World Agroforestry Centre

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# TAKING TO SCALE TREE-BASED SYSTEMS IN RWANDA

## To Enhance Food Security, Restore Degraded Land, Improve Resilience To Climate Change and Sequester Carbon

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## To Enhance Food Security, Restore Degraded Land, Improve Resilience To Climate Change and Sequester Carbon

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# ACRONYMS

| | |
|---|---|
| AF | agroforestry |
| FFS | Farmer Field School |
| HH | household |
| ICRAF | World Agroforestry Centre |
| IP | innovation platform |
| MINAGRI | Ministry of Agriculture and Animal Resources |
| MINALOC | Ministry of Local Government |
| MINIRENA | Ministry of Natural Resources |
| NGO | nongovernmental organization |
| RAB | Rwanda Agriculture Board |
| REMA | Rwanda Environment Management Authority |
| RNRA | Rwanda Natural Resources Authority |
| RWF | Rwandan Francs |
| SWOT | strengths, weaknesses, opportunities, and threats |
| TBEA | tree-based ecosystem approach |
| TBS | tree-based systems |
| TOF | trees on farm |

# CONTENTS



This summary report is based on a longer study in 2015 entitled "Taking to scale tree-based systems that enhance food security, improve resilience to climate change, and sequester carbon in Rwanda," conducted by the World Agroforestry Centre and supported by the World Bank Program on Forests, BNP Paribas, and TerrAfrica.

# EXECUTIVE SUMMARY

The purpose of this study was to improve understanding of the key factors that drive the adoption of tree-based systems (TBS) at scale in Rwanda in order to increase the effectiveness of agroforestry interventions designed to help poor rural farmers enhance their food, income, and energy security. The study assessed differences between and within six land use systems across Rwanda, with a mix of survey, mapping, and focus group methodologies. It also proposed an improved pathway for increased adoption at scale of tree-based systems. Some key findings were as follows.

- There is widespread adoption of agroforestry systems in Rwanda, but the intensity of adoption varies greatly.
- There are pronounced differences across the six land use systems in the types of agroforestry systems adopted, and there is considerable variation within each land use system in the degree of adoption.
- Agroforestry adoption was highest where the population is the densest and farm sizes are the smallest. These areas have intensive farm systems that integrate agriculture, livestock, and wood production.
- Essentially all agricultural land in the country is suitable for some kind of agroforestry.
- Eucalyptus is by far the most common tree planted in Rwanda.
- Timber trees, Eucalyptus, and Alnus were the most common species among species integrated within farms (as opposed to woodlots).
- Multipurpose agroforestry species (Grevillea and Calliandra) and fruit trees are found in lower numbers and have quite significant potential for scaling-up.
- Trees are adopted as part of integrated systems along with crop production.
- There is great potential for intercropping fertilizer and fodder shrubs in crop fields and on terraces to enhance soil fertility and crop yields.
- There is a complex array of factors influencing the adoption of agroforestry systems and the differences observed among the various systems. Proximity to extension services, the history of past interventions, and the availability of tree seeds and seedlings were found to be important drivers to accelerate the adoption of agroforestry at a much greater scale.
- The selection of locally appropriate systems and local factors such as market access and education are important aspects.
- In Rwanda, success in accelerating the scaling-up of agroforestry will be most readily achieved through obtaining strong government and nongovernmental organization (NGO) support, developing agroforestry value chains, and inducing more-vibrant partnerships between research and development agencies.

The policy and regulatory framework of the Rwandan government should infuse tree-based ecosystem approaches (TBEAs) into the national extension agenda. External partners and donors could then support the agenda more vigorously, as guided by the Ministry of Natural Resources in collaboration with the Ministry and Agriculture and Animal Resources and the Ministry of Local Government. External expertise could be harnessed more effectively to provide strategic technical backstopping.

The current extension approaches used for food crops—such as mass dissemination, Farmer Field Schools, and innovation platforms—should now be deployed to create a robust TBEA scaling-up pathway. The Rwanda Natural Resources Authority , which includes the directorate of forestry extension, could chair the forum of partners implementing TBEAs, in collaboration with the Rwanda Agriculture Board and the directorate of agricultural extension at zone level. The national budget can be channeled to accelerate the scale of the agroforestry roll-out through earmarked transfers and the Rwanda Agriculture Board extension services. This would help coordinate the current scattered efforts in TBEA extension undertaken by individual NGOs and projects.


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# INTRODUCTION

Trees are widespread on croplands throughout the world and in Rwanda. Over 43 percent of all agricultural land globally now has greater than 10 percent tree cover. This represents over 2 billion hectares of land and engages more than 900 million people. However, there is great variation in tree cover on agricultural land. During the first decade of this century there has been a major increase in tree cover on agricultural lands in many parts of the tropics, including in Rwanda.

Agriculture accounts for more than one-third of the gross domestic product in Rwanda. It also accounts for 80 percent of total employment and it meets 90 percent of national food needs. The majority of farmers derive their livelihoods from subsistence agriculture on farms smaller than the national average of 0.76 hectares. There is an increasing population and severe pressure on natural resources for food production and energy supply. Farm production and incomes need to be increased with improved agricultural practices. In addition, the country's policy makers are strongly committed to restoring degraded land, promoting sustainable land management, increasing resilience to climate change, and generating ecosystem benefits.

Agroforestry (AF) is defined as the integration of trees in agricultural landscapes. Tree-based systems (TBS) in agricultural lands are widespread in Rwanda. It is important to understand this phenomenon better and to foster an acceleration in tree-based system adoption because of the numerous social, environmental, and economic benefits that would be captured. Most of Rwanda's poor families live in rural areas. The greater spread of tree-based systems could help them in numerous ways to sustain and boost crop yields and to increase and diversify their incomes.

This report summarizes the results of an assessment conducted by the World Agroforestry Centre and supported by the World Bank Program on Forests, BNP Paribas, and TerrAfrica. Researchers studied the adoption of TBS at scale across Rwandan agricultural landscapes. The purpose of the study was to increase the effectiveness of AF interventions designed to help poor rural farmers in Rwanda enhance their food, income, and energy security. The study sought to improve our understanding of the key factors that drive this trend through survey, spatial, and focus group methodologies and to make recommendations based on the findings in order to accelerate the scaling-up process.

An improved pathway for increased adoption at scale of tree-based systems was recommended, based on the analysis of the results of the study. The major research activities included:

- Development of a conceptual framework to guide the research
- Mapping the biophysical and farming characteristics of each of the six major land use systems (and within each system, two sample cells within a single district)
- Spatial analysis to determine current TBS adoption, as well as to identify and map potential areas for agroforestry expansion where scaling-up efforts could best be focused
- Implementation of socioeconomic household surveys
- Synthesis of the views and opinions of stakeholders (farmers, extensionists, policy makers, researchers) through group discussions on drivers, barriers, and enabling conditions for TBS adoption at scale; a two-day workshop included a review of existing extension approaches and recommended actions to enable the design of the best pathways for increased adoption and scaling-up of TBS
- Analysis of existing extension approaches and the recommendation of an integrated approach to enhance the adoption of tree-based systems at a greater scale across the country

# COUNTRY INTRODUCTION

Rwanda is endowed with a great diversity of topography, soils, biodiversity, and ecological regions. It is a hilly country with altitudes of less than 1500 meters in the eastern plateau, rising to between 1500 and 2000 meters in the central plateau area and to above 2000 meters in the west and north. The country has a tropical climate with an average annual temperature of 180 Celsius. Average annual rainfall over the whole of Rwanda is 1111 millimeters, with a variation from 700 millimeters/year in the east to 1600 millimeters/year in the southwest.

The population predominantly depends on agriculture for its sustenance. Almost 75 percent of rural land in Rwanda is currently used for growing crops and for livestock husbandry, while another 21 percent is forested. The area under agricultural production has been increasing over time at the expense of pastures, natural forests, and fallows. Rwanda's environment is currently suffering from various forms of land degradation, soil erosion and declining soil fertility, deforestation, loss of biodiversity, and pollution. This is mainly due to agricultural expansion, unsustainable land management, intensive livestock farming, and unsustainable fuel wood extraction.

Agroforestry has been practiced in Rwanda for hundreds of years. Since the 1970s it has been promoted among smallholder farmers by research, government projects, externally funded projects, and nongovernmental organizations (NGOs). Recently, Rwanda's Vision 2020 has proclaimed the goal of expanding AF practices to over 80 percent of agricultural land. Currently, however, there is still a wide variation in the level of adoption of particular TBS at landscape scale from one site to another, despite the determined efforts of government, NGOs, and donors to promote the scaling-up of AF practices.

The different forms of AF found in Rwanda currently include:

- Farm woodlots—individual tree blocks for wood production, often involving multipurpose wood production such as fuelwood, timber, charcoal, and poles; they are most common on steep slopes and on plots with low soil fertility
- Contour hedgerows—trees planted in rows along contour lines, on contour ditches for erosion control, and on cropped bench terraces, proving stabilization and other products and services; they are also important for production of stakes to support high-value crops, such as climbing beans
- Scattered trees in crop fields—as interplanted or naturally regenerated trees or in alleyways on cropland and in pastures; they include high-value timber, medicinal, cultural, and fruit species, with many of the trees being indigenous
- Home gardens—where trees are mixed with understory crops or pasture for livestock around the home, producing various products and services
- Boundary-planted trees—trees planted or naturally regenerated on field and farm boundaries, along pathways and roadsides

Key practices include farmer-managed natural regeneration, conservation agriculture with trees (for soil fertility regeneration and soil stabilization), and trees in managed or unmanaged fallows.

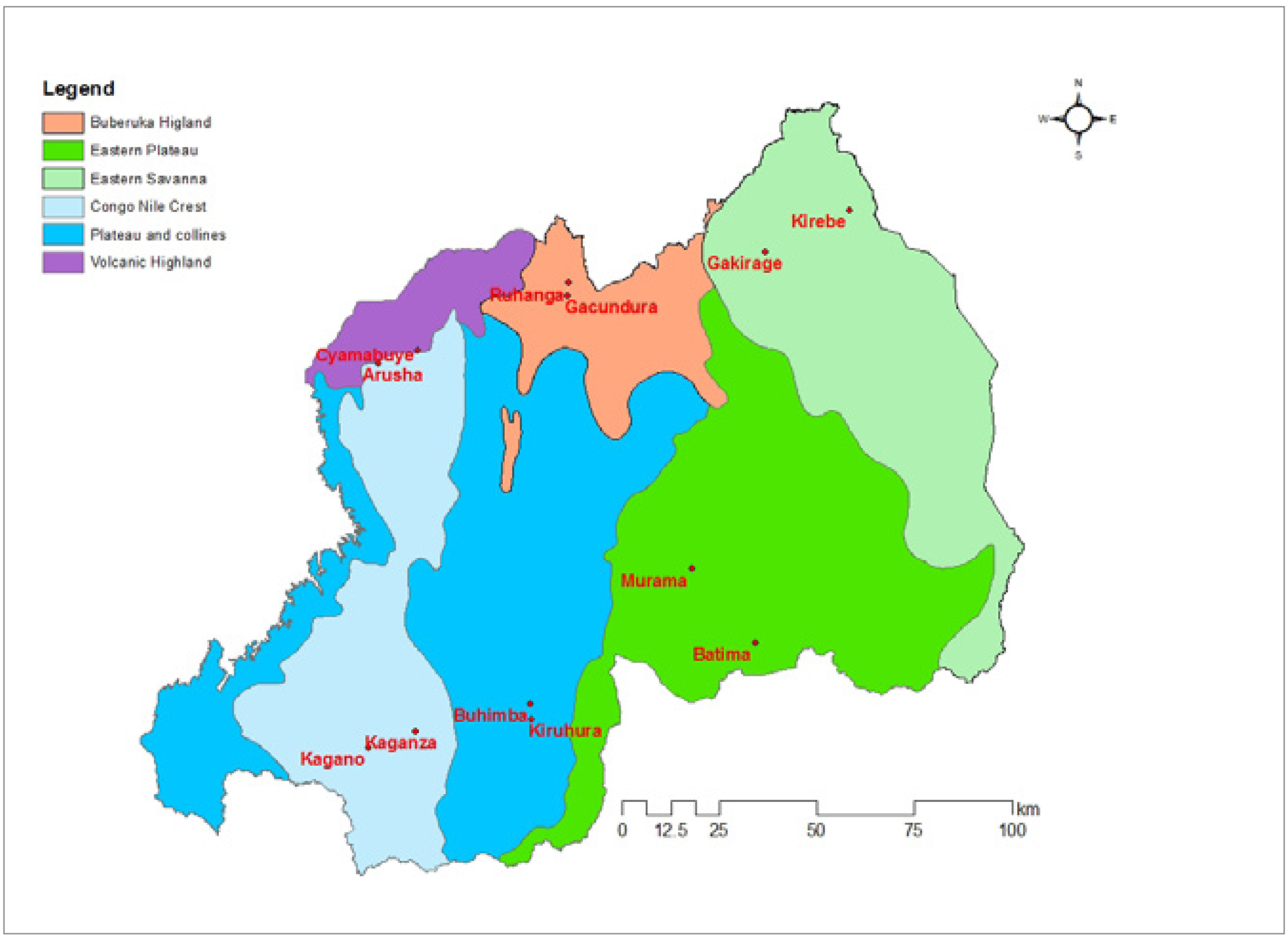
One important characteristic of the traditional AF systems is the retention and management of indigenous tree species such as *Markhamia spp., Ficus spp., Vernonia amygdalina,* and *Erythrina abyssinica* on farmlands, which provide medicine, fertility, clothing, fodder, wood, and other benefits. At present, the Rwandan AF systems are also dominated by a wide range of exotic tree and shrub species that are suitable for a range of diverse land use systems. About 150 tree and shrub species are cultured in the different AF systems of Rwanda. They produce a wide variety of products and ecosystem services.

# DESCRIPTION OF THE SITES

Figure 1 shows the land use systems of Rwanda and the locations of the sites of this study. Table 1 provides a description of each of the sites. Within each land use system, two cells with contrasting tree-crop-livestock systems were selected for the study.

The aim was to select cells with contrasting levels of TBS within each land use system; cell 1 of each pair was selected to represent a relatively high-adoption site and cell 2 to represent a relatively low-adoption site. The exercise for cell selection was pursued through local community consultations via preliminary focus group discussions at district level with local authorities, extensionists, farmer representatives, and NGOs, and the choices were validated by the research team during the field visits in late November 2014.

**Figure 1: Six Land Use Systems and Study Cells in Rwanda Selected for Analysis (the two study cells are identified within each land use system)**



## Table 1: Information on the Regions and Cells in the Study and Survey Sample Sizes

| Region | Description of Region | Cell | Description of cell and household survey participants | History |
|---|---|---|---|---|
| *A. Eastern Savanna, Nyagat. District (lower elevation zone)* | Composed of rangelands, agricultural land (dominated by crops)<br><br>Banana, cassava, maize, bush bean, and rice<br><br>Cattle (free grazing)<br><br>Altitude: 1200-1400 masl<br><br>Rainfall (mm) per year: 800-1000 | *1. Kirebe Cell, Gatebe Sector* | Sparsely populated due to tse tse fly presence<br><br>Individual grazing land demarcated/ enclosed with ***Euphorbia*** fence, seemingly well-protected naturally regenerated ***Acacia sieberanna***, and other species, while crop fields have few trees<br><br>Household survey sample size: 41, or 4.1 percent of total households in the study | Projects emphasize rehabilitation/ restoration, buffer strips |
| | | *2. Gakirage Cell, Nyag. Sector* | Rice irrigation schemes in the valley bottoms<br><br>Farmers manage individual plots, strong cooperative models<br><br>Has a longer history of settlement, is more highly populated, and has lower tree cover than A1.<br><br>Household survey sample size: 39, or 3.4 percent of total households | Projects emphasize buffer strips, nutrition<br><br>RAB Nyagatare Centre has intervened with AF projects and introduced ***Eucalyptus*** woodlots; some are still ongoing |
| *B. Eastern Plateau, Bugesera District (low elevation zone)* | Higher temperatures<br><br>Smallholder mixed system<br><br>Banana, cassava, maize and bush beans<br><br>Cattle and goats<br><br>Altitude: 1200-1500 masl<br><br>Rainfall (mm) per year: 800-1000 | *1. Murama Cell, Nyamata Sector* | Higher altitude site, and high diversity/adoption of fruit trees<br><br>Household survey sample: 41, or 3.2 percent of total households | ACIAR project site<br><br>A sector nursery is nearby, as is RAB watershed<br><br>Local project promoted soil conservation techniques using AF species and grasses, rehabilitation / restoration, nutrition |
| | | *2. Batima Cell, Rweru Sector* | Borders Burundi via Lake Rweru<br><br>Household survey sample: 35, or 1.7 percent of total households | ACIAR project site.<br><br>Active AF interventions to improve fodder production, soil fertility, rehabilitation/ restoration, nutrition<br><br>Close proximity to research station |
| *C. Buberuka Highland, Burera District (highland zone)* | Land fragmentation<br><br>Wheat, maize, climbing beans, tea, Irish potato<br><br>Cattle (zero grazing), sheep, goats<br><br>Altitude: 1900-2000 masl<br><br>Rainfall (mm) per year: 1200-1300 | *1. Ruhanga Cell, Rusarabuye Sector* | Lower population density<br><br>Moderate and radical terraces, Alnus along contours<br><br>Household survey sample: 25, or 2.4 percent of total households | Recent history of AF interventions to rehabilitate / restore the adjacent Rugezi marshland, control erosion<br><br>Proximity to research station (e.g. ISAR/ RAB, ICRAF, FSRP) and more recent interventions in AF (such as Alnus seedlings, Alnus as green manure) by different development projects and NGOs (e.g. Helpage, PGRB). |
| | | *2. Gacundura Cell, Rwerere. Sector* | Acidic soil; some indigenous trees in the homestead; major trees are *Eucalyptus* woodlots<br><br>Household survey sample: 20, or 1.9 percent of total households | Prior AF project site and farming systems research project site<br><br>Former ICRAF-ISAR project site<br><br>Projects emphasize rehabilitation / restoration, control erosion; Alnus seedlings provided by Helpage, RAB |

| Region | Description of Region | Cell | Description of cell and household survey participants | History |
|---|---|---|---|---|
| *D. Volcanic Highland, Nyabihu District (highland zone)* | Irish potato, wheat climbing beans, maize, pyrethrum<br><br>Cattle (free/zero grazing), sheep, goats<br><br>Altitude: 2200-2400 masl<br><br>Rainfall (mm) per year: 1300-1500 | *1. Cyamabuye Cell, Karago Sector* | Valley bottom covered by tea plantations, moderate and radical terraces<br><br>Household survey sample: 50, or 4.7 percent of total households | Support by government (e.g., REMA and LWH) and NGOs (e.g. CARE International, World Vision); projects emphasize rehabilitation/restoration, erosion control<br><br>ICRAF intervention in 2012 to plant Alnus contour and woodlots on hills facing the valley bottom.<br><br>ACIAR tree nursery site<br><br>Alnus seedlings made available in one intervention |
| | | *2. Arusha Cell, Bigogowe Sector* | Favorable pasture and temperatures<br><br>Recently occupied and has undergone deforestation<br><br>Household survey sample: 45, or 5.8 percent of total households | Interventions have focused on AF practices, erosion control, emphasis on rehabilitation/restoration, buffer<br><br>Alnus was promoted under the restoration / rehabilitation programs; seedlings made available<br><br>PAREF project on forest by MINAGRI now under Ministry of Natural Resources<br><br>Rehabilitation plans by RAB/UNICEF on Eucalyptus woodlots, Alnus on terraced crop plots |
| *E. Central Plateau, Huye District (lowland zone)* | Undulating hills<br><br>Cassava, banana, coffee, bush beans, rice<br><br>Cattle, goats (zero grazing), pigs<br><br>Altitude: 1100-1700 masl<br><br>Rainfall (mm) per year: 1000-1500 | *1. Kiruhura Cell, Rusatira Sector* | Predominance of grouped settlements, with many farmers having plots away from the settlements<br><br>Household survey sample: 67, or 5.1 percent of total households | Benefits from tree and fruit seedlings from ISAR (station)<br><br>Proximity to research institution (RAB) |
| | | *2. Buhimba Cell, Rusatira Sector* | Cases of progressive/bench terraces<br><br>Trenches planted with napier grass<br><br>Easy access to milk markets<br><br>Household survey sample: 34, or 3.3 percent of total households | Like E1, was covered by the first and oldest AF project, the GTZ-financed "Projet Agropastoral de Nyabisindu" |
| *F. Congo-Nile Crest, Nyamag. District (highland zone)* | Major natural forests, forest plantations<br><br>Tea, coffee, Irish potato, wheat<br><br>Cattle (free/zero grazing), sheep, goats, pigs<br><br>Altitude: 1800-3000 masl<br><br>Rainfall (mm) per year: 1200-1600 | *1.Kaganza Cell, Tare Sector* | Presence of some toxity in soil<br><br>Household survey sample: 28, or 4.2 percent of total households | Close to well-maintained RAB experimental plot intervention from 1998 on Alnus, Calliandra, Leucaena, Polyscias<br><br>Promotion of woodlots, afforestation/ reforestation, erosion control, buffer (in F1 and F2) |
| | | *2.Kagano Cell, Kirebe Sector* | Cold temperatures and acidic soils; phosphorus deficiency affecting maize; tea on contract model<br><br>Few trees planted on farms except *Eucalyptus* woodlots<br><br>Household survey sample: 39, or 3.5 percent of total households | There have been agricultural projects, but these have been less focused on AF |

# TREE-BASED SYSTEMS IN THE STUDY SITES

Table 2 summarizes the findings on adoption of TBS across the study regions based on spatial and household survey analysis.

### Table 2: Summary of Adoption of TBS across the Study Sites

| Area | Spatial analysis and Household surveys | AF systems by niches |
|---|---|---|
| Highland systems (Buberuka, Volcanic, Congo-Nile Crest) | Higher adoption rates of AF systems in general, especially woodlots and hedgerows, than lowland zones. Proportion of areas (under woodlots and trees on farm (TOF)) occupied by AF as well as densities of TOF is relatively important in the higher altitude land use systems and the Central Plateau. High Eucalyptus adoption.<br><br>Econometric analysis finds that households in D1, F1, F2, and C2 (highlands) were more likely to adopt woodlots. Although this may be true in the percent of households (HHs) adopting, the total area of woodlots is somewhat modest. | |
| Lowland systems (Eastern Savanna, Eastern Plateau, Central Plateau) | Adoption of Grevillea, Senna, and fruits. Moderate Eucalyptus adoption. Mango receives promotion here.<br>In the regressions with lowland system data only, the location of households in the different sites of the lowland region did not affect significantly the propensity to have woodlots. No location dummy variables were significant in explaining the adoption of hedgerow AF system, but the coefficients of the parameters turned out to be positive except for the E2 dummy. | |
| Eastern Savanna | The mapping exercise indicates that the greenspot for AF includes the Eastern Savanna. Grevillea, Avocado, Senna, and Eucalyptus were planted by many households mainly to serve as construction materials (timber, poles) and woodfuel. Relatively lower diversity of tree species on average. The average number of tree species types planted by individual households was 1.5 in Kirebe (A1) and 1.8 in Gakirage (A2). The average number of trees per household was 15.9 in A1 and 50.6 in A2. | Major AF systems were boundary planted trees of Grevillea and Eucalyptus, and scattered trees of Senna in both sites, while Senna was found more in homesteads in A1 and hedgerows in A2. |
| Eastern Plateau | Second highest adoption of diverse tree species. Avocado, mango, Grevillea, Senna, Eucalyptus common. Tree species diversity and density are comparatively higher than in Eastern Savanna despite being in the same agroecological zone. Higher tree density, TOF, and total tree cover in Batima (B2) compared to Murama (B1). | Higher adoption of scattered trees, which include intercrops, trees on contours. In the regressions for the lowlands, the positive and significant location dummy that enhances the adoption of scattered trees was the location of the households in B1. |
| Buberuka Highland | The mapping exercise indicates that the greenspot for AF includes Buberuka. Higher adoption of more diverse tree species, including a wide range of indigenous tree species. Alnus, Eucalyptus, Avocado, Erythrina, and *Acacia **angustissima*** were planted by many households. *A. angustissima* species are well adopted in C1. In addition to Eucalyptus, the top common tree species were more often planted by households in Ruhanga (C1). Relatively high tree species diversity and high number of trees per farm and per ha of farm were both found in the contrasting sites of C1 and C2. | Climbing beans. which were highly adopted in Buberuka was highly associated with bean stakes, fence/tools, Eucalyptus, woodlots, and home compound. Trees scattered on the farms, woodlots, and contour hedgerows found in many households. The majority of households in Buberuka Highland (70 percent+) had home gardens. The higher densities of trees in this land use system arose from hedgerows for soil erosion control, firewood, and fodder supply, mainly Alnus. |
| Volcanic Highland | High adoption site, but only of a few exotic tree species (Alnus, Eucalyptus). Fewer tree species were found compared with the Buberuka highland, but mostly at lower adoption rates. Relatively lower diversity of tree species on average. AF in Cyamabuye (D1) has been established over many years. | The relative abundance of trees in D1 is associated with the presence of woodlots, scattered TOF planted on contour hedges and home gardens, and hedgerows of Alnus for soil conservation. In regressions for the Highlands, the location of households in D2 Arusha was positively and significantly related to adoption of hedgerows. |
| Central Plateau | The proportion of households having trees on farms, and a diversity of tree species, was higher in Kiruhura (E1) site than in Buhimba (E2). Many fruit tree species were present in both sites. There were differences in the adoption rates of tree and fruit species between E1 and E2. | Eucalyptus woodlots, trees scattered on farms, planted on contours, and home gardens. About 90 percent of the reported trees on farms were present in woodlots. However, in E1, there were few woodlots in the area; boundary planting of grass and AF species. |
| Congo-Nile Crest | Keeping fruit species such as Avocado trees in and around the home compounds was a common practice in Congo-Nile Crest. In addition, many households in Kagano (F2) planted Avocado trees on farm boundaries and planted few trees on the farm, except Eucalyptus woodlots on steep slopes. | Eucalyptus woodlots, trees scattered on farm, Avocado home gardens, and Alnus on contours, Grevillea, and Ficus. About 90 percent of the reported trees on farms were present in woodlots. A smaller proportion was also adopted on contour hedgerows. |

**Table 3: Rate and Number of Households Adopting in Each Location, with Tree Species and Densities**

| Study cells | No. of HHs in survey adopting | Area under natural forest (%) | Area under planted woodlots(%) | Trees outside forest (%) | Total tree cover (%) | Total tree cover excluding natural forests (%) | Total number of trees recorded | Trees density on farm (no. trees per ha) |
|---|---|---|---|---|---|---|---|---|
| A1.Kirebe | *30 (73.2%)* | - | - | 10.0 | 10.0 | 10.0 | 506,419 | 39.3 |
| A2.Gakirage | *24 (61.5%)* | - | 0.7 | 1.3 | 2.0 | 2.0 | 7,847 | 4.9 |
| B1.Murama | *40 (97.6%)* | - | 2.9 | 1.1 | 4.0 | 4.0 | 6,563 | 3.1 |
| B2.Batima | *29 (82.9%)* | 0.4 | 4.7 | 2.9 | 8.0 | 7.6 | 28,764 | 13.7 |
| C1.Ruhanga | *23 (92%)* | - | 4.8 | 21.0 | 25.8 | 25.8 | 103,894 | 88.1 |
| C2.Gacundura | *20 (100%)* | - | 2.1 | 5.0 | 7.1 | 7.1 | 17,433 | 20.0 |
| D1.Cyamabuye | *48 (96%)* | - | 12.3 | 13.0 | 25.3 | 25.3 | 22,243 | 33.3 |
| D2.Arusha | *39 (86.7%)* | - | 8.0 | 8.0 | 16.0 | 16.0 | 684 | 0.6 |
| E1.Kiruhura | *60 (89.6%)* | 1.9 | 31.5 | 4.0 | 37.4 | 35.5 | 22,536 | 23.9 |
| E2.Buhimba | *27 (79.4%)* | - | 13.9 | 1.0 | 14.9 | 14.9 | 12,045 | 17.1 |
| F1.Kaganza | *24 (85.7%)* | - | 30.8 | 11.0 | 41.8 | 41.8 | 21,252 | 64.4 |
| F2.Kagano | *37 (94.9%)* | 64.5 | 17.6 | 0.0 | 82.1 | 17.6 | 9,069 | 9.5 |
| Across sites | | 5.6 | 10.8 | 6.5 | 22.9 | 17.3 | | 26.5 |

There is similarity in the characteristics of the AF systems across the sites. However, the highland zones (Bubereka, Volcanic, Congo-Nile Crest) have a higher coverage as well as densities of TOF, or trees scattered on farmlands in linear arrangements, and they have higher adoption rates of AF systems in general than the lowland zones (Eastern Savanna, Eastern Plateau, Central Plateau). The key tree species (Eucalyptus, Alnus) characterizing these AF systems were similar within the highland and lowland regions, though there were some other species more popular in each region. Tree species such as Avocado, Eucalyptus, Alnus, and Calliandra presented interesting trends between relatively higher adoption sites and lower adoption sites.

Given the absence of objective quantitative measures to assess the adoption of TBS at scale prior to this study, the cell/site selection exercise to determine where TBS have been implemented successfully at scale (Cell 1 versus Cell 2) had to rely on subjective opinions of local project partners. Nevertheless, the spatial analyses more or less confirmed that, in all the land use systems except Eastern Plateau, Cell 1 in each region had a higher number of trees on farm, total on-farm tree cover (excluding natural forests), and tree density on farmlands than Cell 2. A breakout of these details and differences is provided in this section. In many of the variables, there seem to be no visual pattern between each of the regions, or even within either the highlands or lowlands.

Table 3 provides information on the adoption rate, average tree species types, average and total number of tree in the stands, tree densities on farm, average land size, and percent of area under trees on farm and planted woodlots. Generally, there is a large difference in tree densities between cells; these densities have a moderate to strong correlation with the average number of tree stands per household. The number of tree stands is not insubstantial, but there also seems to be a wide variation across all of the sites.

**Figure 2: Percentage Coverage of Natural Forest, Woodlots, and Trees on Farm across the Study Sites and Nationally**

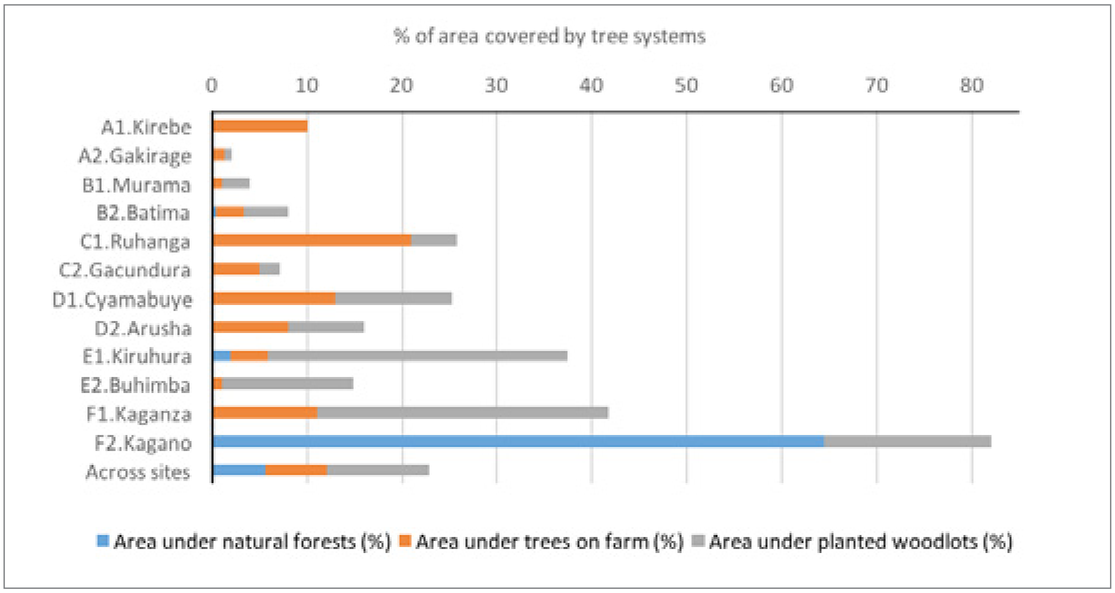



**Figure 3: Number of Trees within Each System, Across Sites**

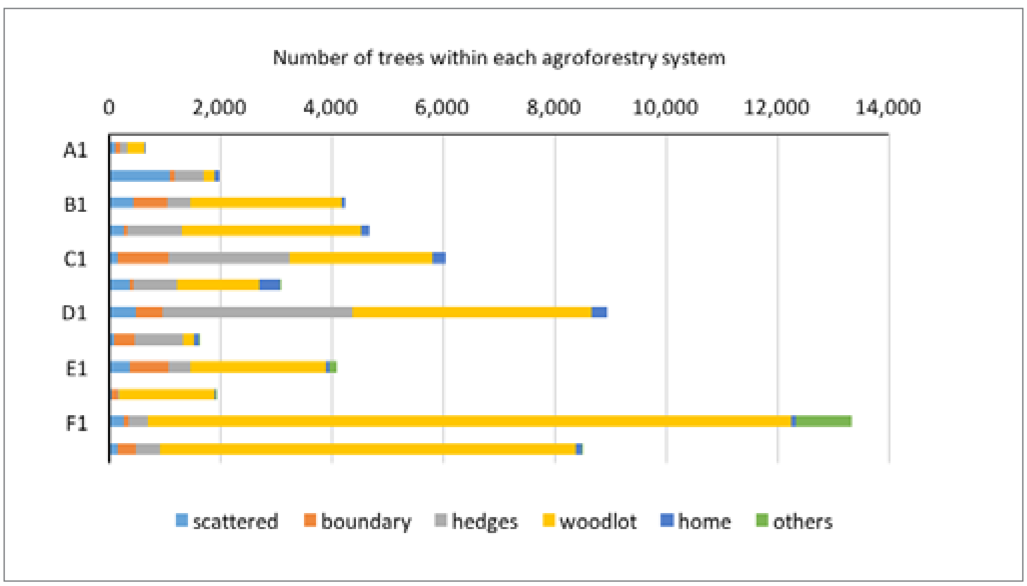



Figure 2 compares the areas under natural forests, trees on farm, and planted woodlots across the sites. Together, these percentages add up to the total tree cover, which ranges from 2 percent in Gakirage (A2) to 82.1 percent in Kagano (F2). The proportion of the area occupied by woodlots and trees on farm through AF of the 12 cells was 6.5 percent of land cover. This proportion ranged from 0 percent (F2) to 21 percent (C1 Ruhanga) among sites. Overall, the coverage of national forests was low, with the exception of Kagano site (F2).

The spatial analyses confirmed that in all of the land use systems there was a higher figure for the number of TOF and for total tree cover in cell 1 than in cell 2 (excluding natural forest cover). The one exception was in the Eastern Plateau (B), where they were similar. There was also variation for the area of trees on the farms among land use systems. However, the area under planted woodlots was different across the sites.

Figure 3 shows the number of trees within each system. D1 and F1 had the highest overall adoption in terms of numbers of trees; in F1, this is driven especially by the numbers of trees in woodlots.

Figure 4 provides information on the percentage of adopting households in each site who have adopted each agroforestry system. Table 4 provides information on the average number of tree stands across agroforestry ) systems. Figure 4 and Table 4 demonstrate that there is diversity in the systems across sites, as well as in the popularity of particular systems. There is considerable variation in the adoption pattern between sites within the same land use system as well as between land use systems, suggesting that the adoption of agroforestry is determined not just by the general agroecological setting but by other factors. Overall, the percentage of households adopting home gardens was the highest among all practices, with scattered trees being the second well-adopted practice.

Contour hedgerows to protect soils from erosion were dominant in Buberuka (C) and in the Volcanic Highland (D), where they have been adopted by over 40 percent of the surveyed farmers. This was followed by the Congo-Nile Crest (F) where adoption was 21–33 percent. Scattered trees, which include trees intercropped with annual crops, were more found most commonly on farms in the Eastern Plateau (E) (40–80 percent), the Buberuka Highland (C) (44–65 percent), the Central Plateau (E) (35–41 percent), and the Congo-Nile Crest (F) (29–41 percent). They were much less common on farms in the Volcanic Highlands (D) (11–22 percent).

More than 70 percent of the households in the Buberuka Highland had adopted home gardens, while the adoption rate varied significantly across the other land use systems, as well as within a system. The adoption of boundary planting was relatively most commonly adopted in the Buberuka Highland and the Central Plateau, but in general its adoption showed little clear geographical pattern. Also, the rate of adoption was not strongly correlated with the number of trees in any particular system.

Woodlots were mainly found in the Congo-Nile Crest, Buberuka Highlands, and Volcanic Highlands, where they were adopted by 28–54 percent of the surveyed households, except in D2 Arusha, which had only 4 percent adoption, comparable to the low adoption rates observed in the Eastern Savanna.

Some discrepancies may be observed in the data in Figure 2 compared with Figures 3 and 4. For example, Kiruhura (E1) has a high area under woodlots, but only 20 percent of the households reported adopting woodlots. Issues like this partially stem from the fact that the data for the latter were taken from survey responses, while the former drew upon data from the spatial analysis. Another explanation is that there may be situations where only few farmers have a lot of land that is devoted to a certain practice, or many farmers have adopted only a small area of an AF system; this will be explored below.

## Table 4: Mean Number of Trees per Household for Different AF Systems in Each Location

| Site Name | Avg. no. trees scattered across the farm per HH | Total no. of trees scattered across farms | Avg. no. trees on boundary per HH | Total no. trees on boundary | Avg. no. hedge-rows per HH | Total no. of hedge-rows | Avg. no. of trees in wood-lots per HH | Total no. of trees in wood-lots | Avg. no. trees on the home-stead per HH | Total no. trees on home-steads | Avg. no. trees (other) per HH | Total no. trees (other) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A1.Kirebe | 11.2 | 112 | 6.9 | 83 | 41.0 | 123 | 151.0 | 302 | 2.9 | 32 | | |
| A2.Gakirage | 107.9 | 1079 | 8.2 | 90 | 104.4 | 522 | 101.0 | 202 | 6.2 | 80 | | |
| B1.Murama | 13.5 | 444 | 31.6 | 601 | 34.5 | 415 | 247.3 | 2720 | 4.6 | 51 | 0.0 | 0 |
| B2.Batima | 18.9 | 264 | 7.8 | 70 | 89.0 | 979 | 1067.3 | 3202 | 7.7 | 170 | 0.0 | 0 |
| C1.Ruhanga | 14.4 | 158 | 64.1 | 897 | 137.0 | 2192 | 365.7 | 2560 | 12.8 | 230 | | |
| C2.Gacundura | 27.7 | 360 | 11.1 | 78 | 98.4 | 787 | 210.0 | 1470 | 27.2 | 381 | 7.5 | 15 |
| D1.Cyamabuye | 42.7 | 470 | 35.0 | 490 | 162.4 | 3410 | 214.8 | 4295 | 12.8 | 281 | | |
| D2.Arusha | 17.0 | 85 | 29.1 | 378 | 41.4 | 869 | 90.0 | 180 | 8.0 | 88 | 3.5 | 7 |
| E1.Kiruhura | 13.6 | 366 | 19.2 | 690 | 57.9 | 405 | 201.8 | 2422 | 4.0 | 64 | 26.8 | 134 |
| E2.Buhimba | 2.8 | 34 | 9.1 | 127 | 14.0 | 14 | 427.5 | 1710 | 2.7 | 19 | 1.5 | 3 |
| F1.Kaganza | 33.8 | 270 | 21.0 | 84 | 55.5 | 333 | 770.1 | 11552 | 5.8 | 87 | | 1000 |
| F2.Kagano | 10.1 | 161 | 26.8 | 322 | 35.3 | 423 | 439.6 | 7473 | 7.1 | 106 | 4.0 | 4 |

**Figure 4: Percent of Households Adopting Various AF Systems in Each Location**

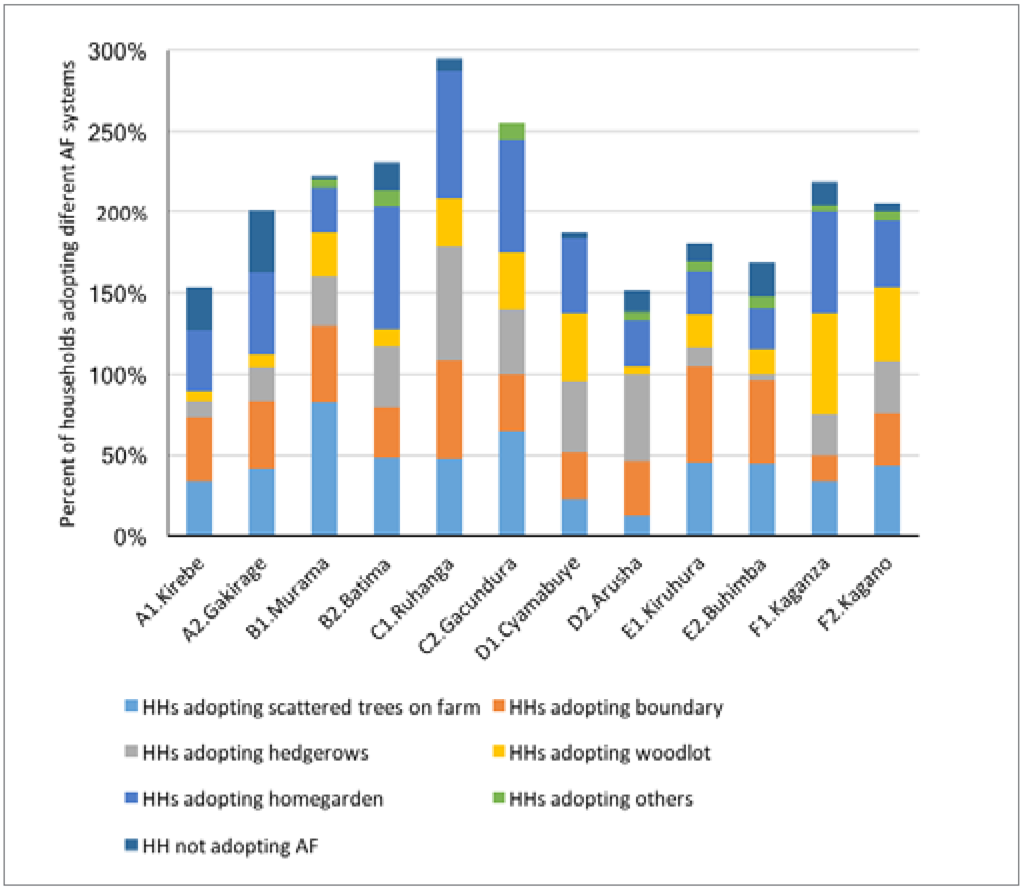



**Figure 5: Comparison of Tree Establishment Methods Used by Adopting Households across the Study Sites**

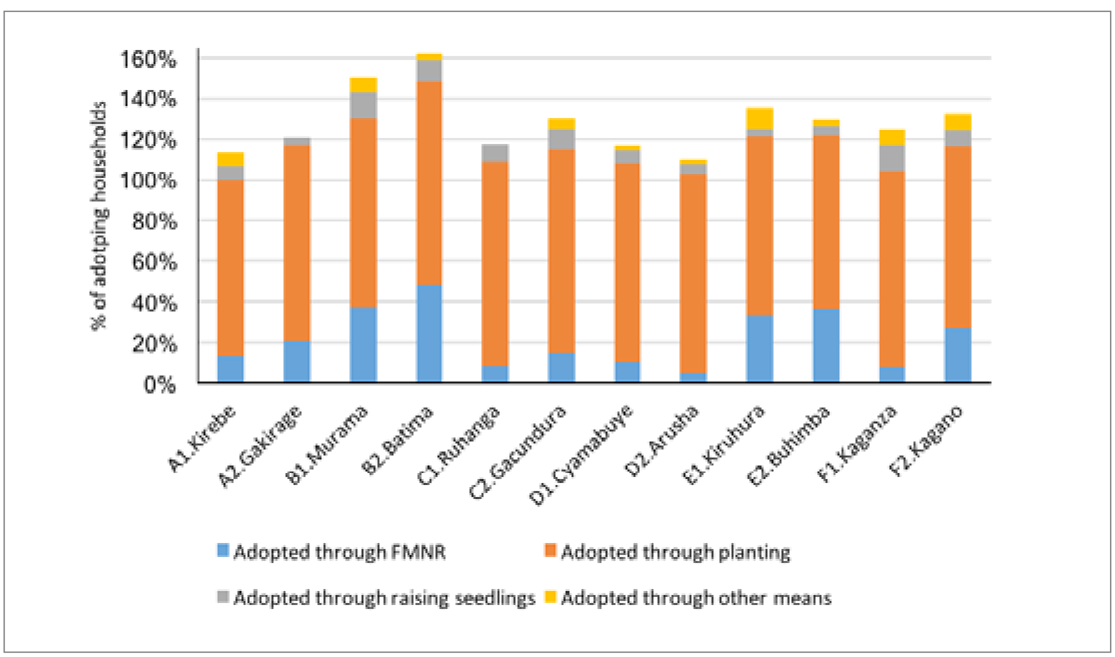


**Figure 6: Relationship between Percent Coverage by Woodlots and Trees on Farm across Study Sites**

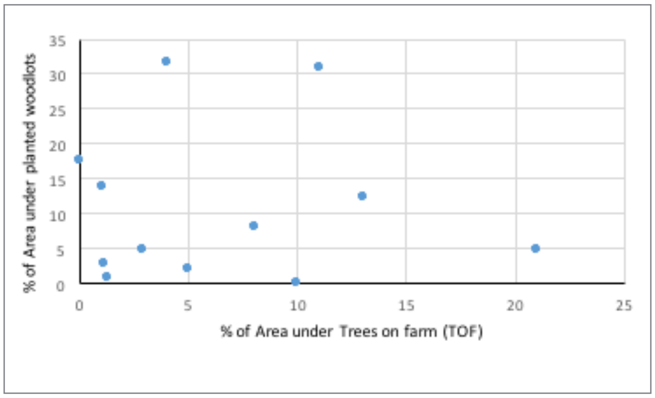



**Figure 7: Relationship between Percent Coverage by Woodlots and Mean Farm Size, excluding Woodlots**

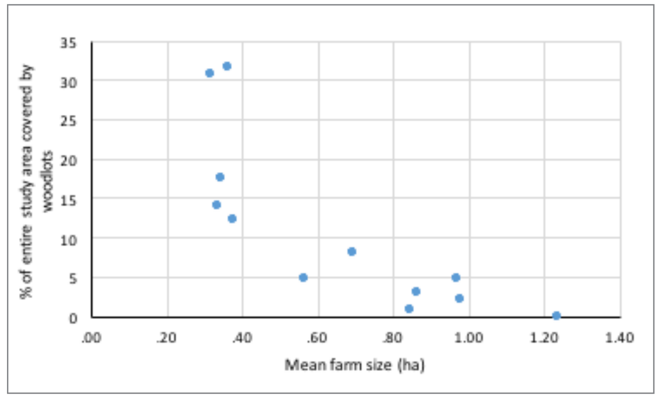
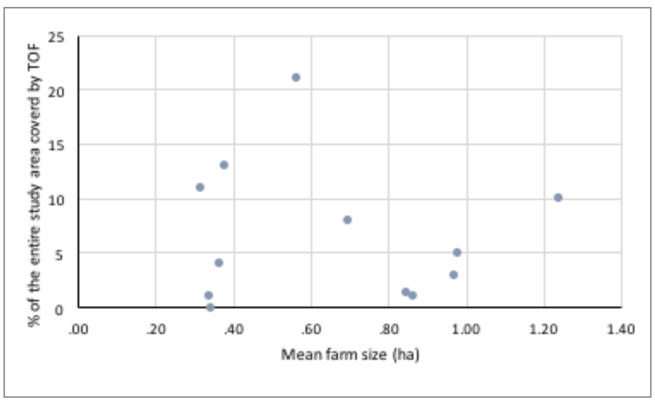



**Figure 8: Relationship between Percent Coverage by Trees on Farm and Mean Farm Size, excluding On-farm Trees**




**Eucalyptus woodlots are among of the most commonly adopted AF systems in Rwanda. About 36–40 percent of farm owners have them on their land. They often provide multiple benefits such as timber, fuelwood, charcoal, and stakes for income and household use.**

Figure 5 compares the tree establishment methods used by adopting households. Survey participants answered whether they established their trees through farmer-managed natural regeneration, planting, raising seedlings, and/or some other means. The majority of households—around 94 percent across the sample—used planting methods. Adopting through planting was moderately and negatively correlated with adoption through "other methods," which implies that it may be a competing methodology.

Figures 6, 7, and 8 show the relationships between the extent of woodlots and TOF across study sites and the relationship of both these variables to average farm size at each site. There was a large variation in the extent of both woodlots and trees on croplands between sites, and no clear relationship between the two. This suggests that there is considerable opportunity to expand both enterprises, as the trees in each may serve different purposes. The extent of woodlots appears to increase with smaller farm sizes when comparing across sites, whereas there is no strong relationship between farm size and the extent of trees on farm. This suggests farm size is not a constraint to adopting woodlots or on-farm agroforestry systems. However, this finding is contradicted by some results at the household level, which suggests that woodlot adoption could be related to other variables that differ across the study sites. Smaller farm sizes are found in the upland sites, which may have a higher prevalence of woodlots because less of the land is suitable for cropping.

There was also no clear relationship between the tree diversity (number of tree species cultivated per household) and the number of trees that were cultivated per hectare. Thus, having more trees did not necessarily mean that there was a greater variety of them.

**Figure 9: Number of Trees in Woodlots Systems, by Species Composition, within and across Sites**

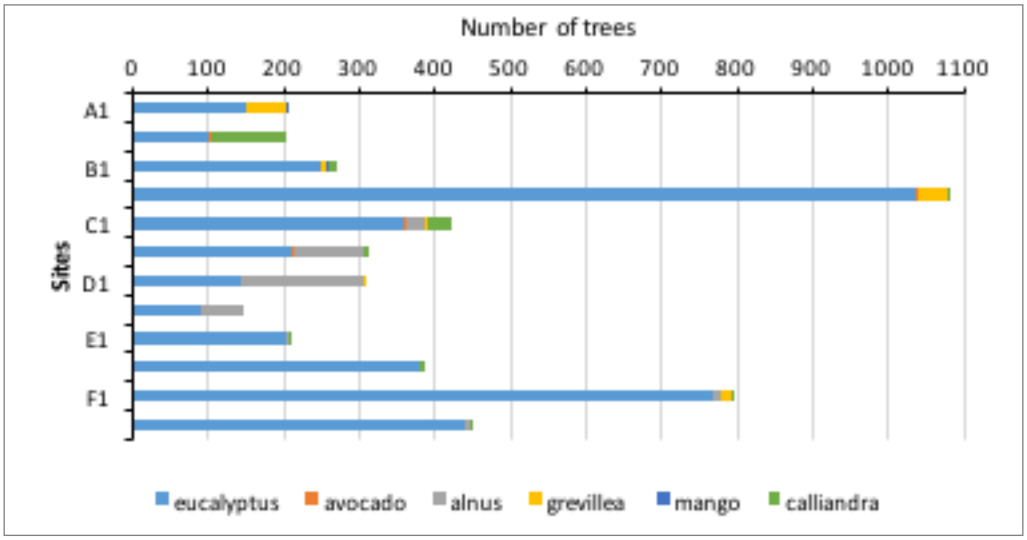
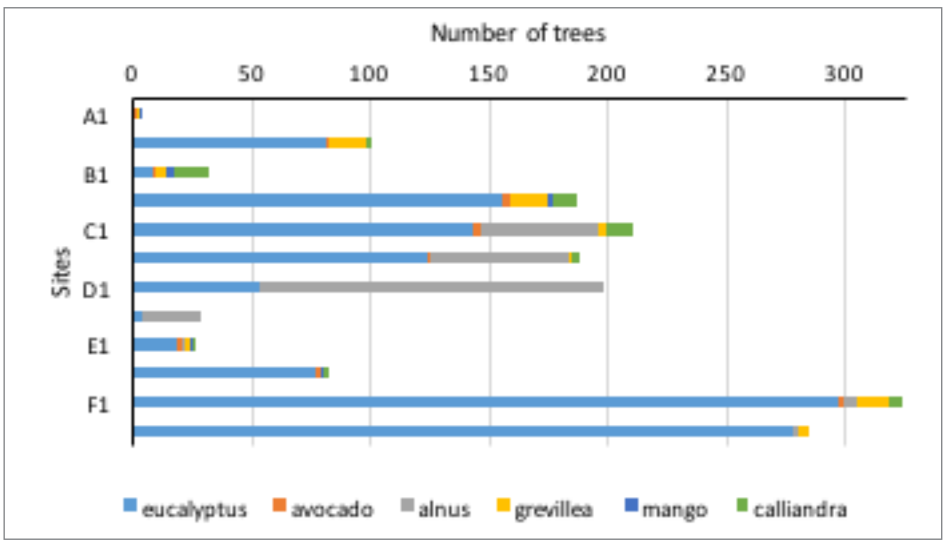



**Figure 10: Number of Trees in Homestead Systems by Species Composition within and across Sites**




The five most commonly adopted tree species in Rwanda were *Eucalyptus spp.*, Avocado, Alnus, Grevillea, and mango. Their spatial adoption rates varied not only among zones but within zones. Eucalyptus is the most dominant species. It is particularly widely adopted in the highland systems, with moderate adoption in the lower elevations of the country. In the Eastern Savanna zone, with a dominance of crop fields in the landscape, Eucalyptus is planted in woodlots, boundary plantings, and homesteads.

Alnus is a multipurpose tree species and is the most well-adopted species at higher elevations. It is found in 80 percent of the surveyed households in Buberuka (zone C). It is not, however, suited to warmer climate zones. Grevillea, fruit trees, and Senna are also common species, especially in the lower elevation zones (and the latter is common in the Eastern Plateau).

Figures 9 through 13 show the numbers of these popular species found in each site within each of the major planting niches on the farm.

**Figure 11: Number of Trees in Boundary Plantings by Species Composition within and across Sites**

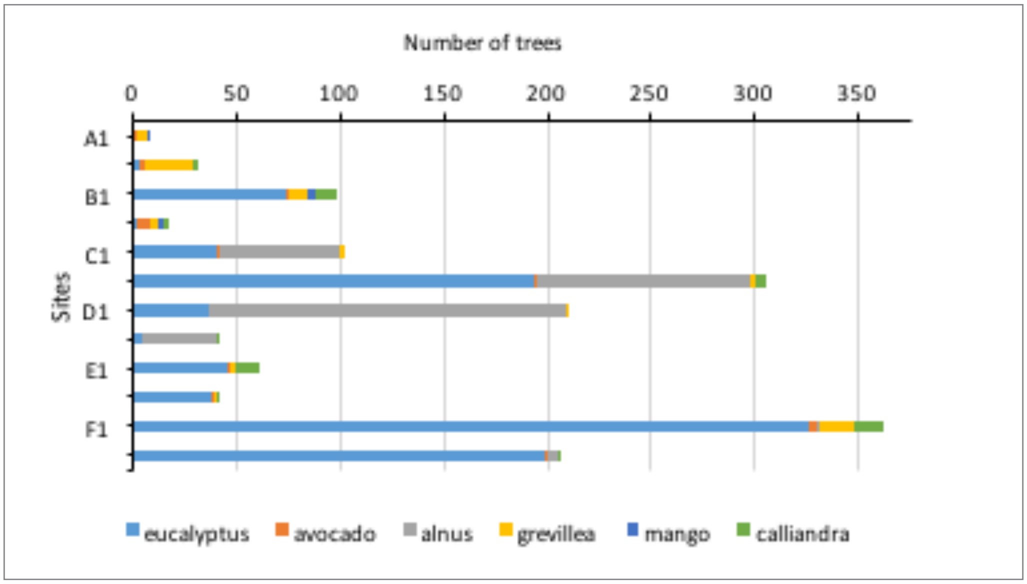



**Figure 12: Number of Trees within Scattered Trees in Crop Fields by Species Composition within and across Sites**

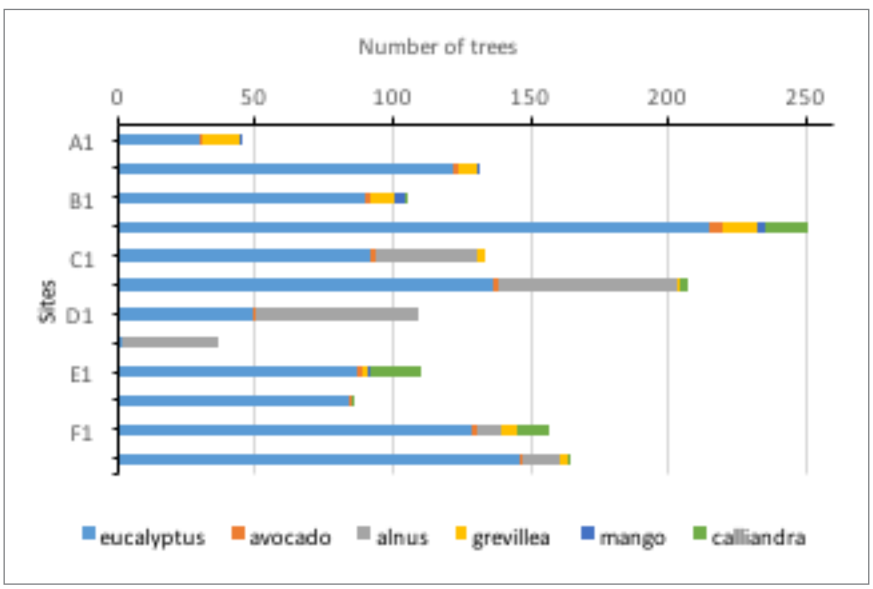
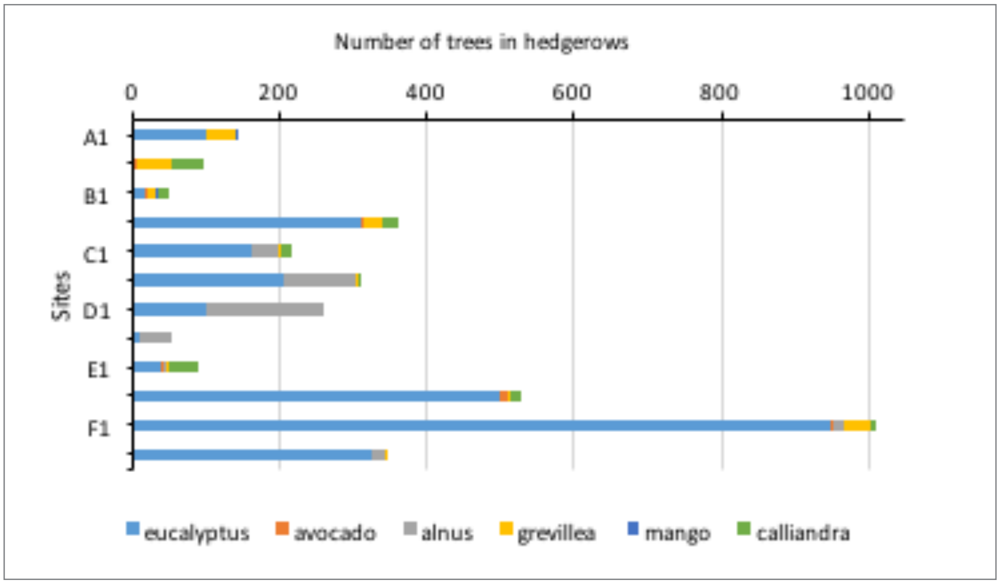


**Figure 13: Number of Trees within Hedgerow Systems by Species Composition within and across Sites**




Figures 14, 15, and 16 show the percent adoption of Eucalyptus, Alnus, and Avocado by agroforestry practice across the sites.

**Figure 14: Percentage of Households Culturing Eucalyptus in Different AF Systems within and acrossSites**

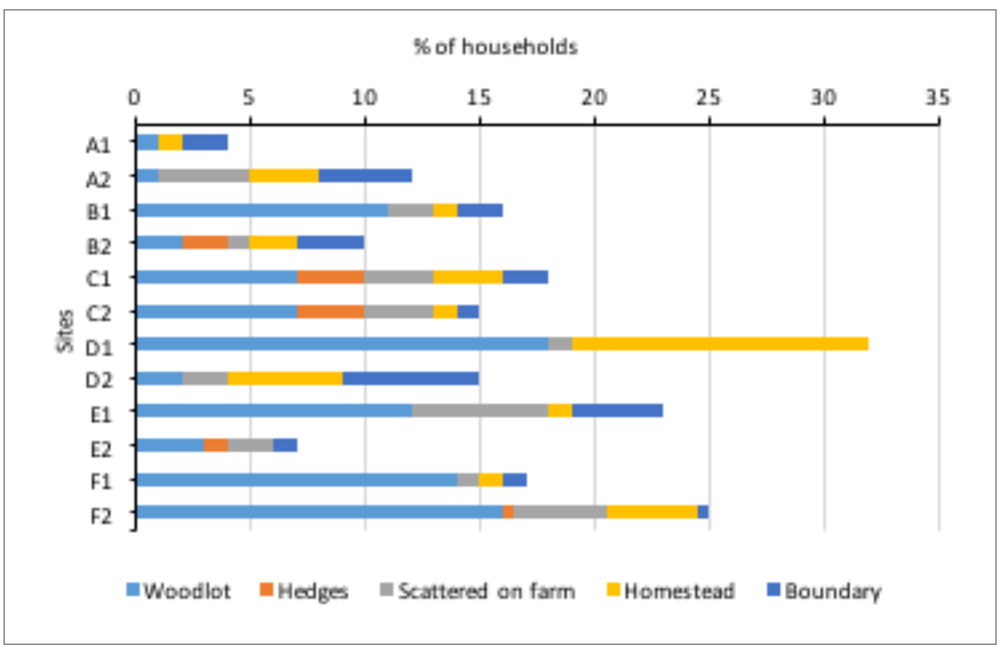


**Figure 15: Percentage of Households Culturing Alnus in Different AF Systems within and across Sites**

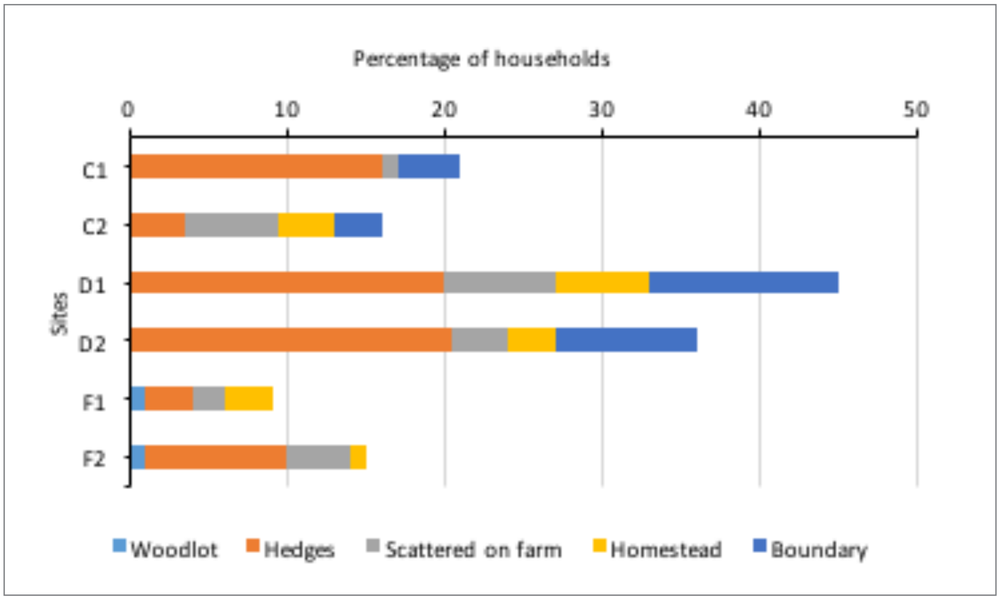
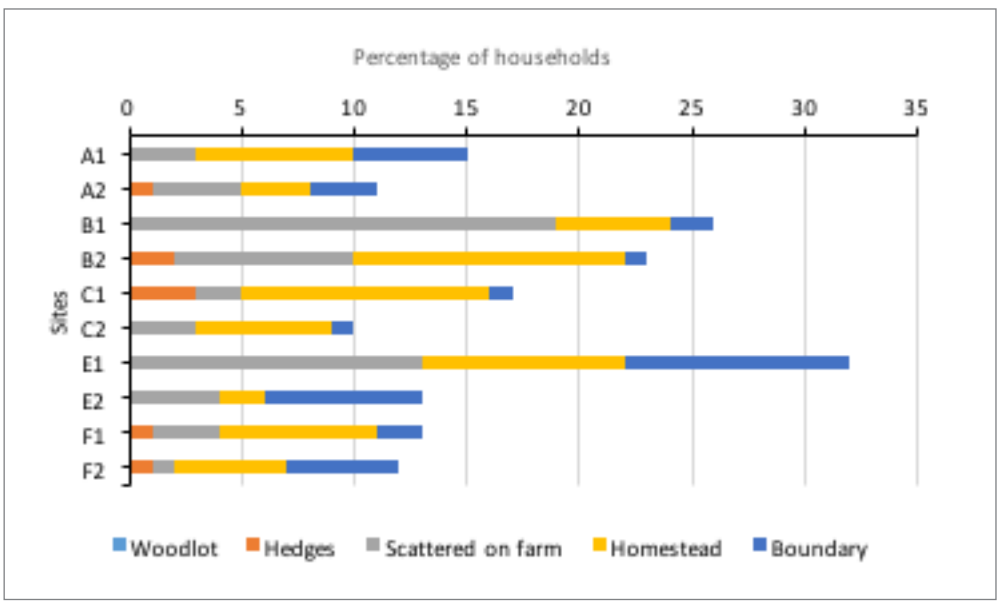



**Figure 16: Percentage of Households Adopting Avocado in Different AF Systems within and across sites**




In the Volcanic Highlands and Buberuka, where Irish potatoes are commonly grown and the land is steeper, Alnus is common and is associated with terraces and hedgerows for erosion control and other environmental services. Grevillea and mangos are not common here. Wheat is commercially grown in the Congo-Nile Crest and was significantly related to Eucalyptus production in woodlots for fuelwood. Bush beans, cassava, rice and banana crops, which are grown more commonly in the Savanna and Plateau systems, are not so commonly associated with hedgerows for erosion control and other environmental services but are more commonly associated with the adoption of species such as Grevillea and mango. Finally, maize and sweet potatoes were more adopted in sites where Alnus is rarely planted, but they were more commonly associated with the adoption of fruit trees.

# TOP USES OF TBS

The farmers ranked the top uses of their TBS for each land-use system (see Table 5 and Figure 17).[1] About 50–80 percent of the surveyed households across the six land-use systems identified woodfuel as the most important utility derived from the tree species that were cultured on their farms. Fruits and bean stakes tended to be the dominant second-ranked utility, while timber/poles were commonly ranked third. The harvest of wood fuel and bean stakes were the dominant motivation among highland households to keep woodlots on their farms. The adoption of hedgerows in both the highlands and the lowlands was also driven by the need for a harvest of woodfuel. This was also a very common motivation to keep scattered trees on their farms and in boundary plantings.

Other utilities seem to be differentiated by geographical location. Proportionally more households in the highlands reported the need for bean stakes, timber/poles, erosion control, and other environmental services, compared with farmers in the lower elevation zones. Hedgerow trees were important sources of staking materials for climbing crops. In the highland region, boundary plantings were also shown to be a significant source of bean stakes. Woodlots in both the highland and lowland regions were observed to be an important source of timber and poles, while hedgerows in highlands were also a source of timber and poles. Home gardens were found to be an important source of timber and poles at the lower elevation sites.

Fruit were reported to be an important utility across all five land use systems. The one exception was a site in the Volcanic Highland zone where cool highland climatic conditions may not be suitable for some fruit tree species. Fruits were ranked especially important at two sites in the Eastern Plateau and Central Plateau. They have a suitably temperate climate and access to the Kigali market. Tree species for fruit were an important component of home gardens.

Over 20 percent of the households in the Central and Eastern Plateau, the Buberuka Highland, and the Congo-Nile Crest—places where zero-grazing was more commonly adopted—reported that fodder was an important utility derived from their on-farm trees and their trees in hedgerows. In contrast, the use of on-farm trees for fodder was less-often reported in the Eastern Savanna and the Volcanic Highland systems, where free-grazing is commonly practiced.

Farmers in Buberuka reported a more diverse set of utilities from their on-farm trees than those in the other land use systems. Their uses included fuel, bean stakes, timber/poles, fruits, erosion control, and environmental services. In addition, hedgerows were reported to be important for erosion control in D2,[2] and fences, tools, and beehives were important utilities in E2.

Environmental services were considered to be significantly related to the adoption of hedgerows in the lower elevations systems. In the group discussions, participants mentioned that the establishment of bench terraces on their farms required the establishment of AF trees in order to ensure their stabilization and the provision of soil fertility benefits. Thus, these uses are an important incentive for TBS adoption on terraces.

**Table 5: Top-Ranked Utilities According to Farmers across the Land-Use Systems (Cells with High Tree Cover)**

| Land use system | Main utilities | | |
|---|---|---|---|
| | 1. | 2. | 3. |
| Eastern Savanna (A) | Woodfuel | Fruit | Timber, poles |
| Eastern Plateau (B) | Woodfuel | Fruit | Timber, poles |
| Buberuka Highland (C) | Woodfuel | Bean stakes | Fruit |
| Volcanic Highland (D) | Woodfuel | Bean stakes | Timber, poles |
| Central Plateau (E) | Woodfuel | Fruit | Timber, poles |
| Congo-Nile Crest (F) | Woodfuel | Timber, poles | Fruit |

1. While this is not discussed in-depth in this Summary document, the research team also calculated utility scores for each household, giving a higher weight to the primary utility than other utilities. For example, if a farmer answered that firewood was the only utility derived from his/her Alnus spp. on farm, this species was given a score of 1.0 for fuel. If Alnus was primarily used for fuel but also for erosion control, then the species got 0.7 as the fuel score and 0.3 as the erosion control score. If two other utilities were mentioned, say soil control and bean stakes, aside from fuel as the primary utility, then the species got scores of fuel 0.7, erosion control 0.15, and stakes 0.15.
2. The Volcanic Highland area is characterized by very steep slopes susceptible to soil erosion. In the correlation coefficients across sites, there is a moderate negative relationship between the percent of flat and moderate slope in a site and the utility reported for soil erosion. There is also a moderate-to-high positive relationship between altitude and utility.

**Figure 17: Percentage Distribution of Households according to the Top Utilities from Tree Species Adopted in the Survey Area**

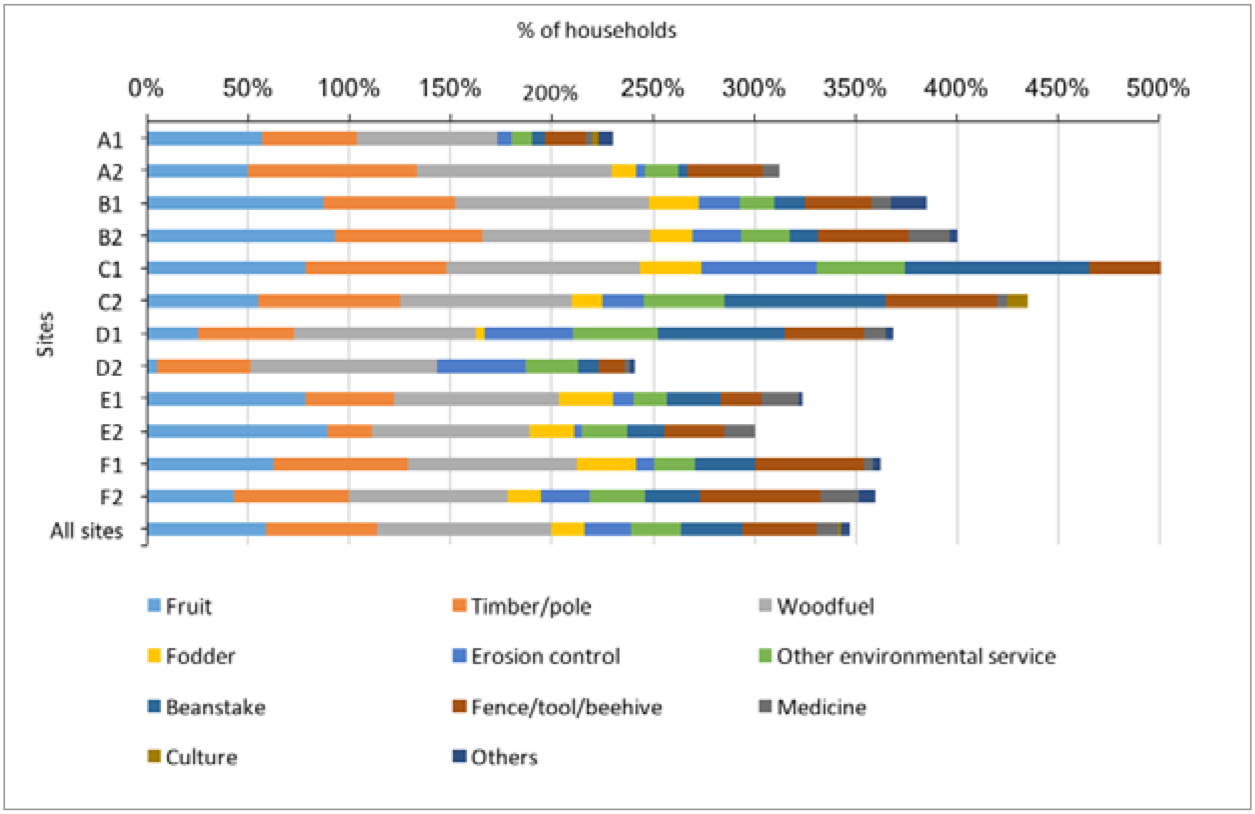
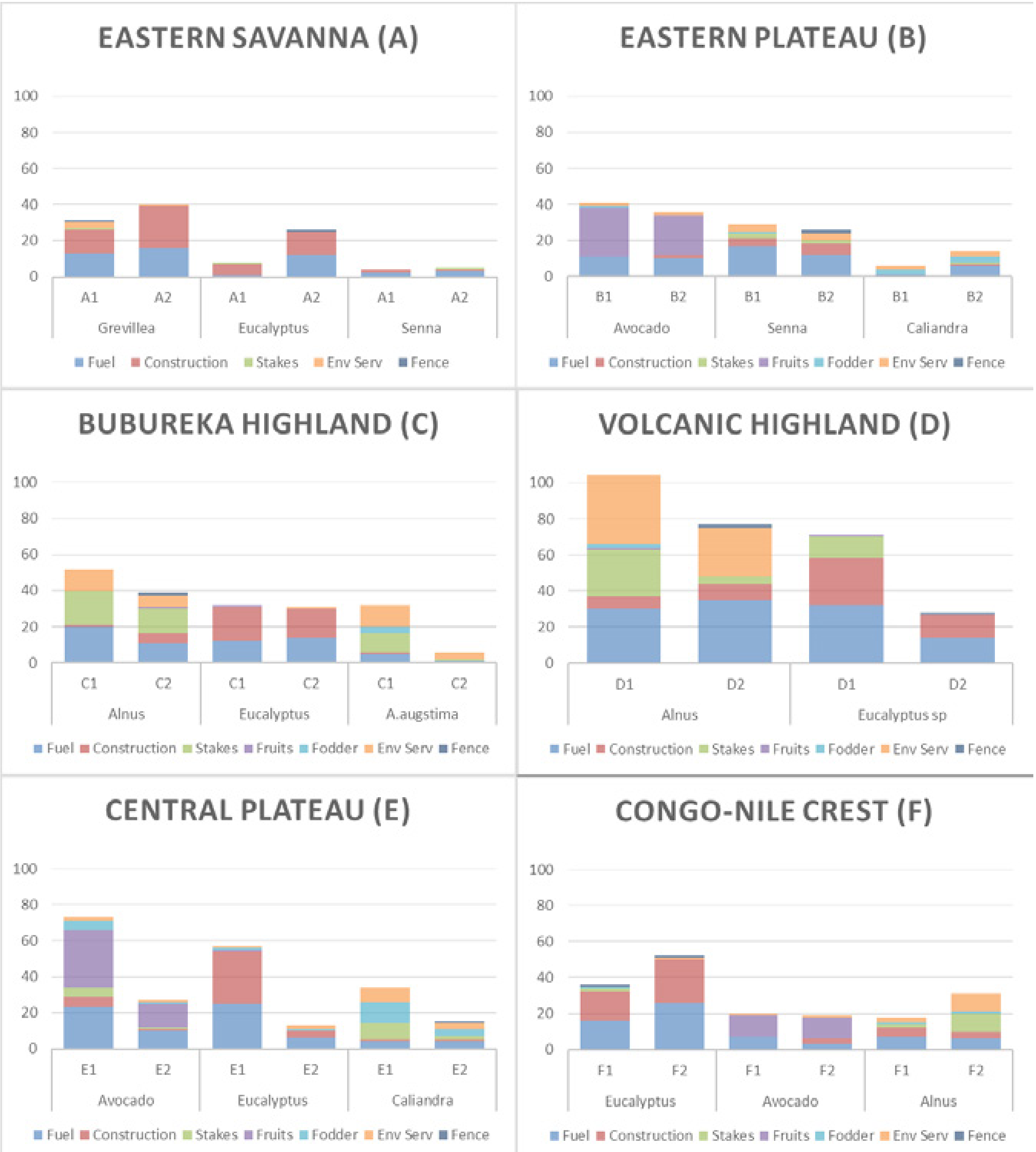



Figure 18 compares the percentages of households reporting different utilities derived from a few key tree species. In the Eastern Savanna, trees such as Grevillea, Eucalyptus, and Senna were planted mainly to serve as construction materials (timber, pole) and woodfuel, while fruits were relatively important in Kirebe (A1). In Gakirage (A2), woodfuel and timber/pole were given priority. In the Eastern Plateau, fruit was a key utility reported by farmers associated with their trees on farm, along with fuel and timber/poles.

In the Central Plateau, Avocado was mainly grown for fruits, but also fuelwood was obtained during the pruning of older trees. Eucalyptus trees were mainly planted for construction materials and fuelwood. Interestingly, some farmers in Buhimba cell (E2) noted their appreciation of its environmental benefits. Calliandra was mainly adopted for fodder, stakes, and environmental services. This leguminous shrub or small tree was well known in Kiruhura (E1) and Buhimba (E2), especially for its high-quality protein supplement to cattle and goat feeding compared with the low-quality fodder and crop residues that are commonly found in this land use system. In the Congo-Nile Crest, while Eucalyptus was considered to provide fuel and timber/poles simultaneously, stakeholders noted that charcoal brings more revenue than timber/poles in this region, making the area the country's major charcoal-producing region. Avocado and Alnus were also prominent in this region for a variety of reasons.

**Figure 18: Percent of Households Adopting Key Tree Species per Utilities in the Six Land Use Systems**



# KEY FACTORS DRIVING ADOPTION OF TBS

This study identified several key factors that drive adoption of TBS in Rwanda, based on spatial, statistical and econometric, and focus group analysis. (See Table 6.) The highest-ranked enabling condition for expanding AF on farms across all land use systems was the availability of seeds and seedlings. This was followed by the availability of land and of training on AF technology. Land-use-specific enabling conditions include, as in the case of the Eastern Savanna and Plateau, the availability of termite-, drought-, and disease-resistant tree species. Farmers in the Central Plateau were the only ones who ranked highly the reduction of poverty as a major enabling condition for TBS adoption, probably due to the relatively high poverty status of farmers in this area. Poor farmers are more likely to perceive that they cannot afford to make the initial investments to establish AF systems because they give higher priority to meeting their basic needs (medical insurance, food requirements, education, housing, etc.).

In Highland systems, farmers appeared to be taking advantage of the diversity of plots and varied topographies to strategically adopt multi-objective TBS systems in specific niches. *Eucalyptus* woodlots for fuel and timber/poles were adopted particularly in sites more dominated with less fertile soils; Alnus contour hedgerows were adopted on bench terrace risers in sites more dominated by steep slopes. A relatively higher proportion of owned plots also provided enabling conditions. In contrast, the agroecological conditions in the Savanna and Plateau land use systems, with their relatively flat landscapes and extensive farming practices, may not provide an attractive incentive for intensively managed TBS. Nevertheless, fruit-based AF systems are popular there.

Within the Highland land use systems, TBS adoption—especially Alnus hedgerows and Eucalyptus woodlots—was higher, with greater commercialization of key cash crops, such as climbing beans, Irish potatoes, and wheat. This connects TBS as an integral part of agricultural intensification in Rwanda. Agricultural extension service accessibility also favored Alnus hedgerows adoption. Plot fragmentation was associated with a higher adoption of Eucalyptus woodlots and with greater adoption of fruit trees and fodder trees.

Better market access and a greater ownership of transport provided economic drivers and enabling conditions for the adoption of commercially valuable tree products such as timber/poles, fruits, and fodder, independent of agroecological patterns. Household head education level correlated significantly with higher tree numbers of mango and Calliandra/fodder shrubs, suggesting that fruit fodder-based TBS were knowledge-intensive, and implying that investments in education/knowledge are required for accelerated scaling-up.

**Table 6: Categorization of Enabling Factors According to Site-Level vs. HH-Level and Biophysical (Suitability) vs. Human (Enabling) Factors**

| | Site-level Factors | Household-level Factors |
|---|---|---|
| Biophysical (suitability) | Climate (climate variability)<br><br>Altitude (in which site the household was located in, altitude of the site)<br><br>Slopes (location variables)<br><br>Soil (location variables, proportion of fertile soils)<br><br>Access to forests, natural vegetation (location variables) | Competition with crops and animals (scores)<br><br>Pests (scores, location variables)<br><br>Access to buffer plantations (location variables)<br><br>Land, plot characteristics (land total size in hectares, current crops – calculated farming activity scores, land fragmentation index – calculated by using Simpson Index, determined by the number of plots and the plot size distribution) |
| Human (enabling) | Population (population divided by area)<br><br>Institutions (as stated in group discussions, NGOs, religious group indicator, distance)<br><br>Infrastructure, road distance (distance, distance in km from homestead to tarmac road)<br><br>Access to markets (access in kilometers, distance to milk, crop, and production collection, markets, irrigating fruit source, etc.)<br><br>Access to quality planting materials and management among the different species (scores, location variables, perceptions calculated for each species)<br><br>Cell office and agronomist (agricultural extension) office accessibility (agricultural extension, cell office and agronomist office indicator, availability of agronomist office in proximity to the household) | Household characteristics (indicator for education level, gender of household head, number of household members, age – members who are over 16, or working age, indicator for people to rely on)<br><br>Household wealth (asset and asset values, such as transport: categorized into domestic goods and farm implements – values in Rwandan Francs (RWF), indicator for participation in savings or credit, distance, off-farm remittance income – estimated values in RWF, categorized into regular and casual sources, livestock ownership – tropical livestock unit, livestock zero-grazing – indicator variable)<br><br>Land tenure, availability / ownership, land use policy (location variables, as stated in group discussions and interviews, land ownership –percent owned versus rented)<br><br>AF Interventions (location variables, as stated during interviews)<br><br>Knowledge of benefits (indicator for household association and marketing participation, distance)<br><br>Migration experience (indicator for migration in household)<br><br>Pastoralism, land husbandry, grazing practices (attitudes of households, livestock zero-grazing – indicator variable) |

# FACTORS AFFECTING ADOPTION: ECONOMETRIC ANALYSIS

While statistical (frequency) analyses of the data can provide descriptive information about adoption at scale, econometric methods can provide further information describing the effects (how large and in which direction, as in whether the effects are positive or negative) of different factors that could have an impact on adoption of TBS. Holding other potential correlates constant, regression coefficients provide information about the difference in the predicted probability of adoption for each one-unit change in the correlate of interest. Although it is not possible to make a causal claim on any of the variables, the model provides a richer story about TBS adoption.

A regression analysis showed a significant variation in the factors driving the adoption of specific AF systems between highland and lowland agro-climatic zones. The most positive and significant variables that influence the adoption of AF were location, utilities of species (woodfuel, timber/poles, stakes for climbing beans, soil erosion control), farm size, and accessibility of extension services.

# SCALING UP TBS

Both the researchers and the farmers' groups view the positive factors (strengths and opportunities) of TBS/AF adoption as more important than the negative factors (weaknesses and threats). They viewed "increased demand and market for AF products" as a very important opportunity. Extensionists viewed "weak coordination and follow up between institutions / government agencies and NGOs implementing projects" as a major weakness.

The potential areas for AF expansion were mapped. The most important priority for AF expansion is from the southeast of the central plateau to the eastern plateau, Bugesera, and the eastern savanna. After accounting for the current tree cover and AF cover, the potential area for AF expansion was estimated to be about 1.5 million hectares.

# SUMMARY OF EVIDENCE

Table 7 summarizes, for each potential factor related to adoption, evidence found from spatial, survey, and group discussion analyses of the research. Factors are organized by biophysical and human categories, and discussions of the strengths, weaknesses, opportunities, and threats (SWOT) are included for many factors.

Appropriate methodologies, systems, and species to adopt may depend heavily on biophysical factors and current farming practices; in other words, adoption must be suitable at the site and household levels. While some patterns clearly emerged from the evidence, there is not yet an explicit picture of suitability at each cell level. Many adopters have used a multipronged strategy in terms of different systems based on suitability, needs, community, and other characteristics. Certainly, technologies and strategies rolled out will have to be tailored at the site level. In addition, since households are heterogeneous within cells, interventions may need to take incomes, participation, and other characteristics into consideration.

### Table 7: Summary of Evidence Found on Each Factor Related to AF Adoption

| **Biophysical (suitability)** | |
|---|---|
| Climate | **Regressions:** Droughts constraint B2 and A2 households from adopting woodlots.<br>**Discussions and SWOT:** Climate variability was listed as a barrier to TBS adoption at scale. Perennial trees provide more sustainable income than annual crops in the event of climate risks. |
| Altitude | **Household surveys:** Environmental services utilities from tree products and services in the highland zones may correspond to economic and agroecological drivers defined by particular farming system requirements that drive high demand for stakes for climbing beans (as highly profitable commercial crops in the regions) and high demand for erosion control and soil fertility, as the regions are susceptible to soil degradation due to highly sloped landscapes.<br>**Biophysical, site-level characteristics, and AF systems by niches:** In highland zones with highly sloped land conditions, farmers value trees not only to control erosion but also for fuel (for both domestic energy and commercial charcoal) and for stakes for climbing bean production. High altitude was highly correlated with steeper sloped landscapes and with higher annual rainfall positively correlated with woodlot and hedgerow adoption. Species such as Eucalyptus and Alnus were negatively correlated with fruit tree adoption.<br>In the Congo-Nile Crest, F2 is located at a relatively higher altitude than F1, and its proximity to Nyungwe Forest makes this site cooler, thus constraining the adaptability and productivity of tree species such as Avocado, Grevillea, and Calliandra. Alnus performs well in the biophysical conditions of high-elevation areas. Grevillea and mangos are more adapted to temperate low-altitude zones.<br>The lowland region is a suitable region for mango production. Lower altitude zones that are relatively flat with extensive cultivation may not require hedgerows to control soil erosion and provide other environmental services.<br>**Regressions:** The adoption of hedgerows was also driven by the need for woodfuel, bean stakes, erosion control, timber/poles, and fodder, meeting multiple needs of the households. |
| Soil | **Biophysical, site-level characteristics, and AF systems by niches:** Eucalyptus woodlots for fuel and timber/poles tend to be adopted in sites dominated by less fertile soils. The proportion of very fertile soils in turn negatively correlated with overall tree number under AF systems. Despite increasing land scarcity and fragmentation in the highland system, farmers may strategically plant woodlots in farm niches with soils rather infertile for crop and livestock farming. Eucalyptus tolerates and performs well on acidic soils that are characteristic of the sites in the Congo-Nile crest. Contour hedgerows can help protect soils.<br>**Discussions and SWOT:** A major justification for not planting trees is a farmer perception that fertile soils don't require TBS, which hinders their adoption in these areas. |
| Slopes | **Biophysical, site-level characteristics, and AF systems by niches:** Alnus contour hedgerows are adopted on bench terrace risers in sites more dominated by steep slopes. In lowland zones with relatively flat landscapes and warmer climates than highland zones, trees are valued for shade, windbreaks, and soil fertility rather than for soil erosion control, while more drought-tolerant species may be better adapted.<br>**Regressions:** Highland sites varied from 25 to over 75 percent in the area of their land with a slope >25 percent. Adoption of hedgerows among the highland sites was greatest where over 75 percent of the land had a slope >25 percent. |
| Pests (e.g., termites) | **Household surveys:** Termite damage was perceived as neutral for Grevillea but scored lower than for the other species. For Eucalyptus, there was a contrasting observation on termite threats whereby farmers in Eastern Savanna (A) perceived it as negative while farmers from highland systems in general, especially those in F1, saw it positively. Farmers in lowland, Avocado-species-adoption sites such as D2 generally perceived fewer problems with termite attacks due to cooler climate than the high adoption sites in Eastern Savanna (A) with warmer climates susceptible to termite threats.<br>**Biophysical, site-level characteristics, and AF systems by niches:** Eucalyptus is more vulnerable to termite attacks in low-altitude, hot climates than in other land use systems of the country.<br>**Regressions:** Termite attacks constrain B2 and A2 households from adopting woodlots.<br>**Discussions and SWOT:** In Eastern Savanna and Eastern Plateau, the enabling conditions of acquiring adapted AF species for termite resistance, drought resistances, and prevalence of tree disease pressure were ranked highly. |
| Access to forests, natural vegetation | **Household surveys:** Geographically, F1 is far away from Nyungwe forest, thus households established trees on farms and woodlots essentially of Eucalyptus in order to satisfy their wood and income needs.<br>**Biophysical, site-level characteristics, and AF systems by niches:** Kagano's (F2) location close to Nyungwe forest helps with major indigenous tree species *Ficus spp* and *Polyscias fulva* species (which thrive in that environment).<br>**Regressions:** The availability of natural vegetation in B2 and A2 reduces the odds of household decisions to grow woodlots since resident households collect wood materials, especially fuelwood, from available natural vegetation of savanna woodlands.<br>**Discussions and SWOT:** A major barrier to planting trees is proximity to public forests where there is free access to wood and non-wood products, albeit illegally in many cases. |

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| Access to buffer plantations | **Biophysical, site-level characteristics, and AF systems by niches:** In Kagano (F2), the encroachment on Nyungwe natural forest and buffer plantations could provide some alternative sources for wood and income. |
| Land, plot characteristics | **Household surveys:** Mean plot size was positively correlated with the adoption of Grevillea.<br>**Biophysical, site-level characteristics, and AF systems by niches:** Farmers seem to be taking advantage of diversity of plots and varied topographies to strategically adopt multi-objective TBS in strategic niches. Correlated with woodlots and homestead as niche, fruit, bean stakes, and especially timber/pole, fodder, fence/tools as utilities, and Eucalyptus and Avocado for species.<br>**Regressions:** Total land size influenced positively the planting of woodlots, but its effect was not significant. Land size was positively significant in explaining the adoption of hedgerows in the Lowland, where the existence of hedgerows was driven by the household demands for woodfuel, fodder, and services such as soil fertility improvement, shade, and protection against wind blows. For the highland, the land size was negatively associated with the adoption of home gardens. The strategic allocation of small but fragmented plots into intensive on-farm activities as reflected by the land fragmentation was positively associated with the adoption of woodlots.<br>**Discussions and SWOT:** Major enabling conditions for tree planting identified included demarcation of land boundaries and low productivity of land. |
| Competition with crops and animals | **Household surveys:** Competition with crops and animals was a constraint on the adoption of Eucalyptus, and positive for all other species. B1 perceived fewer problems than B2 Batima. All the selected sites perceived competitions with crops negatively. Farmers in Buberuka Highland have a long experience in the planting and management of Alnus to reduce competition on crops through pruning and planting at right density. They rated some management factors highly positive, such as less competition with crops/livestock and fewer threats from termite attacks/pests/diseases, but two sites contrasted in rating of factors such as soil moisture, soil fertility, land fragmentation, and land sufficiency.<br>**Discussions and SWOT:** As TBS need to be compatible rather than competing with cropping/farming systems to better optimize resource use, TBS outcomes seemed quite influenced by types of crops grown and degree of commercialization. |
| **Human (enabling)** | |
| Population | **Biophysical, site-level characteristics, and AF systems by niches:** Higher population density was significantly and strongly correlated with more trees in AF systems, woodlots, fuel, and Eucalyptus. |
| Pastoralism, land husbandry, grazing practices | **Household surveys:** The difference observed in tree species diversity and density in D1 (higher) and D2 (lower) was due to the attitude of D2 households oriented mainly on pastoralism rather than agricultural system. The integration of trees on limited size of farmland and rangelands reduced the space for crops and livestock for grazing. In Central Plateau and Eastern Plateau, Buberuka Highland, and Congo-Nile Crest, where zero grazing is more commonly adopted, fewer but over 20 percent of households reported fodder as an important utility derived from their trees on farm, versus lower proportions of farmers reporting in Eastern Savanna and Volcanic Highland, where free grazing is practiced.<br>**Regressions:** Livestock zero grazing was significantly correlated with the likelihood of household choice to maintain hedges on highland farms.<br>**Discussions and SWOT:** The land husbandry practices inside and outside of the consolidated land create niches for tree planting to control erosion, stabilize bench terraces, improve soil fertility, and satisfy the demand for stakes for climbing beans and firewood. Animal grazing (despite the zero grazing policy) was listed as barriers to TBS adoption at scale. |
| Institutions | **Discussions and SWOT:** The partners involved in research and development (extension) are not well coordinated, and their interventions and extension approaches to reaching out the farmers are not harmonized. In many cases, target communities are not involved in all the steps of the project cycle, including identification of the problems, planning, implementation, monitoring, and evaluation of project interventions. This top-down approach has led to low adoption rates of TBS despite free distribution of tree planting materials. This does not ensure sustainability and ownership of the interventions. Farmers' willingness to plant trees on farms will be reduced further if the planting materials have to be purchased.<br>Different approaches used by different partners hinders the adoption at scale of TBS. Inappropriate channels for information from research to extension were cited as a constraining factor to adoption of TBS also. As long as TBS are not considered as a priority in extension and research, farmers are likely to lose focus on agroforestry practices.<br>Access to tree seeds and seedlings that suit the biophysical and socioeconomic characteristics of the farmers is also a barrier to TBS adoption, as the tree seeds and seedlings supply system is too centralized. Nevertheless, these institutions need to be empowered to provide quality services and information. Availability of quality planting materials, extension tools, and sufficient number of these tools could enhance the adoption of TBS at scale. The research and extension organizations should revisit and harmonize their approach in the development of agroforestry in Rwanda. Extension providers viewed "weak coordination and lack of follow-up between institutions/government agencies and NGOs implementing AF projects" as a major weakness. |

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| Infrastructure, road distance | **Biophysical, site-level characteristics, and AF systems by niches:** Tarmac road distance correlates positively with boundary and hedges, indicating these functional AF types can be more prominent in sites more remote from tarmac roads (or, potentially, in mountainous areas more likely to have a longer distance).<br><br>**Regressions:** Households' distance to the tarmac road is positively correlated with the adoption of hedgerows in the lowland. As for hedgerows, the adoption of scattered trees by lowland households is positively and significantly affected by the distance of the household to the tarmac road. For the highland, the distance of the household to the tarmac road was positively associated with home gardens.<br><br>**Discussions and SWOT:** The use of heavy mechanization and hillside irrigation infrastructures tends to reduce the intensive planting of trees on farm. |
| Access to markets | **Household surveys:** Fruits were listed as an important utility in Eastern Plateau (B) and Central Plateau (E), which have better access to Kigali market. Availability of quality inputs was perceived as an enabling condition in B1, as was the affordability of materials in Buberuka Highland. Market access for Eucalyptus was on average perceived positively. Market distance negatively correlated with TBS adoption in terms of utilities such as fruits, timber/pole, and fodder and Avocado as a species, which indicates that better market access (shorter distance) can affect the adoption of commercially valuable tree products production. In Kagano (F2), limited access to tree germplasm and information from extension services could explain the lower involvement of households in intensive tree planting on-farms. Murama (B1) had relatively positive scores for conditions affecting the adoption of Calliandra than those in Batima (B2), which especially rated market access, demand, soil fertility, land fragmentation, and pests/disease negatively. Gacundura (C2) gave relatively low scores (compared with C1) on market access and demand, material affordability, as well as soil fertility and moisture constraints of Alnus. In Kaganza (F1), participants gave high scores for the factors such as the availability, quality, and affordability of materials as enabling conditions. There were positive perceptions for Alnus, with scores over 0.40-0.50 for most of the conditions listed, especially the availability of quality materials and management advantages (less competitions with crops/ livestock, less prone to pests/diseases and termites, and positive impacts on soil moisture).<br><br>**Biophysical, site-level characteristics, and AF systems by niches:** Degrees of commercialization of key cash crops such as climbing beans, Irish potatoes, and wheat were higher in C1 than C2, Volcanic Highland, and Congo-Nile Crest, which corresponded to the higher adoption of Alnus hedgerows and Eucalyptus woodlots.<br><br>**Discussions and SWOT:** Infrastructure and markets are driving the adoption of TBS through increasing demand of tree products (e.g., fruits and woods). The current increase of charcoal prices stimulates tree planting and commercialization. Similar to food crop value chain, the charcoal and fuelwood value chain involves many players, including tree owners, charcoal producers, transporters, and retailers. A major enabling condition for tree planting identified includes availability of tree seedlings. Indigenous tree seed availability can lead to high adoption of AF practices by farmers. A major barrier for not planting trees was existence of tree product substitutes, such as Napier grass for stakes (*Imishingiriro*). Another major barrier to planting trees is unavailability of tree seedlings. Researchers and farmers viewed "increased demand and market for AF products" as a very important opportunity. |
| Access to quality planting materials and management among the different species | **Household surveys:** For Avocado, market access and quality materials were positive, with farmer mean scores over 0.50 (positive conditions), while other factors were perceived more or less neutrally to positive. Market access was especially positive for Eucalyptus over other species, and there were relatively positive perceptions about the availability of quality planting materials. Farmers in Eastern Plateau and Central Plateau perceived the planting material availability relatively positively, while those in Buberuka Highland perceived it negatively.<br><br>**Discussions and SWOT:** The availability of seeds and seedlings contributed to the adoption of TBS initiatives by many households across the land use systems. The major enabling conditions reported by interviewed farmers were resistant trees to the termites, drought, and diseases. Termites, drought, and diseases were more prevalent in Eastern Savanna and Eastern Plateau. Availability of adapted trees in these systems contributed to the adoption of TBS in about 20 percent of the households. |
| Cell office and agronomist (agricultural extension) office accessibility | **Biophysical, site-level characteristics, and AF systems by niches:** The accessibility of agricultural extension was positively associated with TBS adoption indicators, such as overall AF adoption and tree number excluding woodlots, and with direct utilities such as fuel and bean stakes, while it was especially strongly associated with the adoption and higher number of trees for Alnus hedgerows for indirect utilities such as erosion control and other environmental services.<br><br>**Regressions:** The availability of an agronomist office close to households was positive and very significant for the household choice to grow woodlots in the lowland region, where woodlot planting is in general still relatively rare. Therefore, the household access to extension services encourages households to establish woodlots. The probability of adopting hedgerow AF technology increases with availability of a sector agronomic office. For the highland region, the coefficient of the availability of a sector agronomic office was negatively significant in explaining the adoption of boundary planting. |

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| Land tenure, availability / ownership, land use policy | **Household surveys:** This factor was positive for the adoption of all the species types listed. Land ownership was essential for the households to adopt TBS across the different land use systems. Farmers in the Eastern Savanna land use system indicated that they face land shortage (36 percent of respondents) as major constraint to TBS adoption, and this may be explained by the fact that the major activity in this region is livestock rearing in free grazing system in A1 and rice irrigation farming in A2, where farmers cannot afford to incorporate more trees. Land shortage in Buberuka Highland and Central Plateau is due to high land fragmentation resulting from high population density (above 600 habitants/ sq km). Little land and market access for Alnus were perceived relatively negatively to neutral in F1 Kaganza and had a relatively low rating on all the conditions in general in F2 Kagano.<br><br>**Biophysical, site-level characteristics, and AF systems by niches:** A higher proportion of owned plots against rented plots as well as a proportion of plots on slopped land at site level also positively affected some TBS adoption indicators – both overall AF and those excluding woodlots, hedgerows / Alnus and woodlots / Eucalyptus for goods such as fuel, bean stakes, and fence/tools and for services such as erosion control and other environmental services. On small farms, there are appropriate niches for planting AF trees such as boundaries, hedgerows for soil erosion control, low density of high-value scattered trees, and home gardens. Woodlots and alley cropping are not suitable AF on small farms since they compete for space with crops. The adoption of woodlots in D2 was relatively low due to the site-specific conditions such as the lack of land for woodlots, as the land there was mostly demarcated to more profitable farming activities such as pasture for improved dairy cattle or terraced fields for climbing beans/potatoes.<br><br>**Discussions and SWOT:** Land use consolidation was identified as a driver for TBS adoption and scaling-up. A major enabling condition identified for tree planting includes leadership. A major constraint to TBS adoption is land shortage to accommodate trees, especially in the case of tree species that are strongly competitive with crops. Extensionists and farmers indicated that population pressure leading to land scarcity was the critical threats to the adoption of TBS. |
| AF interventions | **Household surveys:** The adoption of Calliandra varied from 5 percent to 25 percent in Eastern Plateau, Buberuka Highland, and Central Plateau, where Calliandra and other leguminous species as soil fertility improvement and fodder were actively promoted under AF initiatives. Farmers in Congo-Nile Crest (F1 and F2), where the adoption was relatively modest, in turn, have long been exposed to forest plantation and management activities implemented by forest projects that operated in the buffer zone to Nyungwe forests (i.e., UGZ 1 and PPF). Alnus was easily adopted as an AF species and was mainly disseminated by ICRAF and ISAR/RAB through on-farm trials for provenance selection, management options, and capacity building. The higher tree species diversity in E1 over E2 could partly be explained by their accessibility and exposure to new tree and fruit species and varieties that are developed in RAB stations and on-farm experimentation. Overall, it is unclear what the exact effect of interventions are.<br><br>**Biophysical, site-level characteristics, and AF systems by niches:** Interventions to improve fodder production and soil fertility in B2 (Eastern Plateau) have helped in the adoption of Calliandra. Proximities to national agricultural research institutes, on-farm demonstration, and provisions of planting materials are some of the important factors to ensure the successful adoption between the sites.<br><br>The insufficiency of seeds and seedlings was mainly observed in Buberuka Highland (31 percent), Eastern Savanna (28 percent), and the Congo-Nile Crest (28 percent). This is due to the shortage of NGOs and projects involved in AF activities in the region in addition to the long distance from the tree seed center located in Central Plateau in southern province. In addition, the policy on seeds production giving monopoly to RAB/ISAR and the lack of a strategy for tree seeds distribution contribute to seeds and seedling insufficient.<br><br>**Discussions and SWOT:** The crop intensification program was also reported to influence TBS adoption and scaling-up since it increases the need for biological control of pests and diseases. It could be a barrier; the use of heavy mechanization and hillside irrigation infrastructures tends to reduce the intensive planting of trees on farm. The one cow per poor household (Girinka) program was also identified as a driver and incentive or precondition. Enabling conditions for TBS include national tree planting day; the existence of nurseries in all sectors of the country; the commitment of the private sector to seeds and seedlings production and supply; the existence of the National Tree Seed Centre; decentralized extension services; performance contracts; media; local meetings, including *umuganda*; and the existence of farmers' cooperatives. In the highlands, a major enabling condition for tree planting identified was projects that promote on-farm tree establishment (PAREF, PAFOR, KWAMP, RSSP, PAP Nyabisindu, DEMP, AAP/ LDCF, PAGReF,ViAF, ICRAF, etc.). |
| Household characteristics | **Household surveys:** Household-head education level correlated significantly with higher tree numbers of mango and with Calliandra/fodder utilities.<br><br>**Regressions:** Household characteristics such as gender of the head of the household, age of the household head, education level of the head of the household, and household size did not significantly influence the choice to have woodlots. Although no significant effects of these variables were found in the highland region, the positive correlation implied that larger households headed by men who are older and educated seem to adopt woodlots. The age of the household head and household size were significantly correlated to the likelihood of household choice to maintain hedges on highland farms in highlands. The signs of the parameter estimates of these variables indicate that younger household heads, bigger household size, households with more domestic asset values, and those practicing less zero grazing are likely to adopt hedgerow AF system. Gender (male) of the household head had a negative sign on the adoption of hedgerows in lowland regions. Household endowment of livestock increases the likelihood for keeping scattered trees in the highlands. The value of domestic assets (positive) was important in the highlands, and household size (negative) was important in the lowland for the adoption decision of home gardens. |

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| Migration experience | **Household surveys:** Migration was negatively correlated with TBS adoption in general, esp. woodlots / Eucalyptus.<br>**Biophysical, site-level characteristics, and AF systems by niches:** Off-farm remittance income was associated with more trees overall, woodlot niches, fruits, woodfuel, fence/tools, and Eucalyptus. |
| Household wealth | **Household surveys:** In the Congo-Nile Crest, Eucalyptus is among the main sources of income for many households through the sale of firewood, charcoal, poles, and lumber. Orange, papaya, and lemon species can help in income generation. Irish potatoes, climbing beans, and wheat were grown more commercially in highland systems than in the savanna and plateau. In contrast, bush beans, cassava, and banana were more commercially grown in the savanna and plateau systems, while rice was more specific to A2. On the other hand, livestock farming was implemented more commercially for cash income in Cell 1 than Cell 2 in specific land use systems. In Central Plateau, reduction of poverty was cited by interviewed farmers (25 percent) as an important prerequisite for increasing trees on farm and the adoption of TBS. In Buberuka Highland, farmers grow beans as a cash crop that provided good incentives to plant Alnus to meet the demand for stakes. Generally, farmer saving group participation had positive associations with more trees in woodlots, for fruit, Eucalyptus, and Calliandra.<br><br>**Biophysical, site-level characteristics, and AF systems by niches:** Mean transport asset value was positively correlated with more trees in woodlot as niches and with Grevillea and Eucalyptus, fruit utility/Avocado.<br><br>**Regressions:** Domestic assets values were significantly correlated with the likelihood of household choice to maintain hedges on highland farms.<br><br>**Discussions and SWOT:** Farmers in Central Plateau were the only ones who ranked highly the reduction of poverty as a major enabling condition for TBS adoption. A major barrier to planting trees is the long time span between establishment and maturity of tree crops to produce benefits from TBS (benefits from TBS take a long time to be generated). The slow growth rate of some indigenous tree species (e.g., *Markhamia lutea: Umusave*) discourages their adoption at scale. The need for a higher income increases the likelihood of adoption of TBS for the production of fruits, wood products, milk, soil erosion control, and soil fertility management. Moreover, having enough income from off-farm activities led to adoption of woodlot plantation and fruit trees. Food-secure households tend to increase adoption of TBS since they aspire to diversify income generation and their food diet. Food-insecure households tend to pursue food production as a priority rather than adopting tree planting that may generate food and income in the long run. The increased income from milk in zero grazing system leads to TBS adoption and upscaling. Off-farm income would serve as an incentive for TBS adoption as far as bank credits can be obtained based on forests land collaterals. Farmer saving and loans groups, associations, and cooperatives are channels for mobilization and sensitization on TBS. The existence of many service providers (financial sources, seedlings production and maintenance, implementation, sensitization, mobilization) involved in TBS was identified as driver for adoption at scale. |
| Knowledge of benefits | **Household surveys:** Alnus, Grevillea, Senna, and Avocado were well adopted by households because they had enough information on the possible benefits. Capacity building (like training, demonstration, and field visits) contributed to the adoption of TBS initiatives by many households across the land use systems.<br><br>**Discussions and SWOT:** Although trees such as fertilizer trees may contribute to enhanced food production, most of them are exotic, and farmers have less information on appropriate species and their benefits. A major barrier to planting trees is limited knowledge on AF technologies. Preconditions to TBS adoption at scale listed by the group included technologies meeting needs and preferences of the farmers; the availability of and access to information; farmers' own preferences and choices; seeds and seedling supply; involvement in plantation; awareness and mobilization campaigns; availability of extension tools; training programs for farmers and extensionists; the use of farmers as facilitators in extension (FFS approach); the Twigire Muhinzi extension approach; the creation of AF clubs; and a bottom-up approach to increase TBS adoption. The current status of indigenous tree species on farm shows that they are at risk of extinction, and some of them are difficult to propagate and regenerate. |

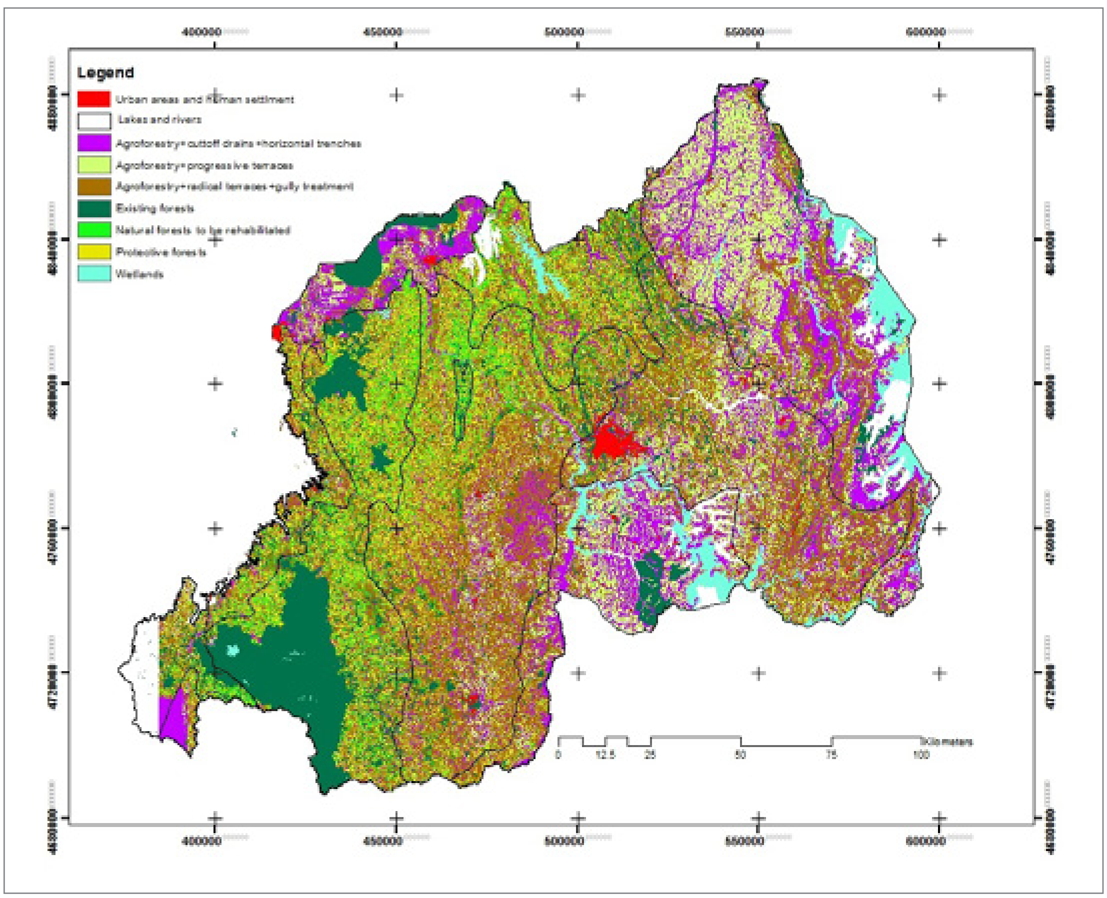
# MAPPING POTENTIAL AREAS FOR AGROFORESTRY

Almost all agricultural land in Rwanda is suitable for some kind of agroforestry system. Table 8 and Figure 19 show how agroforestry systems would be combined with soil protection practices, based on the local slope conditions. In addition, land having slopes greater than 55 percent is considered by law as unsuitable for terraced farming and is to be managed in woodlots and tree plantations.

### Table 8: Estimated Area for Agroforestry Expansion

| Land husbandry practices | Area(ha) |
|---|---|
| Agroforestry on cutoff drains and horizontal trenches | 419,251 |
| Agroforestry for progressive terraces | 417,077 |
| Agroforestry on radical terraces, gullies, and degraded lands | 741,565 |
| Total agriculture land (with and without agroforestry) | 1,577,892 |
| Potential area for agroforestry | 1,483,218 |

### Figure 19: Potential Area of Agroforestry Practices for Expansion in Rwanda



# RECOMMENDATIONS ON TYPES OF AGROFORESTRY BY LAND USE SYSTEM

Sustained adoption of tree-based ecosystem approaches (TBEAs) at scale is only guaranteed if farmers and communities collectively recognize tangible benefits. The following agroforestry practices are recommended to deliver those benefits in the various land use systems of Rwanda, based on the results of this study, on farmer experience, and on decades of agroforestry research.

## For High-Elevation Landscapes: The volcanic systems, Buberuka highland systems, and the Nile Crest degraded areas

In the Highland systems, farmers appear to be taking advantage of the diversity of their plot conditions and the varied farm topographies to adopt multi-objective TBEA systems in strategic niches. Eucalyptus woodlots for fuel and timber/poles were adopted in sites dominated by less fertile soils. Alnus contour hedgerows were adopted for fuel and bean stake production, as well as for soil stabilization and improvement, particularly on bench terrace risers on steeply sloping sites.

Agroforestry recommendations

1. **Tree planting in hedgerows is needed to control soil erosion and to stabilize the terraces on these sloping lands.** Alnus is an excellent and popular species for establishment along the risers of the terraces and on the contours of the fields. Most Alnus is planted on progressive terraces, particularly in volcanic land use systems.

2. **Fertilizer and fodder shrubs can be planted at high densities within crop fields and on the terraces and terrace risers.** The recommended species are *A. acuminata*, *A. nepalensis*, *Acacia angustissima*, and *Vernonia amygdalina*. They are popular for providing high-protein dairy fodder and rich organic fertilizer for crops, as well as for the production of stakes and fuelwood.

3. **Boundary plantings of trees surrounding fields and farms,** particularly for timber, poles and fuelwood production.

4. **Woodlots** are recommended for the steeper, degraded areas of the farm. *A. acuminata* is recommended for these plantings for land restoration and to provide other services and products.

5. **Home gardens**. Popular and recommended tree species around the homestead are *Vernonia amygdalina*, *Ficus sp.*, *Erythryna abyssinica*, and *Markhamia lutea*. The adapted recommended fruit trees include Avocado, tamarillo (tree tomato) and mountain Papaya.

## For Mid-Elevation Land Use Systems

These land use systems have an intermediate annual rainfall and are generally plateau lands.

Agroforestry recommendations

- **Boundary plantings around fields and farms**. This is a major niche for expanded tree plantings. The recommended species include *G. robusta*, *C. serrata*, and fruit trees, including Avocado (*Persea americana*).

- **Woodlots.** Existing woodlots are highly degraded and their management can be significantly improved through the diversification of species from the current ubiquitous presence of Eucalyptus. Recommended alternative species include *Eucalyptus tereticornis* and *G. robusta*. Leguminous shrub species such as Calliandra are suitable for the understory, providing livestock fodder. Leguminous herbaceous species, such as Mucuna and Desmodium, and improved grasses can be established for cut-and-carry fodder and for grazing.

- **Home gardens.** Recommended species for homesteads include Ficus, Vernonia, Erythrina, Avocado, Papaya, Macadamia, and bananas.

- **Fertilizer and fodder shrubs should be planted at high density in the fields and on the terraces for soil fertility restoration.** The recommended species include *Gliricidia sepium, Calliandra calothyrsus*, *Leucaena diversifolia, L. pallida*, *L. trichandra,* and *Vernonia amydalina.*

- **Enhancing scattered fruit trees in fields.** Recommended species include Avocado, Papaya with improved varieties, Arthocarpus (jack fruit), and Guava. The density of trees can also be enhanced through farmer-managed natural regeneration of indigenous tree species.

## For Lower-Elevation, More Dryland Areas

Agroforestry recommendations

- **Boundary plantings around fields, farms, and woodlots.** Recommended species include *Eucalyptus terraticornis, E. camuldulensis*, *G. robusta*, and various *Acacia spp.*

- **Enhancing scattered trees in fields.** This can be particularly enhanced through farmer-managed natural regeneration in dryland fields and pastures.

- **Fruit trees.** There is great potential to enhance fruit tree production in the drier areas with a focus on Mango, Papaya, Avocado, and Citrus, along with market development for the products. Mango production is currently too low even to satisfy local demand in Rwanda, and much mango fruit is imported from Burundi, Uganda, and Tanzania. Superior planting material is needed.

- **Fertilizer and fodder shrubs should be planted at high density in the fields for soil fertility restoration.** The recommended species include *Gliricidia sepium*, *Senna spectabilis*, *Leucaena. diversifolia*, *L. pallida*, and *L. trichandra*.

- **Home gardens.** Recommended species include *Markamia*, Ficus, and *S. spectabilis.*

# POLICY RECOMMENDATIONS

Better market access and the ownership of transport are economic drivers and enabling conditions for the adoption of commercially valuable tree products such as timber/poles, fruits, and fodder. Household-head educational level correlated significantly with higher tree numbers of mango and Calliandra/fodder shrubs, indicating that fruit- and fodder-based TBEAs are knowledge-intensive and that investments in education/knowledge would enhance scaling-up.

The central policy recommendation is that support for agroforestry is fully mainstreamed into extension programs, given the strength of government influence in decision making over crop choices and farming systems in Rwanda and the successful examples of previous agricultural campaigns. Evidence from this study showed that access to agricultural extension services positively influenced the uptake of agroforestry systems. Some systems, such as establishment of hedgerows together with the construction of radical terraces, require significant investment and coordination between multiple farms within a landscape, and therefore facilitation by government and NGOs is a prerequisite.

During the post-colonial period, the agricultural extension system has been greatly expanded. A variety of different models have been tried, including individual methods of extension (farm visits and informal contacts), group methods (group meetings, demonstrations, and field days and tours), and mass extension using media (newsletters, radio, and television). Currently some 14,000 professional extensionists and 200,000 farmer-extensionists are working to extend food crop technologies. The Ministry of Agriculture and Animal Resources (MINAGRI) has introduced the Farmer Field School approach in an effort to address the problem of weak research-extension linkages and grassroots innovation. FFS training courses have been delivered by national-level researchers and/or agriculture advisory services teams at the zonal level. These FFS courses are being implemented under MINAGRI. They now need to emphasize the engagement of the front-line extension staff at the zonal level and to orient the curriculum to the scaling-up of agroforestry practices.

Although the FFS has been instrumental in greatly strengthening farmer-to-farmer extension, at present there is not even one public demonstration site for agroforestry technology. There was also a failure to consistently promote technologies that are most useful and profitable to farmers for their specific conditions. For example, most agroforestry projects have emphasized new technologies (e.g., alley cropping, improved fallows) but they should also promote locally developed systems (e.g., home gardens) that are based on the experiences of farmers.

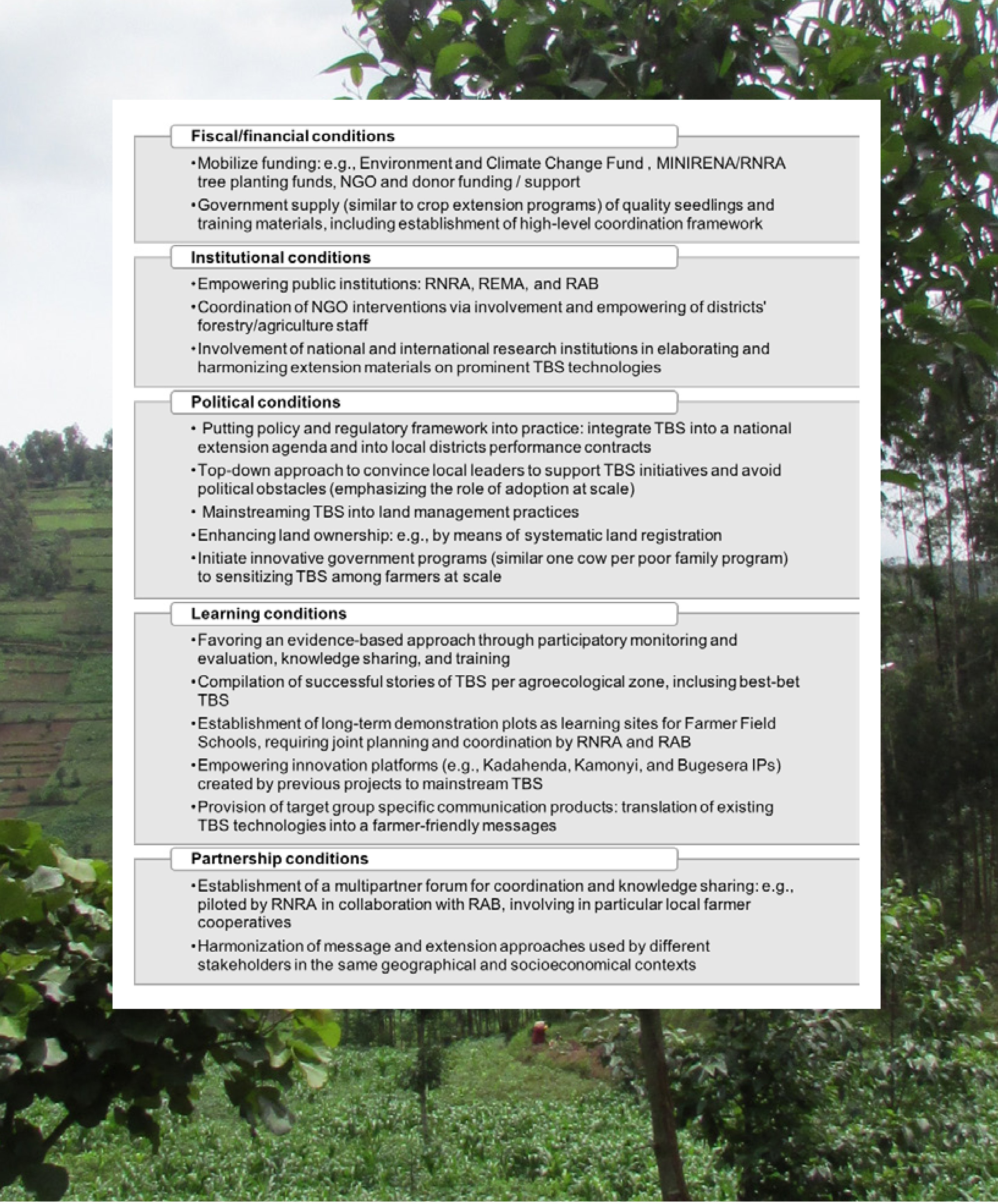
Government has increased the adoption of modern inputs (improved seeds, fertilizers, and pesticides) by smallholder farmers through the bulk procurement of improved seeds and fertilizers from neighboring countries and the distribution of inputs through a network of public and private partnerships. The MINAGRI has used a "supply-push" approach, whereby the government initially supplies the inputs, and farmers are persuaded to use them.

COMESA has recently launched a platform with the EverGreen Agriculture Partnership at the World Agroforestry Centre (ICRAF) to help member countries link their fertilizer subsidy programs with the scaling-up of fertilizer and fodder trees and shrubs. Rwanda can take advantage of this opportunity to spearhead the incorporation of these tree/shrub technologies into farmers' fields on a major scale. This will restore the fertility of the land through an integrated soil fertility approach.

The priorities of government interventions have intensively emphasized food crops rather than TBEAs, even though there are great synergies to be exploited by combining extension for both. Existing TBEA extension approaches in Rwanda are inefficient due to inadequate financial support, technical skills, number of trained extensionists, and bureaucratic inefficiencies. More-effective extension approaches was ranked first in importance by experts and farmers among the barriers to be overcome to accelerate TBEA adoption.

The enormous cadre of food crop extension strength should now be directed to the integration of agroforestry practices with food crop innovations in order to capture synergies and accelerate the spread of TBEAs in the country. This would focus on extending supply-push programs for the provision of seeds and fertilizers to include the provision of quality agroforestry seedlings and training materials and on adapting FFS infrastructure to tackle the scaling-up of TBEAs. The extension approach proposed involves having front-line extension workers (especially at the sector level) engaged in the training courses that are being implemented by MINAGRI. These front-line extension workers can then help train and backstop the facilitators at the cell and village level. FFS can be an excellent way to train farmer facilitators at the cell and village level about agroforestry and TBEAs.

It is critical to get strong central government commitment to implementing TBEAs at scale but also to include agroforestry with the national extension agenda and to include targets for scaling-up in the local districts' performance contracts. A strong top-down signal that scale is critical for agroforestry to contribute to the national AFR100 goal to restore better productivity on 2 million hectares would trigger innovative government



**Fiscal/financial conditions**

- Mobilize funding: e.g., Environment and Climate Change Fund , MINIRENA/RNRA tree planting funds, NGO and donor funding / support
- Government supply (similar to crop extension programs) of quality seedlings and training materials, including establishment of high-level coordination framework

**Institutional conditions**

- Empowering public institutions: RNRA, REMA, and RAB
- Coordination of NGO interventions via involvement and empowering of districts' forestry/agriculture staff
- Involvement of national and international research institutions in elaborating and harmonizing extension materials on prominent TBS technologies

**Political conditions**

- Putting policy and regulatory framework into practice: integrate TBS into a national extension agenda and into local districts performance contracts
- Top-down approach to convince local leaders to support TBS initiatives and avoid political obstacles (emphasizing the role of adoption at scale)
- Mainstreaming TBS into land management practices
- Enhancing land ownership: e.g., by means of systematic land registration
- Initiate innovative government programs (similar one cow per poor family program) to sensitizing TBS among farmers at scale

**Learning conditions**

- Favoring an evidence-based approach through participatory monitoring and evaluation, knowledge sharing, and training
- Compilation of successful stories of TBS per agroecological zone, inclusing best-bet TBS
- Establishment of long-term demonstration plots as learning sites for Farmer Field Schools, requiring joint planning and coordination by RNRA and RAB
- Empowering innovation platforms (e.g., Kadahenda, Kamonyi, and Bugesera IPs) created by previous projects to mainstream TBS
- Provision of target group specific communication products: translation of existing TBS technologies into a farmer-friendly messages

**Partnership conditions**

- Establishment of a multipartner forum for coordination and knowledge sharing: e.g., piloted by RNRA in collaboration with RAB, involving in particular local farmer cooperatives
- Harmonization of message and extension approaches used by different stakeholders in the same geographical and socioeconomical contexts

programs, like the successful one cow per poor family program in 2006 that was spearheaded by the President. MINAGRI has recently committed to retraining its extension agents to implement a program of reaching all farmers with fertilizer and fodder shrub technologies, indicating that this shift in priorities could be under way.

Goals could be set to extend fruit tree portfolios per poor family or trees per primary school pupil. The latter would benefit the 2.4 million pupils in the country and their families. Engaging the youngsters would also help sustain the scaling-up process in the future, since they would drive enthusiasm about TBEAs.

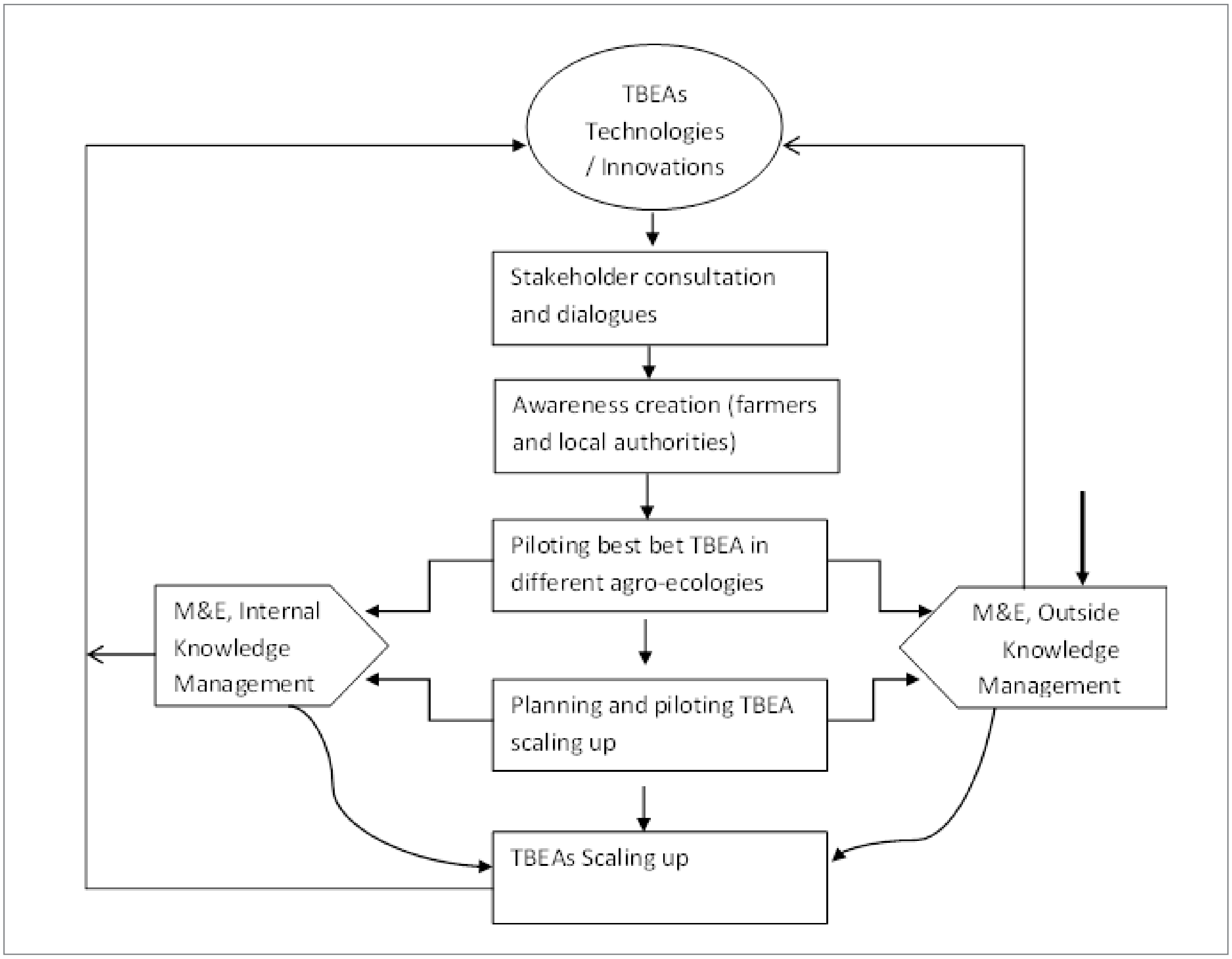
## Collaboration

The scaling-up mission is one that must be addressed by stakeholders at all levels: government, NGOs, business, civil society, rural communities, and individual farmers. However, weak coordination and follow-up between the institutions and government agencies implementing agroforestry projects was ranked second among the strong weaknesses of TBEA adoption in the SWOT analysis. Establishment of a high-level coordination framework of TBEA extension will boost adoption at scale. Public and private institutions involvement in TBEA scaling-up should be empowered to carry the expansion process forward.

The public institutions involved in TBEA extension—namely RNRA, REMA, and RAB, under their respective ministries—should be empowered and coordinated for proper implementation of TBEA scaling-up. Likewise, the NGOs operating in TBEA—such as ICRAF, Vi-Agroforestry, World Vision, Great Ape Trust, and NBDF—should be coordinated and guided by district plans for TBEA scaling-up. Since the institutions that have promoted the original innovations or pilots may not have the capability to scale up or manage the initiative at scale, the permanently employed district forest officers and agronomists should be involved in all TBEA project implementation and should be empowered to sustain the extension after the projects have come to an end. The national (e.g., RAB) and international (e.g., ICRAF and CIAT) research institutions in Rwanda should assist in elaborating and harmonizing the extension materials on prominent TBEA technologies to be used by the public extensionists at the grassroots level.

Partners need to be mobilized to join in the effort of scaling-up. A forum of all partners in TBEA promotion needs to be launched. This could be chaired by RNRA (e.g., the directorate of forestry extension) in collaboration with RAB (e.g., the directorate of agricultural extension at zone division). Partnering with external donors is also critical to empower institutions involved in scaling-up. Local farmer cooperatives such as URUGAGA IMBARAGA need to be involved from the outset of TBEA projects so that

**Figure 20: Linkages of Steps for TBEA Scaling-Up**



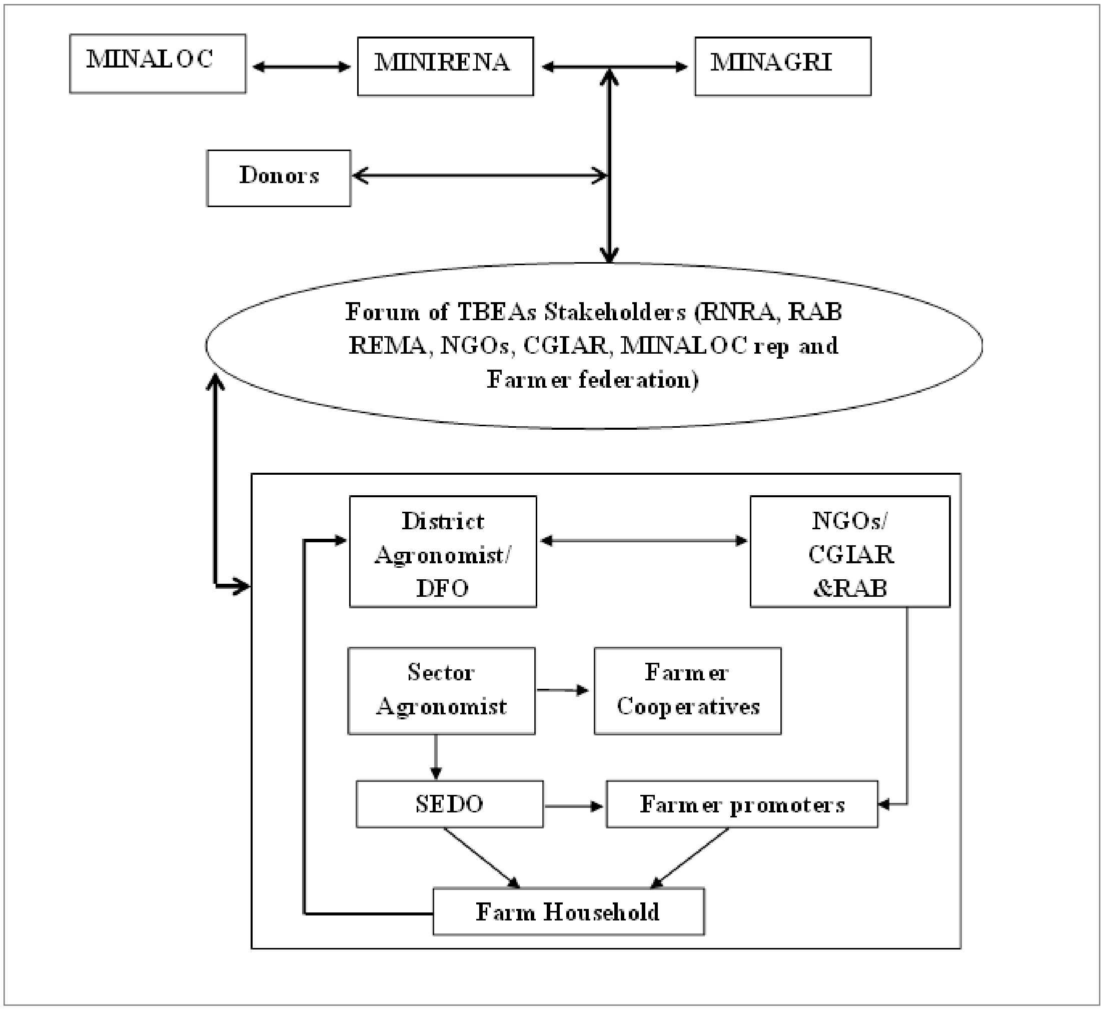

they can take over the initiatives when the projects phase out. The experience from Musanze farmers revealed that most on-farm trees planted by entrepreneurs did not consider farmers' opinions (e.g., on preferred species, niches, and density) and hence were destroyed by farmers in their first year. It is therefore advisable that instead of contracting individual entrepreneurs in tree planting, partnership with local farmer cooperatives should be encouraged. The harmonization of message and extension approaches used by different stakeholders (e.g., RAB, Vi-Agroforestry, World Vision, and ICRAF) in the same geographical and socioeconomical contexts is crucial to avoid uncoordinated messages being delivered to farmers.

## Learning

An evidence-based approach to TBEA scaling-up is needed especially through monitoring and evaluation, knowledge sharing, and training. A compilation of successful stories of TBEAs per agroecological zone should be compiled while planning for the best-bet TBEAs for piloting. Long- term demonstration plots need to be established to be used as didactic materials during Farmer Field Schools. Each district should set up its own demonstration plot to serve as a school for all farmers' associations in the district. This demonstration plot would be managed by the district forest officer and the agronomist.

For the 30 districts of Rwanda, at least 10 best-bet agroforestry technologies can be consistently demonstrated. This would require joint planning and coordination by RNRA and RAB. In addition, the innovation platforms (IPs) (e.g., Kadahenda, Kamonyi, and Bugesera IPs) created by previous projects can be empowered to mainstream TBEAs. The budget to sustain the IPs can be channeled through earmarked transfers that the districts receive from MINIRENA. A translation of existing TBEAs technologies into a farmer-friendly message (all in Kinyarwanda, with illustrating pictures) is needed in the current extension. The innovation-learning-scaling-up cycle involves a linear five-step sequence (see Figure 20).

**Figure 21: Schematic Flow of TBEA Information among Stakeholders**




At grassroots level, knowledge on TBEA should be channeled mainly through farmer promoters in an FFS setting since they are more cost-effective than government extensionists in reaching more farmers, and they are more convincing. A group of farmers with common interests may come together, elect a leader, and set aside land (private or public in collaboration with local leaders) for an agroforestry technology of interest. Trees, crops, and livestock would provide most of the training material and would inform the curriculum. A farmer promoter should then be elected from the group and be trained by extensionists. The integrated curriculum would then be developed in a participatory manner based on demand. After that, the group would establish a tree nursery it would run. This process can be promoted through the Rwanda Landcare movement.

Agroforestry technology that stimulates interest to farmers can then be tested by the group, during which they would be exploring management practices that increase production. The participatory monitoring and evaluation should then be done by the farmer-promoter and by government extensionists at cell level (a socioeconomic development officer) on a weekly basis. The sector agronomist would monitor the groups at a monthly level and report to the district agronomist/ forester, who would then evaluate the performance of the group toward achieving the district's targets.

When NGOs have extensionists working with farmer groups, they would also report on the district agronomist/forester to compile the data on TBEA adoption at district level. For each agricultural season, the forum of TBEA stakeholders would then assess the adoption of TBEAs at the country level. They would adjust and refine the roadmap toward achieving the adoption rate targeted at the policy level and they would provide continuous feedback to the ministries (MINAGRI, MINIRENA, and MINALOC), which would refine the policy spaces needed for TBEA adoption at scale. The flow of TBEA information among stakeholders is illustrated in Figure 21.

# TAKING TO SCALE TREE-BASED SYSTEMS IN RWANDA

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