + \delta p + \beta X + e \tag{1}$$

where Y stands for the farm yield, p is the treatment variable (equals 1 if agroforestry is practiced, and 0 if otherwise), X is the vector of all other independent variables selected for this study, α is the constant, δ the coefficient of the treatment variable p, β is the vector of coefficients of the control variables X, and e is the error term. The details on the study variables are described in Table 1.

Methods of Data Analysis

While examining the contribution of agroforestry to small-scale farm production, the coarsened exact matching (CEM) technique was used to establish the comparability between the treatment group (that is the group of agroforestry adopters) and the control group (the group of non-agroforestry adopters). The technique consists of computing the level of homogeneity before and after matching, which is estimating by L1 statistic given by the equation 2 (Iacus et al., 2009).

$$L_1(f, g) = 1/2 \ \Sigma | f_{l1\ldots lk} - g_{l1\ldots lk} | \tag{2}$$

The discretized variables are hereby cross-tabularized as X_1*...*X_k for the treatment and control groups distinctly and record the k-dimensional relative occurrences of $f_{l1\ldots lk}$ and $g_{l1\ldots lk}$ units for both the treated and control groups. Greater values imply more disparities across the groups, with a maximum value of $L_1 = 1$, which indicates total heterogeneity. Perfect homogeneity (up to coarsening) is demonstrated by $L_1 = 0$.

In addition to CEM technique, the use of two independent T-test samples represents a convenient analytical method to compare the mean values, The equation 3 describes the formula used to compute the T statistics (van Elst, 2019):

$$T_{n_1, n_2} = \frac{\bar{X}_{n_1} - \bar{X}_{n_2}}{SE(\bar{X}_{n_1} - \bar{X}_{n_2})} \ t(df) \tag{3}$$

where T denotes Student statistics; n_1 stands for sample 1, and n_2 stands for sample 2; $\bar{X}_{n_1}$ is the estimated mean score of the sample 1, and $\bar{X}_{n_2}$ is the estimated mean of the sample 2; SE the standard error

$$SE(\bar{X}_{n_1} - \bar{X}_{n_2}) = \sqrt{\frac{S_{n_1}^2}{n_1} + \frac{S_{n_2}^2}{n_2}}$$

where $S_{n_1}^2$ is the computed variance for the sample 1; $S_{n_2}^2$ is the computed variance of sample 2; t implies Student distribution; finally, df the degree of freedom; $n_1 \geq 50$ and $n_2 \geq 50$. This indicates that at least 50 observations should be available for both, the treatment and the comparison groups. Equation (3) was used to compare the mean yields of 305 agroforestry farms (treatment group or sample 1) and 96 non-agroforestry farms (comparison group or sample 2) operating in the volcanic highlands of Rwanda. We also conducted the farm-yield comparison between agroforestry adopters and non-adopters in four districts covering our study area, namely Burera, Musanze, Nyabihu, and Rubavu.

Results

From the T-test, results in Table 2 show a significant difference of farm yields between the practitioners and non-practitioners of agroforestry in the region of Volcanic Highlands of Rwanda. For each district, results indicate that the difference is very highly significant ($P < 0.01$) in Burera district and nonsignificant ($P < 0.10$) in Rubavu, Musanze and Nyabihu districts.

Concerning the contribution of agroforestry to improving farm yield, we estimated four models. For the sake of comparison, we employed the ordinary least squares (OLS) approach (Model 1), OLS combined with CEM weights (Model 2), Tobit regression (Model 3), and Tobit combined with CEM weights (Model 4) to examine the effect of agroforestry on small-scale farm yield. Results from CEM analysis show that the level of homogeneity became 0.361 after matching process while it was 0.758 before matching, which resulted in the reduction of heterogeneity (increase in the level of homogeneity, respectively) between adopters and non-adopters of agroforestry. This implies that results from econometric estimations that include CEM weights seem more reliable.

Results (Models 3 and 4) point to positive influence of agroforestry adoption on small-scale farm yield, even though the effect is not significant. This could be due to the fact that we used cross-section data; we expect that the impact could be significant if longitudinal data were used. From the estimations, results show that the variables with positive and significant effect on farm yield are farm investment cost, access to market, cooperative membership, as well as return of plan residues to the soil. On the other side, land size and farm experience have negative but significant effect on farm yield.

Table 1. Definition, measurement and descriptive statistics of the study variables

Variables	Mean (Std. Dev.)	Definition
Dependent variable		
Farm yield	11159.86 (7181.258)	Crop production per hectare (Kgs.)
Independent variables		
Age	40.566 (9.037)	Crop producer's age in years.
Sex (female = 1)	481 (.500)	Crop producer's sex (it is equal to 1 if female, and 0 if otherwise)
Farm experience (in years)	17.758 (8.751)	Experience of the crop grower (the number of years)
Education	3.257 (1.673)	The level of education of the crop grower (categories: 0 = no formal education to 5 = university*)
Family size	4.964 (2.032)	The number of the individuals living in the household of a crop grower
Farm size	3220.963 (1604.274)	The area of land used for agriculture (in square metres)
Combination	4.012 (.984)	Combination of crop and animal husbandry (Likert scale 1 to 5)
Residue	2.618 (1.329)	Application of crop residue in the soil (Likert scale 1 to 5)
Rotation	3.411 (1.165)	Practice of the crop rotation (Likert scale 1 to 5)
Manure	4.696 (.581)	Application of manure (Likert scale 1 to 5)
Cost	298000 (200000)	Value of all variable factors of production in Rwandan francs (RwF 298 000 are equivalent to € 217.76, while RwF 200 000 are equivalent to € 146.14).
Price	309.898 (191.421)	Selling price per one kilogramme of crop product in Rwandan francs (RwF 309.89 are equivalent to € .23, while RwF 191.42 are equivalent to € .24).
Cattle	2.171 (1.169)	Number of cows owned by a household
Cooperation	1.095 (.293)	The farmer's membership of an agricultural cooperative (equals 1 if yes, and 0 if otherwise)
Credit access	.631 (.483)	Crop producer's access to loan (equals 1 if yes, and 0 if otherwise).
Market access	.496 (.501)	The farmer's access to output market (equals 1 if yes, and 0 if otherwise)
Extension services	.708 (.455)	The farmer has access to extension services (equals 1 if yes, and 0 if otherwise)
Land tenure	.91 (.286)	Land ownership security (equals 1 if the farmer has a land leasing certificate, 0 if otherwise)

Note: * The level of education is measured by the categories: 0 = no formal education, 1 = primary not complete, 2 = primary complete, 3 = secondary not complete, 4 = secondary complete, 5 = university.

One Euro (1 €) is equivalent to RwF 1 368.51 as of April 16, 2024.

Table 2. Comparison of farm yields between agroforestry adopters and non-adopters across districts in the study area

	Burera			Musanze			Nyabihu			Rubavu		
	1*	0	Diff	1	0	Diff	1	0	Diff	1	0	Diff
Yield	4466	2669	1798	7442	7566	123	14822	15412	-591	18911	17004	1907
t-stat			-2.59			0.11			0.85			1.37
P-value			0.006			0.457			0.800			0.087
Obs	74	27	101	85	16	101	74	26	100	72	27	99

Note: * 1 implies agroforestry adopters, while 0 denotes non-agroforestry adopters; Diff. denotes difference

Discussion

Results (Table 3) point to positive influence of agroforestry adoption on small-scale farm yield. This finding is aligned to Amadu et al.'s (2020) declaration that agroforestry could boost agricultural output, especially when the investments are most oriented in climate-smart agriculture. It also supports Castle et al. (2021) who convey that agroforestry actions have highly significant impacts on crop yields.

Results also reveal that farm investment cost, access to market, cooperative membership and return of plant rests to the soil have substantially positive effect on farm productivity. In line with these findings, the productivity of farm households is negatively impacted by the cost of agricultural inputs (Kassie, 2016). For the role of market access, Reinold (2023) showed that the access to market increased agricultural yield by encouraging the uptake of machinery, boosting the employment of wage labour, as well as enabling the switch from pastoralism to stable shed feeding. They used labor-intensive and land-saving practices like barn-feeding and efficiently used extra family labour, which increased their productivity levels (Reinold, 2023). As for the contribution of cooperative membership on crop productivity, Ortega et al. (2019) found that cooperatives were a crucial organisation for developing farmer ability, encouraging the use of better farm techniques and quality inputs thus raising production. Our results highlighted the positive effect of the return of plan residues to the soil on small-scale farm productivity. It seems that this is the first study that examined the contribution of plant residues to crop productivity. Further works are necessary to validate this finding.

On the other side, results revealed a significantly negative influence of land size and farm experience on small-scale farm yield. Using plot-level statistics from Rwanda, Ali and Deininger (2015) also pointed to a substantial inverse link between cultivated land area and farm output per hectare. The reverse connection between cultivated land area and crop yield in Rwanda appears to be primarily caused by labour market flaws as opposed to other unobserved factors. In contrast, Blanc et al. (2016) indicate that crop productivity is negatively affected by the size of the farmed plots. Sheng and Chancellor (2019) examined the link between the total factor production and the area of cultivated land and its probable causes. The findings suggested that farmers' capital decisions might have a favorable impact on the connection between crop output and farm size. The employment of machinery may increase the level of crop yield among smallholders compared to their bigger counterparts since the productivity benefit of large-scale farms is anticipated to disappear when farmers use contract services to substitute self-owned machinery.

In addition, Muyanga and Jayne (2019) proved a U-shaped association between cultivated land area and crop output per hectare. Their results showed that the theory of the opposite connection was valid for farms with a size of 0 to 3 hectares. Such a connection is generally horizontal when the land size ranges from 3 to 5 hectares, while a definite positive correlation occurs between 5 and 70 hectares. Almost all productivity indices show that farms between 20 and 70 hectares provide higher yield than farmsteads less than 5 hectares.

Finally, our results showed a positive effect of farmers' experience on crop productivity. This finding supports Balogun et al. (2015) who highlighted that farming experience significantly affected the farm productivity among pumpkin producers in Nigeria.

Table 3. Effect of the agroforestry practice on the farm yield

	Model 1	Model 2	Model 3	Model 4
Yield	OLS	OLS-CEM	Tobit	Tobit-CEM
	Coeff. (SD)	Coeff. (SD)	Coeff. (SD)	Coeff. (SD)
Agroforestry	.004 (.065)	.001 (.063)	.002 (.058)	.002 (.06)
Age	.153 (.225)	.057 (.245)	.152 (.195)	.058 (.232)
Sex	.076 (.049)	-.041 (.06)	.075 (.048)	-.042 (.057)
Education	.005 (.018)	.004 (.019)	.004 (.016)	.003 (.018)
Married	.009 (.054)	.041 (.063)	.009 (.053)	.04 (.059)
Family size	-.003 (.025)	-.014 (.025)	-.003 (.022)	-.013 (.023)
Landsize	-.724*** (.128)	-.61*** (.112)	-.728*** (.077)	-.613*** (.106)
Farm experience	-.209*** (.073)	-.144 (.092)	-.209*** (.065)	-.146 (.087)
Cattle	.066 (.071)	.107 (.088)	.065 (.066)	.108 (.079)
Cost	.872*** (.111)	.829*** (.073)	.876*** (.058)	.83*** (.069)
Market	.869*** (.153)	.57*** (.155)	.872*** (.126)	.571*** (.148)
Cooperative	.214 (.139)	.169 (.133)	.211** (.094)	.175 (.127)
Combination	-.013 (.026)	-.011 (.026)	-.014 (.027)	-.01 .025
Fumure	.102 (.064)	.045 (.069)	.103 (.060)	.043 (.066)
Residue	.111* (.058)	.034 (.07)	.112** (.053)	.034 (.066)
Rotation	.06 (.066)	-.008 (.075)	.06 (.058)	-.008 (.071)
Agriculture	-.028 (.055)	-.079 (.078)	-.028 (.06)	-.078 (.074)
Tenure	.044 (.115)	.08 (.118)	.046 (.088)	.078 (.112)
Region	-.018 (.077)	.039 (.073)	-.02 (.062)	.039 (.069)
Constant	3.216*** (.896)	3.271*** (1.026)	3.206*** (.725)	3.276*** (.974)

Continued. Table 3

	Model 1	Model 2	Model 3	Model 4
Yield	OLS	OLS-CEM	Tobit	Tobit-CEM
	Coeff. (SD)	Coeff. (SD)	Coeff. (SD)	Coeff. (SD)
Mean dependent variable	8.992	9.157	8.992	9.157
SD dependent variable	0.932	0.820	0.932	0.820
(Pseudo) R-squared	0.770	0.812	0.542	0.683
Number of obs	378	194	378	196
F-test / Chi^2	49.557	39.756	553.597	324.808
Prob > F / Prob > Chi^2	0.000	0.000	0.000	0.000
Akaike crit. (AIC)	503.353	188.523	510.017	192.460
Bayesian crit. (BIC)	582.051	253.880	592.649	261.301
L1 stat before coarsening	--	0.758	--	0.758
L1 stat after coarsening	--	0.361	--	0.361

Note: *** $P < 0.01$, ** $P < 0.05$. Farm size and cost are log transformed.

Conclusion

The extant study has inspected the implication of the agroforestry actions on small-scale farm productivity in the Volcanic Highlands of Rwanda. The study adopted the coarsened exact matching (CEM) approach to establish the comparability between the treatment group (agroforestry practitioners) and the control group (non- practitioners of agroforestry). The results showed that agroforestry practitioners had significantly higher farm yields than non-practitioners. Even if this effect is not statistically significant, the adoption of agroforestry seems to have a positive impact on small-scale farm productivity. Additionally, the results demonstrate that a number of variables, namely farm investment costs, market accessibility, cooperative membership and the return of plant rests to the soil, greatly impact farm yield, while farm experience and the size of cultivated land have a negative but substantial influence on farm yield. These results suggest that government schemes and stakeholder initiatives should concentrate on promoting the uptake of agroforestry, encouraging farmers to establish and join agricultural cooperatives, and ensuring small-scale farmers' access to markets. Consequently, having access to agricultural markets should make it possible for small-scale farmers to earn a steadily rising income, which may encourage them to adopt agroforestry. These results advocate that the Government and development associates should encourage and accelerate the adoption of agroforestry structures. To do so, the authorities should initiate the increase support to agroforestry adoption through proximity of extension services, as well as availability of quality plant seedlings. Furthermore, the governmental support for the sustainability of farm cooperatives, coupled with the financial support for enhancing farm investments are recommended. Moreover, the study urges continued and expanded market access to crop farmers so as to sustain the farm income and thus the sources for farm investments.

Future research should prioritize a holistic assessment of agroforestry's influence on farm-level economic performance. This investigation should move beyond single-output analyses to capture the complex interactions between trees, crops and livestock within the entire farm system. By employing a comprehensive economic framework, researchers can elucidate the true impact of agroforestry on farm profitability, risk mitigation, and overall economic sustainability.

Credit Authorship Contribution Statement

Aristide Maniriho: Study design, review of literature, design of the research methods, data collection and analysis and writing the manuscript. F**erdinand Nkikabahizi and Pascal Kayisire:** Data collection and analysis, review of literature of the manuscript. **Edouard Musabanganji:** Statistical analysis, design of research methods, interpretation of the statistical results in relation to the research questions.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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