Australian Government

Australian Centre for International Agricultural Research

World Agroforestry

CGIAR RESEARCH PROGRAM ON Forests, Trees and Agroforestry

TREES FOR FOOD SECURITY-2 PROJECT

RWANDA HIGHLIGHTS

Rwanda Agriculture Board (RAB) · University of Rwanda · World Vision · IMBARAGA · anafe African Network for Agriculture, Agroforestry & Natural Resources Education · CSIRO

Project overview

The 'Developing integrated options and accelerating scaling up of agroforestry for improved food security and resilient livelihoods in Eastern Africa' project also known as Trees for Food Security phase 2 (T4FS-2) is an Australian Centre for International Agricultural Research (ACIAR) funded project aimed at improving food security and smallholder livelihoods through the widespread implementation of appropriate locally adapted agroforestry practices in key agricultural landscapes of Rwanda, Uganda and Ethiopia.

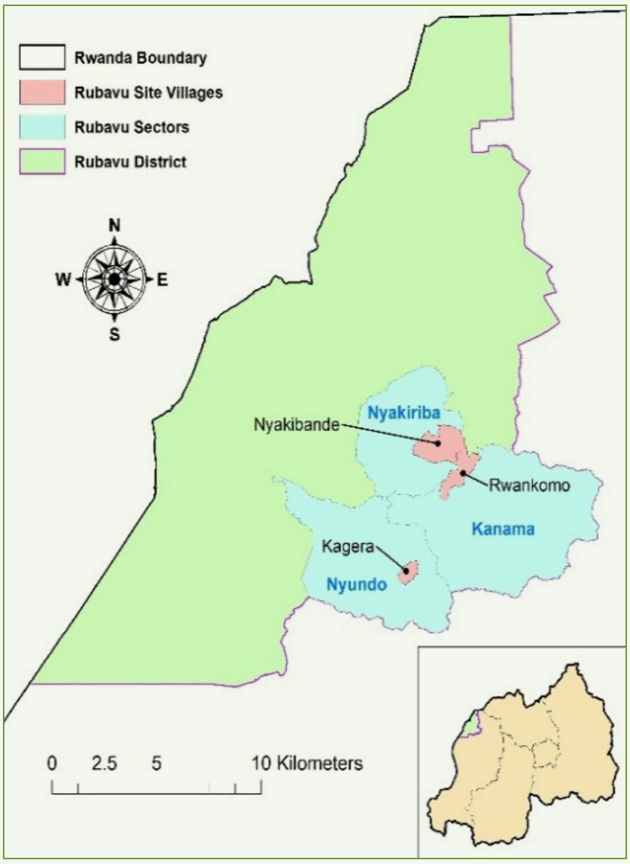
In Rwanda, focus has been on agroforestry research for development to address pressing challenges including malnutrition, poverty, land degradation, climate change and low agricultural productivity. The T4FS project Phase 2 in Rwanda built on achievements of Phase 1 to scale up and increase adoption of agroforestry by smallholder farmers.

Where the project works

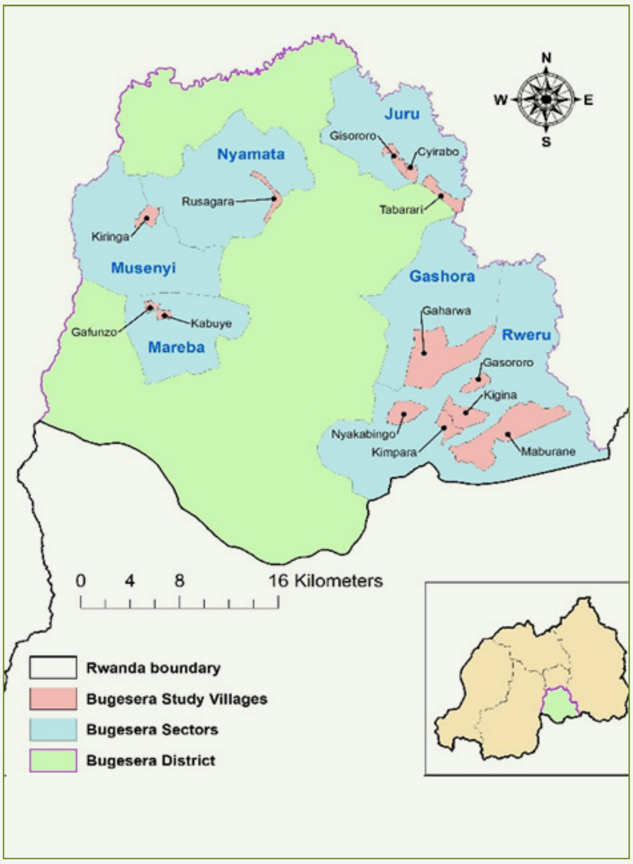
The project intervention sites are located in Bugesera district within the semi-arid zone and in both Nyabihu and Rubavu districts within the humid agroecology of the country. In addition to the sites covered during Phase 1, Phase 2 expanded interventions to new areas as follows:

- Bugesera district: Nyamigina in Mareba sector; Musenyi in Musenyi Sector; and Maranyundo in Nyamata Sector;
- Rubavu district: Bisizi and Gikombe in Nyakiriba sector; Kamuhoza in Kanama Sector;
- Nyabihu district: Gihira in Karago sector and Ruhengeri in Mukamira sector.

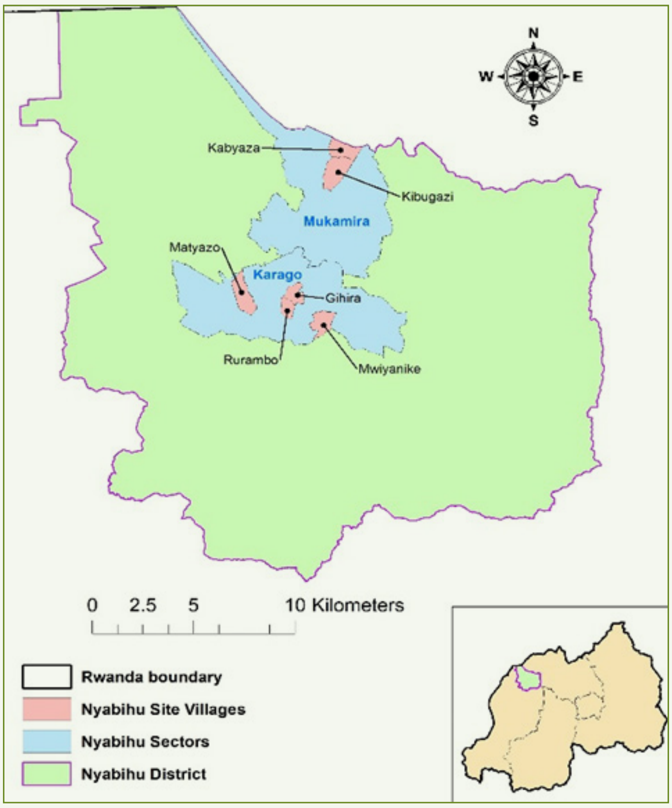
Rubavu Study Villages



Bugesera Study Villages



Nyabihu Study Villages



Map 1: Project sites across Nyabihu, Rubavu and Bugesera districts in Rwanda

Project partners

The project is implemented by World Agroforestry Centre (ICRAF) in partnership with Rwanda Agriculture and Animal Resources Development Authority (RAB), University of Rwanda (UR), World Vision Rwanda (WVR), Urugaga Imbaraga, African Network for Agriculture, Agroforestry and Natural Resources Education (ANAFE), and Commonwealth Scientific and Industrial Research Organization (CSIRO). In addition, the project interacted closely with local governments from Districts to village levels in the way of gathering action plans as well as benefiting from their support in community awareness and mobilization campaigns to implement scaling up/out strategies.

Project achievements

1. Project reach

Through various project activities, more than 30,000 people and another over 80,000 have been directly and indirectly reached. Both in Bugesera and Gishwati agro-ecologies.

Table 1: T4FS-2 project participants in Rwanda

Activity	Number of people directly participating in the project	Total number reached*
Capacity development	4446	11115
Farmers involved in Participatory trials	3183	7958
Tree seedling distribution in RRCs	7246	18115
Tree seedling distribution outside RRCs	11520	28800
Umuganda	4056	10140
Other activities: sensitization meetngs, exhibitions	1997	4993
Postgraduate students (PhD and MSc)	4	4
Total	**32452**	**81125**

*Multiplied by 2.5 which is the average number of people in a household

2. Participatory Trials: farmers testing different agroforestry technologies on their farms

Different types of participatory trials have served as the basis for testing various agroforestry options that adapted to a broad range of farming contexts. A total of 2,290 trials have been established both in Bugesera and Gishwati.

Table 2: Types and number of farmer trials established between 2017-2020

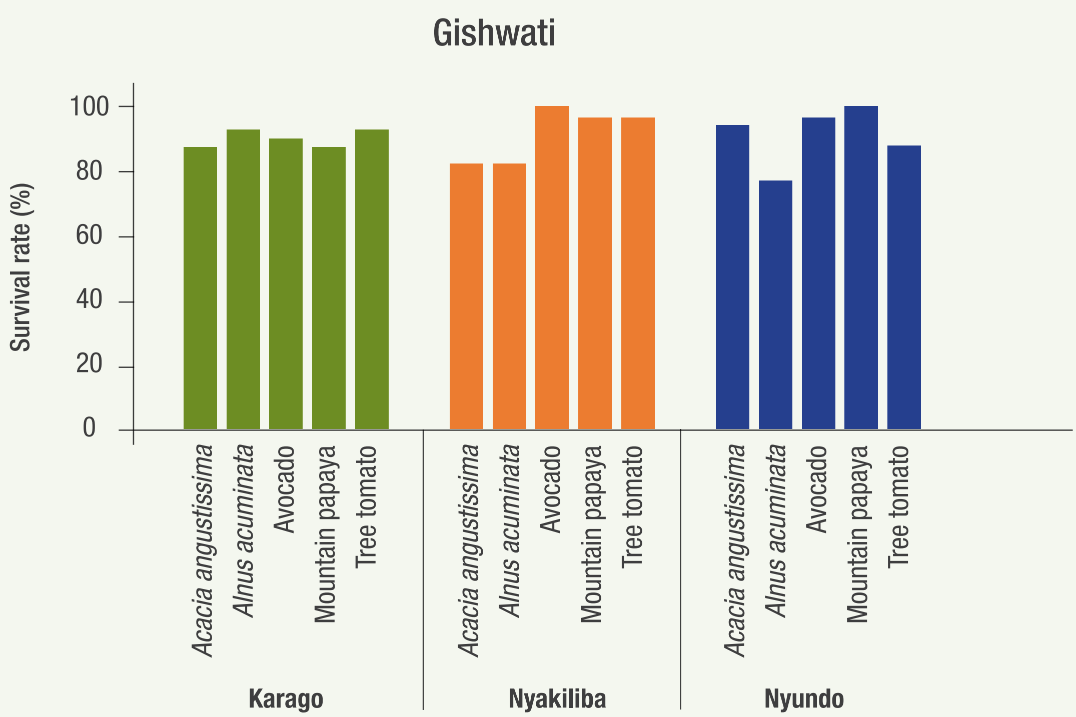
Types of participatory trials	**Bugesera**		**Gishwati**		**Total**	
	Number of trials	**Number of farmers**	**Number of trials**	**Number of farmers**	**Number of trials**	**Number of farmers**
Tree biomass incorporation	401	306	208	153	609	459
Soil Conservation	9	9	174	1370	183	1379
Stakes for climbing beans	193	114	347	273	540	387
Sub-total	603		729	1796	1,332	2,225
Fruits for improved nutrition and income generation						
• Tree tomato	504	504	245	245	749	749
• Grafted avocado	85	85	23	23	108	108
• Grafted Mango	62	62		0	62	62
• Pawpaw	39	39		0	39	39
Sub-total	690	690	268	268	958	958
Total	**1,293**	**690**	**997**	**2,064**	**2,290**	**3,183**

The number of participatory trials increased depending on famers' preferences and agro-ecology. The most preferred trials included fruits for improved nutrition and income generation (958 trials) followed by tree biomass incorporation (609 trials).


Set up of Alnus biomass incorporation at Gishwati (left) and early development of the trial on the use of wood stakes on climbing bean at Bugesera (right)

Survival of Fruit and Multi-Purpose Tree seedlings

In various sites at Gishwati, the survival rates of two agroforestry species - *Alnus acuminata* and *Acacia angustissima* - and three fruit species – Tree tomato, Avocado and Pawpaw (mountain papaya) – were high, greater than 85%. In Bugesera, the survival rate of nearly all fruit species was approximately 75% with some differences among the fruit species and within the sites. For instance, at Juru, more than 95% of the planted avocado survived after planting while the survival rate of tree tomato was very low (26%). The best surviving fruit species (≥ 80% survival rate) included tree tomato and avocado at Mareba; avocado at Musenyi, tree tomato and mango at Nyamata, and tree tomato at Juru.



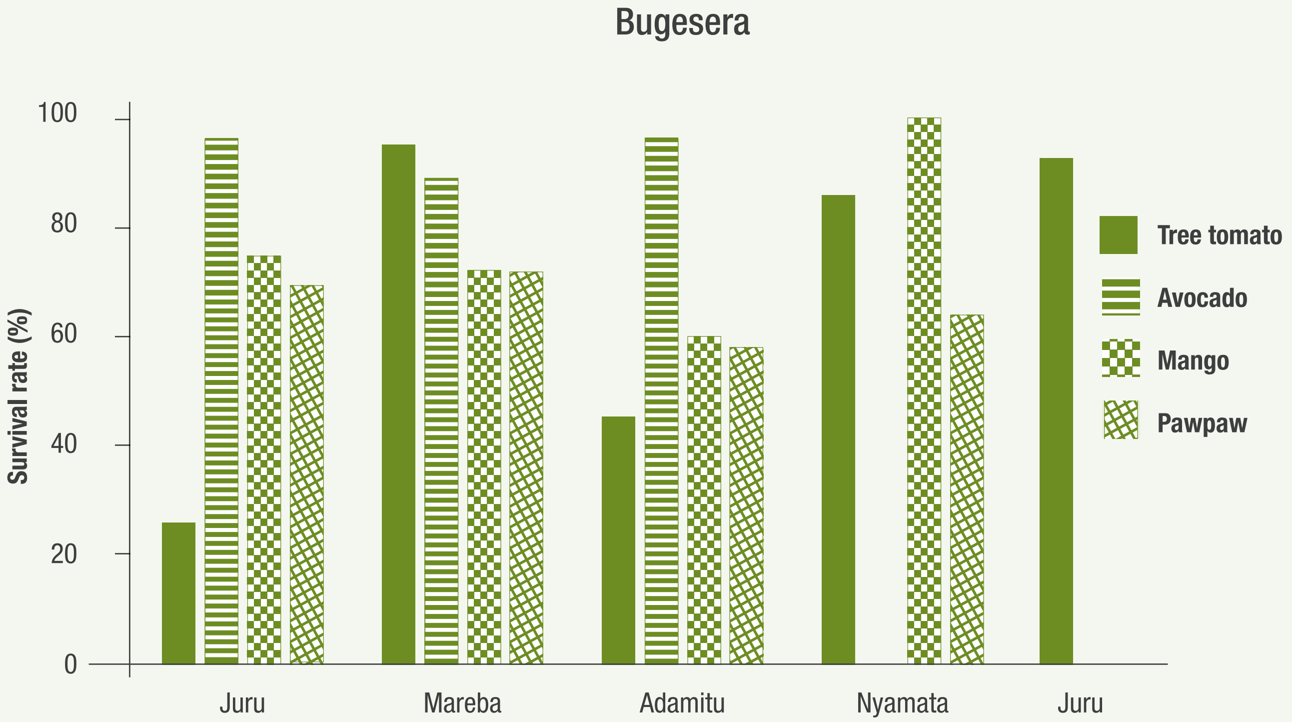


Figure 1: The survival rate (%) of fruit species and multipurpose trees (MPTs) planted on different sites at Gishwati (left) and Bugesera (right)

Tree tomato adapted to the majority of the sites after field planting. From field assessments, fruit species were mostly planted in home compounds and orchards. The high survival rates indicated the importance attributed to fruit trees for nutrition and income generation hence the farmers had implemented the required management practices to increase the fruit survival after planting. The more common practices by the farmers included weeding, fencing, watering, fertilizer and pesticide application.

The use of wood stakes to increase yield of climbing beans

Climbing beans require strong stakes for high yields. However, high prices and lack of quality staking materials have hindered growing of climbing beans. Previously farmers used overgrown Napier grass, maize and sorghum stalks and cassava as stakes. To address this challenge, the project tested selected MPTs specific to contexts - *Eucalyptus* sp., *Calliandra calothyrsus*, *Senna spectabilis*, *Vernonia amygdalina*, *Gliricidia sepium, Grevillea robusta, Lantana camara and Leucaena diversifolia* in Bugesera, and *Alnus acuminata, Acacia angustissima* in Gishwati.

In Bugesera, the use of wood stakes increases the yield of climbing beans from the baseline of 0.7 tonnes per hectare to 2.5 tonnes per hectare ($t\ ha^{-1}$) depending on the type of stake used. Climbing beans had 3 to 4 times greater yield than that of the bush beans in farmer trials. The highest yield of climbing bean was recorded when *Senna spectabilis* and *Gliricidia sepium* stakes were used.

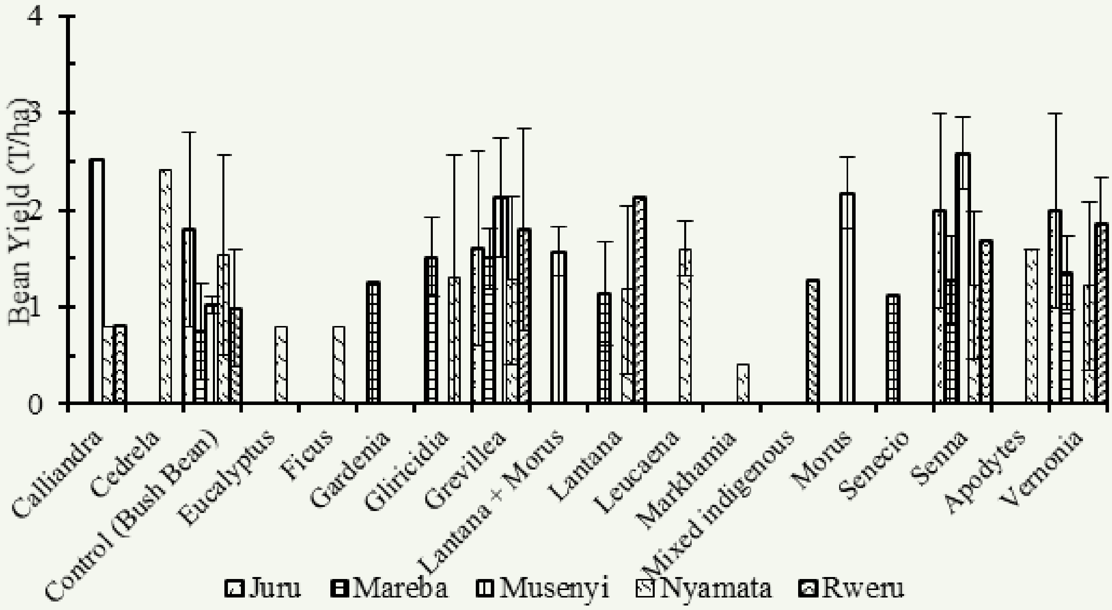


Figure 2: The survival rate (%) of fruit species and multipurpose trees (MPTs) planted on different sites in and Bugesera

In Gishwati, the use of Alnus and Acacia stakes increased climbing bean yield from the baseline of 1.3 t ha^{-1} to 2.0 t ha^{-1}. Gishwati farmers were impressed by the higher yields of bean and the durability of these stakes compared to Pennisetum.

Field visit to the participatory trial on the use of wood stakes on climbing beans at Bugesera

Tree biomass incorporation improved soil fertility and led to higher crop yields

In Bugesera, tree biomass incorporation trials were established in various sites to evaluate crop yield responses to green biomass from several agroforestry species- *Senna spectabilis*, *Gliricidia sepium*, *Vernonia amygdalina* and *Lantana camara,* incorporated alone into the soil or combined with mineral fertilizers namely, Diammonium Phosphate (DAP) and Urea and all compared to non-fertilized plots.


Rwerinyange, a farmer inspecting the performance of maize following application of Senna biomass at Mareba Sector, Bugesera district (left) Maize crop performed better in Alnus biomass incorporation trials in Gishwati (right)

The application of tree biomass combined with mineral fertilizer (Urea and DAP) increased bush bean yield from the baseline of 0.7 t ha^{-1} to 3 t ha^{-1} while Gliricidia biomass + DAP increased maize yield from the baseline of 1.6 t ha^{-1} to 3.8 t ha^{-1}. The findings of the study revealed that the tree biomass of all species combined with mineral fertilizers led to higher crop yields where soils and climate factors were favorable. The application of DAP and Urea coupled with tree biomass resulted into comparatively the highest maize grain yield.

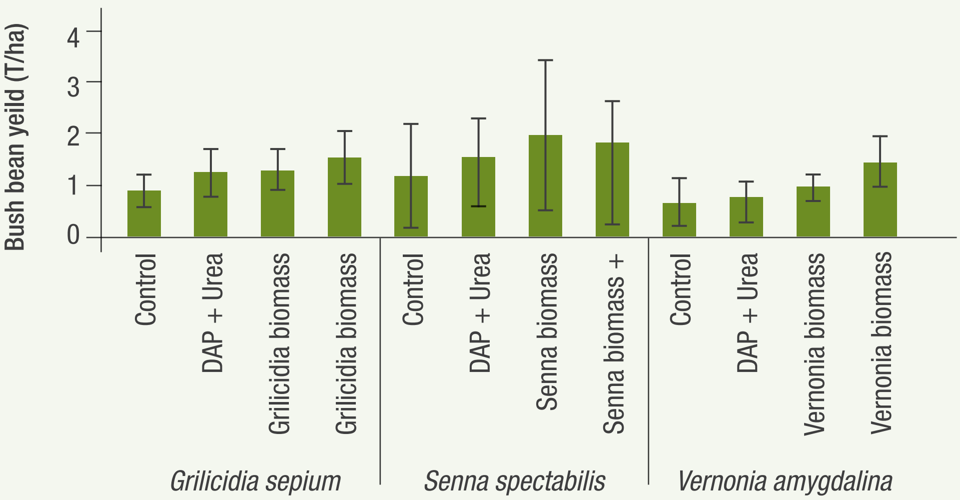


Figure 3: Bush bean yield response to application of tree biomass and mineral fertilizers in Bugesera

In Gishwati at Karago Sector, potato yield was 13.7 t ha^{-1} in plots treated with Alnus biomass plus nitrogen, phosphorous and potassium (NPK) fertiliser 10.8 t ha^{-1} where NPK alone was applied and 8.6 t ha^{-1} in plots with Alnus biomass alone. Untreated plots produced lower yield (8.6 t ha^{-1}) statistically the same as that obtained with incorporation of Alnus biomass alone.

In Nyundo sector, Alnus biomass + NPK achieved the highest maize grain yield (3.9 t ha^{-1}) significantly different from that recorded in the control treatment and in plots where NPK alone and Alnus biomass alone were applied. The maize grain yield recorded in control plots, in plots with NPK alone and Alnus alone was statistically identical and amounted to 2.2 t ha^{-1}. Across all the sites, the maize yield varied significantly among the farmers, from as low as 2.3 t ha^{-1} to 5.5 t ha^{-1}. The variation was due to differences in soil fertility status and farmers' management practices.

Tree tomato shown good performance and fruit yield in farmer trials

In Bugesera, tree tomato fruit maturity occurred from 9 months to about 11 months after planting. Plants with larger Root Collar Diameter (RCD) were likely to produce many fruits. The number of fruits per tree ranged from 16 to 66 depending on site conditions. The average production of fruits of tree tomato was evaluated at 159 kg per beneficiary household per season.

In Gishwati, the average total height and diameter of tree tomato were 1.94 m and 3.90 cm respectively. Taller plants of tree tomato had 2.4 m while the shorter ones recorded 1.5 m. The diameters of tree tomato ranged from 2.2 cm to 4.7 cm. However, there was a very high significant difference in the growth parameters among the farmers. The average crown diameter ranged from 1.1 m to 2.3 m. The crown diameter was positively correlated with the total height in almost 63% of the cases and with the number of fruits produced in 40% of the cases. The average number of fruits produced per tree was about 100, with no significant differences among farms ($p>0.05$). Similarly, the correlation between the root collar diameter and the diameter at breast height was positive and significant for nearly 48% of the cases but the later was negatively correlated with the number of fruits per tree. This implied that tree tomato with smaller diameter at breast height (DBD) tended to produce less number of fruits. Vigorous trees, measured by their root collar diameter (RCD), were likely to produce higher number of fruits in 34% of the cases. The larger the RCD, the more tree tomato fruits were produced.

First production of tree tomato grown by the farmer Fernand Ntibagirirwa at Nyabibuye village

3. Long term trials

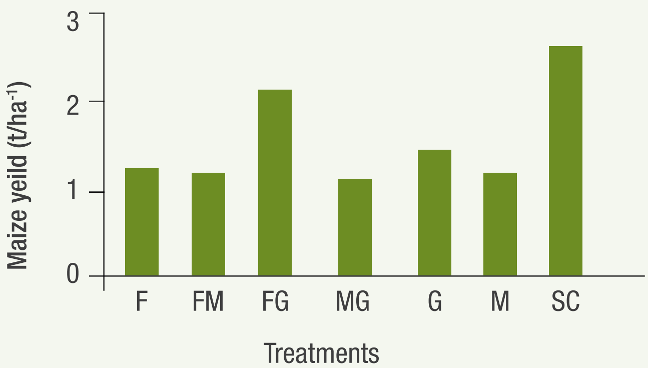
Karama Agroforestry Long term Trial (left) and Tamira Long term trial (right) in October, 2019. Athanase Cyamweshi, a PhD student undertaking tree-crop interaction studies in these trials is in purple tee-shirt

Agroforestry long term trials were established in sub-humid (Gishwati, Karago site) and semi-arid (Bugesera, Karama site) regions of Rwanda to assess the long-term effect of tree cover change on soil fertility, water and crop productivity as explained below

The presence of trees enhanced crop yields in long term trials

In Karama long term trial, maize planted was subjected to various treatments. These included different combinations of tree species in a plot and a crop alone treatment added for comparison purposes with trees treatments. The treatments are: (1) *Faidherbia albida*, (2) *Faidherbia + Markhamia lutea*; (3) *Faidherbia+Grevillea Robusta*, (4) Markhamia L. (5) *Markhamia L. +Grevillea R.*; (6) *Grevillea robusta;* (7) Crop alone.

The evaluation of the effect of tree species and their combination on maize yield indicated that yield in sole crop (without trees) was significantly higher (2.6 t ha^{-1}) than the yields recorded in other treatments.



F = *Faidherbia albida*

FM = *Faidherbia albida + Markhamia lutea*

FG =*Faidherbia albida + Grevillea robusta*

G=*Grevillea robusta*

M=*Markhamia lutea*

SC= sole crop with no trees

Figure 4: Maize yield under different tree species, plantation mixtures and in open field in Karama Long term trials

Tree management, particularly pruning, has positive effect on crop productivity

A tree management treatment was introduced and consisted of pruning *Grevillea robusta* at 50% and 75% pruning to assess the efficient tree management practice to be recommended to farmers. Results showed that the highest maize yield was recorded by the treatment of *Markhamia lutea* (6.1 t ha^{-1}) followed by the treatment of sole maize crop (5.2 t ha^{-1}). Plots consisting of the combination of pruned *Fairdherbia* and *Grevillea* following farmers' practice (50% pruning) resulted into higher maize yield, identical to the yield obtained in sole crop. In general, pruning Grevillea, Fairdherbia and Markhamia at 50% recorded numerically the highest yield, except in pruned grevillea trees at 75% branch pruning.

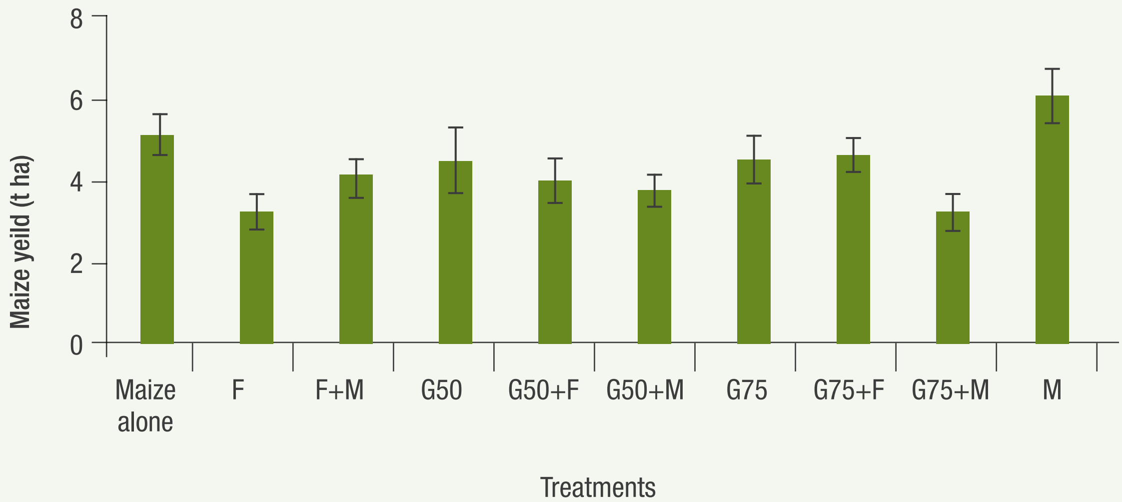


Figure 5: Tree species and management effect on maize yield in Karama long term trial. F, G and M mean Faidherbia albida; Grevillea robusta and Markhamia lutea, respectively. 50% and 75% mean the levels of pruning) of G. robusta. Error bars represent standard error of means.

In Tamira Long Term Trial, the effect of tree management on wheat yield was assessed, the treatments comprising pruning Alnus trees at 75% and 90% (farmer practice), application of alnus biomass (B), no alnus biomass application (NB) and crop alone without trees (C). The results showed that treatments with Alnus biomass yielded higher than without green manure. The highest yield was found in plots with no trees, followed by the plot with 90% pruning.

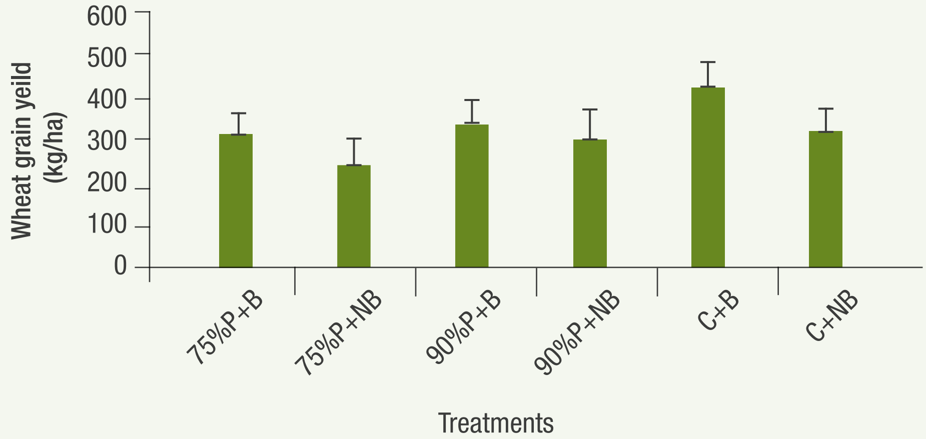


Figure 6: Alnus tree pruning and green manure effects on wheat yields in Tamira Long Term Trial. B means treatment with incorporated alnus green manure. NB means treatment with absence of green manure; C means plots with crop alone without trees; the numbers 75% P and 90%P corresponds to the percentage of Alnus tree pruning.

Alnus-based agroforestry system store large amounts of carbon dioxide and offer other ecosystem services in the Sub-humid region of Rwanda

To understand carbon sequestration and other benefits of *Alnus acuminata,* a survey of 146 households, tree inventory over 13 ha of farmland and destructive measurements of 172 stems were made in the project area within the sub-humid western province of the country. It was found that over 75% of the sample households had alnus trees in their farms. The trees provided stakes for climbing beans, firewood and timber. The trees also were reported to improve soil fertility and control soil erosion. The average alnus tree density per farming household ranged from 130 and 161 trees per hectare, with an average total height of 7.7 m and diameter at breast height of 16.3 cm.

The largest biomass proportion was found in stems (70.5%) while branch and leaf biomass represented about 16.5% and 13% of the total biomass, respectively. At farm level, aboveground biomass of alnus trees was estimated at an average of 27 megagrams per hectare (Mg ha^{-1}) representing 13.6 mega grams of carbon per hectare (Mg C ha^{-1}). Biomass carbon increased with tree size, from 7.1 Mg C ha^{-1} in 3 years old trees to 34.4 Mg C ha^{-1} in 10 years old trees. However, biomass carbon decreased with increasing elevation from 21.4 Mg C ha^{-1} at lower elevation (2011-2110 m) to 9.6 Mg C ha^{-1} at higher elevation (>2510 m). Alnus-based agroforestry significantly contributed to carbon sequestration, although the magnitude of these benefits varied with tree age and elevation. Therefore, Alnus tree planting on farms as exemplified by the project, could meet local needs with respect to wood products (stakes for climbing beans, timber, fuelwood) and other ecosystems services such as soil fertility improvement, erosion control, carbon sequestration and climate regulation.

Methods used for the estimation of tree biomass including standing tree measurements (A); destructive sampling for tree biomass partitioning (B) and determination of oven-dry weight of tree biomass samples (C)

Increased tree cover plays a role in enhancing crop productivity

Phase 1 and Phase 2 of the T4FS project contributed largely to the increase of tree cover in Bugesera and Gishwati agroecologies. Socio-economic surveys and on-farm inventories involving 107 households in Bugesera and 146 households in Gishwati indicated that many farmers (35.3%) have learnt to grow trees on farms. Trees of a suite of tree species were grown mainly for fuelwood (24.2% of respondents), soil fertility improvement (34.7%) and were appreciated for their compatibility with crop (30.1%). In many cases, trees were scattered on agricultural land for 37.5% of the cases. Grevillea was frequently planted in Bugesera (14.8%) and Alnus in Gishwati (83.9%). The main crops grown with trees were beans (31.5%). The yield of beans decreased (0.36 t ha^{-1}) in area without trees compared with area covered with trees (0.63 t ha^{-1}). This trend was the same for other crops. Lack of seedlings was cited as a constraint to expanding the tree cover on farmland by nearly 25% of the surveyed households in Bugesera and 40% in Gishwati, suggesting that access to quality tree germplasm in sufficient quantities targeting specific areas could increase tree cover and benefit millions of farmers in Rwanda.

4. APSIM and SIMILE modeling

A modelling capability is now available that dynamically links the SIMILE a farm-scale livelihood modelling dynamically to APSIM plot-scale biophysical modelling for agroforestry. To implement this in Rwanda, data were collected from a field experiment in a gliricidia-maize/bean system, and modelling has commenced for plant production using APSIM, and farm-scale modelling has been designed using SIMILE.

Data indicate that including gliricidia in the farming system and using its biomass to fertilize adjacent cropping zones can improve the yield of maize within these zones if gliricidia rows were 6m or more apart (Fig. 7). Maize yields were suppressed if rows were only 3m apart. These general responses could be simulated using APSIM, and simulated yields averaged across the whole field (effective yield) were only higher if maize rows were 6m or more apart (Fig. 8).

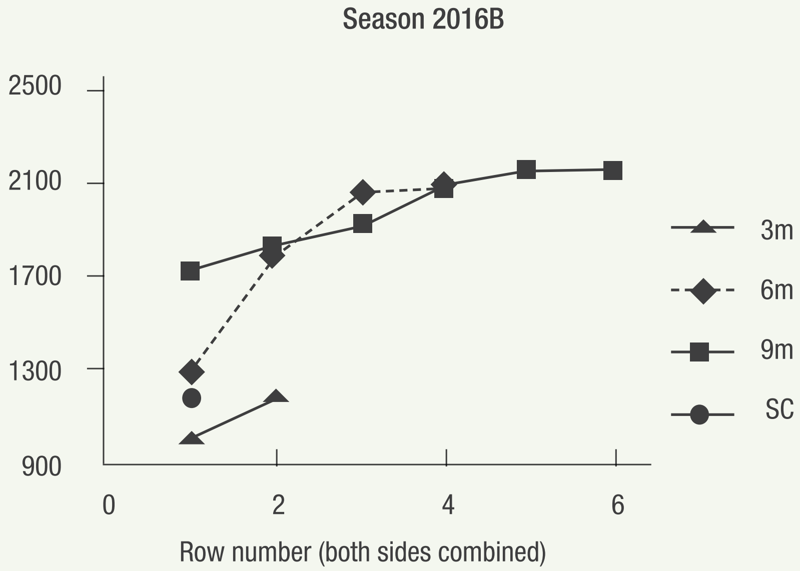


Figure 7: Effect of gliricidia row spacing and maize row number (away from the gliricidia row) on maize yields for the 2016B season at the gliricidia experiment in Rwanda

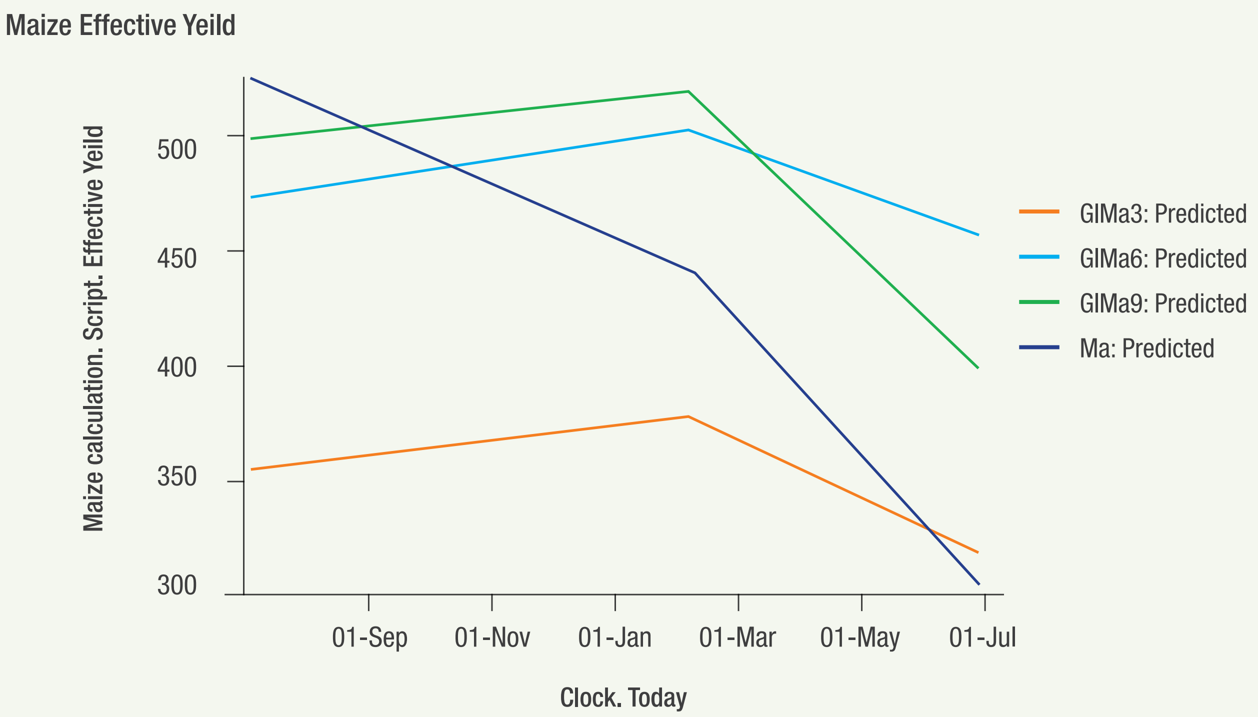


Figure 8: Simulated effect of gliricidia row spacing on effective maize yields

Using gliricidia branches as stakes for climbing beans in a maize/bean rotation system increased bean yields 61-135% (Table 3), but simulation of beans has not yet commenced.

The schematic diagram below indicates interactions of plot- and farm-scale models using APSIM and SIMILE that follows soon.

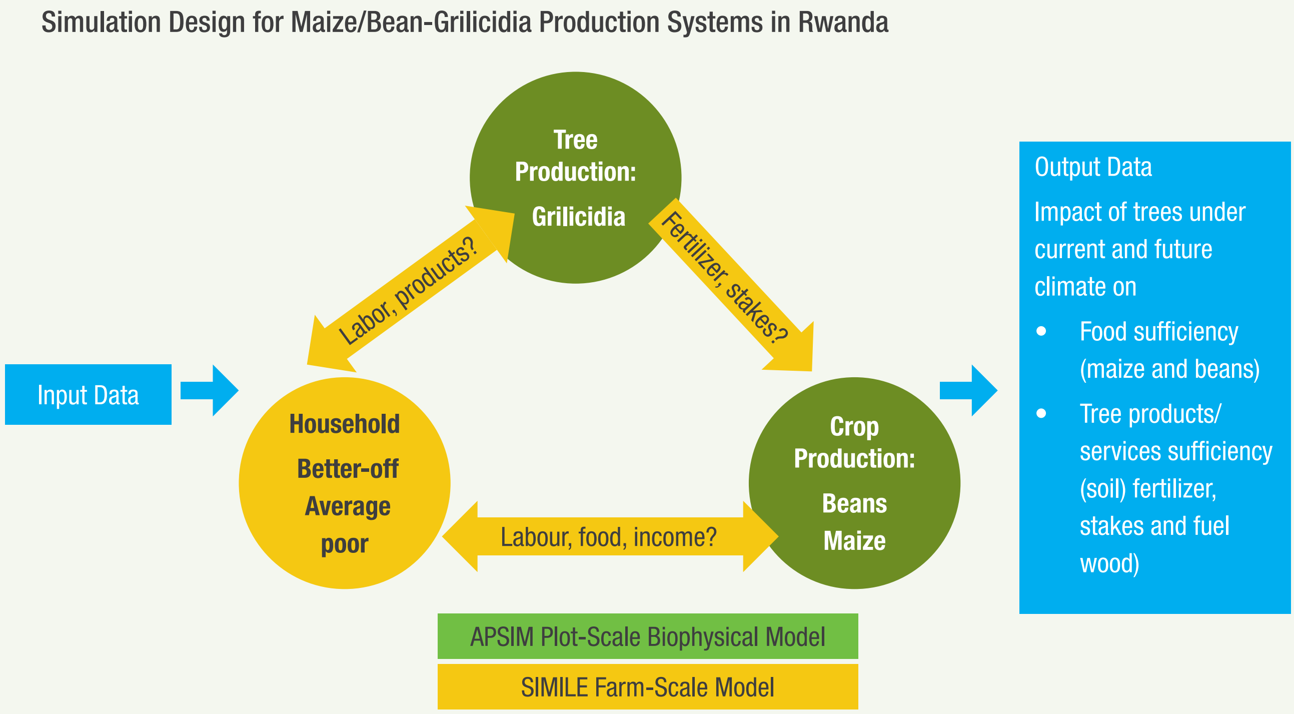


Table 3: Effect of gliricidia row spacing on yields of bush and climbing beans

Spacing Treatment	Bush beans [1]Beans (kg ha^{-1})	Climbing Beans (kg ha^{-1})	Increase %
3m	212[a]	499[b]	135
6m	486[b]	776[b]	60
9m	473[b]	826[b]	75
Sole Crop	704[c]	1130[c]	61

[1] The same letter within a column are not statistically significant (P=0.05)

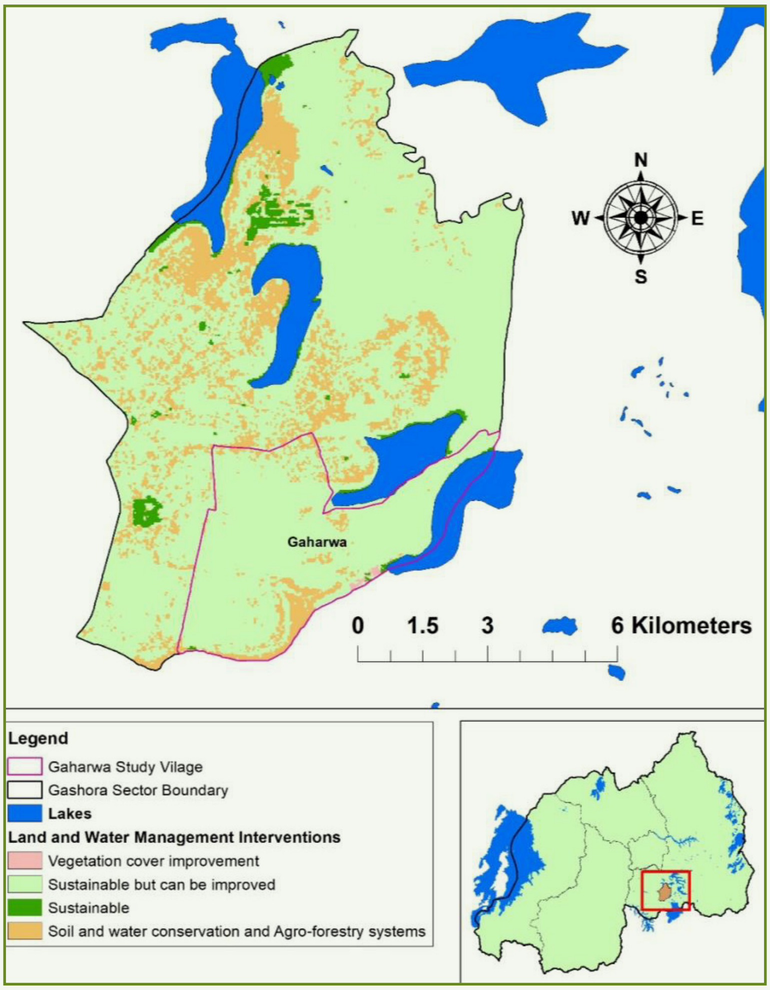
In addition, maize yield in the maize zones relative to maize-only was simulated in a gridded pattern across the whole country. Competition for water and nitrogen led to relative yields less than 1.0, with the least (0.2) in the east where competition was greatest (Fig. 9).

5. Agroforestry for land and water management

Lake Karago before and after sustainable land management interventions © Anne Kuria

A total of 66 maps have been generated from geospatial analyses of the biophysical parameters- rainfall, topography/slope, land use and cover, and soil type as well as socio-economic aspects such as the poverty indices and population density. Another 33 maps were produced which provide appropriate land and water management interventions based on the context. For instance, land and water management options were identified for all the sites in Gashora sector, Bugesera district. The mapping found that nearly 70% of Gashora landscape was sustainable but could be improved by implementing land and water management interventions. The area requiring soil and water conservation (SWC) and agroforestry interventions was 16.27Km^2 or 16.5% of the sector. The proportion of the sector deemed sustainable was 9.8%.

Gashora Sector Land and Water Management Interventions



Map 2: Land and Water Management Interventions for Gashora Sector

The planting of multipurpose tree species such as *Alnus acuminata*, *Acacia angustissima* and *Gliricidia sepium* has helped to improve soil fertility as well as reduce erosion. At the same time, these trees are contributing to the increase of tree cover in the country hence contributing to local microclimate moderation and carbon sequestration. In Gishwati site, households have benefitted from soil and water management technologies through establishment of erosion control structures such as terraces and planting of agroforestry trees to strengthen the structures in Rubavu and Nyabihu. Tree growing on farms, terracing as well of adoption of sustainable farming practices has contributed to reduced siltation in Lake Karago in Nyabihu District.

6. Policy and Stakeholder Engagement

Through the project, ICRAF and RAB have contributed to the development of the National Agroforestry Strategy and Action Plan. The development of the ten-year strategy was spearheaded by the Food and Agricultural Organisation (FAO) in Rwanda. The strategy provides a roadmap for coordinated actions and agroforestry development in the country to meet its national targets and global commitments such as the Bonn Challenge.[1]

The T4FS-2 Project has aligned its interventions with other government strategies and programmes such as the National Strategy for Transformation (NST) and National Forest Policy.[2] It has contributed to building the capacity of the government staff in agroforestry development. On request by the Ministry of Natural Resources, the project supported the development of various training and extension materials including manuals on agroforestry options, tree nursery management, grafting techniques of fruit trees, on-farm tree planting and management, and pests and diseases management in agroforestry.

The T4FS-2 project was also linked with several projects in the country such as Land Husbandry, Water Harvesting and Hillside Irrigation (LWH)[3], Forestry Landscape Restoration, Regreening Africa, harnessing the potential of trees-on-farms for meeting national and global with biodiversity targets.[4] Moreover, the project has collaborated with the farming communities, local authorities and church leaders.

7. Rural Resource Centres (RRC): Platforms for learning and supply of quality tree germplasm

The two Rural Resource Centres (RRCs)-Karama and Karago[5] established during the first phase of the project continue to facilitate production of quality fruit and multipurpose tree planting materials as well as serve as platforms for dissemination of agroforestry knowledge. Another fourteen RRCs have been established in Mulindi in Bugesera, Kayonza, Gatsibo and Nyagatare by Rwanda Agricultural and Animal Resources Development Board (RAB).

Karago RRC operated by Kadahenda Innovation Platform (left) and a Cooperative Nursery supported by the project (right) at Juru Sector

[1] https://www.bonnchallenge.org/pledges/rwanda

[2] https://www.minecofin.gov.rw/fileadmin/National_Strategy_For_Trsansformation_-NST1.pdf

[3] https://www.gafspfund.org/projects/land-husbandry-water-harvesting-and-hillside-irrigation-project-lwh

[4] https://www.worldagroforestry.org/project/harnessing-potential-trees-farms-meeting-national-and-global-biodiversity-targets

[5] https://www.worldagroforestry.org/publication/karama-and-karago-rural-resource-centres-new-approach-delivery-agroforestry-technology

In addition, the project has also partnered with community-based groups, farmer cooperatives to establish satellite nurseries to produce and provide quality tree germplasm. These have been distributed to the wider community including schools, churches, and health centers for planting on their land.

Through the RRCs, and satellites nurseries supported by World Vision Rwanda and IMBARAGA, a total of 1,019,965 seedlings have been produced and distributed during the second phase. These seedlings are valued of about USD 128,820.

Table 4: Tree and fruit seedlings produced and distribution during phase 2 of the T4FS project

Type of nursery	Fruit seedlings	MPT seedlings	Total
Rural Resource Centres (Karama, Karago)	53,468	196,389	249,857
Project supported Cooperative nurseries (Satellite nurseries)	129,180	640,928	770,108
Grand Total	**182,648**	**837,317**	**1,019,965**

The satellite nurseries operated by farmers cooperatives and individual farmers provided employment and generated substantial income to their members, enabling them to buy assets such as land, build or rehabilitate houses, pay for health insurance and school fees.

8. Scaling out activities through Umuganda

Planting of trees on farm during Umuganda

Awareness raising on agroforestry after Umuganda

In Rwanda, every last Saturday of the month has been set aside for community work commonly known as 'Umuganda'. The project has used this as a platform to sensitize communities on importance of agroforestry. This action has brought together farmers, local authorities, and diverse stakeholders in agroforestry to plant trees on sites participatory selected. Messages on the importance of agroforestry, agroforestry species and tree management as well as sustainable land management were disseminated. Umuganda has also been used as an approach to distribute seedlings and promote tree planting efforts for soil conservation and erosion control especially at Karago and Nyundo. For instance, through Umuganda in 2017, the farmers planted nearly 10,000 seedlings of Alnus and Acacia in Gishwati. Similarly, during the same year, farmers in Bugesera planted 23,260 seedlings of a diverse range of tree species comprising *Grevillea, Calliandra, Leucaena,* Senna and *Gliricidia*.

9. Tree-based value chains and financing options

Some of the identified viable value chains include tree nurseries, Grevillea and tree tomato. The financing options identified include equity capital-building of savings; group savings- cooperative; linking of cooperatives to financial institutions.

A smallholder tree tomato farmer on her farm © Alis Okoji

10. Tree tomato value chain competitiveness

To shape the tree tomato industry in Rwanda for the benefit of smallholder farmers and the Rwandan economy at large, it is critical to understand the industry's competitive forces and their underlying causes. A study on the competitiveness of tree tomato industry was conducted in order to determine factors that influence the competitiveness of the tree tomato value chain and propose strategies that could help to improve the competitiveness of tree tomato value chain in Rwanda. 120 farmers from Bugesera and Nyabihu Districts of Rwanda and traders were surveyed using a semi-structured questionnaire. Porter's (1998) theory for the determinant of competitiveness was used as a base in designing the questionnaire to capture the enhancing factors influencing competitiveness success. In addition, focus group discussions were held with tree tomato producers and with some traders/distributors and also stakeholders like representatives of ICRAF, Rwanda Agricultural Board, National Agricultural Export Board, Ministry of Commerce and Financial institutions.

The findings of the study show that the factors that hamper the tree tomato value chain competitiveness in Rwanda include the bargaining power of suppliers reported by 63 percent of interviewees, the bargaining power of buyers reported by 58.43%, the severity of the threat of new entrants reported by 22.28%, the intensity of rivalry in existing key competitors reported by

65.60%, the severity of the threat of substitutes reported by 71.74%. The strategies proposed to improve the competitiveness of tree tomato value chain comprise the improvement of linkage between and collaboration of tree tomato chain actors which could lead to the reduction in transaction costs, improvement of the farmers' level of integration into the value chain and farmers' technical know-how and production capacities in order to play an improved crucial role in the value chain. The formation of farmer cooperatives will also give voice to the farmers. Further, the potential buyer of restaurant/hotels/other institution consumers can spell out certain product criteria and also assist farmers in their production activities to ensure a regular supply of tree tomatoes to the buyers. The tree tomato value chain in Rwanda has a strong rivalry from imports from Tanzania. This competition can provide an opportunity for the spread of innovation along the tree tomato value chain which in the long run will make the tree tomato industry in the Rwandan sector more competitive either on local, regional, and international markets.

11. Review of agroforestry curriculum

An institutional assessment was conducted to gather as well as provide current information on how agroforestry is incorporated in existing education programs. The survey targeted teaching staff and programme managers from two universities, one Integrated Polytechnic and six Technical and Vocational Education and Training (TVETs) Institutions offering forestry or agroforestry courses. Some of the challenges highlighted from the survey include lack of access to electronic resources and teaching which is more theoretical as opposed to practical due to lack of training equipment and tools. Among the key recommendations include integration of entrepreneurship, continuous training for TVET trainers especially those teaching agroforestry/forestry and review of the agroforestry curricula for adaptation and integration of emerging concepts.

In March 2019, ANAFE organized a regional agroforestry curricula development workshop which was held at Kenyatta University in Nairobi. The aim of the workshop was to develop an innovative agroforestry curriculum guide to address the gaps identified during the survey on status of agroforestry curricula and extension training in the different project regions. There were several training staff from the University of Rwanda who participated in the regional workshop. Using the Regional Innovative Agroforestry Curriculum Guide developed in the workshop, the University of Rwanda has been able to review its two undergraduate programs – agroforestry and forestry. Following this exercise, 20 modules out of the 24 modules were wholly or partially revised translating to 75% of topics contained in the guide. In the University of Rwanda alone, an average of 200 undergraduate students will benefit from the reviewed program each academic year. The University of Rwanda has gone a step further by sharing the Regional Innovative Agroforestry Curriculum Guide with other nine institutions including higher learning institutions and 2 TVETs teaching agroforestry in Rwanda to facilitate them in reviewing their programs. As a follow up activity to the development of the agroforestry curriculum, ANAFE also conducted an online training workshop on training materials development and teaching staff from the University of Rwanda took part in the training.

12. Impact assessment in Rwanda

An impact assessment study was undertaken in the project sites- Bugesera, Nyabihu and Rubavu districts to understand the effectiveness of participatory trials in scaling out agroforestry interventions being tested by the farmers as well as unravel the pathways through impacts from the interventions manifested. A total of 573 farmers were sampled from both project and non-project sites. Focus group discussions, interviews with key informants and face to face interviews were used to collect data.

Preliminary results from the study indicate that more farmers in the project sites than in the non-project sites have taken up promoted agroforestry practices such as tree planting, use of quality germplasm, grafting, biomass incorporation. A significant increase in the percentage of households taking up different agroforestry practices was noted in the sites that have benefited from the two phases of the project. There also has been significant increase in the proportion of farmers taking up tree tomato production in the project sites compared to the non-project sites. The study recommends for cost-effective and sustainable options for providing quality germplasm to the farmers while building their entrepreneurial capacity need to be explored including linking farmers to private sector actors to improve efficiency in the supply and distribution of disease-free planting materials for tree tomato and other fruit trees. Another key finding was an increase in tree density and diversity. This may be attributed to increased access to more diverse species including sensitization of farmers of the benefits of having different tree species by households in the project sites.

Focus group discussion with women during impact assessment study © Ruth Kinuthia

13.Capacity development

Approximately 4,450 beneficiaries, comprising 1,788 male and 2,662 female have been reached through various capacity development activities as shown in the table below. The capacity of the technical and scientific staff across partner institutions was developed by conducting training on Open Data Kit (ODK) for data collection, soil sampling and measurement, and appropriate land and water management technologies.

Table 5: Number of people reached through the various capacity development activities in Rwanda

Capacity Development activity	Male	Female	Total
Academic and professional trainings (Undergraduate, postgraduate and Internships)	11	15	26
Project staff training (Open Data Kit (ODK), soil sampling and measurement, land and water management technologies)	34	21	55
Training of Extension Staff (agroforestry, extension, ODK)	38	20	58
Farmer trainings (seedling production, mango/avocado grafting, participatory trials, tree tomato management)	1705	2606	4311
Total	**1788**	**2662**	**4450**

Field practical during the training on soil sampling and measurement (left) and appropriate land and water management techniques (right)

Awareness meeting on agroforestry (left) and farmer training on participatory trials (right) at Bugesera

The project has also developed a web-based Interactive Suitable Tree Species Selection and Management Tool for Rwanda.[6] The tool helps to evaluate the suitability of trees by matching the environmental conditions of the area, associated products and ecological functions of the species and the socio-economic contexts of the farmers. Translation of the tool into local language and conversion into a mobile application is planned.

Success Stories

Green manure from *Alnus acuminata* boosts crop yields in the Rwandan highlands

The high cost of mineral fertilisers puts them beyond the purchasing power of many smallholder farmers limiting their use, especially for crops not subsidized by government schemes, such as potatoes and beans. Biophysical factors constraining agricultural production include soil erosion, low organic matter and nutrient depletion caused by continuous cropping without addition of adequate fertilizers to compensate soil nutrients exported in crop residues and through nutrient leaching.

Declining soil fertility has transformed several previously highly productive areas into low production zones. Previous studies indicate that this arose through negative nutrient (Nitrogen, Phosphorus and Pottasium) balances. This situation exposes farmers to food insecurity and calls for new thinking to rebuild crop productivity in Rwanda by investing in options that are likely to be adopted by farmers. Leaf biomass from nitrogen fixing trees (known as fertiliser trees) for example, can complement little available organic fertilisers (compost, manure) at farms level to improve soil fertility and boost crops productivity.

[6] *http://apps.worldagroforestry.org/suitable-tree/rwanda*

Incorporating Alnus green manure on the farm

Alnus acuminata[7] is a widely adopted nitrogen-fixing tree in the Rwandan highlands. It is used by farmers to obtain stakes, erosion control and firewood but rarely as green manure. In 2014/2015, Kadahenda Innovation Platform promoted application of *Alnus* green manure combined with a source of phosphorus (DAP), increased yields of beans (by between 31 and 74% over farmer practice of manure or compost alone) and potatoes (by 20 to 57% over the DAP+Urea normally used by farmers) in the Karago area. Potatoes, as a cash crop, contribute to income for households in the area. Today, the use of *Alnus* green manure supported by T4FS-1 and T4FS-2 to improve soil fertility is common practice in Karago as observed at Tamira in Rubavu district, Western province of Rwanda.

Most abundant nodules observed on lateral roots were effective with red colour inside the nodules. Marie Jose a local farmer, said that she had been using Alnus as stakes, firewood or poles but never knew it was a powerful source of green manure with high potential of improving soil fertility. She and other farmers reported that, "*Now, besides, compost and manure, we have another important type of fertiliser*". Yadufashije, another Karago farmer stressed that using green manure reduced the cost of urea on his potatoes. Yankurije Theogene added that, "*When you consecutively apply for many seasons (four to five), the soil becomes dark in colour, which is a sign of good soil health*". These farmers have increased the density of trees planted on their own farms and trained other farmers to use green manure. Around Tamira, farmers are asking for Alnus seedlings to grow.

Abundant nodules observed on lateral roots with addition of Alnus green manure

[7] Cyamweshi RA, Muthuri CW, Mukuralinda A, Kuyah S. 2019. Alnus acuminata: an effective fertilizer tree for smallholder farmers in sub-humid regions of Rwanda. Poster, World Agroforestry Congress, Montpellier, France *https://www.worldagroforestry.org/publication/alnus-acuminata-effective-fertilizer-tree-smallholder-farmers-sub-humid-regions-rwanda*

Tree tomato generates income and fights malnutrition

Ripe tree tomato fruits

Through T4FS-2 project, farmers of Bugesera learnt from Nyabihu Kadahenda Innovation Platform and planted 500 seedlings of tree tomato *(Cyphomandra betacea)*. More famers are planting tree tomatoes and raised farm income enough to invest in other livelihood (buy more lands, house rehabilitation, goats etc). In addition to income generation, it contributes to improved nutrition. Through exchange visit between Kadahenda and Bugesera farmers, the latter learnt about the socio-economic importance of tree tomatoes and decided to try them in Bugesera known as an unsuitable area for growing tree tomato.

Emmanuel Tuyizere is champion farmer[8] who worked with the project to expand tree tomato cultivation in Bugesera. When he was taken to Kadahenda during field visits he said, ‘Even though tree tomato is likely to be unsuccessful in Bugesera, let us try it there’. He then took 500 seedlings from RRC Karago to plant on his own farm in Bugesera semi-arid region. At the first harvest, he produced one tone from 500 seedlings planted. He sold the fruits at the local market (500 RWF per kg) and Kigali market (800 RWF per kg equivalent to US$ 1).

Twagiramungu Vianney is another champion farmer at Mareba sector, Bugesera district, who has planted 116 tree tomatoes. At maturity, he was able to harvest 20 kg of fruit per week, which he sold to his neighbours and local market. Towards the end of 2019, he reported earning income of 230,000 Rwandan Francs or US$ 250 after only few months of harvest.

Since the start of TF4S- 2, farmers from Bugesera Innovation Platform (IP) have managed to plant more tree tomatoes and earned income from selling tree tomato fruits, seeds and seedlings. Many more farmers are investing in tree tomato production to meet the rising market demand, especially in Kigali City. Tuyizere, a farmer from Bugesera has now increased the number of planted tree tomato to nearly 8,700 and owns a nursery where he raises and sells seedlings to the farmers. As a result, 120 neighboring farmers are growing tree tomato. Tree tomato farmers have improved their nutrition and household incomes, enabling them to buy foods, assets (land, cows), renovate houses, pay health insurance and school fees. For instance, Tuyizere had a very small land which was insufficient for growing all the food required by the family. The income accrued from tree tomato has enabled him to buy additional land where he is able to grow diverse crops including tree tomato. The money from tree tomato allows him to buy other foods on market for improving nutrition such as milk and meat.

Harvested tree tomato fruits

[8] Mwita C. 2018. Long walk after genocide: How Rwandan farmer made it. *https://theexchange.africa/industry-and-trade/agribusiness/long-walk-after-genocide-tree-tomatoes-impact-rwandese-farmers-life-as-he-smiles-to-the-bank/*

In the project sites, the production of tree tomato has brought about positive externalities to non-planters through the consumption of purchased fruit. In fact, the fruits are rich in vitamins, iron, dietary fibre and minerals[9] sufficient to enhance family nutrition.

Durable stakes from trees enabling growing of nutritious and high-yielding beans

Climbing beans grown in Gishwati require staking support to ensure optimal growth. The availability and high cost of staking material continues to be a major issue constraining the production of climbing beans and hence threatening food security in Karago and Bahimba areas in the Western province of Rwanda. Farmers in the degraded landscapes mostly use Napier grass (*Pennisetum purpureum*), which they describe as of low durability and weak in supporting beans, leading to low bean production. On the other hand, farmers with access to tree stakes reportedvigorous growth and higher bean production. To sustainably address this situation, the T4FS-2 project introduced agroforestry interventions that not only provide stakes but also contribute to improvement of soil fertility.[10] Three tree species were introduced- *Acacia augusitissima, Alnus acuminata* and *Vernonia amygdalina.*

Farmers described trees which produce good stakes for the beans as: those that have fast growth rate and good coppicing ability (*Eucalyptus sp.* and *Alnus acuminata*), and those trees that produce more stakes per individual tree (such as, *Ficus thonningii*). Other qualities include: length of stakes, strength of stakes and durability. Durability was described as the ability to be utilized for many seasons without breaking or being attacked by insects. From local knowledge studies, farmers ranked *Eucalyptus sp.* and *Arundinaria alpina* stakes as being the most durable (lasting from five to seven planting seasons); followed by *Alnus acuminata* and *Vernonia amygdalina* (four to five seasons), *Grevillea robusta* and *Ficus thonningii* (three to four seasons), while *Pennisetum purpureum* only lasted one season. Joseph Desiré,

Strong stakes from trees to hold additional weight as climbing beans grow and produce pods

[9] Mukuralinda A, Mutaganda A, Twagirayezu D, Kiptot E, Muthuri C, Musana BS.2016.Cyphomandra betacea. Factsheet. Kigali, Rwanda: World Agroforestry (ICRAF) *http://apps.worldagroforestry.org/downloads/Publications/PDFS/LE16226.pdf*

[10] Njoki C, Mukuralinda A. 2020. More stakes, more climbing beans, less malnutrition: Rwanda finds a solution in agroforestry. *https://www.worldagroforestry.org/blog/2020/04/03/more-stakes-more-climbing-beans-less-malnutrition-rwanda-finds-solution*

a local farmer said, "*On my one-acre farm, I have planted 35 Alnus, 15 Acacia and 10 Vernonia. I'm happy about these new tree trees because the farm yield has doubled from between 20-25 kg to 40-50 kg of climbing beans. This is enough to consume at home, sell at the local market and retain seeds for the next planting season*". Similarly, Mbahingana Ildephose, a farmer in Nyundo Sector reported that he had planted *Acacia angustissima* trees and already harvested bean stakes twice. As opposed to napier grass, Acacia provides strong stakes for climbing beans to grow with vigor and produce higher yields.

Take home message

- Several farmers in the project sites have taken up tree and fruit (tree tomato) planting in various agroforestry systems, production and use of quality germplasm, tree biomass incorporation for improving soil fertility, soil conservation practices with Alnus and Acacia, and use of wood stakes for enhancing climbing bean yields.

- Tree cover has increased in the project sites with a large number of households adopting different agroforestry practices being observed in the sites that have benefited from the two phases of the project.

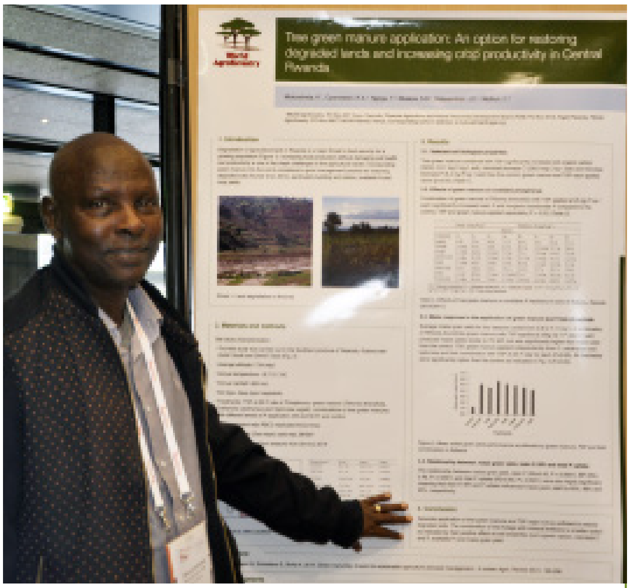
- Farmer trials and participatory trials generated a learning platform and are efficient and an impact-oriented scaling strategy. They are mechanisms for sharing findings from the trials as well as farmer generated innovations with other farmers to realize impact at scale.

- Targeted capacity development activities coupled with the building of community of practices including farmer cooperatives and farmers grouped in Innovation platforms (IPs) increased the uptake of agroforestry and socio-economic impacts among the farmers;

- Economic impacts of agroforestry practices and technologies promoted by the project range from improved knowledge in agroforestry practices, expansion of tree tomato cultivation for nutrition and income, increased crop productivity through tree biomass incorporation and use of agroforestry wood stakes on climbing bean to significant economic returns from the selling of tree tomato and extra food production which have enabled the farmers to buy assets and meet other family needs such as payments of health insurance and school fees

- Aligning the project activities with government policies, engaging local authorities and linking with other projects' interventions in the country constituted an effective scaling strategy and facilitated adoption of agroforestry options by the farmers.

Gallery



Athanase Mukurulinda, ICRAF Country Representative-Rwanda at the 2019 World Congress on Agroforestry © World Agroforestry

TF4S-2 Project Team together with the former Australian High Commissioner to Kenya, Burundi, Rwanda, Somalia, Tanzania and Uganda, H.E John Feakes during his visit to Rwanda © World Agroforestry/ Ake Mamo

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