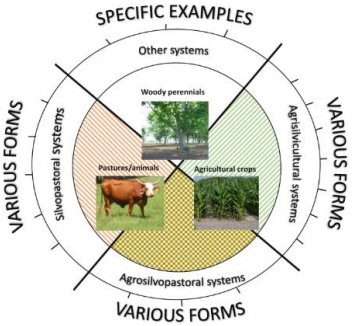

The effectivness of agroforestry on agricultural productivity and erosion control in Rwanda

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Abstract

Agroforestry bridges the gap that often separates agriculture and forestry by building integrated systems that address both environmental and socio-economic objectives. Agroforestry can improve the resiliency of agricultural systems and mitigate the impacts of climate change. Existing research suggests that integrating trees on farms can prevent environmental degradation, improve agricultural productivity, increase carbon sequestration, generate cleaner water, and support healthy soil and healthy ecosystems while providing stable incomes and other benefits to human welfare. This research aims to provide for identifying and adopting the evidence demonstrating the effects of agroforestry practices and interventions on agricultural productivity, erosion control, ecosystem services, and human well-being.

To study the effectiveness of agroforestry on agricultural productivity and erosion control in Rwanda, raw data was collected with the aid of a questionnaire and focus groups. It was found that most farmers (95.6%) adopted and were fully engaged in agroforestry while all the officials made up to the mark. Woody species like *Grevillea robusta*, *Cassia siamea*, *Albizia spp*, *Acacia albida*, *Persea americana*, and *Mangifera indica* were found to be tree species the most integrated with crops in all the provinces of Rwanda. It was evident that farmers practice agroforestry to enhance the overall sustainability of farming systems by improving agricultural productivity and preventing erosion.

Keywords

Agroforestry; Soil erosion; Agricultural productivity; Rwanda

Contents

1 Introduction

Agroforestry is a multi-functional land use system that can be described as agriculture with trees and livestock. It is an Agroecosystem that combines agriculture and trees to address conservation needs and build more profitable and weather-resilient farms, ranches, and communities. It refers to the integration of trees in agricultural landscapes.

Agroforestry systems take advantage of the most poorly understood interactions that occur amongst crops, trees, and livestock. Agroforestry has been demonstrated to present numerous benefits which include the conservation of biodiversity, regulation of natural pests and diseases, regulation of soil, increased air and water quality, efficient cycling of nutrients, and resilience to climate change (Ramil Brick et al. 2022). This form of land management is not a new idea, and dates to at least the Middle Ages in the developing world, and probably earlier in other cultures (Nair, 1993). Trees and woody species play critical roles in both preventing land degradation and restoring degraded, deforested landscapes (Bayala and Harmand 2023). Land degradation is exacerbated by climate change, which can result in biodiversity loss and jeopardize the livelihood of local communities (UNCCD 2019). The results will be useful for informing the public to adopt agroforestry and officials to make policy and decision makers towards integrating into the farming system.

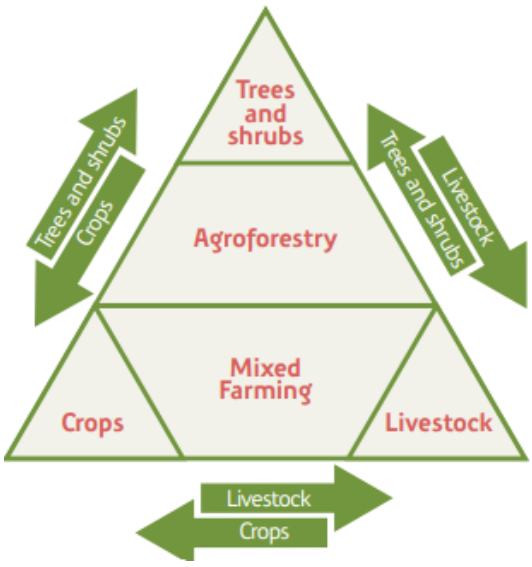

Figure 1. Agroforestry involves the integration of trees and shrubs with either crop, livestock, or mixed farming.

Term agroforestry was introduced by John Bene through Canada's International Development Research Centre in the early 1970s and highlighted the benefits of a multi-functional land use system (Cannell 1988). Further, the progress led to the establishment of the International Council for Research in Agroforestry (ICRAF) in 1978 to promote agroforestry research in developing countries (ICRAF 2000).

1.1 Principles of agroforestry

As the Rwandan population increases, there is a growing need for multi-functional land use systems that can meet the multiple demands for food and firewood production, environmental and biodiversity protection, and have the capacity for adaptation and resilience to climate change (REMA 2011). In Rwanda, agroforestry can be a sustainable alternative to traditional agricultural practices by reducing its negative impacts by, for example, regulating soil, water, and air quality.

Moreover, there is growing evidence that agroforestry systems increase overall productivity. In agroforestry systems, productivity can be measured using the Land Equivalent Ratio which compares the yield from growing two or more components together versus the yield from growing them separately (Ramil Brick et al. 2022). Agroforestry systems do not need as much pesticide and fertilizer as traditional monocropping systems, thus reducing the cost of farming inputs, eutrophication, and pollution. When livestock are introduced into the system, agroforestry can also reduce feeding costs, and apart from crops and livestock, agroforestry systems can produce outputs from the trees such as food, fuel, fodder, fiber, and timber which could yield an increase in economic profit due to the multiple outputs from this type of system.

In addition, these multiple outputs reduce the risk associated with producing one product during shortage periods due to adverse weather conditions or crop disease.

Bucagu (2013) reported that the agroforestry systems also benefit from increased animal welfare by protecting from wind, rain, sun, and cold. furthermore, shrubs or trees offer protection from predators and encourage natural animal behavior such as foraging. Lastly, agroforestry systems can also have recreational benefits.

1.2 Need for agroforestry and soil control in Rwanda

Even though Rwanda has abundant agroforest but is significantly facing erosion that leaves farmers vulnerable to the vagaries of climate. Rwandan farmers are heavily reliant on rain-fed subsistence agriculture. The lack of erosion control means farmers have limited ability to cope with soil degradation. These limitations are estimated to cost the economy one-third of its growth potential (NISR 2021). Investment in appropriate agroforestry and erosion control measures is an urgent option to increase agricultural productivity and to ensure that farmers have options for coping with the coming climate changes and soil degradation.

Zada et al. (2022) reported that agroforests are designed and operated to provide food, firewood, timber, erosion control, water holding, flood, and drought management, environmental services, and recreational activities, etc. it can be regarded as the need for enhancing food security, restoring degraded land, improving resilience to climate change and sequestering carbon and erosion control.

REMA (2010) mentioned the benefits depending on the situation and application, agroforestry practices can: 1) protect valuable topsoil, livestock, crops, and wildlife; 2) increase productivity of agricultural and horticultural crops; 3) reduce inputs

of energy and chemicals; 4) increase water use efficiency of plants and animals; 5) improve water quality; 6) diversify local economies and on-farm income; 7) enhance biodiversity; 8) improve air quality and sequester carbon and 9) support working lands at the landscape scale. Agroforestry can help reduce conflict between rural and urban land uses by creating "Eco-belts" that serve as a zone of transition and help to reconnect agriculture, people, and communities. Applying these practices at a landscape scale to create a more functional landscape that can contribute to the quality of life for many people (Vargas-Hernández 2020; Hülsmann et al. 2013).

Furthermore, agroforestry practices provide opportunities to integrate productivity and profitability with environmental stewardship resulting in healthy and sustainable agricultural systems that can be passed on to future generations (USDA 2014).

2 Materials and methods

2.1 Description of the site

The total geographical area of Rwanda is 26,338 km$^{2.}$, currently agricultural land is the primary source of the component with almost 12,000 km^2 and only 8400 km^2 are suitable for agriculture. The second broad current land cover category is two groups of forests: natural forests of 1,389 km^2 and plantations of 3,873 km^2, and other savannah and shrubland woods of 1,980 km^2. Together, they cover 30.4% of the country's dryland surface by December 2019. All built-up areas, including roads, are 2,888 km^2 or 11% of the country's surface, 1,500 km^2 of which are rural settlements. Two-thirds of the rural settlements are small, disjointed parcels of poorly used agricultural lands. These lands may potentially be added to the stock of consolidated agricultural lands, once the rural system is transformed. 2068 km^2 are wetlands, including buffer zones, and 1637 km^2 of water bodies, also with buffer zones close to the list.

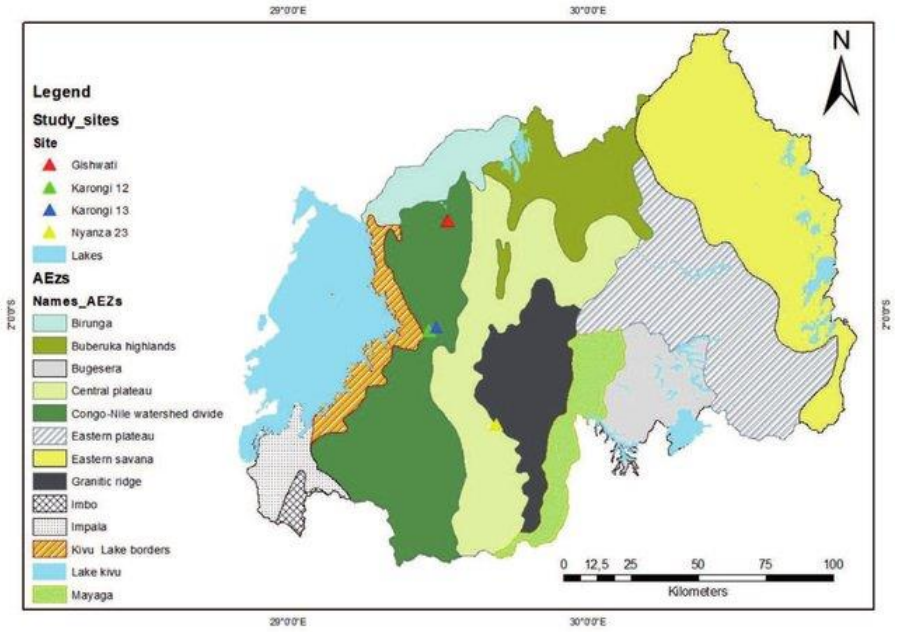

Figure 2. Rwanda Systematic map showing the agro-ecological zone dense with agroforestry.

The systematic map (Figure 2) identifies, collects, displays, and describes available evidence on the impacts of agroforestry on agricultural productivity, ecosystem services, and human well-being in Rwanda. The current study covers the primary beneficiaries (farmers and officials) from all five provinces of Rwanda. Research is designed to capture the studies related to agroforestry practices and their interventions in agricultural productivity and erosion control in all provinces.

2.2 Field and data collection

To study the effect of agroforestry on agricultural productivity and erosion control in Rwanda, raw data was collected with the aid of a questionnaire and focus groups. The collected data were consolidated to get all the data required for analysis. The selection was made to get enough raw information from farmers and officials in the agriculture and environmental sectors to satisfy our objectives. In all provinces, 430 farmers and 40 officials from agricultural and environmental sectors were selected for the study. Farmers were screened through the TWIGIRE MUHINZI program and officials were from different agricultural agencies.

Farmers	
Kigali	30
west	100
East	100
North	100
South	100
Total	430

Officials	
west	10
East	10
North	10
South	10
Total	40

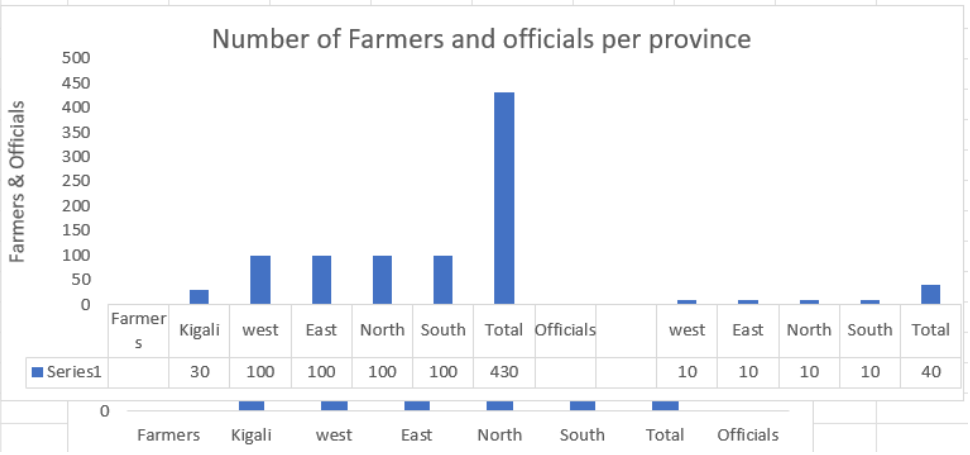

Figure 3. Number of farmers and officials interviewed during research.

2.3 Data analysis

The Quantum Geographic Information System 3.24.0 was used for map extraction and location of provinces where data were collected. Species and survey data were summarized using Excel.

2.4 Type of agroforestry systems in Rwanda

According to Mukuralinda et al. (2016) and Noeldeke (2022), there are several types of agroforestry systems used in Rwanda. As shown in Figure 3, common configurations include:

1. Silvopastoral systems which consist of a combination of trees or shrubs with forage and livestock, it is mostly done in the Western and Eastern provinces of Rwanda.

2. Silvoarable systems which are widely spaced woody vegetation intercropped with annual or perennial crops, also known as alley cropping systems, this system is more adopted in almost every province of Rwanda.
3. Forest farming systems which are forested areas used for harvesting crops for medicinal, ornamental, or culinary uses.
4. Home gardens that combine trees or shrubs with vegetable production in urban areas like Kigali, Muhanga, Rubavu, and Nyagatare.

Silvopastoral and silvoarable systems tend to be more frequent in Rwanda. Thus, the current study took into consideration the same.

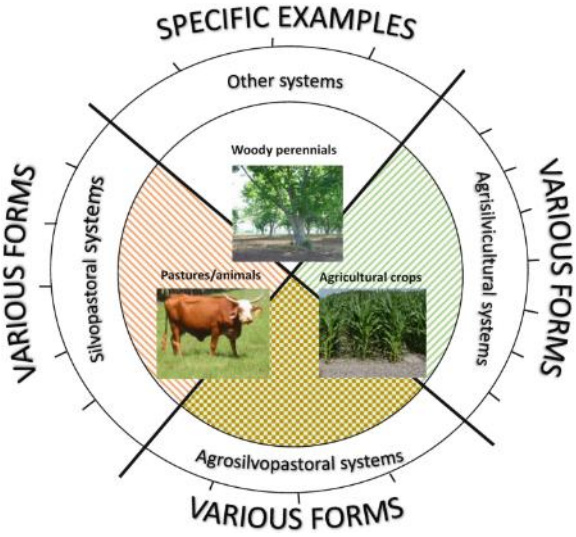

Figure 4. Types of agroforestry systems in Rwanda.

Depending on the agroforestry practice adopted in Rwanda, the arrangement of components, and the types of trees, shrubs, and crops planted, there will be differing interactions that take place thus, each having potentially different outcomes.

3 Results and discussion

The research found that farmers' engagement in agroforestry and its adoption was 95.6% (Figure 5) while all the officials made up to the mark. 73% of the respondents were aged between 25 and 45 years and 27% were above 45 years. The on-farm woody species like *Grevillea robusta*, *Cassia siamea*, *Albizia spp, Acacia albida, Persea americana, and Mangifera indica* were found to be the most tree species integrated with crops in all the provinces of Rwanda. It was evident that most farmers practice agroforestry to enhance biodiversity, soil fertility, and overall sustainability of farming systems by improving agricultural productivity and preventing erosion. Farmers mostly shared nearly the same different techniques such as boundary planting, home gardens, scattered trees on farms, windbreaks, belts, and woodlots for different purposes. The motivation behind agroforestry is therefore multi-fold.

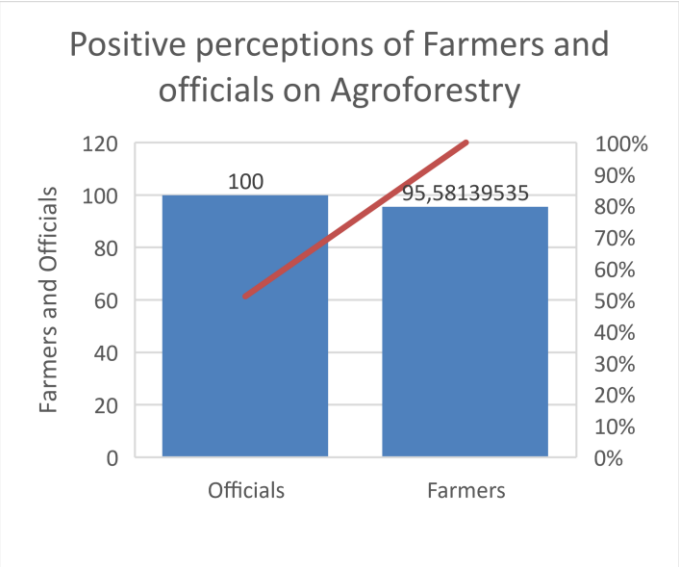

Figure 5. Farmer's and official's positive perceptions of agroforestry.

3.1 Effect of agroforestry on agricultural productivity

In areas practicing agroforestry shows increases the soil fertility and productivity, high organic matter, and nutrient content due to relative reduction in evaporation, coverage of soil, retention of water, and decomposition of woody materials and leaves. Soil presents more microorganisms and becomes dark brown showing the presence of more nutrients in it that influence the rapid development and growth of crops, it has the soil that has the physical, chemical, and biological properties that are necessary to support plant growth.

3.2 Effect of agroforestry on erosion control

Agroforestry is found to increase erodibility (resistance of soil to be eroded). The anchorage of roots of trees into the soil, coverage of soil, and interception of raindrops prevent a direct hit on barren soil, soil aggregation, and binding, this leads to control of any type of erosion whether wind and water erosion on percentage between 12-60% under influence of other factors like duration of raining and intensity, physiography, and climate.

Table 1. Perceptions of farmers and officials on the effectiveness of agroforestry on agricultural productivity increase and erosion control.

Treatment	Farmers		Officials	
	Agricultural productivity	Erosion control	Agricultural productivity	Erosion control
Eastern Province	94	89	10	8
Kigali	26	12	9	9
Western Province	100	76	10	9
Northern Province	98	65	10	8
Southern Province	93	83	10	9

4 Conclusions and recommendations

4.1 Conclusion

The greater spread of agroforestry could help farmers in numerous ways to sustain and boost crop yields and to increase and diversify their incomes. The research shows an overvelming perception of farmers and officials that the integration of trees within crops can improve agricultural productivity, and forage quality, enhance animal welfare, foster soil erosion prevention and nutrient cycling, and diversify income generation. Hence, by adopting agroforestry, farmers can create harmonious and resilient ecosystems that benefit both their farming system and the environment. If they embark on this journey, farmers can contribute to the transformation of the agricultural landscape towards a more sustainable future.

4.2 Recommendations

Farmers are recommended to grow agroforestry tree species along with crops on the farm to increase biodiversity, and production and to control erosion simultaneously. In addition, officials are recommended to increase the awareness of agroforestry and its effectiveness to encourage farmers to adopt the same.

5 Acknowledgments

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6 Conflicts of interest

The authors declare that they have no conflict of interest.

7 Data availability

The authors confirm that all data generated or analysed during this study are included in this research paper. Raw data is available on request from authors.

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