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RESEARCH ARTICLE

ECONOMIC VALUATION OF ECOSYSTEM SERVICES PROVIDED BY AGROFORESTRY UNDER CLIMATE CHANGE EFFECTS IN THE FOOTHILLS OF MUMIRWA, BURUNDI

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ABSTRACT

Natural resources are facing serious degradation all over the world as a result of rapid population growth. This galloping population puts pressure on agroforestry ecosystems around the world. Yet, developing countries do not have methods to appraise the economic value of services provided by these ecosystems. They offer many opportunities to improve people's livelihoods. However, trapped in the socio-economic development process, agroforestry faces different threats including: deforestation, soil degradation, pollution, overexploitation of biotic and abiotic resources, etc. This work has contributed to identify agroforestry ecosystems and their services in order to determine their value. It will contribute to raising awareness among public and private decision-makers on the importance of agroforestry in terms of its input to protecting the environment and maintaining economic activity and ensuring populations' well-being. Applying the market price and avoided cost method, the work focused on analysing the economic value of ecosystem services provided by agroforestry in the foothills of Mumirwa. Results showed that ecosystem services provide a yearly average of 548,647.6 FBU while the minimum sum of a household is 300,000 FBU and the maximum is 1,200,000 FBU yearly. However, these methods used to assess ecosystem services remain complex. They are very often limited to direct use values and therefore, ignore non-use values constituting an important part of the total economic value of biodiversity. The study proves that agroforestry provides various environmental and economic benefits. From an economic point of view, households diversify their sources of income through agroforestry practices found on their farms. In a context of climate change, agroforestry ecosystems contribute to the reconstitution degraded landscapes and soil's regulation.

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INTRODUCTION

Throughout the world, environmental issues occupy a crucial place in debates related to the sustainability of national economies, food security, health and well-being, because of their impact on well-being and standards of living. One of the most topical is climate change, which is responsible for the degradation of human well-being and the damage caused to natural ecosystems, exacerbating the precariousness of life on planet earth. It has become the focus of academic and official attention at levels beyond the efforts of any single state. Climate change poses an unprecedented threat to populations in developing countries who are already struggling to maintain their food security and livelihoods (Achir, 2016). Awareness of the harmful and sometimes irreversible effects of human activities on the environment led to an increase in interest in nature conservation from the 1970s onwards, which began with the Stockholm Conference (Cazalet, 2004), and in particular with the creation of the United Nations Environment Programme (UNEP).

The introduction of agricultural practices, particularly the use of agroforestry, is an important aspect (Place, 1998). Agroforestry is a natural resource management system which integrates trees into farms and agricultural landscape to diversify and sustain production, and increase the resilience of rural landscapes and livelihoods. Agroforestry is one of the land use practices that have existed for centuries on all continents (ICRAF, 2003; FAO, 2001). In Africa, the measurement of the economic value of biodiversity using the ecosystem services approach is still underdeveloped (Christie *et al*., 2008; Christie *et al*., 2012; Abaza, and Rietbergen-McCracken, J. 1998). According to an analysis carried out on the basis of publications by various authors (Christie *et al*., 2012), compared with developed countries, there are few applications of biodiversity economic valuation methods in developing countries. Agroforestry contributes to the creation and maintenance of multifunctional landscapes that are resilient to climate change. By diversifying production and income, agroforestry systems reduce farmers' vulnerability to commodity price volatility (Gockowski and Van Asten, 2012).

Problem statement: Across the world, studies evaluating the ecosystem services of agroforestry are less frequent. Although it is now accepted that agroforestry produces important services that can be valued by humans directly or indirectly, on a real or theoretical market (Costanza *et al*. 1997; MEA, 2005; TEEB, 2010), it is not always easy to identify these services; there is still a lack of knowledge about their economic value. To remedy this situation, a study was conducted to assess the ecosystem services provided by agroforestry. The study is structured around the following research question: What is the economic value of the ecosystem services provided by agroforestry in the MUMIRWA backwaters?.

The aim of the investigation was to determine the economic value of agroforestry ecosystem services in the context of challenges such as climate change and the degradation of natural resources in MUMIRWA.As well as to determine the importance of agroforestry ecosystems, it contributes to preserve natural resources in the MUMIRWA foothills. The research is based on the hypothesis that "in a cultivated landscape, the economic value of the services provided by agroforestry ecosystems is explained by the natural resources of these ecosystems, livestock, household size, level of education and other relevant variables". Thus, sustainable conservation of natural capital influences household production and impacts their resilience to climate change, especially through diversification of income sources.

Conceptual and theoretical framework of the research: The framework summarizes constituted steps of research. It clarifies and providesknowledge that could inform sectors including policy makers in promoting ecosystem management strategies and improving the welfare of agroforestry practising households in the study region and beyond.

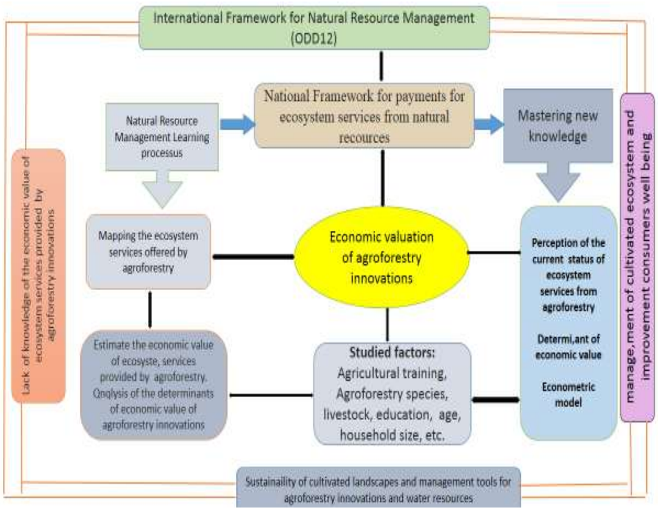


Figure 1. Conceptual and theoretical framework

In fact, the international framework for natural resource management highlights the importance of agroforestry practices. Even so, the national framework has not set up a mechanism for ecosystem services payment from natural resources. Scientifically, when we reflect on the value of agroforestry innovations, we notice knowledge gap on the subject and all services rendered by agroforestry are taken at face value. A methodical learning process must be initiated to: i) map the ecosystem services provided by agroforestry; ii) estimate the value of the ecosystem services provided by agroforestry; iii) analyse determinants of the economic value of agroforestry systems on the basis of the household economy in the Mumirwa region, in order to achieve the sustainability of cultivated landscapes on the basis of robust management tools such as : optimize species diversity by choosing complementary trees and crop, design the space to encourage interaction between the various components of the system). From such an analysis, new knowledge can be generated such as: 1) the perception of the state of the art of agroforestry ecosystem services; 2) the determination of the economic value of agroforestry ecosystem services; and finally, 3) an econometric model linking socio-economic determinants and the effectiveness of agroforestry practices in landscapes.

EMPIRICAL REVIEW

Evolution and importance of agroforestry: Agroforestry is grappling with the degradation of soil structure, the arrival of new pests, the multiplication of pesticide-resistant insects and weeds, and a temperature and rainfall regime altered by climate change. In this context, they have no choice but to rethink their farming practices, rotations, cropping systems, business management, strategies and investments (Tartera, C, 2014). In developing countries in general, and in Burundi in particular, population growth is increasing demand for wood and food products, and future needs can only be met by plantations, which are a model par excellence for creating resources and preserving degraded natural forests (Muliele, 2008). Burundi's considerable natural resources make a critical contribution to the livelihoods of Burundians, particularly the poorest. The subsistence farming to which the majority of the population is devoted and remains precarious. In the Mumirwa region, farmers live mainly off land that is increasingly eroded and impoverished by over-exploitation and faulty cultivation methods. This situation compromises not only any rural or socio-economic development plan, but also the ecosystem and ecological balance (WWF, 2012).

Agroforestry is based on various techniques such as: i) soil conservation techniques; ii) cropping techniques and iii) crop rotation. Agroforestry is a land-use system involving the spatial and temporal combination of trees or other perennial woody plants with crops and/or livestock on the same plot of land (Mémento de l'agronome, 1991). Agroforestry systems are characterised by ecological and economic interactions between their various components. These associations are characterised by: 1) a deliberate desire to establish and maintain the association through extensive maintenance; 2) positive and significant ecological and economic interactions that occur at the interface of the two vegetation strata; and finally 3) varied production and, as far as the trees are concerned, all forms of fuelwood, service wood, timber and all other products derived from leaves, fruit, roots and their by-products. An important socio-cultural role in many societies, since associations (tree savannahs, allotment gardens, etc.) are the first forms of land development.

The advantages of agroforestry: Agroforestry offers a number of advantages. These include agri-environmental benefits such as improved soil fertility, through the mineralisation of leaf litter on the surface (NGO, 2006), and above all through the deep degradation of dead annual roots in the soil (Dupraz, 2002). From an economic point of view, agroforestry systems exploit the soil to the maximum. Every part of the land is considered suitable for growing useful plants. The emphasis is on once-planted perennial multipurpose crops that provide benefits over a long period of time. These benefits can include building materials, food, fodder, fuel, fibre and shade. Environmentally, agroforestry improves the natural fertilisation of soils, making it possible to reduce the use of inputs. It also helps to protect the soil from erosion and protects groundwater. It also helps to diversify landscapes, maintain biodiversity, effectively combat the risk of fire and fix atmospheric nitrogen.

Economic valuation and typology of ecosystem services in agroforestry in landscapes: For more than a decade now, environmental issues linked to public goods (climate change, biodiversity, water quality) and their application in sectoral policies (agriculture, land use planning) can no longer be addressed without reference to the concepts of ecosystem service and environmental service. With the rise in importance of the concept of sustainable development initiated in the late 1980s and the popularisation of the notion of biodiversity, studies aimed at assessing the contribution of biodiversity to the development of human societies have multiplied. Current political commitments (Convention on Biological Diversity, International Treaty on Phylogenetic Resources, FAO) have given rise to a number of scientific initiatives aimed at assessing biodiversity and its uses, using approaches ranging from describing its state of conservation to measuring the monetary value of its contribution to human well-being.

Table 1. The main species of Burundian agroforestry and their uses

Scientific name	Usefulness	Common name
Caliandra	Biofertiliser Animal nutrition	
Leucaena	Biofertiliser Bio pesticide	Mukobwandagowe
Tifrosia	Biofertiliser Bio pesticide	Ntiruhunwa
Neem	Biofertiliser medicinal	Nime
Vernoniaamygdalina	Medicinal	Umubirizi
Ficusvallichoude	Cultural	Igikuyo
Ficusingens	Cultural	Umumanda
Ficusgnapholearpa	Cultural	Igitoboro
Ficusexperata	Cultural	Umuseno
Stericuliatragacanta	Cultural	Umutakataka
Stericulia Africana	Cultural	Imbonekerakure
Euphorbia turicalli	Construction	Umunyari
Passiflorafoetida	Nutritional	Amabungo
Sporoboluspyramidalis	Nutritional	Agatsindangumba
Asystasiagangetica	Nutritional	Agatikaruzi
Balanitesaegyptica	Construction	Umugirigiri
Euphorbia candelabrum	Construction	Igihahe
Cynodonnlemfuensis	Medicinal	Urucaca
Sesbaniasesban	Medicinal	Umunyegenyege

Source: Summary based on PNRzireports on species management

Table 2. The main standard methods and their limitations (source: own research)

Category	Method	Description	Advantages/ Limitations
Methods based on real markets	Market prices	Used to measure direct use value (supply service)	Easy to drive, less time and effort but problem of market distortion, price not equal to real value
	Replacement costs	Often used to measure indirect use value (regulating service)	Difficult to conduct in developing countries due to lack of data
	Avoided damage costs	Often used to measure indirect use value (regulating service)	Difficult to conduct in developing countries due to lack of data
	Travel costs	Often used to measure the value of recreational services	Estimates only the value of recreational services. In the case of developing countries, the difference between domestic and foreign tourists can bias the estimate.
	Hedonic pricing method	Used to measure indirect use value (regulating services)	In some cases, it is difficult to identify the service valued in the land price. It requires a great deal of information, which makes it difficult to apply in developing countries.
Methods based on fictitious markets	Contingent valuation	For all services, it measures total economic value	Allows measurement of the value of use and non-use, difficult to carry out in developing countries (low income, level of education of respondents, familiarity with the complex concepts of biodiversity, etc.).
	Modelling choice	All services measure total value	Same limitations as EC Protocol are very complex and considered unsuitable for developing countries.
	Deliberative monetary valuation	All services measure total value	Participatory method that enables stakeholders to learn and be trained, problem of representativeness of the sample
	Mediated modelling	All services measure total value	More complex than CE and time and resource consuming, its advantage is that it can be adapted according to the data available.

Source: Aoubid. S and Gaubert. H 2010

Typologically speaking, specialists have developed a classification based on three main periods: the pre-MEA, 2005 typologies, the classification of the MEA, 2005 report and the post-MEA typologies. This typological paradigm lists ecosystem goods such as food and services such as waste treatment, which represent the benefits that human populations derive, directly or indirectly, from ecosystem functions (Costanza *et al*. 1997). The following five classes emerge:

Provisioningservices: These refer to direct human consumption. These are the material products provided by ecosystems: food, fresh water, raw materials (wood and fibre) and medicinal resources;

***Regulating services**:* These are the benefits derived from the regulating functions of ecosystems: regulation of local climate and air quality, carbon sequestration and storage, mitigation of extreme phenomena, wastewater treatment, prevention of erosion and maintenance of soil fertility, pollination, biological control.

***Cultural services**:* These relate to the non-material benefits that people derive from contact with ecosystems: entertainment, tourism, effects on mental and physical health, aesthetic value and inspiration for culture, art and design, spiritual experience and serenity.

***Supporting services**:* The support and functional mechanisms of ecosystems that enable biodiversity to produce services useful to humans. They encompass virtually all other services and include species habitats and the maintenance of genetic diversity, soil formation, photosynthesis, the recycling of fertilising substances and the primary production of biomass. In terms of values, environmental economists have developed several methods for measuring the total economic value of environmental goods and services, or part of that value. Total economic value (TEV) distinguishes between two main categories of value: use value and non-use value. Use value refers to the benefits derived from the use (consumption or other use) of natural assets. They include actual, direct and indirect use (goods and services) and potential use (option or insurance value). Non-use values are linked to the satisfaction of knowing that a natural asset exists. They include altruistic values towards future generations (legacy values) and towards non-human species (existence values). Furthermore, the economic valuation of natural assets is at the heart of environmental economics. It is based on consumer theory. In this way, the variation in well-being engendered by nature for individuals is measured by the notion of consumer surplus. These methods can be summarised in the following table:

MATERIAL AND METHODS

Presentationof the study area: The area covered by this study is the Mumirwa region, more specifically in the rural communes of

Bubanza province in western Burundi. Mumirwais an escarpment of the Congo-Nile ridge on the Burundian coast. The topography of Burundi is highly varied. The country is divided into 5 eco-climatic regions (Fig. 3). From west to east, there are the Imbo lowlands, which correspond to a collapse trough of the Western Rift Valley, the steep Mumirwa region, the mountainous area (the Congo-Nile ridge), the central plateaux and the Kumoso and Bugesera depressions. Altitudes range from 774 m on the shores of Lake Tanganyika to 2,670 m on the mountain ranges, gradually dropping to 1,200 m in the east of the country. The Mumirwa region is an escarpment dotted with very narrow ridges intersected by numerous torrential rivers flowing down from the peaks to the plains. The slopes are very steep and variable. In fact, the altitude rises from 1,000 m to almost 2,000 m from the Rusizi plains to the Congo-Nile ridge, over a distance that varies from 3 km between the lake and the Batoza massif to 30 km to the north of the mid-Rusizi plain.

$$n = \frac{1{,}96^2 * 0{,}5(1-0{,}5) * 6082}{1{,}96^2 * (1-0{,}5) + (6082-1) * 0{,}05^2}$$

$$n = \frac{3652{,}4012}{10{,}4654} = 348{,}997764 = 349$$

Modelling: We used an econometric multiple regression model: we've chosenthis method run our econometric model in quality of multidimensional data. As a special case of linear model, it is the natural generalization of simple regression.The endogenous or explained variable is the overall value generated by agroforestry (production is valued globally).

$$VG = \beta_0 + \beta 1SUPER + \beta_2 SEX + \beta_3 AGE + \beta_4 EDUC + \beta_5 FORMAGR + \beta_6 TMEN + \beta_7 ARAGRO + \beta_8 MIBOISE + \beta_9 FOURR + \beta_{10} BOV + \beta_{11} CAPR + \beta_{12} VOL + \beta_{13} PORC + \beta LAP_{14} + \beta_{15} ETAMA + \varepsilon_i \quad \ldots\ldots\ldots(2)$$

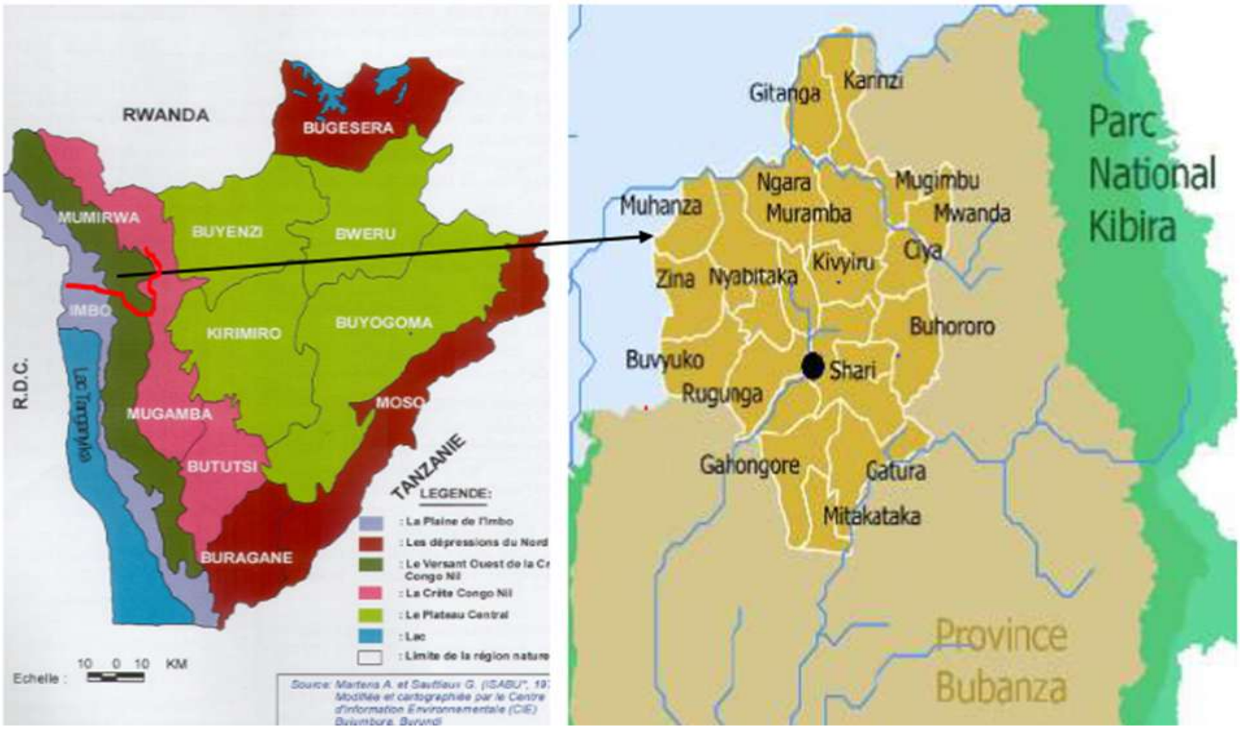


Figure 2. Map of Burundi's 5 eco-climatic regions

Sampling method

Sample size: Our activity, which included focus groups, surveys and monitoring of plots in the farming environment. Since the study was carried out as part of a project, the sample consisted partly of households supported by ADISCO and partly of households considered as controls. The latter category was randomly selected from households spread over 9 hills in the three rural communes of Bubanza province. To determine the sample size, we used the equation (1) developed by Louis M. Réa and Richard A. Parker (1997). This approach gives a significant sample that can represent the total population.

Equation: $$n = \frac{tp^2 * P(1-P) * N}{tp^2(1-P) + (N-1) * Y^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

With:
n: sample size
N: total population size
P: probability giving the maximum value here 0.5
tp: 95% confidence interval corresponding to 1.96
Y: 5% margin of error

We took the sample at the 95% threshold, i.e. at the 5% confidence interval taking the value of 1.96. The size of the population to be sampled is therefore:

RESULTS AND DISCUSSION

This study is carried out in the households of Mumirwa to estimate the value of agroforestry ecosystems resulting from the association of crops with trees in the rural communes of Bubanza province.

Principal Component analysis: PCA

Principal component analysisis used to transform variables that are correlated with each other into decorrelated variables known as "principal components". More precisely, this method aims at reducing the number of variables applied to individuals, in order to simplify observations while retaining as much information as possible. Only one, two or three variables known as "principal components" are retained.

Descriptive statistics: The overall value generated by agroforestry ecosystem services is presented in table 3.

Table 3. Descriptive statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
Y2022	349	548647.6	149888.1	300000	1200000

Source: constructed by the author using STATA 15

Ecosystem services provide an average of 548,647.6FBU, while the minimum sum is 300,000FBU and the maximum is 1,200,000FBU over the course of a year. These results are estimates, as some producers store their production with cooperatives. They estimate the quantity stored for one cropping period. These values are estimates, as the Burundian population generally lives on subsistence farming. Households do not produce for the market and are unable to quantify how much they have consumed in previous periods. In addition, the sample surveyed was unable to specify the value of certain agroforestry products such as unsold fruit.

Model estimation results

The statistical tests that explain the relevance of the model were first checked before commenting the signs of various coefficients. This involves presenting the results of the econometric regression of our model presented above. The results were obtained using STATA 15 software and concern data collected from farmers by means of questionnaires and entered into Excel.

Before interpreting these results, we first check whether the assumptions already made for our multiple regression are verified. To this end, we check the hypotheses normality of the errors.

Error normality test

H0 = no normality of errors
H1: presence of error normality

From the results in this table we can see that the errors follow a normal distribution, since the probability of the chi2 test is less than 5% (0.05 < 0.0000). Here we accept hypothesis H1 that the errors are normal.

Interpretation of the coefficients: Given the results of the model, all the coefficients in the model are non-zero except for the area. Here, area has a zero coefficient because the value taken is constant for all respondents.

Table 4. Model estimation results

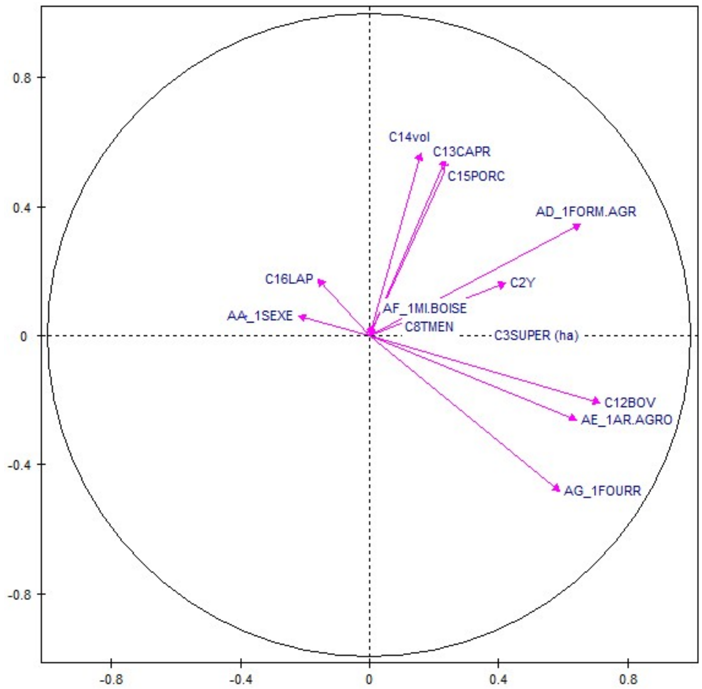
Y2022	Coef.	Std. Err.	T	P>t	[95% Conf.	Interval]
SUPERha	0	(omitted)				
SEX	32941.96	15857.26	2.08	0.003	1747.897	64136.03
AGE	-335.9248	1226.383	-0.27	0.060	-2748.44	2076.59
EDUC	1695.236	11901	0.14	0.001	-21716.15	25106.62
FORMAGR	58851.24	18075.24	3.26	0.001	23294.01	94408.48
TMEN	-20504.53	5435.611	3.77	0.091	9811.711	31197.35
ARAGRO	25360.66	20152.51	-1.26	0.004	-65004.26	14282.93
MIBOISE	21915.98	14666.64	-1.49	0.013	-50767.89	6935.924
FOURR	48278.57	18088.84	2.67	0.001	12694.58	83862.56
BOV	16962.16	9223.882	1.84	0.005	-1182.863	35107.18
CAPR	6626.879	5092.293	1.30	0.014	-3390.571	16644.33
VOL	-2516.069	3288.401	-0.77	0.445	-8984.94	3952.803
PIG	11510.25	7584.356	1.52	0.130	-3409.533	26430.03
LAP	-20.21577	3344.068	0.01	0.995	-6558.163	6598.595
ETAMA	-65219.24	17151.15	-3.80	0.000	-98958.62	-31479.86
_cons	497343.8	51583.74	9.64	0.000	395869.3	598818.2

Source: Authors via STATA 15

Table 5. Error normality test: sktestresidus

Variable	Obs	Pr(Skewness)	Pr(Kurtosis)	adj chi2(2)	Prob>chi2
Residu	345	0.0001	0.3298	14.35	0.0008

Source: Authors via STATA 15



Source: authors via SPAD V 5.5

Figure 3. Principal component analysis

This is due to the fact that the households have farms of various sizes, which means that all the data collected are reported in units of one hectare in order to allow a comparative study between those who have received agricultural training or adopted agroforestry practices and those considered as controls. Other variables such as gender, level of education, agricultural training, agroforestry trees, micro afforestation, fodder, as well as animal-based variables such as cattle, goats and pigs, have positive non-zero coefficients. In other words, they positively explain the model. An increase of one unit for an explanatory variable result in an increase of as many units in the coefficient of this variable for the explained variable. The variables that negatively influence the model are age, household size, livestock such as poultry, and marital status.

Principal Component analysis: PCA

The PCA method shows which variables are correlated with each other. Variables in the same quadrant have the same correlation. Variables such as income, agricultural training (FORMAGR), cattle (BOV), goats (CAPR), forage (FOURR) are in the same part of the figure. On the one hand, the first quadrant is made up of the variables poultry (VOL), goats (CAPR), micro afforestation, pigs (PORC) and agricultural training. This correlation is explained by the fact that the dynamics that benefit from this training are encouraged to raise animals for the base course. Households report that the income from the direct use of ecosystem services is channelled into supplying these small livestock. On the other hand, variables such as cattle, fodder and agroforestry trees are included in the same framework; the interpretation is the same as the previous one. In other words, those who have cattle in their herd also have ecosystems in terms of fodder and agroforestry trees, which are used to feed livestock and transform the organic manure needed to reconstitute and fertilise the soil.

Farmers' perceptions

Ecosystem services provided by the ecosystems identified in Mumirwa.

Table 5. Attributing value to ecosystem services

Ecosystem service	Freq.	Percent	Cum.
1= Soil fertility management	29	17.26%	17.26%
2= Combating water erosion	15	8.93%	26.19%
3= Wind erosion control	10	5.95%	32.14%
4= moisture conservation	15	8.93%	41.07%
5= Biological control	65	38.69%	79.76%
6= Best performance	14	8.33%	88.10%
7= to compensate for climatic contingencies	20	11.90%	100.00%
Total	168	100.00%	

Source: Constructed by the authors using STATA 15

The proportions and values in Table 5 show how farmers assess the contribution of agroforestry ecosystems. The majority of households - 65 households out of 168 people who have adopted the introduction of new agroforestry species, or 38.69% - say that these ecosystems provide better biological control services; 29 households, or 17.26% of this category, say that agroforestry trees help to fertilise the soil, and 20 households, or 11.90%, say that agroforestry species help to mitigate climatic hazards. The other services mentioned by households were better crop yields, combating water and/or wind erosion and moisture conservation. From these responses collected from farmers, we can categorise the services provided by ecosystems as direct use services and non-use services.

Constraints for farmers in integrating trees into their farms: Of the 349 households, 181 did not prefer to combine trees and crops. The constraints that prevent farmers from intentionally mixing trees in their fields are of several kinds. This table shows that among the 181 households, 9 households (4.97% of the sample) farm fields that do not belong to them, 21 households (11.60% of the sample) say that the trees create shade and prevent crops from developing properly, 54 households (29.83%) say that the trees in the field take up a lot of space, 12 households (6.63% of the sample said that they did not want trees in their field, 34 of the households (18.78%) said that trees created shade and prevented crops from developing properly, 31 of the households (17.13%) said that trees created competition with crops, and 20 of the households (11.05%) did not want trees.

Table 6. The major constraints that often prevent farmers from integrating trees into crop production

Constraints	Freq.	Percent	Cum.
1 = I don't own the field I'm farming	9	4.97	4.97
2 = Trees don't make good boards	21	11.60	16.57
3 = These trees occupy large areas	54	29.83	46.41
4 = I don't want trees in my field	12	6.63	53.04
5 = These trees create shade and prevent crops from developing properly	34	18.78	71.82
6 = Trees create competition with crops	31	17.13	88.95
7= Other to specify (I'm missing some trees, the appearance)	20	11.05	100.00
Total	181	100.00	

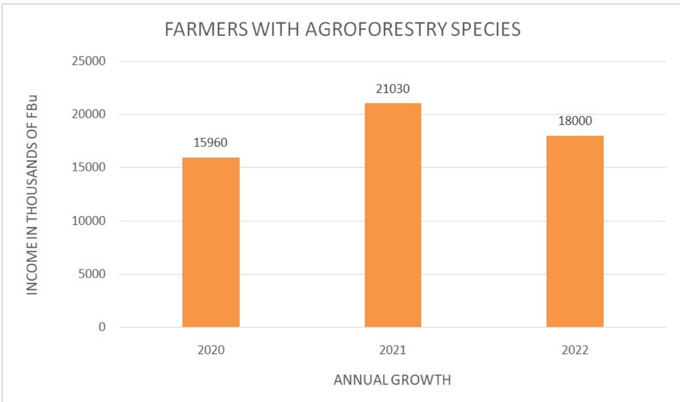
Source: Constructed from field data using STATA 15

From these results we can see that the fields farmed by most of the farmers do not belong to them, those who do not want trees in their fields and those who say that trees create competition with crops or shade, this allows us to easily deduce that they do not have enough knowledge and the others say that they lack trees, and yet there is a multitude of agroforestry trees.

Socio-economic effects of agroforestry innovations: This sub-section presents the economic value or yearly income of farmers who associated agroforestry species to their farms on the one side, and the income of farmers who plants farms crops exclusively on the other side. It further highlights the benefits of agroforestry as perceived by households in Mumirwa and, its contribution to climate change resilience.

Estimating the economic value of ecosystem services

Economic value for beneficiary households

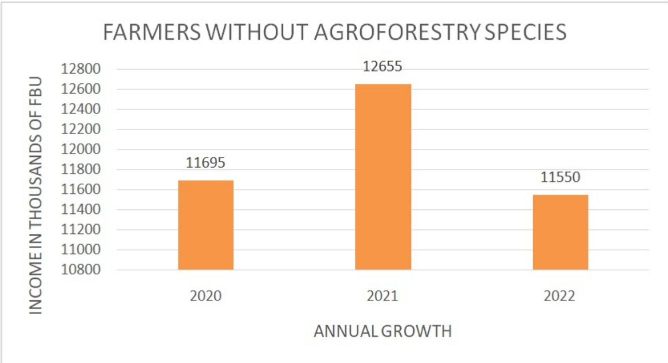


Source: Constructed by the authors using STATA

Figure 4. Revenue curve

This figure shows the change in production from 2020 to 2022 for those using agroforestry practices. Agroforestry practices were implemented in 2020; there was an increase in revenuein 2021, but production fell slightly in 2022. The growers explained that this was due to the climatic shocks that occurred in the country during the growing season. The following figure shows the change in ecosystem value from 2020 to 2022 for the control population not using the agroforestry innovations. The curve for 2022 has fallen below those for 2020 and 2021. Growers say this is because of the climatic changes that have affected their fields during this year's growing season. Climatic hazards affect everyone without distinction.

Producers who have not adopted innovative practices suffer the consequences, as they concentratetheir production resources on the purchase of inputs (chemical fertilisers and pesticides).



Source: Constructed by the authors using STATA

Figure 5. Estimated income for non-doers

If climatic conditions remain favourable, they will record a slightly satisfactory production range, but still lower than those using organo-mineral inputs. This is the situation in 2021; the curve has grown in relation to the curve for 2020 because, all other conditions being equal, the climate has been favourable. The difference between the two previous observations is as follows: if there is a climate shock, production will fall much more for producers who do not practise agroforestry because their soil is degraded and will cost them more to restore. Farmers who practise agroforestry innovations explained that instead of buying chemical fertilisers, they ferment organic manure themselves from crop residues mixed with natural resource products (agroforestry species already mentioned). With these innovations, benefits can be seen in several directions: the funds intended for the supply of inputs other than seeds are invested in livestock farming to have sufficient organic manure thanks to the recycling of crop residues by the livestock. In addition to supplying livestock, organic manure replenishes the soil, increasing other plant growth and enriching the soil with nutrients that are essential for crops.

Benefits of agroforestry as perceived by households in Mumirwa: Well-designed agroforestry systems increase beneficial interactions between crop plants while minimising unfavourable interactions. The most common interaction is competition, for example for light, water or soil nutrients. These interactions involve not only crops and trees but also interactions with animals.

Effects of agroforestry adoption for beneficiary households: The beneficiaries of the support have got organic matters from green manure derived from fast growing tree species which are used instead of the chemical fertilizers or other synthetic inputs. This technical system contributes alsoto combat rodents and field pests. These products are made from natural resources. The funds that were earmarked for the purchase of these inputs are invested in livestock breeding and improved welfare. They invest in livestock, where each household has at least cattle, goats, pigs and other domestic animals. These indicators show the economic value of the ecosystems provided by agroforestry.

Effects of agroforestry adoption for control households: Results reveal that the number of livestock (cattle, goats, pigs) of producers who do not benefit from the support of development actors is not significant. The reason is that they are referred to as control households who have not adopted agroforestry practices. They have, of course, their own livestock, but in smaller numbers than the beneficiaries. The reasons for this difference are that the funds that could contribute to the supply of animal equipment are channelled into the purchase of inputs. If the weather changes for the worse, these producers suffer doubly. Results also have shown that farmers lose out significant investment in inputs trying to acquire chemical inputs because their livestock is limited and this ends up in poor economic returns after each agricultural season.Those who mix plants and trees in their fields get a considerable benefit because their revenue become increased. These practices restore resilience and viability by creating stable incomes that contribute to rural development. From field observations during our investigation, it was found that the highest number of cattle, goats and pigs is two, five and three respectively. The majority of this sample have no livestock, unlike those who adopt agroforestry practices.

Contribution of agroforestry to climate change resilience: The results of this work prove that farmers who introduced agroforestry species in their farms receive multiple benefits. During the rainy season, violent winds and glacial rain ravage crops. These agroforestry ecosystems slow down the wind and kinetic energies and protect crops or plants. More technically agroforestry contributes to climate change mitigation in two ways: 1) by sequestering carbon in the biomass, 2) by avoiding greenhouse gas emissions. Agroforestry helps to improve crop yields, diversify income strengthen the sustainability and climate resilience of the food system. It creates habitats for biodiversity and protect people and livestock in certain circumstances from climate hazards.

Effects of agroforestry practices on the soil status: The results of chemical analyses on soil samples from the different agroforestry practices are given in Table7. Before the beans were planted, the carbon content was 2.04%, the nitrogen content was 0.332% and the pH was 6.83.

Table 7. Soil survey before planting beans

N.O	Sample	no Labo	pH (water)	carbon %	Total nitrogen
1	SOL.BUBANZA	L2289	6,83	2,04	0,332

Source: ISABU laboratory results for soil samples supplied by ADISCO

After the beans were planted, with the use of organic fertiliser, the pH remained almost stable (6.83 to 6.8); the percentage carbon rose from 2.04 to 2.51 and the percentage total nitrogen rose from 0.332 to 2. With the use of chemical fertilisers, the pH rose from 6.83 to 7.17; percentage carbon varied from 2.04 to 2.32 and percentage total nitrogen fell from 0.332 to 0.208. With the use of chemical fertilisers and organic matter, the pH decreased from 6.83 to 6.35; percentage carbon decreased from 2.04 to 2.03 and percentage total nitrogen decreased from 0.332 to 0.311.

DISCUSSION

Farmers' perceptions of the importance of agroforestry: Agroforestry offers numerous ecosystem services, both for agricultural producers and for society in general. Without being a panacea, agroforestry, with its multiple environmental and economic functions, can help the agricultural and forestry sectors find innovative solutions to current problems, including lack of profitability, environmental impact and sometimes,the negative public perception of agroforestry. Better still, agroforestry can improve the quality of life of citizens and producers by diversifying incomes and contribute to the economic revitalisation of regions while respecting the sustainable management of the natural resources present on the land. LABANT Pierre (2010) believes that the association of trees with agricultural activities, judiciously organised in space and time, makes it possible to establish complementary relationships. In the context of climate change, agroforestry plays a major role in resilience in the face of this change**.** By restoring the landscape using different species, the leaves and branches of trees slow down the kinetic energy that causes the deformation of arable land that is favourable to agriculture.

Socio-economic effects of agroforestry on production: Results further show that, the producers are fully involved in the ecosystem services of agroforestry in the formation of their income. Production increases as a result of soil transformation, but the main gain lies in the fact that expenditure on inputs such as chemical fertilisers, DDT and other pesticides is redirected towards other investments. Income sources are diversified. Many indicators are used by farmers to assess the improvement in living conditions brought about by ecosystem services. The increase in yields on fertile soils is in line with the work of Kissou (2014). Agroforestry practices restore resilience and viability by creating stable incomes that contribute to rural development. These results are in line with those of van der Ploeg *et al*. (2019).

Mechanisms for preserving natural resources: Ecosystem services result from the maintenance and prevalence of ecosystems. Several factors need to be taken into account when developing strategies for adaptation and resilience to climate change. Multidisciplinary approaches should therefore dominate (LOCEAN *et al*. 2015). This is also a suitable model for preserving natural resources (species and water-related resources). Agricultural innovation requires identifying and understanding the existing practices of the target populations, who have often developed significant knowledge about adapting to unfavourable environments and climatic shocks. Traditional and scientific knowledge should be combined through participatory approaches to improve the management of existing agricultural systems. Adaptation strategies have a better chance of being adopted, appropriate and successful if they are based on indigenous knowledge. The political and economic factors that influence farmers' decisions to adjust their practices are the major factor in introducing and raising awareness of certain decisions. In the case of Burundi's stall rearing policy, agroforestry remains a driving pillar for the success of this system because it diversifies the resources needed to feed livestock. Indeed, institutions that function well, and governance systems play a major role in adaptation.

CONCLUSION

The results provethe relevance thatagroforestry contribute to improve revenue resources of population. This mechanism allows famersto develop resilience to climate change. The soil is reconstituted through the decomposition of organic matter from plants buried in the soil. This is the basis for concluding that the ecosystem services offered by agroforestry are not only theprovisioningservices. From an economic point of view, agroforestry has revealed the existence of a diversity of financial resources. Farmers who practise agroforestry have more livestock and a good income. Agroforestry offers also regulating services and supporting services. This category provisioning services involve direct human consumption of the material products provided by ecosystems: food, fresh water, raw materials (wood and fibre) and medicinal resources. This validates the hypothesis that agroforestry services are economically viable. The results of the research show that ecosystem services provide an average of 548,647.6FBU, while the minimum sum for a household is 300,000FBU and the maximum is 1,200,000FBU over the course of the year. However, these methods of valuing ecosystem services remain complex. They are very often limited to direct use values and therefore ignore non-use values, which nevertheless make up a large part of the total economic value of biodiversity. The study shows that agroforestry provides a range of environmental and economic benefits. From an economic analyse, households diversify their sources of income through agroforestry practices on their farms. In the context of climate change, agroforestry ecosystems contribute to soil reconstitution. It provides benefits from the regulating ecosystems ‘functions: regulation of local climate and air quality, carbon sequestration and storage, mitigation of extreme phenomena, wastewater treatment, prevention of erosion and maintenance of soil fertility.

Agroforestry ecosystem services are not limited to direct use. There are benefits arising from the regulating functions of ecosystems, such as regulation of the local climate and air quality, carbon sequestration and storage, mitigation of extreme events, waste water treatment, prevention of erosion and maintenance of soil fertility, pollination and biological control. Over time, with the promotion of agroforestry practices, the soil is gradually replenished. Support services, which are the functional mechanisms of ecosystems that enable biodiversity to produce services useful to humans. They encompass virtually all other services and include species, habitats and the maintenance of genetic diversity, soil formation, photosynthesis, the recycling of fertilising substances and the primary production of biomass. In terms of the policy implications of the results, this study suggests that creating favourable conditions for granting agricultural credit or subsidies to producers could boost ecosystem services in agroforestry ecosystems. These loans or subsidies will enable them to acquire the equipment and inputs they need to implement agroforestry practices more successfully. In addition, decision-makers should aim to take greater account of local knowledge when introducing or developing agroforestry techniques, while the approaches used to support producers should aim to better integrate agriculture and livestock farming in combination with trees, enabling them to increase the production of organic manure and improve their resilience by diversifying their products.

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