Net benefits of silky oak (*Grevillea robusta*) for small farmers in Musanze District, Rwanda

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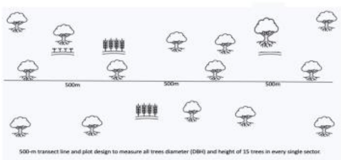

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Abstract

This study was conducted in Musanze district, Rwanda, to evaluate the net benefits of silky oak (*Grevillea robusta*) production for small farmers. A semi-structured questionnaire was administered to 100 households distributed in four villages. The cost-benefit ratio was used as a decision-making tool. A diameter tape and a Haga altimeter were used to measure the DBH and height of grevillea and other dominant agroforestry tree species. Results indicate that 66% of laborers were family members, gaining 625 Rwf per person day with grevillea production (US$ 0.61, with 4-8 hours of work per day. Also, results show that farmers earn 57,950 Rwandan Francs (Rwf) per hectare per year (US$ 57.48 from grevillea products (stakes, poles, charcoal, and timber), whereas the mean investment in grevillea production is 54,200 Rwf ha^{-1} year^{-1} (US$ 53.76). The net farm income is 3,225 Rwf (US$ 3.2 ha^{-1} year^{-1}). The net benefit from grevillea product is affected by poor farmer data record as the majority of 67% of respondents has not attended any formal education**.** However, farmers gain additional benefits of US$ 628, US$ 298, and US$ 224 ha^{-1} year^{-1} from potatoes, maize, and bean, respectively, depending on their crop choice during intercropping with grevillea. The benefit-cost ratio is 1.06, which highlights the modest profitability of growing grevillea on the farm. In addition, soil erosion control, soil fertility increase, landslide prevention, shade provision, microclimate improvement, and biodiversity conservation were reported as ecosystem services of grevillea on the farm. Growth performance of grevillea (diameter at breast height, tree height, and volume) is analyzed in all four villages. The study shows that growing grevillea is profitable for smallholder farmers via tree products and farm benefits, including ecosystem services aspects.

Keywords

Grevillea robusta; Net benefits; Small farmers; Rwanda

Contents

1 Introduction

The uptake of diversified farming systems is constrained by costs, benefits, and farmer preferences which stagnate the development of agroforestry innovation (Staton et al. 2021). Nevertheless, agroforestry innovation was considered one of the solutions to food insecurity due to numerous benefits for improved food availability, income generation, mitigation of climate variability and climate change, fuelwood, fodder, and fruits (Gush 2017).

Agroforestry projects in Rwanda primarily use exotic fast-growing plants for different multipurpose functions like timber production, firewood, and improved crop production by increasing soil fertility (Ndayambaje and Mohren 2011). Native species are less common as they grow slowly, and their silvicultural prerequisites are also uncertain (Ceccon et al. 2015). *Grevillea robusta*, here-in-after called "grevillea," was introduced at the beginning of the 20th century and other agroforestry species, mainly for aesthetic reasons and shading of tea and coffee plantations in Rwanda (Mugunga 2009). Grevillea has various functions for Rwandan farmers. They use this tree species as a shelter for small crops and animals, timber, poles, firewood, mulching, fodder, and it grows across the agro-ecological zones of Rwanda (Bucagu et al. 2013). Furthermore, grevillea has significant importance in environmental management by sequestrating carbon dioxide, preventing landslides, and enhancing microclimate (Zdruli et al. 2017).

Despite the contribution of agroforestry tree species on the farm, the adoption is still limited. Recently, the Rwandan Government has implemented agroforestry technology in forest adjacent communities to mitigate forest pressure and boost the livelihood of the local populations (Kiyanet al. 2017). However, insufficient financial analysis, illiteracy, lack of availability of farm inputs, seedlings, and socio-cultural factors are among the limitations that oppose the adoption of agroforestry (MINAGRI 2018; Kiyani et al. 2017).

Therefore, there is a need to assess the net benefits of grevillea to the livelihood of farmers by identifying its performance on-farm and to undertake a financial evaluation, with family labor inputs and intangible benefits or costs of grevillea among other agroforestry tree species.

2 Methods

This study was conducted in Musanze District in the Northern Province of Rwanda, located at 1°30' 27.5"S and 29°36' 23.8" E. Due to mountainous terrain and high rainfall, the area is vulnerable to soil erosion. Musanze ranges between 2,000 and 3,000m above sea level (Nahayo et al. 2013). Hence, temperatures are moderate, with an annual average temperature of 16^{o}C and an annual precipitation of 1,400 mm.

2.1 Site selection and sampling

A two-stage cluster sampling was performed to select respondents. Farm households have voluntarily agreed to be included in the study. In the southern part of the country, four neighboring sectors were purposely selected (sub-district units) to reduce travel distances. Then randomly, one village in each sector was taken. Farm households were identified through a quasi-random process by going to the center of each village and then using a randomly generated cardinal direction and random number 'n' as a guide to visit the n^{th} house in the specified direction.

A total random sample of 100 households from Busogo, Gataraga, Rwaza, and Shingiro sectors were selected (Figure 1). The sectors under this study were selected in reference to a situation analysis of Musanze District (2015), which revealed that those areas still face some challenges, mainly by soil erosion caused by extensive agriculture, which experiences low crops productivity and requires modern agricultural techniques. A semi-structured questionnaire was used to collect data on silvicultural treatments, farmers' preferences on grevillea constraints and the importance of tree components on-farm, ecosystem services, farmer inputs, costs and benefits from on-farm tree products of grevillea.

An inventory on the growth of grevillea trees was conducted following a transect walk, where 15 trees were counted in each village. There were 500m of distance from one measurement’s point to the next and DBH, and total tree height was measured (Figure 2).

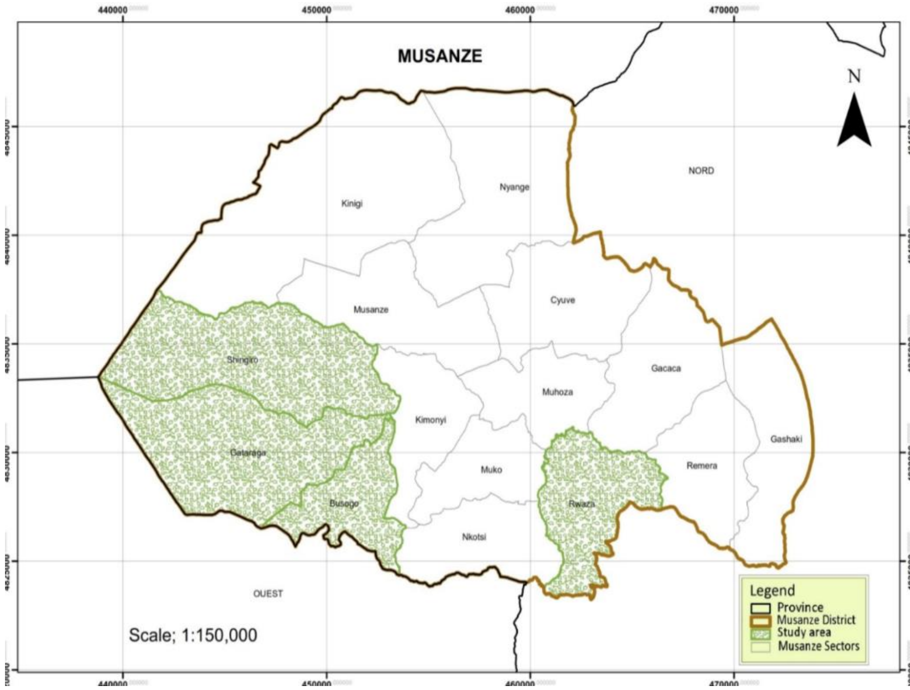

Figure 1. Map of Musanze district.

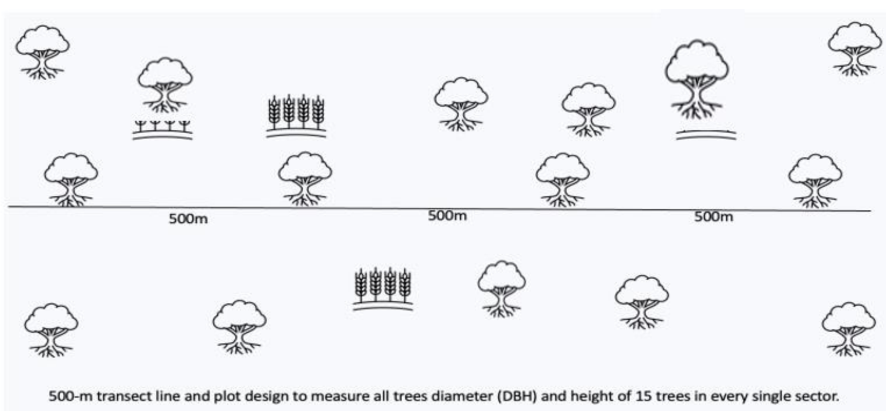

Figure 2. Tree sampling design in the study area (Musanze District).

2.2 Data analysis

Microsoft Excel was used in data entry, and the data were subjected to descriptive statistics (frequencies, percentage), variance and standard deviation using a statistical package for social scientists (SPSS) version 16. Moreover, the total household income was quantitatively evaluated from sampled households. Data about annual household benefits and costs from tree products (timber, firewood, poles, and charcoal) and family labor were computed in Microsoft excel.

2.3 Benefit-Cost analysis

The following calculations are used to estimate the net benefit of grevillea production:

- Contribution margin = total revenue – total variable cost
- Return to family labor = contribution margin * (family labor inputs in person-days)$^{-1}$
- Opportunity cost of family labor = benefit the family must have forgotten to participate in the grevillea production
- Net benefit= contribution margin - opportunity cost of family labor

The benefit-cost (BC) ratio is applied to decide if a production line (e.g., grevillea) is worth pursuing. BC ratio = total benefits * (total costs)$^{-1}$ the underlying variable are represented in Table 1. If BC is greater than 1 the production activity is economically feasible.

Table 1. Selected variables under investigation.

Investigated variable	Specification	Reliability Checking
Social	Gender	Three methods checked the reliability of information: **Conduct pilot test**. Small sample size was used before a large one after those irrelevant questions were removed. **Establish face:** the questionnaire was given to people who understand the topic and went through it and check if the questionnaire would have captured the topic under investigation; moreover, questionnaire was given to the supervisor and co-supervisor for further improvement **Test-retest reliability** by giving the questionnaire to the same respondents twice over a period then comparing the response at the two-time point.
	Age	
	Marital status	
	Education level	
	Family member	
Economic	Land size	
	Labor sources	
	Income sources	
Variable production cost	Technician	
	Log extraction	
	Protection	
	Labor	
	Tending	
	Pruning and thinning	
	Log transport	
	Planting	
	Seedlings	
Production and annual revenue	Firewood	
	Poles	
	Stakes	
	Building materials	
	Charcoal and logwood	

2.4 Land equivalent ratio

The Land Equivalent Ratio (LER) can be used to understand how many units of land of separate crop field and tree plantation would yield the same amount of crop and tree products as one unit of land of integrated crop-tree-fields (agroforestry). In this study, the tree products were evaluated with zero, as many trees are still young, leading to simplified, slightly underestimated LER values. To compute LER values, the fresh yield weight of dominant crops, namely maize, potatoes, and beans, were used separately and also in grevillea agroforestry system: Simplified LER = yield of crop X under grevillea * (yield of crop X alone)$^{-1}$.

Where X stands for maize, potatoes and beans. A simplified LER of greater than 1 indicates a positive interaction, i.e., the mixing of the crop with grevillea leads to increased yields and benefits. Tree volume estimation: For a rough and ready stem wood approximation of tropical tree species located in the same region and receiving the same treatments, the volume is estimated with the following equation (FAO, 2012): V = f * BA * H where: V = stem wood volume in (m^3), f = form factor of 0.42 derived from stem analysis (Silva et al., 2016), BA = tree basal area (m^2), H =total tree height (m).

3 Results

3.1 Social characteristics of respondents

The survey revealed that 61% of the farmers are female and 39% are male, and 71% are married. Some 67% of respondents had not attended any formal education, and their age spread from 23 years to over 63 years. Female, illiterate, and elderly people dominate farming activities, which could have implications on agricultural technology development, including agroforestry.

3.2 Economic characteristics of respondents

As indicated in Table 2, 47% of respondents own land sizes between 1-2 ha, and only 11% have lands over 3 ha. More than 69% rely on agriculture as the main source of income. Farming activities are mainly provided by family labour (66% of respondents) and to a smaller degree by hired labour (34%). Family members work around 4-8 hours per day. In 40% of the farms, the farming activities contribute 100% of the income.

Table 2. Economic characteristics of respondents.

Parameters	Frequency (%)	Parameters	Frequency (%)
Land size		Source of incomes	
0.5ha-1ha	34	Agriculture and Livestock	11
1.0ha-2ha	47	Agriculture	69
2.0ha – 3ha	8	Small business	20
Over 3ha	11		
Labour sources		Farming contribution	
Family	66	Up to 100%	40
Hired	34	Up to 75%	16
		Up to 50%	33
		Up to 25%	11

3.3 Revenue from grevillea production

On average, farmers earn 57,950 Rwandan francs (Rwf) (US$ 57.48 from grevillea products per hectare per year (Table 3). The mean revenue from firewood is 8,200 Rwf (US$ 8.13, and 64% of respondents earn between 5,000-10,000 Rwf (US$ 4-9). On average, households produce 93 kg of firewood. The mean income from poles is 9,000 Rwf (US$, 8.92), and 70% of farmers get income between 5,000-10,000 Rwf (US$ 4-9), whereas the mean number of the poles was approximately 11. About 53% of farmers earn incomes between 0-

5,000 Rwf from stakes (US$ 0-4), with a mean income of 4,850 Rwf (US$ 4.81), while the mean weight of sold stakes is 60.5 kg and a half of total production is auto consumed.

Table 3. Grevillea products at smallholder farmers.

Grevillea products	Frequency (%)
Charcool	15
Firewood	28
Poles	15
Stakes	29
Timber	13

The mean income from building materials is 12,100 Rwf (US$ 12), and more than 92% of respondents get an income between 10,000-15,000 Rwf (US$ 9-15), while the mean number of building materials (cowshed and pigpen) is 10. The mean income from charcoal is 7,500 Rwf (US$ 7.43), and all farmers respondent's get an income ranging between 5,000-10,000 Rwf (US$ 4-9), and the average weight of charcoal is 86.5kg. The mean income from logwood is 16,300 Rwf (US$ 16). Some 36% of respondents reported incomes ranging between 20,000-25,000 Rwf (US$ 19-24), while the mean number of logwoods is approximately 29. About 20% of respondents get incomes between 5,000-10,000 Rwf (US$ 4-9) and 10,000-15,000 Rwf (US$ 9-15 respectively (Table 4).

Table 4. Production and annual revenue per hectare from *Grevillea robusta*.

Revenue from Grevillea products (in Rwf)	Production	Frequency (%)	Median income (Rwf)	Equivalent Median income (US$)
Firewood	93 kg	100	**8,200Rwf**	**8.13**
[0-5000]		11	2,500	2.47
[5000-10000]		64	7,500	7.43
[10000-15000]		25	12,500	12.39
Poles	10.9 poles	100	**9,000 Rfw**	**8.92**
[5000-10000]		70	7,500	7.43
[10000-15000]		30	12,500	12.39
Stakes	60 kg	100	**4,850 Rwf**	**4.81**
[0-5000]		53	2,500	2.47
[5000-10000]		47	7,500	7.43
Build-up materials	10.1	100	**12,100 Rwf**	**12**
[5000-10000]		8	7,500	7.43
[10000-15000]		92	12,500	12.39
Charcoal	86.5 kg	100	**7,500 Rwf**	**7.43**
[5000-10000]		100	7,500	7.43
Logwood	28.9 kg	100	**16,300 Rwf**	**16.16**
[5000-10000]		20	7,500	7.43
[10000-15000]		20	12,500	12.39
[15000-20000]		24	17,500	17.35
[20000-25000]		36	22,500	22.31
Total Revenue			**57,950**	**57.48**

1US$ = 1008.14 Rwf

3.4 Variable production cost of grevillea

The wood production with grevillea extends over 20 or more years. The survey only records average yearly inputs as reported by the farmers. From this, the mean annual cost of grevillea production is 54,200 Rwf (US$ 53.76) per hectare, composed of costs for the technician, log extraction, tree protection, labor activities, tending, thinning, and pruning activities, log transport, planting, and seedlings (Table 5).

Table 5. Annual variable production costs per hectare of grevillea.

Items cost	Frequency (%)	Median cost in Rwf	Median cost in (US$)
Technician		**7,400**	**7.34**
[0-5000]	2	2,500	2.47
[5000-10000]	98	7,500	7.43
Log extraction		**17,750**	**17.6**
[5000-10000]	86	7,500	7.43
[10000-15000]	11	12,500	12.39
[15000-20000]	3	17,500	17.35
Protection		**2,500**	**2.47**
[0-5000]	100	2,500	2.47
Hired labour		**2,500**	**2.47**
[0-5000]	100	2,500	2.47
Tending		**2,500**	**2.47**
[0-5000]	100	2,500	2.47
Pruning and Thinning		**8,200**	**8.13**
[5000-10000]	86	7,500	7.43
[10000-15000]	14	12,500	12.39
Log transportation		**8,350**	**8.28**
[5000-10000]	83	7,500	7.43
[10000-15000]	17	12,500	12.39
Planting		**2,500**	**2.47**
[0-5000]	100	2,500	2.47
Seedlings		**2,500**	**2.47**
[0-5000]	100	2,500	2.47
Total Variable cost		**54,200**	**53.76**

1US$=1,008.14 Rwf

3.5 Benefit analysis of grevillea

Table 6 indicates the benefit analysis of grevillea production in the Musanze district. The contribution margin is 3,750 Rwf (US$ 3.71). The return to family labor is estimated as the contribution margin of family labor input divided by the amount of family labor for grevillea production and results in 625 Rwf (US$ 0.61) per workday.

The adopted opportunity cost for family labor of 525 Rwf has been estimated, and this is affected by the farm's location near Musanze town. Hence, the net benefit of grevillea production amounts to 3,225 Rwf (US$ 3.2) per hectare per year. The benefit-cost ratio of 1.06 indicates a small financial benefit of growing grevillea. Costs of land are not included as smallholder farmers are not paying any rent for land for tree planting purposes.

Table 6. Benefit analysis of grevillea products in Musanze district.

Items	In Rwf	(US$)
Total revenue	57,950	57.48
Total variable cost	54,200	53.76
Contribution margin	3,750	3.71
Return to family labor	625	0.61
Opportunity cost of family labor	525	0.51
Net benefit	3,225	3.2
B/C ratio	**1.06**	

3.6 Importance of grevillea components on-farm and ecosystem services

Some 87% of respondents reported soil erosion control as one of the core benefits, whereas 64% of respondents highlighted that Grevillea components enhanced both biodiversity conservation and soil fertility (Table 7). Similarly, 79% and 65% of respondents agreed that Grevillea provided shade and controlled landslides. However, 36% and 35% disagreed that Grevillea improved soil fertility and influenced both landslide and microclimate.

Table 7. Importance of grevillea components on-farm and ecosystem services.

Importance of Grevillea components	Statement (n=100)	
	Yes	NO
Soil erosion control	87	13
Soil fertility	64	36
Landslide	65	35
Shade provision	79	21
Microclimate	65	35
Biodiversity conservation	64	34

3.7 Contribution of grevillea to crop yield improvment

The mean yield for the sole potato fields was 4.85 t ha^{-1}, whereas, in the fields of potatoes and grevillea, it was 7.75 t ha^{-1} (Table 8).

It means that the yield and income in the combined tree-crop fields were 1.6 times the yield of sole fields. For maize and beans, the mean yield in the sole crops was 1.88 t ha^{-1} and 1.38 t ha^{-1}, respectively, whereas, in the combined fields, the yield was 2.76 t ha^{-1} and 1.84 t ha^{-1}, respectively, indicating that the yield and income were1.5 and 1.3 times higher in the combined tree-crop fields.

3.8 Land equivalent ratio

The land equivalent ratio (LER) for potato = 7.75/4.85 = 1.59, LER maize = 2.75/1.87 = 1.47, LER beans = 1.84/1.38 = 1.33, and the mean LER is 1.52.

3.9 Constrains to the adoption of grevillea for the small farmers in the Musanze district

Some 89% and 81% of respondents' report that insufficient research associated with research costs and lack of seedlings are the major constraints (Table 9). In addition, 79% and 73% agree that land tenure and lack of product markets are the next important constraints that stagnate grevillea's adoption. However, more than 94%, 83%, and 80% of respondents report that limited extension services, limited aid agencies, and lack of access to credit are no constraints for them to adopt grevillea. Musanze is a volcanic region where some of its remote villages are not easily accessible for public goods. This affects the availability of seeds as well as agroforestry extension services.

Table 8. Analysis of crop production of 100 farms in sole cropping or combined cropping with grevillea.

Dominant crops	Area (ha)	Frequency (%)	Median Yield (t/ha)	Revenue (Rwf)	In US$
Irish potato	In sole field		**4.85**	**1,059,240**	**1,050.68**
	[0-5]	53	2.5		
	[5-10]	47	7.5		
	Yield in AF systems		**7.75**	**1,692,600**	**1,678.93**
	[0-5]	42	2.5		
	[5-10]	11	7.5		
	[10-15]	47	12.5		
Maize	**Yield in the sole field (t/ha)**		**1.875**	**641,063**	**635.88**
	[0-2]	65	1		
	[2-5]	35	3.5		
	Yield in AF systems		**2.755**	**941,935**	**934.32**
	[0-2]	43	1		
	[2-5]	46	3.5		
	]5-8]	11	6.5		
Beans	**Yield in the sole field (t/ha)**		**1.38**	**678,822**	**673.34**
	[0-1]	56	0.5		
	[2-3]	44	2.5		
	Yield in AF systems		**1.84**	**905,096**	**897.78**
	[0-1]	44	0.5		
	[2-3]	45	2.5		
	[4-5]	11	4.5		

Table 9. Constraints to the adoption of *Grevillea robusta* for the small farmers in the Musanze district.

Farmers 'Constraints	**Statements**		**Explanations**
	Yes	No	
Insufficient fund	6	94	Government interventions
Limited extension services	13	87	Government extensions
Insufficient information	89	11	Uninterested field research
Limited aid agencies	17	83	Governments interventions
Land tenure	79	21	Little access to land and land shortage and fragmentation
Lack of seedlings	81	19	Lack of nurseries
Lack of access to credits	20	80	Unwilling to request credits
Lack of products market	73	27	Bad quality of products

3.11 Farmer's preferences on management, growth and use of agroforestry tree species

Farmers rated the species on management criteria of growth and use (Table 10). A rating of 5 was considered excellent, a rating of 1, poor. Results indicate that grevillea is compatible with crops and it has a higher disease resistance. Moreover, it has moderate growing rate, wood appearance and straightness as well low quick in drying and burning quality.

Table 10. Farmers preferences on management, growth, and use of agroforestry tree species.

Species	Management and growth			Use of Timber		Use of firewood	
Criteria	Compatibility with crops	Speed of growth	Resistance to insects	Wood Appearance	Straightness	Quick in drying	Durability of fire (burning quality)
Grevillea	4.01	2.89	3.87	2.9	2.87	1.91	1.88

3.11 Growth of grevillea agroforestry system

From the number of trees recorded over annual age classes from 5-15 years in four farms, the age class 5 years has double to the other classes, and 16-year-old trees were very rare (Figure 3). Hence, timber products are presently only prematurely cut for self-consumed products, which affects the net benefits of the trees and selling perspectives. The diameter development of grevillea in four sites show some low differentiation, e.g., grevillea has its largest average stem diameter of 17.3 cm in Rwinuma farm, and its smallest of 16.2 cm in Kabwenge farms (Table 11). The largest mean stem basal area of grevillea is 0.03 m^2 in Rwinuma, while the smallest is 0.02 m^2 in Kabwenge, Kabaya, and Kabuga farms (Table 11).

Table 11. Growth development of grevillea of 5–16-year-old in the 100 surveyed farms.

Farm Location		DBH	BA	Height	Volume	MAI
Kabwenge						
	Average	16.2	202.3(0.02)	17.1	0.18	1.81
	Variance	13.17	0.0001	24.07	0.018	0.019
	St dev	3.6	0.0096	4.91	0.13	0.13
Kabaya						
	Average	17.1	228.6(0.02)	18.1	0.22	1.99
	Variance	15.94	0.000145	36.3	0.028	0.11
	St dev	3.99	0.012	6.03	0.16	0.33
Kabuga						
	Average	16.8	221.6 (0.02)	18.2	0.22	1.84
	Variance	68.38	0.00015	37.71	0.028	0.08
	St dev	8.26	0.012	6.14	0.16	0.28
Rwinuma						
	Average	17.3	237.7 .03)	17.6	0.21	1.75
	Variance	15.23	0.0014	17.96	0.015	0.08
	St dev	3.9	0.011	4.23	0.12	0.28

The highest mean tree height of 18.2 m was recorded in Kabuga, whereas the lowest of 17.1 m was found in Kabwenge farm location (Table 11). The largest mean stem volume of 0.22 m3 is recorded in Kabaya and Kabuga farm and the smallest of 0.18 m^3 in Kabwenge farm (Table 11). Taking the stem volumes on a per hectare basis, the largest mean annual increment (MAI) of 1.99 m^3 ha^{-1} yr^{-1} is achieved in Kabaya farm and the smallest of 1.75 m^3 yr^{-1} in Rwinuma farm (Table 11).

4 Discussion

4.1 Socio-economic characteristics of respodents

The majority of women in agriculture are living in rural and per urban areas of Rwanda, where the dominant activity is subsistence agriculture. Also, the results revealed that the majority of smallholder farmers are elderly persons and have not attended any formal education. This is interpreted because educated people are reluctant to involve in small-scale agricultural practices because they have better remunerated alternatives.

MINAGRI (2018) acknowledges that the formal education level for smallholder farmers is low. However, the number of farm laborers having primary education is increasing. Agriculture is the primary source of income as most households are less educated, and rural agriculture still relies on traditional knowledge. The land fragmentation is attributed to parents giving their children a portion of their land when they get married for each generation to the other, which leads to land size reduction. The results are in line with MINAGRI (2018), which reports 30% of farmers own less than one hectare of land (0.2 ha).

4.2 Revenue from grevillea products

The income earned from grevillea products was 57,950 Rwf (US$ 57.48) per year per hectare, which is higher than farmers' investment of 54,200 Rwf (US$ 53.76). Even though farmers gain low income from grevillea products, they continue to grow grevillea because they have gained benefits from associated crops as well as future benefits from mature trees products, and this is supported by the findings of Valdivia et al. (2012), who labeled profitability concerns as major barriers to the adoption of agroforestry. The net benefit calculation from grevillea product is affected by poor farmer data record as the majority at 67% of respondents had not attended any education. A significant number of grevillea trees are not mature to produce marketable products, and the market prices are volatile. Some grevillea products like firewood and charcoal are used at home, mainly for cooking. This is attributed to the fact that the use of other sources of energy like gas is not yet adopted.

Similar results were found by Hoffmann et al. (2015) who found that having access to firewood and charcoal for cooking purposes is essential for the world's poor. Moreover, results showed that poles, stakes, and built-up materials generate income for smallholder farmers, and many houses are and have been built using these trees because the soil is poor in clay content which makes it difficult to use bricks. Poles are used in roofing, and stakes are very important for bean production by supporting the plants. Likewise, farmers gain additional benefits of US$ 628, US$ 298, and US$ 224 from potatoes, maize, and bean production, respectively, by intercropping with grevillea. Likewise, income from charcoal and logwood is attributed to the fact that charcoal and logwood from grevillea are locally available and affordable by poor households. Results concur with Bucagu et al. (2013), who reported that grevillea was the most preferred of various timber species. Also, these results are in full agreement with De Giusti et al. (2019) and Sollen et al. (2020), who reported that most trees in the area are used for fuelwood and the charcoal economy outweighs the planting costs of trees with high climate change mitigation benefits.

4.3 The variable production of grevillea

Even though smallholder farmers are investing in agroforestry, results indicate that the mean investment of 54,200 Rwf per hectare (US$ 53.76) is low compared to the other income-generating activities. This is attributed to the fact there are usually only a few trees per hectare (on average 156 tree/ha), that farmers do not have to do or ignore some practices like thinning and pruning and mostly use seedlings that are naturally regenerated. Only low investments for tree protection are necessary because of low disease incidence and severity. Labor costs are low because manpower is available at low wages. Similar results are reported by Armengot et al. (2020) that agroforestry systems do not increase pest and disease incidence compared with monocultures under good cultural management practices. The benefits and cost ratio of 1.06 indicates that grevillea investments are profitable or breaking even in the study area. This is because grevillea provides many products like stakes, poles, fuelwoods, and charcoals that are economically affordable for households in their daily needs, either in direct use or sold. Once the trees grow a bit older, the profit margin may even increase because of the relative higher value of sawn timber. Similar results were found by Njenga et al. (2017), who indicate that charcoal made from grevillea pruning material has a high calorific value and is preferred by smallholder farmers. The results also concur with estimated costs and benefits of Rahman et al. (2017) based on farmers' and experts' assessments, which show that the two investigated agroforestry systems have higher net present value and benefit-cost ratio (b/c) than the two swidden cultivation systems.

Tree ownership also creates more permanent rights to farmland and is prestigious in the community. Agroforestry products (fruit, vegetables, etc.) have high monetary value and help strengthen social cohesion when shared with neighbors (Nair 2010).

4.4 Importance of tree components on-farm and ecosystem services of grevillea

The positive effects found of grevillea on crop yields are attributed to the planting pattern, including rows, scattered on-farm, and buffers. Comparing the income from sole and combined fields reveals that the combined area avails 1.46 and 1.33 times more income from maize and bean, respectively, compared to their sole cropping. This could have different reasons: first, it cannot be excluded that farmers have planted grevillea on different, more fertile fields, which have not been checked in the interviews. Second, it could be explained by the contribution of grevillea to prevent soil nutrient loss and soil erosion, nutrient cycling through leaf fall and pumping nutrients from deeper soil layers to the subsurface horizon, where they become accessible to crop roots. The second explanation is preferred, as tree-increased crop yields are also found by other authors. E.g., Wong et al. (1995) inform that *Calliandra calothyrsus*, *Grevillea robusta, Leucaena diversifolia Improve* maize yield from 3 to 6 t dry matter ha^{-1} on an Oxisol in Burundi.

The equivalent land ratio values also reveal a positive interaction between grevillea and associated crops (potato, maize, and bean). The higher productivity of the intercropping system compared to the monocropping may have resulted from the complementary and efficient use of growth resources by the component crops (Li et al. 2006). Similar results are reported by Matusso (2014), indicating that the land equivalent ratio is significantly affected by the intercropping systems and that the total LER showed a significant yield advantage of intercropping maize and soybean over component sole crops.

4.5 Farmer's preference and adoption constraint for grevillea

Farmers prefer to grow grevillea on the boundary, scattered, over the farm in home garden and woodlots because these are the standard practices that contribute to soil fertility, reducing soil erosion, wind protection; moreover, the occurrence of scattered woodlots is explained by the farmers' small land size due to population growth and land fragmentation. Furthermore, smallholder farmers prefer different agroforestry species based on their management, growth, and uses. Farmers indicated in the interviews that grevillea is compatible with crops. The compatibility of grevillea is due to the leaflet system, which allows radiation to reach planted crops and promote growth. In contrast, alder has an association with nitrogen-fixing bacteria in the rhizosphere (Frankia alni), making its interaction with the surrounding crops mutually beneficial (Nouioui et al. 2016).

The low compatibility of eucalyptus with crops is attributed to its high-water consumption, making water less available to the associated crops. This makes eucalyptus questionable in a dry environment that experiences water shortages (Liu et al. 2017). Still, it produces a higher valued timber than the other agroforestry trees around the Musanze district. Moreover, eucalyptus has high burning quality attributed to fact that eucalyptus is very sensitive to crown fires, as the oil in the leaves burns like fuel. Similar results are reported by Albaugh et al. (2013), who inform that many eucalypts can coppice, making this genus an ideal candidate for use as a biofuel feedstock.

Significant constraints for adopting grevillea by small farmers are seen in the limited research that informs and provides a new direction for agroforestry, and the lack of seedlings due to an insufficient number of nurseries of agroforestry species.

The second and third essential constraints stagnating the adoption of grevillea are land tenure and lack of product markets. Farmers are reluctant to grow trees on land which does not belong to them. In contrast, limited extension services, limited aid agencies, and lack of access to credit were identified by farmers as no constraints to adopt grevillea because of government provides interventions including free seedling, provision, demonstration plots and incentives.

4.6 The growth of grevillea agroforestry system

The growth of grevillea differs across farm locations. Based on farmer's experiences, the significant difference is influenced by soil types where clay-loams, clay sands, and volcanic soils, which are normally fertile and more productive dominate in Kabaya and Kabuga farms. The lower growth performance of the tree species planted in Rwinuma and Kabuga is attributed to the fact that soils are shallow, stony, sandy and less fertile. Moreover, the management practices influence the performance of studied species within and between farms. The results are in line with Karinganire (1995), who found significant effects of soil fertility and soil types on growth performance of exotic species in contrasting agro-ecological zones of Rwanda.

5 Conclusions

This study aimed to assess the net benefits of grevillea (*Grevillea robusta*) for small farmers in Musanze district, Rwanda, with a focus on the contribution margin and labor inputs, the importance of tree components on-farm, their intangible benefits regarding soil fertility, soil erosion control, and landslide protection, and investigates on farmer's preference and adoption constraints for grevillea.

Results indicate that farmers are benefitting from adopting grevillea in agroforestry systems. Dominant crops integrated with grevillea yielded more than the sole cropping systems. This is evidenced by the combined crop fields of potato, maize, and bean with trees, where the mean yield is 1.6 times larger than on the sole crop fields without trees.

The combined fields availed 1.46 and 1.33 times more income for maize and beans, respectively, as their corresponding sole cropping. Hence, growing grevillea is profitable for smallholder farmers for tree products as well as crops productivity improvement.

The farmers in Musanze district confirmed the significant importance of grevillea on the farms for tangible and intangible benefits as soil erosion and landslide control, soil fertility improvement, and biodiversity conservation. The farmers prefer to grow grevillea in scattered arrangements and stated that insufficient research associated, and lack of seedlings were the major constraints for the adoption of grevillea.

The growth performance of planted exotic species varies across farms location and is connected to the soil types. Hence, growing grevillea is profitable regarding grevillea products and its effect on the associated crop, as well as its intangible benefits. Based on the findings of this study, the following recommendations are formulated:

1. Establishment of nursery for different agroforestry tree species, government intervention for the innovation of agroforestry product markets and for tree yield improvement.
2. Smallholder's farmers are encouraged to continue integrating grevillea on their farms and to use management practices such as pruning and thinning to enhance good tree products and crop yields.

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